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Preface

This document contains the abstracts of the ICCS18 - 18th International Conference on Composite Structures, that took place at the Hotel Epic Sana, Lisbon, Portugal, from June 15-18, 2015.

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List of Abstracts

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6090 | A STUDY ON THE DESIGN PRINCIPLE AND NUMERICAL SIMULATION OF A NEW TYPE OF BUCKLING-RESTRAINED BRACE

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In this paper, the Mechanical properties of the FRP-steel composite slab have been studied and a new type of FRP-steel composite section buckling-Restrained brace, named FBRB, has been proposed to improve the mechanical and energy dissipation of all steel BRB. FBRB is a kind of BRB, whose inner core is FRP-steel composite slab. In order to investigate the Mechanical properties of the FBRB, one general and one proposed BRBs have been designed and the numerical models have been established in ABAQUS. The numerical results have showed that the inner plate stress of FBRB is more uniform than the general one, and FBRB can overcome the local buckling of the inner core. It also shows that FBRB has a better second stiffness, higher load capacity and better energy dissipation capacity, which means that FBRB can serve as an effective passive energy dissipation device for structures.

8603 | LAYERWISE APPROACH TO ANALYSIS OF A FUNCTIONALLY GRADED CYLINDRICAL SHELL VIBRATION AND DYNAMIC BEHAVIOUR

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Summary:
A layer-wise finite element approach is developed to the analysis of thick functionally graded material (FGM) cylindrical shell with finite length under dynamic load. For this purpose, FGM cylinder is divided into many sub-layers and then the general layer-wise laminate theory is formulated by introducing piecewise continuous approximations through the thickness. The radial displacement field is approximated both linearly and in quadratic form, through each "mathematical" layer. The FGM shell properties are controlled by volume fraction as an exponential function of radius. The virtual work statement yields the 3-D governing equations which are then reduced to 2-D differential equations and the resulting equations are solved by finite element in the axial direction. Results are obtained in terms of the time history of the displacement and stress components with different exponents of functionally graded material. The results for static loading and the first natural frequencies are also compared with the solutions of previous problems in the literature. In addition, the natural frequency and mean velocity of the radial stress wave propagation for different exponents of functionally graded material (FGM) are studied and compared to similar ones obtained for FGM cylindrical shell of infinite length.
The present study is a continuation of Shakeri and co-worker's researches [1, 2 and 3]. In this work, the cylindrical layer-wise approach is made into the analysis of thick functionally graded cylindrical shell with finite length, subjected to dynamic load. The governing equations are derived from virtual work statement. Firstly, the FGM cylinder is divided into many sub-layers and then the full layer-wise shell theory as a powerful approach is used to discrete FGM cylinder of finite length in the thickness direction. The linear and quadratic approximations of the displacement components in the thickness direction are considered. Next, the 3-D governing variational equations are reduced to 2-D differential equations. At this stage, the resulting equations are solved by using finite element method. The numerical results are presented for infinite and finite length FGM cylindrical shell under axisymmetric load and compared with similar ones in the literature.
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6356 | Thermal and wear analysis on the effect of different compositions of flyash in Mg/SiC composite (Composite materials on thermal analysis)

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Metal matrix composites are used mostly in space ships, aerospace, automotive, nuclear, biotechnology, electronic and sporting goods industries, but due to their high cost, experiments are usually done to reduce the cost of the composites and inexpensive materials are utilized for metal matrix composites. Fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste byproduct during combustion of coal in thermal power plants. So, composites with fly ash can be used to reduce the cost of the metal matrix for applications in automotive and small engine applications. This could be achieved by reinforcing the Mg-composites with a high strength component. This work aims to experimental evaluation of thermal behavior of Mg-composites reinforced with SiC in addition with variation of fly ash. Magnesium reinforced with SiC particles were prepared by powder metallurgy technique. Furthermore the micro structural analysis and micro hardness test were carried out to see the behavior of material properties towards heating and cooling. It is found that there is no reaction and grain growth in the specimen prepared. Optical images revealed there is no grain growth in any of the material used at elevated temperatures. The micro hardness of composite is increased by 30 % than that of aluminum composite. Wear rate shows a greater improvement of 10% wear resistance than that of aluminum composite.

7670 | Study of the performance of concrete to water and salt freeze-thawing conditions (Durability of concrete)

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Properties of concrete subjected to freeze-thaw cycles in water and in the 1% and 3% NaCl solution were investigated in this paper. Through the experiment, dynamic elastic modulus, weight loss and compressive strength of the concrete were measured after different numbers of freeze-thaw cycles. The microstructure and the characterizations of pore structure of concrete were analyzed on the basis of mercury intrusion experiment. The test results show that the compressive strength reduced and the weight loss increased subjected to freeze-thaw cycles. Furthermore, the compressive strength and weight loss of concrete in NaCl solution were larger than those in water. It is also shown that the contents of NaCl solution has the great influence on the pore structure of concrete at different freeze-thaw cycles. When the pore structure of concrete became larger, the deterioration process of concrete subjected to the frost damage became worse.

7963 | The Heat Treatment of HSS based copper infiltrated composites (The microstructures of Metal Matrix Composites)

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High hardness, mechanical strength, heat resistance and wear resistance of M3/2 grade high speed steel (HSS) make it an attractive material for manufacture of for example valve train components. In this application, the material must exhibit resistance to oxidation, high hot strength and hardness, and superior wear resistance. Metal matrix composites were produced by the infiltration technique. Since technological and economical considerations are equally important, infiltration of high-speed steel based skeleton with liquid cooper has proved to be a suitable technique whereby fully dense material is produced at low cost. Infiltration is a process that has been practiced for many years. It is defined as "a process of filling the pores of a sintered or unsintered compact with a metal or alloy of a lower melting point". Heat treatment of infiltrated composites is one of the ways to improve their functional properties.
Attempts have been made to describe the influence of Heat Treatment® on properties of HSS based composites. The powder compositions used to produce skeletons for further infiltration were M3/2, M3/2+20%Fe and M3/2+50%Fe. The powders were cold pressed at 800 MPa. The green compacts were subsequently sintered for 60 minutes at 1150C in vacuum. These as-sintered specimens were used for copper infiltration. Heat Treatment were realised in nitrogen for 20 minutes at 900C and then cooling in oil to room temperature. After Hardening composites were quenched for 120 minutes at 180C. A qualitative EDX analysis revealed the presence of both MC type vanadium-rich carbides and M6C type tungsten and iron rich carbides. The as-infiltrated composites were subsequently tested for Brinell Hardness, tribological properties and bending strength.
The mechanical properties of the HSS based composites are strongly dependent on the iron powder content. The additions of iron powder decrease the hardness of HSS based composites, but doesn't changes their bending strength.
heat treatment protected by patent PL 397462 A1
KEYWORDS
High speed steels, iron, copper, infiltration, composites, Heat Treatment

7964 | The influence of production parameters on microstructure and properties of Al – SiC composites (The microstructure of metal matrix composites)

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Metal matrix composites (MMCs) have evolved significantly during the past 30 years. Great interest of this group of the materials is caused because of their attractive properties, such as specific strength and stiffness. Most of the commercial works on MMCs are focused on aluminium or aluminium alloy as the matrix material. It is possible to add hard particles such as: Al_2O_3, AlN, SiC, TiC and TiB_2 to primary aluminium alloy powders by the conventional premixing process to improve wear resistance of the sintered aluminium alloy.
Attempts have been made to describe the influence of sintering atmosphere and chemical composition on the microstructure and properties of Al – SiC composites. Mixtures of 100%Al and Al – 2.5% SiC, Al – 5% SiC, Al – 7.5% SiC and Al – 10% SiC were produced by tumbling for 30 minutes in the Turbula T2F mixer. The powders were subsequently cold pressed at pressure 300MPa in a rigid die on a single action press. The green compacts were sintered in nitrogen at 600°C and in vacuum at 600°C for one hour.
The specimens were subsequently tested for Brinell hardness and the bending strength. They were also analyzed by means of both light microscopy (LM) and scanning electron microscopy (SEM).
The main objective of this work was to determine influence of chemical composition and the manufacturing parameters on microstructure and properties of Al – SiC composites produced by powder metallurgy technology.

Keywords: Al – SiC composites, sintering, microstructure, cold pressing

7997 | Effective properties of a composite with long fibres (Research of RVE via homogenization)

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Composites reinforced with short fibres are well known and we can easily predict their effective properties. Composites reinforced with long fibres however are less researched and pose a problem regarding its Representative Volume Element (RVE). An RVE is the smallest volume that represents the material as a whole which means the RVE has the same properties as any volume taken from any position in the medium. The fibres in the composite that will be studied are considered infinite in length, where every fibre crosses from one edge to another in a microstructural image. The problem is with this type of fibres the RVE theoretically tends towards infinity. In reality, we can only work with finite dimensions so it is necessary to get around this problem using numerical analyses. In this study we show that it is possible to stabilise the properties of the composite even though the RVE approaches infinity. However one question remains to be answered : are the properties effective or not?

Keywords—Representative volume element, heterogeneous materials, long fibres, microstructure, finite element, bulk modulus, shear modulus, thermal conductivity

8059 | An Innovative Method of Suppressing Drilling-Induced Delamination in Composite Tube (drilling and machining)

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Numerous industrial sectors adopt fiber-reinforced composite materials for a variety of products thanks to the high specific strength and stiffness of the materials. In addition to flat plates, the tubes provide additional dimension of structural freedom for use in transportation goods and trusses. While drilling is widely known as an indispensable machining process for joining the structures made of composite materials, the drilling-induced delamination defects are often much more serious in tubes than in flat plates, in particular at the exit inside the tube when drilling normally from outside, due to the curvature of the tube workpiece. Delamination of composite material deteriorates the strength of the parts in service, which is not only the mechanical weakening but also the safety concern. The common industrial practice of applying a backup to support the exit side in drilling the plates can however not be feasible for the tubes. An innovative method is proposed in the current study using the water icing inside the tube. The negative thermal expansion of water during the liquid-to-solid phase change provides expansive compression force of tens of Newtons against the inside of the tube for suppressing the delamination growth at exit when drilling the tube. The experimental results show the delamination extent can be reduced by 50%. The water icing is easily remelted and removed as well as recycled with little environmental concerns after use. The proposed innovative method is effective and inexpensive for industry.

Keywords: Composite material, Drilling, Delamination, Tube, Ice

8127 | Pressure reconstruction for three-dimensional water entry problems (Office of Naval Research (ONR))

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As composite structures are increasingly integrated in marine vessels, the need for developing accurate models of fluid-structure interactions during hull slamming becomes more and more pressing. During such events, the vessel is subjected to highly impulsive loadings, which may lead to undesired structural vibrations and even failure. Thus, the prediction of the spatiotemporal evolution of the hydrodynamic loading experienced by marine vessels during sea keeping and maneuvering is of fundamental importance for structural design. Enabling such a prediction requires addressing several open questions, such as: what is the role of structural flexibility on hydrodynamic loading? How is energy transferred from the solid to the fluid and vice-versa during water entry? What is the role of the water jets and the spray on the hydrodynamic loading? And to what extent two-dimensional models of water entry should be considered accurate? In this work, we seek to contribute to answering the latter question through the analysis of the three-dimensional (3D) water entry of a rigid wedge. Experiments are conducted on a rigid wedge with 25º deadrise angle and falling from an impact height of 50 cm. The wedge has an approximately square base with length and width of 200 mm. We utilize planar particle image velocimetry (PIV) to estimate the 3D velocity field during water entry. In particular, we perform experiments on thirteen vertical planes along the length of the wedge to measure the cross-sectional velocity field and five vertical planes along the width of the wedge to measure the axial velocity. Afterwards, the cross-sectional velocity data are augmented with the axial velocity information using a cubic spline interpolation scheme to ultimately estimate the complete 3D velocity filed in the fluid. The pressure is evaluated by solving the 3D incompressible Navier-Stokes equations, whose kinematic components are predicted from PIV data. Results show that the cross-sectional velocity magnitude decreases as the measurement location moves away from the mid-span of the wedge, while the axial velocity component significantly increases in the proximity of the edges. These findings confirm our expectation that 3D effects are minimal at mid-span of the wedge, while they tend to be relevant close to the edges of wedge. Moreover, we find that the distribution of the hydrodynamic loading is remarkably influenced by the variation of the axial velocity component. Specifically, the hydrodynamic loading sharply decreases towards the edges of the wedge, reaching nearly one third of the values attained at its mid-span.

8265 | Vibration-assisted machining of fibre-reinforced polymer composites: Surface integrity in edge trimming (Composites machining)

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A fibre-reinforced polymer (FRP) composite consists of two phases of materials with very different mechanical properties. The fibres, such as those made of carbon or glass, are brittle and much stronger than the polymer matrix. When an FRP composite is subjected to mechanical machining, it always suffers from various surface and subsurface damages. To minimise the damage, an ultrasonic elliptic vibration-assisted (EVA) machining technique has been developed, which applies micro-scale vibrations to a cutting tool to facilitate the material removal.
This paper aims to characterize the EVA machining on the edge trimming of FRPs. Both finite element and experimental studies were carried out to understand the effect of fibre orientation on the surface integrity of the machined FRPs. It was found that when the fibre orientation is less than 90□, bending-dominated fibre fracture is prevalent above the cutting path, leading to a serious surface/subsurface integrity especially the delamination. When the orientation is above 90□, nevertheless, crushing-dominated fracture governs the material removal, which to a certain extent improves the integrity. However, compared with a traditional process, the EVA edge trimming can reduce the fibre orientation effect through localised fibre fracture, and greatly improve the surface integrity.

8567 | Theoretical and numerical analysis of RC beams externally strengthened with SRG and SRP systems tested to flexure (Rehabilitation, strengthening and repair)

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This work presents the results obtained from a numerical and theoretical analysis carried out on a set of reinforced concrete (RC) beams externally strengthened to flexure by using Steel Reinforced Grout (SRG) and Steel Reinforced Polymer (SRP) systems. These new composite materials consists of unidirectional high-carbon steel fiber fabric reinforcing mesh, which can be embedded in an inorganic matrix (SRG) or in an organic matrix (SRP). They are systems capable of ensuring the same advantages of Fiber Reinforced Polymer (FRP) strengthening systems, as easiness of application, low invasiveness and reduced intervention time, but with a lower cost, higher environmental sustainability, better fire resistance and a higher compatibility with existing structures, compared to FRP materials.
Some studies on SRP and SRG systems are available in the current literature and all have shown the potentialities of these systems in improving structural performance of masonry and concrete elements and, at the same time, their difference with respect to FRP particularly in terms of bond behavior.
Up to day, for these innovative strengthening systems, are not yet available in literature reliable bond-slip models, aimed to simulate the interface behavior between the external reinforcement and the concrete substrate, and specific analytical models capable to predict the theoretical behavior of structural elements externally bonded with SRP and SRG systems.
In order to give a contribute to this topic, this work analyzes the structural behavior of RC beams externally strengthened to flexure with innovative composite materials, applying interface bond-slip laws and analytical models proposed for FRP systems.
The numerical simulations were carried out by using a two-dimensional (2D) finite element model. The nonlinear behavior of all materials (steel reinforcing bars, plain concrete, and external reinforcing system) was modeled by appropriate constitutive laws, while the connection between concrete surface and external reinforcing layer was simulated by a cohesive element and a suitable damage model. The effectiveness of some current bond-slip models used, up to day, for FRP systems, was checked. The numerical results have highlighted the influence of the adopted FRP interface law on the structural behavior at ultimate of strengthened RC beams. In fact, a careful analysis of the mechanical behavior of the interface between external strengthening system and concrete substrate is of fundamental importance to understand the delamination failure phenomenon as it can be carried out only using numerical methods, because of the difficulties of detecting the actual stress and strain distribution in physical experiments.
In order to evaluate the flexural strength some analytical models to predict the maximum axial strain developed in FRP systems at the onset of intermediate debonding failure, have been used (for example the ACI 440.2R-08 and CNR-DT 200 R1/2013 guidelines).
The comparisons between numerical/theoretical results and experimental data, in terms of load-displacement curves, load-strain curves, deflections at maximum loads and cracking patterns, have highlighted the reliability and adaptability of the studied bond slip laws and analytical models.
Finally, considerations concerning the strength and ductility of the strengthened beams were made.
This work may form the basis for future studies regarding numerical modelling and design guides of externally bonded SRP and SRG systems.

8658 | MESO SCALE MODELLING OF CONCRETE USING MICROPLANE BASED APPROACH (MESO SCALE MODELLING OF CONCRETE)

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Concrete is composite, highly heterogeneous material, with randomly distributed defects of different sizes and shapes. The mechanical behavior of such material is greatly influenced by the geometry and the properties of the microstructural components. Since a reliable prediction of concrete behavior cannot be based only on experimental studies, computational analysis is a fundamental tool for better understanding of microstructural phenomena induced by the interaction between different components. Most of the engineering studies available in the literature consider concrete as a homogeneous material formulated within the framework of continuum mechanics. Although nonlinear macroscopic models for concrete can realistically predict its global behaviour, they are unable to capture some important phenomena from the meso level that are strongly influenced by material heterogeneity.

In the present contribution a meso scale model for concrete is proposed. In the model concrete is considering as a two-phase composite material, i.e. aggregate and mortar are discretized by three-dimensional finite elements. The presence of interfacial transition zone (ITZ) between aggregates and mortar is not explicitly accounted for. The numerical simulations are carried out using 3D finite element code MASA [1]. As a constitutive law for mortar the microplane model is employed [2]. Aggregate particles of different sizes are randomly generated. They are assumed to be linear elastic. Three-dimensional finite element simulations for concrete cylinder loaded in uniaxial compression are carried out. The results of numerical simulations show very good agreement with the experimental data reported in [3], confirming the validity of the proposed meso-scale model for concrete.

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8659 | MESO SCALE MODELLING OF CFRP CONFINED CONCRETE USING MICROPLANE BASED APPROACH (MESO SCALE MODELLING OF CFRP CONFINED CONCRETE)

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Many experimental and numerical studies have been devoted to the confinement of circular reinforced concrete sections loaded in uniaxial compression. However, relatively limited number of studies investigated square and rectangular cross-sections. The experimental investigations on square sections date back to the tests performed by Mirmiran et al. [1], where the effects of the corner rounding radius on both strength and ultimate strain were clearly demonstrated. Recently, the effects of corner rounding radius were extensively investigated in [2], where compression tests were performed on concrete specimens loaded in uniaxial compression. The sections of all specimens were considered as inscribed in a square section (150x150 mm) with six values

of the corner radius: 0, 15, 30, 45, 60, and 75 mm, so that with the latter the circular section was also included in the study.

It is well known that the behavior of concrete columns confined with CFRP strongly depends on the interaction between mechanical properties of CFRP and lateral dilatation of concrete. Therefore, to correctly predict the performance of CFRP confined concrete members it is important to have a model capable to reproducing the mechanical behavior of the unconfined concrete realistically. With these premises, a meso scale model for concrete is proposed, where the material is treated as a two-phase composite material, containing coarse aggregates and mortar matrix. The numerical simulations have been performed using the three-dimensional finite element code MASA [3], in which the constitutive law for concrete (matrix) is based on the microplane model [4]. The model was first calibrated [5] and subsequently the series of numerical investigations are carried out in order to investigate the influence of the shape of the cross-section specimens loaded in uniaxial compression on the performance of CFRP. Comparing the numerical results with the experimental data reported in [2], it is demonstrated that the proposed modeling approach is able to realistically replicate the stress-strain relationships for the whole set of the tested specimens.

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8700 I Interface compatibilization of high performance thermoplastic composites by surface activation and supramolecular assembly as a versatile way to obtain environmental friendly adhesion promotion (Interface engineering / High performance thermoplastic composites)

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Replacement of thermoset matrix by thermoplastic is a major area of research in aeronautic and aerospace industries in order, among other things, to increase the application range and to reduce the costs due in particular to formulations and to the complex implementation of thermoset. One of the challenge linked to this replacement relies on the fibre - matrix interface compatibilization of thermoplastic composite materials based on polyether ether ketone (PEEK) reinforced with continuous carbon fibres. In the framework of this study and so as to develop effective solutions to improve the fibre - matrix compatibility, particular attention was paid to the reinforcement material that is high modulus pitch-based carbon fibre with high thermal conductivity. PEEK is one of the most promising high performance thermoplastic polymer and arouses a strong interest as a replacement polymer for thermoset matrix to the extent where it can be used according to the severe space and aerospace specifications. However, the shaping process of PEEK-based composites, which must be performed at elevated temperatures comprised between 380 and 400°C, appears to be challenging due to the following points: (i) the oxidation of polymer matrix, (ii) the commercial sizing thermal degradation and therefore the difficulty to choose a suitable sizing chemistry because of the incompatibility of lot of polymers and macromolecules at such elevated temperatures, and (iii) the chemical and structural stability of the pitch-based carbon fibre surface. Furthermore, there is a limited knowledge about the processing and shaping of such high performance composites in literature.
An innovative and versatile method, inspired by supramolecular layer-by-layer (LbL) assembly, is used to modify the carbon fibre surface in order to improve the compatibility and the quality of the fibre - matrix interface, and therefore to obtain a high performance composite material. Indeed, coatings obtained by adsorption of polymers macromolecules onto solid surfaces have been studied for decades because they allow the fabrication of thin films having tailored structures and properties. Despite very promising results, this technique does not allow to deposit films onto large substrates and with a high throughput. Hence, the main objective of this work is to develop a versatile technique enable to quickly coat fibre surface for the development of environmental friendly adhesion promoters.
To this aim, we will use an alternative to the so called “Layer-by-Layer” technique which allows to elaborate a coating based on the coalescence and intermixing of polyelectrolyte complexes with or not thermoplastic pre-polymer. The complexation mechanisms occurring when two oppositively charged partners are put together under different physical parameters (pH, ionic strength, T°C, stirring conditions...) will be investigated. The system will be applied in the field of composite materials and in particular for the improvement of fibre - matrix interface. Thus, a large part of this presentation will be focused (i) on the carbon surfaces characterization in order to study (ii) the interest of an additional step related to the surface activation performed by atmospheric plasma treatments, and (iii) on the surface modifications with these complexes by aqueous-based formulations applied in accordance with sizing treatments. This approach is an innovative challenge that allows the possibility to improve interface quality. Self-assembled interphase based on weak forces such as electrostatic forces and hydrogen bonds are proposed as the driving force for designing our coatings. The main results show that inert carbon surfaces can be selectively modified and activated by specific atmospheric plasma treatments and stable polyelectrolyte/high performance thermoplastic complexes can be dispersed in water in such a way that a sizing treatment can be apply by immersion and spray.

8830 I Application of PMI Syntactic Foams in Honeycomb Sandwich-Structured Composite Repair (Syntactic Foams in Honeycomb Sandwich-Structured Composite Repair)

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Like their metal counterparts, composites are damage-prone. To restore the load bearing capacity of damaged composite structure suitable repair technique has to be applied. Repair techniques, developed over the years, for metallic structures, are not directly applicable to composites; therefore, adequate and efficient composite repair techniques have to be developed. The extent of damage induced determines whether the deteriorated composite

component needs to be repaired or replaced. The choice between replacing or repairing a structural component is governed by a number of factors such as the availability of spares, feasibility of repair, structural integrity requirements and inspection requirements for the repair. In most cases, component replacement is not economically feasible solution; thus, repair is the only viable solution.
The article presents application of PMI (Polymethacrylimide) syntactic foam, as a repair material for damaged high density honeycomb core, in sandwich structured composites. ROHACELL® WF110 foam is used for repairing mechanically damaged (partial-through) NOMEX® HRH 10-96 honeycomb core. The effectiveness of PMI as a repair material was verified experimentally by performing 4-point bending tests on specially manufactured GRP (glass reinforced plastic) with honeycomb core composite beams in the elastic material region. A complete 3D stress-strain field was determined using finite element approach, and the results obtained were compared with the experimental data.
It was found that PMI syntactic foams represent good material candidates which can be used as the alternative repair material for damaged honeycomb cores in sandwich composite structures. However, when making the selection of the repair core material (PMI foam) it is of paramount importance that the stiffness of the repair plug matches, as close as possible, the stiffness of the parent core structure. A repair plug, stiffer than the surrounding sandwich core structure attracts more load to the region of the repair. This may result in exceeding the allowable strength of the structure. A repair with a lower stiffness, compared to the parent structure diverts the load from the repair, possibly causing the parent structure overstress. While ensuring that the stiffness of the repair plug and core structure are matched, a positive strength margin of safety could be achieved.

8833 | Properties and Structure of Sintered Materials with Borides (Metal Matrix Composite)

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The aim of that research-work is analysis of borides effect on the properties and structure of sintered materials obtained by Powder Metallurgy (P/M) route. Boron and borides are activators of the sintering process of iron and iron based prealloyed powders. Under this research project obtained were P/M materials based on prealloyed and diffusion bonded powder type Distaloy SA, with the following chemical composition: Fe-1.75%Ni-1.5% Cu-0.5%Mo with borides: NiB and Fe2B. Boron contents in sintered materials is as follows: 0wt%, 0.2wt %, 0.4wt% and 0.6wt%.
P/M materials were manufactured by mixing powders, compacting and sintering. After the sintering process, there were performed density, porosity measurements and hardness tests as well as mechanical properties were carried out. Also structural investigations were done using optical microscope and SEM/EDS and XRD phase analysis. A comparative analysis of the effect NiB powder, Fe2B powder on the changes appeared in the microstructure and mechanical properties of sintered materials based on prealloyed powder were performed.

9056 | Structural Properties and Mechanical Behavior of the Reinforced Titanium Fiber on Al-Si/SiCp Metal Matrix Composite by Powder Metallurgy (Metal Matrix Composite)

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Aluminum and its alloys have been developed for automotive application due to superior lightweight, high-specific strength, remarkable malleability, excellent castability and high corrosion resistance. In case of Al-Si alloys with Si for hypoeutectic and eutectic composition, these alloys are widely used as cast Al alloy due to excellent casting performances, i. e. low casting shrinkage, high mobility and low hot-shortness. In addition, Al-Si alloys with Si for hypereutectic composition perform high wear resistance, superior corrosion resistance and improved high-temperature strength by crystallization of primary Si phase. Especially, these alloys by powder metallurgy have a near-net shaping property. Recently, it has been attempt to increase mechanical properties of Al-Si alloy by ceramic reinforcements. Unfortunately, it still needs further improvement of low wettability between matrix material and ceramic reinforcement and surface modification of oxide layer on matrix material in manufacture of MMCs.
The aim of this study is improvement of bonding surface between Al-Si matrix powders with SiC particles by Ti metal fiber as reinforcement. Ti fiber has an effect to increase bonding force among Al-Si powders with SiC particles because of these binary systems have native values for mutual mixing enthalpy between Al-Ti and Si-Ti. In addition, low thermal expansion of Ti can be controlled shrinkage of sintered body during the cooling process. The modified Al-Ti and Si-Ti surfaces and Ti fiber reinforcement are improved mechanical properties in this study. The upgraded properties in sintered Al-Si/SiCp + Ti fiber MMCs will be discussed in detail.

Keywords: Aluminum, Titanium fiber, Powder metallurgy, Metal matrix composites, Mechanical property

6980 | Composite Notch Behaviour - From Coupon to Airbus A350XWB (1. Plenary lectures)

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Composite Notch Behaviour - From Coupon to Airbus A350XWB

With the entry into service of the Airbus A350, Airbus has completed a 40 year journey in the pioneering development and practical delivery of Composite Aircraft Structures.

This lecture will chart that journey by considering the efefcts of notches on composite behaviour from the micro to the macro scale. How do you move from theory and laboratory level coupons into a practical certified large Civil Airliner.

The lecture will illustrate how Academia and Industry can work together.

6982 | Computational Materials Design on Polymer-Matrix Composites (1. Plenary lectures)

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Polymeric clay nanocomposites are a new class of materials which have been the subject of extensive researches during last years. These material have a great multifunctional thermo-mechanical properties such as low permeability and flame retardancy which are the results of using high aspect ratio clays inside polymeric matrix. Unlike the traditional composite materials, the morphology of the polymer-clay nanocomposite is more complex. Beside numerous experimental and theoretical studies on this topic, there is still considerable ambiguity in theoretical and experimental investigation of the fracture and damage in these materials.

In this study, a phase-filed model for brittle fracture is used to investigate the fracture behaviour of the fully exfoliated clay epoxy nanocomposites. The crack initiation and propagation inside the nanocomposites is simulated using phase-field model which does not require predefined crack path. The effect of several parameters such as clay weight ratio, clay aspect ratio and material parameters of the clay and matrix is investigated.

The results of this study can help to get a better understanding of the fracture mechanisms in the clay epoxy nanocomposites. It also provides a method to computationally design the clay epoxy nanocomposites with a desirable mechanical properties.

7759 | Composite structures for proton exchange membrane fuel cells (PEMFC) and energy storage systems (ESS) (1. Plenary lectures)

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Since conventional power generation relies much on fossil fuels, which produces pollutants, fuel cells are needed in the future because they provide electric power with less pollutants and high efficiency. One of the most promising fuel cells is the proton exchange membrane fuel cell (PEMFC) because it has highest power density with low operating temperature, which makes it suitable for portable applications. Also energy storage becomes a major concern with the introduction of renewable electricity from wind and solar energies because the electricity has to be used whenever it is generated, and their quality of electricity should be improved by the energy storage system (ESS). One of the most promising ESS is the vanadium redox flow battery (VRFB) because it has an infinite operating cycles with non-explosiveness.
Although they have been considered as future energy conveniences, they have not been widely employed because their structures such as bipolar plates (BP), endplate (EP) or flow frames (FF) are made of either brittle graphite, weak polymers or ceramic coated stainless steel to meet the requirements of high electrical conductivity under strong acid environment such as the target values of Department of Energy (DOE) of USA.
To circumvent the weak characteristics and difficulty of manufacturing of these structures, the carbon composite BP and the hybrid composite endplate (EP) composed of carbon and glass composites for the PEMFC and VRFB and the glass composite flow frame (FF) for the VRFB have been developed. The design methods for these structures with the appropriate processing techniques are explained in detail. The performances and endurance tests for these structures have been evaluated and compared to the targets of DOE. Finally an ultralight PEMFC of 200 W for unmanned aerial vehicle (UAV) and a VRFB of 20 kW for electricity storage have been manufactured and their performances are presented.

8281 | Layerwise Optimization and New Extensions for Lay-up Design Problems of Laminated Composite Plates and Shells (1. Plenary lectures)

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Laminated fiber composites are well known as tailoring materials, and the laminated structural components, such as laminated composite plates and shells, have been regarded as good application target of optimization. In previous related studies, the lay-up design problems have been solved either by mathematical programming or meta-heuristic approaches. The mathematical programming approaches, which are basically gradient-based non-linear programming, are mathematically well-defined, but improvement of design variables tends to be trapped in local solutions. In meta-heuristic approaches, the genetic algorithm (GA) and particle swarm optimization (PSO) are frequently used these days due to the easiness in cording and searching capability of global solutions, but they require a large number of structural analysis due to their basic nature as random search using many individuals.
In 2003, the first paper was published (Narita, J Sound & Vibr., vol.263, pp.1005-1016) to deal effectively with the lay-up design problems in bending vibration, static deflection and buckling. This is called the layerwise optimization (LO) approach, because one-dimensional optimization is made in each layer instead of considering all the combinations of fiber orientation angles in all layers. In the concept of LO, use of a simple physical observation “In the bending of thin laminates, the outer layer has a greater stiffening effect than the inner layer and therefore has a greater influence on the mechanical behaviors of the laminates” is made, and the procedure to the optimization problem is advocated as “the optimum lay-up design can be obtained by determining the optimum fiber angle for each layer sequentially in the order from the outermost to the innermost layer”.
The LO is an approximate approach, but significant reduction in the number of structural analysis and accuracy in optimization were already demonstrated in many papers for static bending, bending vibration and buckling problems of laminated plates and shells. The approach is also independent of types of structural analysis, and has been actually used with semi-analytical methods (e.g., Ritz method) and numerical methods (e.g., commercial and self-made FEM programs). In the present plenary lecture, the idea of LO is reviewed and some recent extensions of the idea are introduced to wide variety of lay-up design problems.

8582 | AMPEROMETRIC BIOSENSORS BASED ON OXIDOREDUCTASES IMMOBILIZED ON NANOPARTICLES OF NOBLE METALS (1. Plenary lectures)

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A majority of known physico-chemical analytical methods have a number of disadvantages, such as a low selectivity and sensitivity, high costs and complexity of the equipment, insufficient operation and storage stability. Thus, the development of new highly selective and sensitive methods for determination of the target biosubstances in clinical diagnostics and food industry is an important analytical task. Nanocomposite materials, consisting of enzymes conjugated with gold (AuNPs) and silver (AgNPs) nanoparticles, are promising biorecognition tools with improved catalytic properties in construction of amperometric biosensors.
The current work provides development and characterization of novel amperometric biosensors of third generation based on using oxidoreductases, immobilized on nobel metals NPs. Horse radish peroxidase (PO) and glucose oxidase isolated from the fungus Penicillium adametzii (GO) were employed in our experiments for assay of hydrogen peroxide and glucose as the target analytes.
AgNPs and AuNPs, as well as their hybrids were synthesized using chemical reduction of the appropriate salts. Scanning and transmission electron microscopy, as well as spectral methods proved the nanosizes of resulting NPs conjugated with enzymes. The new methods of nanocarrier's biofunctionalisation were proposed. BioNPs were obtained by immobilizing of PO and GO on the chemically activated NPs. The study of catalytic properties of the enzymes conjugated with NPs showed that Au/AgNPs are the most effective for PO, whereas AgNPs and Ag/AuNPs are optimal carriers for conjugation with GO.
Obtained bioNPs were used as bioselective elements of amperometric sensors selective to hydrogen peroxide and glucose. The bioNPs-based biosensors have demonstrated improved physico-chemical characteristics: better storage stability and a broader (10-fold increased) linearity of the signal in comparison with bio-electrodes, constructed without using NPs. The developed amperometric biosensors were exploited for testing real samples of wines in comparison with other analytical approaches. The values of the analyte's contents obtained with different methods demonstrated a strong correlation. The proposed low-cost laboratory prototypes of biosensors, selective to glucose and hydrogen peroxide, would be promising for clinical diagnostics and food quality control, especially in wine making.

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8891 | Design and failure prediction of composite repair systems for corroded pipelines. (1. Plenary lectures)

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The present work is concerned with the analysis of composite repair systems for metallic pipelines undergoing elastic or inelastic deformations with localized corrosion damage that impair the serviceability. The main motivation is the rehabilitation of corroded pipelines conveying produced water in offshore oil platforms. Although the operating pressure of these pipelines is not very high, the water temperature is between 60 and 90ºC, which can be a major shortcoming for the use of polymeric material as repair systems. Tensile and burst tests were performed evaluate the performance of composite reinforcements applied to defects machined in pipeline test specimens. Preliminary ideas for a methodology to estimate the failure pressure of a reinforced specimen with arbitrary localized corrosion damage are presented.

8898 | NON-LINEARITY AND ANISOTROPY AT NANOSCALE (1. Plenary lectures)

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Generally speaking, non-linear behaviour of materials and structures takes place when the deformation does not vary proportionally to the loading acting on the given material/structure. Additionally, increasingly complex behaviour of structures arises when the material neither isotropic nor homogeneous. The behaviour (either linear or non-linear) of structures made of heterogeneous and/or anisotropic materials has always been a key challenge for scientists and engineers. The usual way to solve any type of structural problem at the macroscale (the space at which we exist and live) is to apply continuum mechanics. The concept of continuum is based on the fact that a body (structure) that can be continuously sub-divided into infinitesimal elements with properties being those of the bulk material. However, on a microscopic scale, materials have cracks and discontinuities and certain physical phenomena cannot be modelled assuming the materials exist as a continuum, meaning the matter in the body (structure) is no longer continuously distributed and does not fill the entire region of space it occupies. If we go further deep, we can say that materials at nanoscale are composed of atoms that act as particles separated by "empty" spaces (electron clouds). Of course, the continuum mechanics principles that we apply at macroscale should not be applied to nanoscale. Despite this unsurpassable barrier, both non-linear and anisotropic effects also occur at nanoscale and, sometimes, they are akin to their macroscale counterparts.

This plenary talk focuses on the explanation of non-linear behaviour and anisotropy of materials at nanoscale. Because materials for structural applications should be in solid state and possess improved stiffness and strength, there is no better nanomaterial to investigate than carbon-based aggregates. Graphene and carbon-nanotubes are known as the stiffest and strongest materials. In this lecture, the behaviour of graphene and carbon-nanotubes is shown to be not only highly anisotropic, as their response depends markedly on the loading direction, but also highly non-linear, as their response (deformations) do not vary proportionally with the loading. These non-linear effects arise not only from the loss of stiffness of the nanostructure as a whole (e.g., buckling and instability) but also from either breaking of covalent bonds (between carbon atoms) or slippage of other atoms surrounding the carbon-based aggregates (e.g. composite materials). To achieve these goals, Molecular Dynamics simulations (MD) are performed. In this plenary talk, several results will be presented and discussed, which comprise (i) curves relating the energies with the applied loadings, (ii) plots of deformed shapes and failure modes of carbon-aggregates and (iii) curves relating the acting stress with the strain. Finally, some concluding remarks are drawn about the major differences found between the results at nanoscale and those that we usually assume at macroscale (in common sense).

8926 | FE Shell Formulations for Layered Composite Structures (1. Plenary lectures)

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The efficient load-carrying capabilities of shell structures make them very useful in a variety of engineering applications. The most common mathematical models used to describe shell structures are based on the Kirchhoff or Reissner-Mindlin assumptions, but the continuous development of new structural materials requires more accurate theories.
Layered structures are increasingly used in aerospace, automotive, and ship vehicles. The so-called advanced composite materials were developed as part of aerospace vehicles during the second part of the last century. Nowadays, there are examples of fighter and commercial aircrafts, helicopters, and

gliders whose structures are entirely made of composite materials. The analysis of multilayered structures is difficult when compared to one-layered ones. A number of complicating effects arise when their mechanical behavior as well as failure mechanisms have to be correctly understood. This is due to the intrinsic discontinuity of the mechanical properties at each layer-interface to which high shear and normal transverse deformabilty is associated. An accurate description of the stress and strain fields of these structures requires theories that are able to satisfy the so-called Interlaminar Continuity (IC) conditions for the transverse stresses. Moreover, the transverse anisotropy of multilayered structures make it difficult to find closed form solutions and the use of approximated solutions is necessary. It can therefore be concluded that the use of both refined two-dimensional theories and computational methods become mandatory to solve practical problems related to multilayered structures.
The finite element method has been the fundamental numerical procedure for the analysis of the shells. It is known that when a finite element method is used to discretize a physical model, the phenomenon of numerical locking may arise from hidden constrains that are not well represented in the finite element approximation. Recently, the author adopted the Mixed Interpolation of Tensorial Components (MITC) to contrast the locking. According to this technique, the strain components are not directly computed from the displacements but they are interpolated within each element using a specific interpolation strategy for each component.
The works [1] and [2] present shell elements based on the Unified Formulation and displacement formulation (Principle of Virtual Displacement) that show good properties of convergence. Both equivalent-single-layer and layer-wise refined theories are considered for the analysis of composite structures. Subsequently, the Reissner's Variational Mixed Theorem (RMVT) has been adopted to derive the governing equations [3]. The RMVT permits one to assume two independent fields for displacement and transverse stress variables. The resulting advanced finite elements therefore fulfil a priori the interlaminar continuity of the transverse stresses. The main idea is to interpolate the transverse stresses (that are modelled a-priori by the RMVT) using the same strategy of the MITC. In this way, the IC conditions are satisfied and the shear locking is contrasted at the same time.
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8935 | Modeling the effects of cure induced chemo-mechanical processes on the strength of fiber reinforced composites (1. Plenary lectures)

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A novel computational model is introduced to analyze the effect of the curing process on the in-service performance of fiber reinforced composite structures. A novel polymer curing model based on the notion of polymer networks that are continuously formed in a body of changing shape due to changes in temperature, chemistry and external loads is used in conjunction with multiple fiber representative volume elements (RVE) to assess the strength of the RVE when subjected to mechanical load after virtual curing. Nonlinear material behavior, including damage and failure, is incorporated through continuum damage mechanics in conjunction with the mesh-objective crack band model. It is shown that significant stresses can develop during cure, and depending on the cure cycle, the matrix material can be subjected to damage prior to insertion in service. The notions of composite strength are re-examined in light of the results obtained.

8951 | Cork in composite structures: from low to high energy dynamics (1. Plenary lectures)

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Due to their cellular structure, open and closed-cell foams, porous materials and some natural cellular materials are generically and fundamentally good energy absorbers. Mechanisms such as cell wall buckling and collapse, plastic deformation and fracture explain this particular behaviour. However, the capability of such materials to absorb energy strongly depends on their microstructure (i.e. cell or pore structure, size, dispersion and arrangement), base material properties and loading induced strain-rates. Cork is a natural foam composed of closed cells of suberin, an impermeable and visco-elastic material. Cork composites can have a wide range of densities (0.2-1.5 g/cm3) with strengths ranging from 1 to 30 MPa. The constitutive behaviour of most cellular materials, including cork and most of its composites, and their strain-rate dependency are the main factors defining their applicability as efficient energy absorbers. A detailed description of the microstructure and behaviour of cork and its composites will be given, focusing on its strain-rate dependency and energy accumulation and absorbing capabilities. Examples will be given, through numerical analysis and quasi-static and high strain-rate experimental testing, of how to assess the potential of the use of cork in structural and energy absorption applications. The importance and relevance of using such materials in critical situations and extreme conditions, such as in the aerospace, defence and nuclear industries, will be explored in detail, with a large number of examples and results/observations being provided. Focus will be on defence applications (e.g. blast wave mitigation and protection against ballistic impact), low energy impact (e.g. crashworthiness), personal protection and structural integrity (e.g. earthquake mitigation).

9017 | STRUCTURAL COMPOSITE MATERIALS FOR AEROSPACE APPLICATION. MAIN ACHIEVEMENTS AND FUTURE TRENDS (1. Plenary lectures)

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Composite materials are used on aerospace application since many decades to replace aluminium alloys to save weight and make aircraft utilization greener. Today, structural parts of last generation aircraft use about 53% by weight of composite material. If there is still some possibilities to increase composite materials share, the mains stoppers are :
- utilization of composite for parts loaded in 3D,
- utilization of composite for structural parts with a continuous service temperature over 150°C
- utilization of composite materials for parts where electrical conductivity is needed.
If some technical tricks of the trade have been used to overcome these show stoppers, progresses are needed in the future to propose adapted materials and retrieve more benefits in weight saving. The constant increase of aircraft demands linked with the increase of number of composite parts to produce, require an automation of the manufacturing process to produce parts at lower cost with increased manufacturing quality.
For the materials, if aramid fibers have been used in the past with glass fibres, today carbon fibres are more and more used for structural applications. Glass fibres are still present for specific properties and aramid fibres are less and less selected. For the matrices, epoxy resins have been used since the

beginning, and are still present in large quantities on last generation of composite materials. Some progresses have been made for damage tolerance properties and processability. For health and safety aspect during the manufacturing process, some products have been qualifies to replace some potential dangerous ingredients of the formulation. Thermoplastic matrices are now used on some parts and could be used more intensively on next aerospace product generation. For future composite materials, the door is open to propose multifunctional materials with additional properties such as electrical conductivity, vibration damping, damage tolerance performance…

9164 | A FIRST STEP TOWARD A EUROCODE FOR THE DESIGN AND VERIFICATION OF WHOLE FRP COMPOSITE STRUCTURES (1. Plenary lectures)

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Over the last twenty years, several innovative solutions, both within and outside Europe have confirmed the usefulness of whole composite structures realized with Fibre Reinforced Polymers or Plastics. These solutions are often imposed by specific needs. such as requirement for speed of assembly on site or for enhanced resistance to aggressive environments, which in turn reduces maintenance costs. In addition, the lightweight of the FRP composite makes the assembly and the launch of the structure easier, beside offering a geotechnical advantage for all structures that have to rest on deformable soils. Within this context, the use of so called FRP pultruded profiles, shell structures and sandwich panels is particularly advantageous for applications in the Civil Engineering field. FRP pultruded profiles are widely used for the construction of buildings for industrial or residential purposes, lock doors, and also for the construction of bridges and bridge decks, both pedestrian as well as traffic bridges carrying all classes of wheel loads.
Notwithstanding all the opportunities offered by FRP composites, it appeared necessary with a standardization work for both the production of FRP structural elements and the practical rules for the design and verification of structures made of such elements. Several countries have contributed to the drawing up of appropriate guidelines, among which it may be appropriate to mention the following ones:
EUROCOMP Structural Design of Polymer Composites (Design Code and Background Document, Finland, France, Sweden, UK, 1996);
CUR 96 Fibre Reinforced Polymers in Civil Load Bearing Structures (Dutch Recommendation, 2003);
BD90/05 Design of FRP Bridges and Highway Structures (The Highways Agency, Scottish Executive, Welsh Assembly Government, The Department for Regional Development Northern Ireland, May 2005);
DIBt DIBt – Medienliste 40 für Behälter, Auffangvorrichtungen und Rohre aus Kunststoff, Berlin (Germany May 2005);
CNR-DT 205/2007 Guide for the Design and Construction of Structures made of Pultruded FRP elements (Italian National Research Council, October 2008);
ACMA Pre–Standard for Load and Resistance Factor Design of Pultruded Fiber Polymer Structures (American Composites Manufacturer Association, November 2010);
DIN 13121 Structural Polymer Components for Building and Construction (August 2010);
BÜV Tragende Kunststoff Bauteile im Bauwesen [TKB] – Richtlinie für Entwurf, Bemessung und Konstruktion (Germany, 2010).
The experience so far gained through the realization of whole FRP composite structures in many European and non-European countries, as well as the theoretical and experimental knowledge gained in this field makes it possible today to develop a single set of guidelines to be shared within the EC countries. These guidelines may compile a body of rules to be applied to the design and execution of full composite structures, based on the considerable scientific and technological progress achieved by member countries in this field. The availability of Guidelines will facilitate the free movement of FRP materials and contractors in the field building and construction within the European Community. This field offers all the prospects for a progressive expansion, with substantial positive consequences of economic nature. Such a development would undoubtedly be favoured by the existence of a body of shared rules able to ensure a uniform level of safety in the production and the use of FRP structures.
To achieve this outcome, CEN-TC 250 has appointed a Working Group (WG4) with the fulfillment of drawing up a scientific and technical report on Fibre Reinforced Polymer Structures. Members of this WG, under the convenorship of prof. L. Ascione, have been many experts from several European countries (L. Feo was one of them). The present lecture will summarize the main aspects of this report, which has been recently delivered by WG 4 and is now in the phase of transformation to CEN specifications.

9380 | Nonlocal effects in composites (1. Plenary lectures)

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Stress analysis of composites is usually performed within the framework of the theory of ‘homogenization’: if the scale of the microstructure is small relative to macroscopic dimensions, the material behaves ‘on average’ as though it is homogeneous, and local fluctuations about this average due to microscopic heterogeneities can be deduced from analysis of representative volumes subjected to prescribed mean strains.
Therefore, the macroscopic problem is analysed by assuming the body homogeneous and the stress and strain fields, solution of the homogenized problem, can be interpreted as ‘local averages’ of the actual, rapidly-varying, strain and stress fields. More precisely, at least for composites whose microstructure is considered as random, the ‘local averages’ are ensemble averages; for composites with periodic microstructure, the averaging is performed over ‘fast variables’. In either case, the ‘local average’ is not precisely a local volume average, except in the special case that the computed averages are uniform and the microstructure has an appropriate property of spatial invariance.
These procedures of “homogenization” can fail for some special practical problems in mechanics and of high importance for structural design such as in the case of fracture (see Luciano and Willis 2003 and 2005) or the localization phenomenon.
Still in the context of periodic microstructures, Triantafyllidis and Bardenhagen 1996, Boutin 1996, and later Smyshlyaev and Cherednichenko 2000 have studied the influence of the higher-order terms of the series expansion on the macroscopic behavior of linear elastic composites.
This approach of series expansion, which has been initiated by Sanchez-Palencia 1980 and 1987, has shown to be a rigorous and efficient method for introducing the effect of the macroscopic gradient of strain on the local response of linear composites. The asymptotic expansion method introduces the scale factor ϵ defined as the ratio between the characteristic length of the microstructure and the one of the applied macroscopic loading (see Bakhvalov, N.S. and Panasenko,1989). When this scale factor ϵ is very small compared with 1, there is a strict separation of the micro and macroscopic scales. In practice, the limit $\epsilon \to 0$ is taken in the expression of strains and stresses, and the standard homogenization framework can be used. When the parameter ϵ is close to 1, no homogenization is valid anymore. When ϵ is lower than 1 but not negligible before 1, the solution can be approximated by keeping higher-order terms in the series expansion. All these terms are then obtained by solving a hierarchy of higher-order elasticity problems with prescribed body forces and eigenstrains whose expressions depend on the solution at the lower-order (Boutin 1996, Smyshlyaev and Cherednichenko 2000).
In the case of random media, Drugan and Willis (1996), obtained approximation for the gradient and higher-order terms in the series expansion.
On the contrary, Luciano and Willis (2000, 2001 and 2003) obtained bounds, in the Fourier space, on the fully nonlocal constitutive laws for composites and laminates by using micromechanics.

These procedures, however, leads to inaccurate predictions close to any boundary, and a more complete analysis, accounting for nonlocal interactions between inhomogeneities, is necessary also for finite bodies. If the microstructure is specified precisely (e.g. if it is known to be periodic), an exact calculation can be performed, at least in principle. If however, the microstructure is random, some other approach is necessary.
The present authors, by following the procedure proposed in (Luciano and Willis, 2005 and 2006) develop an approach, based on a stochastic variational principle and the approximation of Hashin and Shtrikman (1962a,b). It generates an integral equation, whose kernel is related to a Green's function defined for the body in question that is obtained via finite elements.

9474 | Active Morphing Composites and Structures: Challenge and Prospect (1. Plenary lectures)

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As one kind of smart materials, shape memory polymers (SMPs) and their composites (SMPCs) are capable of changing shapes, stiffness, strain or sizes when exposed to an external stimulus, including heat, electric and magnetic field, solution and light, etc. The special features make them become the promising materials for shape changing and memory structures, which extends broad applications in the future. Advantages of SMPs and SMPCs are fast response, long lifetime, high resilience, light weights, stretchable, low cost and easy processing. In particular, their stiffness can be changed in a large scale when triggered by temperature or other stimuli. Moreover, they can also deliver active properties and autonomic responding. Multiple shape memory effect, multistage stimulus and reversible actuation are also systematically investigated, indicating that this kind of materials not only remember more than two shapes but also respond diverse stimuli.
Currently, the potential applications of SMPs and SMPCs in multifunctional and structure materials are developed. The high-performance, loadbearing substructures of aircraft, satellites and robots are designed for structural efficiency. Active functions such as sensing, actuating, energy harvesting, and propulsion are added by attaching components to the actuated bending, extending, and folding structures that would promote the development of large-scale deployable structures and morphing wings. Nowadays, the deployable space hinges, boom and three-longeron truss structures have been developed, designed, analyzed, fabricated, evaluated for the future aerospace application. Besides, smart mandrels based on SMPs, which are dimensionally accurate, rapidly removable, and reusable, have been developed for fabrication of complex-curved composite structures. 4D printing has also been generated through adding another dimension, the time-dependent shape change, to 3D printing. Other applications for novel SMPs and SMPCs include smart sensors, tactile displays, self-healing systems, smart textiles, biomedical devices etc. Most widely recognized potential is for fabricating flexible display, anti-counterfeiting brands, artificial blood vessels, and information carriers. Furthermore, the composites with such special functions do not need to be restricted to solid constituents, but can incorporate fluid networks.
SMPs and SMPCs have enormous impacts on number of fields and could significantly accelerate the advancement of novel composites and structures that have excellent performances including shape changing and memory, variable stiffness, and so on. They demonstrate significantly potentials for the applications of composite materials and structures.

5402 | Investigation of Microstructure and Texture of Al-Al2O3-B4C Composite Produced by Accumulative Roll Bonding (ARB) Process (2. Analysis of composite beams, plates and shells)

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In this study, accumulative roll bonding process was used to manufacture an aluminum matrix composite with dispersed anodized alumina and boride carbide particles. The anodizing and accumulative roll bonding processes are used in this paper for manufacturing high-strength and highly-uniform composites. Furthermore, the microstructure evolution and deformation texture of the composite samples are reported. The microstructure of the fabricated composites after eight cycles of the accumulative roll bonding process showed an excellent distribution of reinforcement particles in the aluminum matrix. The results indicated that after accumulative roll bonding process, the overall texture intensity increases and a different-strong texture develops. The main textural component is the Rotated Cube component.

5675 | COMPARITIVE STUDY OF CONCRETE FILLED STEEL TUBE STRUCTURE WITH TRADITIONAL REINFORCED CONCRETE AND STEEL STRUCTURES (2. Analysis of composite beams, plates and shells)

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The objective of the present study is to understand the behavior of the Concrete Filled Steel Tube (CFST) system for high-rise building and to design structural systems including effects of the lateral loading. Also study of the confinement effect in concrete due to steel tube is done. Comparative study on CFST, RCC and Steel structure with 20 storey with all structural systems as frame structure is carried out. CFST category is also further subdivided in three types, with only rectangular CFST columns, with only round CFST columns and with both CFST columns and beams. Determination of the design load-carrying capacity and subsequently comparison to Euro code and AISC method with manual results and SAP 2000 results was done.

6367 | Analysis of cylindrical sandwich structures under moving loads (2. Analysis of composite beams, plates and shells)

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An analysis of cylindrical sandwich structures with weak orthotropic core subjected to patch loading is presented. A high order theory model combined with a novel formulation technique are used to predict the static response of the structure. The face-sheets are considered as thin shells that follow the first order shear deformation theory, whereas the core is considered as a linear elastic medium. The effects of core elastic and shear stiffness, curvature to length ratio, and stacking sequence and orientation on the core's stresses and displacements are presented. The case of a moving load is explored and performance charts are generated to design and optimize the structure in response to the patch loads. In particular, considering an orthotropic core with

quasi-isotropic lay-up in the face-sheets, limit the variation of the transverse core shear stress and provide an efficient structural design configuration.

6374 | Active shape and vibration control for piezoelectric bonded smart structures using various geometrically nonlinear theories (2. Analysis of composite beams, plates and shells)

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Piezoelectric integrated thin-walled smart structures with cross-ply or angle-ply laminates are increasingly applied in many fields of technology. Due to the high costs of experimental investigations, an accurate nonlinear finite element model (FE) is required for the shape and vibration control of smart structures. This paper is going to develop various geometrically nonlinear FE model based on first-order shear deformation hypothesis. The geometrically nonlinear theories considered in the models are including von Karman type nonlinear theory, moderate rotation shell theory, fully geometrically nonlinear shell theory with moderate rotations and large rotations. Several examples of composite laminated structures are investigated, and some of the results will be compared with those in the literature.

6832 | Analysis of Randomness Function Frequency Response of Composite Plates (2. Analysis of composite beams, plates and shells)

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This paper realizes a numerical treatment of uncertainty for the modulus of elasticity in structural composites. The choice of the elastic modulus is justified to be an extremely influential in the dynamic response of structures design variable, as any variation may involve, for example, the possible existence of damage in the structure. The treatment is performed via numerical finite element modeling considering a probability distribution for the modulus of elasticity. The answers will be expressed through the frequency response functions (FRF's) of the material obtained in the MatLab ® programming environment.

Key-words: randomness; function frequency response (FRF’s); structural composites.

6852 | Equilibrium of a Guastavino helical stair (2. Analysis of composite beams, plates and shells)

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An analytical structural study of general helicoidal timbrel staircase shell is presented. The analysis is based on the assumption that the material is unilateral, namely a no-tension material in the sense of Heyman; in particular the safe theorem of Limit Analysis is adopted. In the spirit of the safe theorem the structure is stable if a statically admissible stress field can be constructed; for the unilateral material here employed, singular stress fields, that is stress concentrated on surfaces (membranes) or lines (arches) are allowed. The statically admissible stress fields that I construct, combining membrane stresses and 3d diffuse uniaxial stresses, are purely compressive and balance transverse loads either uniformly distributed or localized. A simple order-of-magnitude calculation confirm that bending and torsion resistance is small compared to the structural demand, and that the level of compressive stresses required to balance the load is below the limit compressive threshold.

6883 | Study on the behavior of slim-floor composite structures (2. Analysis of composite beams, plates and shells)

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Slim-floor structures offer a range of benefits which must be considered in the context of the projects. The shallowness of the floors is achieved by placing the slabs and beams in the same plane. An added benefit is that a flat shape is achieved and there are none of the interruptions found with down stand beams. Another important advantage provided by the slim-floor systems is the increase of fire resistance as the steel beam is contained within the depth of the floor deck. In order to assess the influence of the concrete in the flexural behavior of the shallow floors, a numerical study based on experimental results was carried out. The computational model of an encased beam subjected to bending was calibrated and the results compared to the flexural behavior of the same beam in the conventional solution. The results showed the interaction between concrete and steel increases the resistance of the element, reducing instabilities and also producing slenderer solutions when compared to the reinforced concrete structures.

6934 | Buckling of Composite Plates under Biaxial Compressive Loads (2. Analysis of composite beams, plates and shells)

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This research paper presents studies on the buckling performance of carbon/epoxy plate that are loaded under biaxial compressive loading. Finite element models are developed using commercial softwares ANSYS and Abaqus. The focus of the study is on the simplified plate design utilising angle-ply laminates, [±θ], and its effectiveness relative to designs from existing works in the literature.

The influence of boundary conditions, plate aspect ratio, loading conditions and ply orientations on the buckling performance of the composite laminate are also studied. The performance of composite laminate, such as [±25] and [±20] are compared with conventional and dispersed layups. Results show that [±θ]n orientation can achieve better biaxial buckling performance, as compared to conventional layups. In addition, comparable performance can be obtained with lesser plies. The results have been verified with analytical solutions that have been presented in the literature.

7014 | Nonlinear Dynamic Instability Analysis of Laminated Composite Stiffened Plates (2. Analysis of composite beams, plates and shells)

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A finite element nonlinear dynamic instability analysis of laminated composite stiffened plates subjected to uniform in-plane harmonic edge loading along the two opposite edges is presented in this paper. The eight-noded isoparametric degenerated shell element and a compatible three-node curved beam element are used to model the plate skin and the stiffeners, respectively. As the usual formulation of degenerated beam element is found to overestimate the torsional rigidity, an attempt has been made to reformulate it in an efficient manner. The Green-Lagrange strain displacement relationship is adopted to formulate the system matrices for both plate skin and the stiffener. The total Lagrangian approach is adopted in the formulation. Bolotin method is applied to analyze the dynamic instability regions. The frequency convergence criterion is used to find the instability frequency range.

7054 | Experimental investigation of failure process of the compressed channel-section GFRP laminate columns assisted with the Acoustic Emission method (2. Analysis of composite beams, plates and shells)

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The paper deals with experimental investigations of thin-walled channel section columns subjected to static compression. The columns under consideration were made with the autoclaving technique from 8 layers of a glass/epoxy unidirectional prepreg tape. Five different symmetrical layers' arrangement have been taken into account. The considered columns have been loaded with the force values from zero to the maximum load destroying the profile what allows to observe the columns' behavior till their failure. The strain-gauges measurement technique have been employed to determine the equilibrium paths, the buckling loads and the post-buckling behaviour. During all tests the AE equipment AMSY-5 made by Vallen firm for detection of acoustic emission phenomena have been applied. The use of the Acoustic Emission method allowed to investigate the behavior of composite structures in the phase prior to their destruction. However, a detailed analysis of the full AE signal allows identification of many damage mechanisms prior to the structure's destruction. The results of experimental investigation have been used to validate the proposed FE model allowing to analyse the post-buckling behavior and - together with the well-known failure criteria - determine the failure load.
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7545 | EFFECT OF TRANSVERSE CRACKING IN [θm/90n]s COMPOSITE LAMINATES WITH HYGROTHERMAL CONDITIONS - DESORPTION CASE - (2. Analysis of composite beams, plates and shells)

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Two analytical approaches were used to predict the effect of transverse cracks on the stiffness degradation, Shear-lag model and variational approach for [θm/90n]s composite laminates and under different environmental conditions by the variation of temperature and transient moisture concentration distribution in desorption case. Good agreement is obtained by comparing the prediction models and experimental data published by Joffe. Furthermore the cracked angle-ply laminate is submitted to hygrothermal conditions. The transient and non-uniform moisture concentration distribution gives rise to the transient relative reduction of the longitudinal Young's modulus. The obtained results represent well the dependence of the stiffness degradation on the cracks density, fibre orientation angle of the outer layers and transient hygrothermal conditions.

7575 | Preliminary theoretical study on shear lag effect of the PC box girder bridge with a constant depth and corrugated steel webs (2. Analysis of composite beams, plates and shells)

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The prestressed concrete (PC) box girder bridge with corrugated steel webs is a promising steel-concrete composite structure. It has been constructed worldwide. Since 1970s there has been much research about the mechanical behaviors of this kind of bridges. However, the study on shear lag effect of the PC box girder bridge with corrugated steel webs is seldom found, and there also has been no relating guideline in the design standards or codes for the design purpose by now. In this paper, based on the energy variational principle, the theoretical solution of the PC box girder with corrugated steel webs with a constant depth is derived, with the assumptions that the flange longitudinal displacement expressed as a three-order polynomial function and the strain energy of the corrugated steel webs equals to zero. The shear lag coefficient at a certain cross section is then calculated based on the theoretical solution. Finally, the comparative study on the shear lag effect between the simply supported corrugated steel web bridge and the corresponding concrete web bridge is carried out when the uniformly distributed loads and concentrated loads are respectively applied. The results show that the shear lag effect in the corrugated steel web girder is more obvious than that in the concrete web girder.

7597 | The transient responses analysis of ply-dropped laminated composite beams by a developed reverberation–ray

matrix method **(2. Analysis of composite beams, plates and shells)**

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This study proposed a developed reverberation-ray matrix (DRRM) analysis method to analyze the transient responses of ply-dropped laminated composite beams based on classical laminated beam theory (CLBT) and the first shear deformation theory (FSDT) subjected to impulse force load. The developed reverberation-ray matrix is demonstrated in the global coordinate system, which represents the multi-reflected and scattered waves in the ply-dropped laminated composite beam. To validate the developed analysis method, we analyze the velocity response and discuss the wave propagation of a laminated cantilever beam with ply-drops under a smoothed triangular impact load. The axial-flexural and axial-flexural-shear coupled effects due to ply stacking sequences are also analyzed. The velocity transient responses of the ply-dropped laminated composite beam are also solved by the developed reverberation-ray matrix method (DRRMM) under a half-cycle pulse force. Compared with the spectral element method (SEM) and finite element method (FEM), the proposed approach provides results that are in good agreement with previous findings. The DRRMM has some advantages of the simpler and faster solving process, very few computing elements, the higher order accuracy of solutions in frequency domain.

7611 | A mixed variational, higher order zig-zag theory for highly heterogeneous layered structures (2. Analysis of composite beams, plates and shells)

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The bending response of laminated composite and sandwich plates is modelled using a higher-order variant of the Refined Zigzag theory originally introduced by Tessler and co-workers. The governing equations are derived using the Hellinger-Reissner mixed variational principle. The theory provides accurate predictions of the bending deflection and axial stresses for thick plates to with nominal errors compared to 3D elasticity solutions found in the literature. The advantage of the Hellinger-Reissner mixed formulation is that it captures the transverse stresses of a laminated beam accurately a priori, without the need for additional stress recovery steps. As a result, the axial and stress profile within highly heterogeneous layered structures, such as sandwich beams or laminates with delaminations, can be captured in a computationally efficient manner. This allows the theory to be coupled with fracture mechanics criteria to predict the onset of delamination growth. Finally, the relative influence of the zig-zag effect on different laminates is quantified using two non-dimensional parameters.

7656 | Geometrically nonlinear vibrations of slender meso-periodic beams (2. Analysis of composite beams, plates and shells)

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Geometrically nonlinear vibrations of slender Euler-Bernoulli beams are investigated. It is assumed that the bending and tensile stiffness and material density are periodically varying along the beam axis. It is also assumed that the beam can interact with periodically inhomogeneous viscoelastic subsoil. We assume that the period of inhomogeneity of a beam and subsoil properties, called the mesostructure parameter, is much smaller than the beam total length and still larger than its cross-section dimensions.
Problems of vibrations of such beams are described by a system of coupled, nonlinear differential equations. In the considered cases, the coefficients of the aforementioned equations are highly-oscillating, non-continuous, periodic functions of the x- coordinate. This causes significant problems in obtaining analytical solutions even in the small deflections regime.
In the field of structural mechanics, many methods of averaging mechanical properties of the structure are used, amongst them those based on asymptotic homogenization of differential operators. These methods lead to approximate models of the considered problems. The actual structure is replaced with a corresponding one, with effective properties and the original mathematical model is replaced by differential equations with constant coefficients. These methods usually neglect the effect of the periodicity cell size.
A non-asymptotic model based on the concept and basic principles of the tolerance modelling technique is proposed. Separation of meso- and macro-scale is done by a certain decomposition of unknown displacements into their averaged and fluctuating part and averaging the Lagrange function over a periodicity cell. In that way a system of differential equations with constant coefficients, some of which explicitly depend on the mesostructure parameter, is obtained.
The proposed model can serve as a tool in parametric analysis of problems under consideration. Solutions to the tolerance model of slender periodic beams can be obtained through an analytical-numerical method, using Galerkin orthogonalization and Runge-Kutta forward numerical integration.

7659 | Natural vibrations of thin microstructured FG plates (2. Analysis of composite beams, plates and shells)

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The dynamic behaviour for thin functionally graded plates with a special tolerance-periodic microstructure in planes parallel to the plate midplane is considered. The plates are assumed to have this microstructure along only one direction, but along the perpendicular direction the plate properties are constant. Considered plates consist of many elements treated as plate strips of length l, called the microstructure parameter. It is assumed that two adjacent elements are nearly identical, but two distant ones may differ significantly. Moreover, the plates of this kind have the size of the microstructure being of the same order as the plate thickness d, d~l.
Dynamical problems of these plates are described by partial differential equations, having highly oscillating, tolerance-periodic, non-continuous coefficients. These equations do not serve as a good tool in analysis specific problems of these plates. Hence, there are proposed various averaged models represented by equations with smooth, slowly-varying coefficients which replace the above mentioned equations. Plates of this kind can be treated as made of a functionally graded material, and here will be called microstructured functionally graded plates. In order to describe various thermomechanical problems of functionally graded structures or composites the known modelling methods, proposed for macroscopically homogeneous composites, are applied. Amongst them there have to be mentioned models of periodic plates based on the asymptotic homogenization method.
The first aim is to derive the so-called asymptotic-tolerance model equations of the microstructured functionally graded plates with the microstructure size of an order of the plate thickness, which describe the effect of the microstructure size. The second aim is to apply these equations and equations of the tolerance and the asymptotic model to analyse free vibration frequencies for microstructured plate strips with various boundary conditions and different functions describing a distribution of material properties. Results are obtained by using the Ritz method and for certain cases they are compared to those

calculated by the finite element method.

7671 | A simplified method to estimate the shear strength of steel-concrete-steel sandwich deep beams (2. Analysis of composite beams, plates and shells)

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Steel-concrete-steel (SCS) sandwich beams consist of a concrete core sandwiched between the outer steel plates. Composite action between the two materials is achieved through mechanical connectors like headed studs and tie bars. They also help to enhance the vertical shear capacity. The SCS system features high bearing capacity, good ductility and integrity, as well as excellent performance in impact resistance and leakage prevention. In recent years SCS structures are widely used in large sized structures like bridges, tube tunnels, nuclear power plants and core tube of high-rise buildings, which are strictly required on their seismic performance.
The flexural performance of SCS members is similar to reinforced members with equal steel bars in tension and compression. The resisting pattern is relatively clear. By contrast the shear behavior is complicated with more influencing factors. As shear becomes rather critical in thick members, such as that used in offshore structures and road decking, it is imperative to investigate the shear resistance of SCS members.
Based on the experimental study and the analytical model proposed previously, a simplified method is further discussed in this paper to estimate the shear strength of SCS deep beams (beams with shear span/depth ratio under 2.0). The calculation results of the simplified method show consistency with the previous model and the experimental results.

7686 | Validation of anisotropic damage model for the simulation of textile reinforced concrete shells exhibiting strain-hardening response (2. Analysis of composite beams, plates and shells)

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Textile reinforced concrete (TRC) is a layered composite material consisting of fine aggregate concrete matrix which is reinforced with several layers of carbon or glass textile fabrics. Thin-walled shell structures made of TRC can be used for the fabrication of shell structures with high load bearing capacity and complex geometries. TRC exhibits an anisotropic behavior due to the orthogonal structure of the textile fabrics and due to the development of multiple cracks. The multiple cracking of the matrix leads to strain hardening effect. Moreover thin TRC shell elements exhibit mostly a geometrically nonlinear behavior under transverse loading as well. For this reason finite strain theory should be taken into account within the simulation. In order to establish a method for the simulation of TRC shell structures an anisotropic damage model of microplane type is presented in this paper. This model works with a modified damage function to ascertain the level of deterioration of material. This damage function is calibrated on the basis of a tensile test on a TRC specimen and afterwards the model is validated by means of a series of bending and slab tests. To represent more practical aspects of the computational model a singly curved TRC shell structure is simulated. This structure has been fabricated in institute of concrete engineering in RWTH Aachen University and tested under a transverse distributed load inducing tensile stresses in large portion of the shell. Finite element simulation of this structure is included in this paper to assess the capability of the model for the prediction of crack formation and estimation of load bearing capacity.

7701 | Deflection and strength of a five layer sandwich beam – a nonlinear hypothesis (2. Analysis of composite beams, plates and shells)

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The first models of the three layer sandwich beams were presented by Libore, Butdorf and Reisner in 1948, and this models were developed in next year's. Because of their excellent properties, for example the high im-pact and heat resistance, good acoustic absorption, these structures are widely used in aerospace, automotive, rail and shipbuilding industry. Sandwich structures with a light core (e.g. polyurethane or metal foam) are sub-ject of contemporary studies.
The paper is devoted to five layer sandwich beam consisting of two outer layers (metal sheets), one core (met-al foam) and two binding layers (e.g. glue). The beam is simply supported and subjected to continuous con-stant intensity of the load, over the entire length of the beam. A mathematical model of the field of displace-ment, which includes a shear effect and a bending moment, will be formulated. Basing on the principle of sta-tionary total potential energy the system of equilibrium equations will be derived. Then will be approximately solved. The deflections, normal and shear stresses will be calculated for the family of the beams with different dimensions and material properties. For comparison reasons a finite element model of the beam will be formu-lated. The influence of the thickness and mechanical properties of the binding layers on the deflection of the beam under bending will be analysed. The comparison of the results obtained analytically and numerically will be presented in Figures and Tables.

7776 | Adaption of the FIB bulletin 14 design guideline for externally bonded bending reinforcement made of a Textile Reinforced Cement composite (2. Analysis of composite beams, plates and shells)

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Until now the most commonly used materials for externally reinforcing concrete structures are Carbon Fibre Reinforced Polymers (CFRP). Design guidelines exist for these CFRP-reinforcing materials and are described in the FIB bulletin 14. However, other cement matrix strengthening materials, such as Textile Reinforced Cement (TRC) composites are emerging, due to the increasing fibre volume fraction that can be achieved in production and the

resulting relatively high mechanical capacities. Currently, no design guidelines exist for the strengthening of concrete structures with these cementitious composite materials. This paper contributes to the adaption of the FIB bulletin 14 for TRC by proposing new design parameters for the modelling of debonding failure. To achieve this, 24 single lap shear tests, with different bond lengths and TRC thicknesses are performed and thoroughly analysed. Finally, the adapted design rules are evaluated by tests on 0.6 meter span TRC reinforced beams. Due to a difference between the observed (failure in composite action) and predicted (failure by loss of composite action) failure mode, the FIB bulletin 14 underestimates the ultimate bending load. These observations indicate the need for a new design method for TRC external reinforcement that goes beyond the adaption of the parameters in the existing CFRP design.

7791 | Analysis of Composite Plates with Stiffener Run-Out by pb - 2 Rayleigh Ritz Method (2. Analysis of composite beams, plates and shells)

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Fiber-reinforced laminates are very important in the aerospace sector as structural components and they are often designed as stiffened panels. To increase weight savings, it is becoming increasingly interesting use of composite cocured/cobonded assemblies but is well known that the weakest areas of such structures are typically the bond lines where premature failure is likely to happen due to stringer run-outs. Those phenomena, such as buckling, that might generate significant out-of-plane displacements, may cause skin-stringer debonds leading to complex and potentially catastrophic failure modes. For these reasons, as a general design principle, most of thick-sectioned primary structures are designed not to buckle, so it stands to reason that a precise calculation of the buckling and postbuckling behavior is essential in order to minimize the structural weight.
Furthermore, it is known that composite laminates have relatively low transverse shear stiffness and also in relatively thin composite laminates the shear deformation plays an important role in the global and local behavior of such structures. For this reason, the classical laminate plate theory (CLPT), which neglects the effects of out-of-plane strains, often provides not accurate and reliable results. Among the numerous theories used for laminated plates that include the transverse shear strain, the first-order shear deformation theory (FSDT) appears adequate for the engineering estimation of structural responses of composite laminates and simultaneously has some advantages due to its simplicity and low computational cost with respect to higher order theories. For plate bending and buckling analysis, the Rayleigh-Ritz method has been shown to be accurate and computationally efficient, whereas it's drawback usually lies in the choice of suitable displacement functions to satisfy the geometric and kinematic boundary conditions, resulting often restrictive in the type of plate boundary condition that is possible to model.
Recent developments concerning the analyses of rectangular plates, introduced the use of the pb-2 Rayleigh-Ritz method, which defines the displacements functions by the product of a boundary polynomial describing the plate's kinematic boundary conditions, with an orthogonal polynomial. There are significant benefits in using such displacement function, because the kinematic boundary conditions are easily satisfied by defining a suitable boundary equation.
This paper uses the pb-2 Rayleigh-Ritz method, with an orthogonal polynomial based displacement function, to study the elastic bending, buckling and postbuckling behavior of generally restrained rectangular stiffened plates with stiffener run-outs subjected to combinations of in plane uniaxial and biaxial compression, in plane shear and out of plane load actions. The basic bi-dimensional function is formed by the product of all the boundary equations, whose combination corresponds to free, simply supported or clamped edges. The orthogonal polynomials adopted are those of Chebyshev, Hermite and Legendre, and the degree of these displacement functions can be increased until the desired accuracy of the solution is reached. At this preliminary stage, the stiffeners are idealized as offset beams and a formulation based on the penalty method is used to enforce the congruence restraints between plate and stiffeners. A computer program was developed to solve the above-mentioned problems with the aim to provide a tool that can be used for analyzing a wide range of configurations and load cases. To verify the validity and the robustness of the present method, computed results were compared with those obtained by other methods and authors.

7851 | Acoustic Induced Vibration Response Analysis of Honeycomb Panel (2. Analysis of composite beams, plates and shells)

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The purpose of this paper is to develop a vibro-acoustic response analysis and verification method and process for structure that made from honeycomb panel. Up to now, most approaches for structure vibro-acoustic response analysis was to realize the acoustic behavior of structure due to structural vibration. The method was solving Helmholtz equation with boundary condition defined by the response along the boundaries of the structure due to exciting force. This paper describes a systematized structure vibro-acoustic analysis procedure for structure that subject to a sound source on its boundaries instead of exciting force. In this approach, at first, the numerical model of acoustic field and the honeycomb panel structure model are established and verified separately. These two validated models are then combined into one structure and acoustic model for vibro-acoustic analysis. The analysis result of combined model is refined and validated through correlation with physical test in a lab.
Finally, the validation procedure is developed by correlation of the combined model analysis result with physical test in the lab. In the future, this technical procedure can be used to predict the vibro-acoustic response of satellite during launch and thus be able to promote the development of our domestic satellite industry.

7870 | Finite elements for nonlinear free vibrations analysis of smart laminates subjected to in-plane loadings (2. Analysis of composite beams, plates and shells)

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Advanced composites, able to provide multi-functional capabilities besides the traditional structural functions, has been gaining attention in many technological fields. This inherent coupling of different physical fields can be exploited in transducer applications, structural health monitoring, vibration control, energy harvesting and other applications. Magneto-electro-elastic (MEE) composite materials are attracting increasing consideration as they couple mechanical, electrical and magnetic fields and this makes them particularly suitable for smart applications. Generally, single-phase materials exhibit either piezoelectric or piezomagnetic behavior and no direct magneto-electric coupling is observed. However, the full magneto-electro-elastic coupling can be obtained by using composites with both piezoelectric and piezomagnetic phases that provide the magneto-electric effect through the

elastic field. These MEE composites are obtained in the form of multi-phase materials, i.e. piezoelectric and piezomagnetic particles and/or fibers, or in the form of laminated structures, with piezoelectric and piezomagnetic layers stacked to achieve the desired coupling effects. Multilayered configurations appear to be more effective than bulk composites.
For the analysis and design of MEE structures, reliable and efficient modeling tools are required. Analytical solutions are available for simple configurations and, actually, numerical approaches need to be deployed for complex analyses. Fully-coupled 3D finite element solutions for multilayered plates and shells present very high computational costs; 2D laminated plate theories and the corresponding finite element solutions have been developed with the aim of reducing the analysis effort while preserving a suitable level of accuracy. In the framework of 2D plate theories, finite elements solutions based on equivalent-single-layer or layer-wise modeling have been proposed implementing different order theories. Recently, an equivalent single-layer approach for multilayered MEE plates and its finite element solution have been proposed by the author, who developed an effective purely mechanical plate model as result of the condensation of the electro-magnetic state to the mechanical variables. This model was systematically extended to refined equivalent-single-layer and layer-wise plates theories approaching the problem through a suitable application of the Carrera Unified Formulation (CUF). Finite element solutions for magneto-electro-elastic multilayered plates obtained by theories with different expansion order have been presented.
In the present work, a unified framework based on CUF is presented to develop layer-wise and equivalent-single-layer plate models for the nonlinear free vibrations analysis of MEE laminates. Variable kinematics with von Karman strains is assumed and approximated by standard isoparametric finite elements. Under the assumption of quasi-static behavior of the electromagnetic fields, the electromagnetic state of each single layer is preliminary determined by solving the corresponding governing equations coupled with the proper interface continuity and external boundary conditions. This allow condensing the electromagnetic state into the plate kinematics and the layer governing equations are inferred by the principle of virtual displacements. This approach identifies effective mechanical layers, which are kinematically equivalent to the original smart layers. These effective layers are characterized by stiffness and inertia load properties, which consider the multifield coupling effects as their definitions involve the electromagnetic coupling material properties. The layers equations are finally assembled enforcing the mechanical interface conditions. This allows obtaining the smart plate FE resolving system, which involves mechanical nodal variables only. Numerical results are presented.

7921 | Morphing structures: A refined, computationally-efficient solution for von Kármán shells (2. Analysis of composite beams, plates and shells)

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Morphing shells are nonlinear structures with the ability to shape-change and adopt multiple stable states. By exploiting this concept designers may devise adaptable structures, capable of accommodating a wide range of service conditions. This has the potential to minimise the design complexity and cost.
At present, models predicting shell multistability are often a compromise between computational efficiency and result accuracy. In this work, the multistability of thin composite shells is investigated through an accurate and computationally efficient energy-based method. The membrane and bending components of the total strain energy are decoupled using the semi-inverse formulation of the constitutive equations. Transverse displacements are approximated using Legendre polynomials and the membrane problem is solved in isolation by combining compatibility conditions and equilibrium equations. The result is the total potential energy as function of curvatures only. The minima of the energy with respect to the curvatures give the stable configurations of the shell.
The accurate evaluation of the membrane energy is a key step in order to correctly capture the bifurcation points. Here the membrane problem is solved by adopting the Differential Quadrature Method (DQM), providing accuracy of results at a relatively small computational cost [1]. The new model is validated against benchmark results, including: the multi-mode morphing of the unsymmetric thermally-actuated laminates [2], the tristable behaviour of a doubly-curved shell [3] and the snap-through load for a thin unsymmetric laminate [4]. The main advantages of the proposed model are summarised as follows:

- Accuracy of results: Using Legendre polynomials to approximate the transverse displacements, we have been able to capture accurately the values of the membrane and of the bending components of the total strain energy, as it is clear from the comparison with Eckstein et al. [2].

- Boundary conditions satisfied point-wise: Discretising the membrane problem using the DQM permits satisfaction of the boundary conditions in a point-wise fashion, as opposed to a weak form [3].

- Computational efficiency: The membrane problem has been solved combining compatibility conditions and equilibrium equation. This keeps the computational cost at minimum since the resulting differential operator is a small sparse matrix. The efficiency is particularly evident from the ability to capture the snap-through load with greater accuracy and using fewer degrees of freedom compared to the solution found using standard polynomial basis function [4].

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7926 | An approach based on the variable separation for finite element modeling of free edge effect for composite plates (2. Analysis of composite beams, plates and shells)

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Composite and sandwich structures are widely used in the weight-sensitive industrial applications due to their excellent mechanical properties. For composite design, accurate knowledge of stresses is required. But, they exhibit complex behavior due to anisotropy which renders the Classical Laminates theory inacurate. So, 3D FEM could be used but it drives to prohibitive computational costs. Other approaches consist of 2D theoretical models which can be classified as (i) the Equivalent Single Layer Models (ESLM), (ii) the LayerWise Model (LWM), (iii) the Zig-zag model.
This work deals with the assessment of an alternative approach based on the separation of variables for the modeling of the free edge effect in laminated composite plates. This is of major importance for damage of composite structures. The displacement field is approximated as a sum of separated functions of the in-plane coordinates x,y and the transverse coordinate z. This choice yields to an iterative process that consists of solving a 2D and 1D problem successively at each iteration. In the thickness direction, a fourth-order expansion in each layer is considered. For the in-plane description, classical Finite Element method is used.
Numerical examples involving several representative laminates subjected to uniaxial tension, widely used in literature, are addressed. The capability of the present LW method to capture the steep transverse stress gradients occurring in the vicinity of free edges is shown. Quasi-3D results can be obtained avoiding high 3D FEM computational cost.

7948 | An Advanced Computational Technique for the Development of Refined RMVT Based Shell Theories: The Axiomatic/Asymptotic Approach (2. Analysis of composite beams, plates and shells)

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The present work deals with the study of the effectiveness of the higher-order terms in the development of shell theories by using an axiomatic/asymptotic approach. The methodology consists in the evaluation of the contribution given by each single degree of freedom (DOF), independently from its location in the displacement field, in terms of accuracy of the results, once fixed an error parameter. The use of the proposed computational technique leads to the so-called Best Shell Theory (BST). This nomenclature is justified by the fact that the derived BST permits one to obtain the highest accuracy with the lowest number of DOFs. Generally it can be applied to different kinematic descriptions, such as Equivalent Single Layer (ESL), Zig-Zag (ZZ) and Layer-Wise (LW). The proposed approach along with the variable-kinematics shell theories are derived by combining Reissner's Mixed Variational Theorem (RMVT) and Carrera's Unified Formulation (CUF).With the application of the RMVT the transverse stresses become primary variables in the analysis along with the displacements and are modelled with a LW kinematics description. However, on the other hand, ESL, ZZ and LW approaches can still be efficiently used for the displacement variables. The Hierarchical Trigonometric Ritz Formulation (HTRF) is then used as solution technique to evaluate the free vibration characteristics of anisotropic thick deep composite cylindrical shells. Several study-cases are performed in order to provide a detailed explanation on the importance of carrying out a comprehensive axiomatic/asymptotic analysis in order to achieve the highest accuracy of the results with the lowest computational cost. The proposed advanced shell models are assessed by comparison with 3D elasticity solutions, when available in literature, and 3D FEM solutions obtained by exploiting the use of FEM software. Convergence of the formulation is thoroughly examined. The effect of significant parameters such as orthotropic ratio, stacking sequence, aspect ratio, lamination angle, length-to-thickness and radius-to-length ratios on the natural frequencies is discussed.

7957 | Influence of partially restrained (PR) moment connection on the overall behavior of composite steel plate shear wall (CSPSW) (2. Analysis of composite beams, plates and shells)

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Nowadays, steel plate shear walls are one of the most commonly lateral force resisting systems applied in high-rise buildings. To prevent instability of the steel plate that occurs during moderate more frequent seismic events, causing periods of disruption of functionality and occupancy due to exchange of the steel shear panels, its stiffening seems as rational option. One way of stiffening the steel plate, which proved to be efficient as well as economically viable, is use of reinforced concrete panels placed on one or both sides of the steel plate. Such systems are called composite steel plate shear walls (CSPSW) and have high ductility, improved ultimate capacity and stable hysteretic behavior providing excellent energy dissipation. Steel columns and girders of such systems serve as boundary members to resist gravity loads and overturning moment, while the composite infill panels provide major resistance to shear forces. Composite panels dramatically increase system lateral stiffness thus avoiding excessive drift and reducing seismic demands on the steel frame. These facts allow application of partially restrained (PR) beam-to-column connections. PR connections are more cost-effective than fully restrained (FR) ones, and enable simpler and faster erection of the structure. Moreover, due to composite panels above and below the beam-to-column connections which act as gusset plates and stiffen the connection and frame members there is no need to utilize FR connections. Behavior of the CSPSW with PR connection will be obtained through experimental test of 1:5 scale specimens under monotonic and cyclic loading in order to characterize seismic behavior parameters (stiffness, energy dissipation, ductility as well as ultimate capacity). The experimental data will serve for calibration of the numerical model needed for detailed parametric analysis of connection influence on composite steel plate shear wall system behavior.

7968 | Analysis of a Orthotropic Cylindrical Cantilever Beam under Transverse Loading (2. Analysis of composite beams, plates and shells)

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Curved and straight tubes are structures that are frequently used by the aerospace, offshore and infrastructure industries. Prediction of the state of stress and strain in different layers of curved and straight tubes are of theoretical interest and practical importance. Stresses in a thick arbitrary laminated cylindrical cantilever beam under transverse loading is investigated by layerwise theory. The most general displacement field of elasticity for arbitrary laminated orthotropic straight tube is developed. A layerwise theory is then employed to analytically determine the local displacement functions and the interlaminar stresses under transverse loading. Some design guidelines are developed based on the results.

8045 | Experimental and numerical study on temperature dependent anisotropic visco-elastic properties of the printed circuit board (PCB) patterns (2. Analysis of composite beams, plates and shells)

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A warpage of printed circuit board (PCB) induced by reflow process became the one of the major concerns in the production of multilayer PCB. It is because the warpage can cause serious reliability problems in solder ball interconnection between the semiconductor chips and PCB layers. Moreover, the number of layers in one PCB is increased dramatically over the years for the high integration. Therefore, it is essential to predict the warpage of multi-layerd PCB to increase the reflow process reliability. However, it has been impossible to conduct the warpage analysis of PCB by using a convention full modeling in finite element analysis considering each of the patterns and their thermo-visco-elasticity due to long computing time and its complexity.
In this work, an equivalent visco-elastic modeling technique of several PCB patterns (line, square, and grid) was proposed to simplify a finite element model of the PCB for the cost-effective simulation based on the classical laminate plate theory. Also, an experimental verification was conducted using a beam-transfer vibration test. From the study, the visco-elastic properties of each PCB patterns with respect to time and temperature were measured compared to the equivalent model proposed in this work. As a result, good agreement between equivalent model and experimental results could be successfully achieved. The proposed visco-elastic properties modeling technique were successfully used in the finite element analysis for the warpage prediction of the multi-layerd PCB sturucture.

8085 | Failure mechanisms of sandwich beams with stainless steel mesh faces and aluminum foam core under static and dynamic loading conditions (2. Analysis of composite beams, plates and shells)

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The foamed aluminum panels and sandwiches manufactured using powder metallurgical technique represent new class of structural materials possessing enormous application potential in lightweight constructions, mainly as an alternative to wood, plastics or various expensive sandwiches. This paper investigates the collapse mechanisms of composite sandwich beams under static and dynamic loading conditions. Closed-cell aluminum foam AlSi10 with 400±10 kg/m^3 density was used as core material, while stainless steel mesh is the faces materials. In order to characterize these composite materials first were carried out a complete static and dynamic tests for both faces and sandwich core as follows: tensile and three point bending tests on steel mesh for two different directions; compression and three point bending tests on foam material respectively.
The compression tests of the sandwich core were carried out on cubic specimens (16.5 mm x 16.5 mm x 16.5 mm) without skin, while three point bending tests were carried out on rectangular bar samples with dimensions: thickness = 17 mm, width = 17 mm, span length = 75 mm. The tensile and bending tests of sandwich faces were tested in both cases: without metallic foam inside of the stainless steel mesh (before to be bonded to the foam structure) and with metallic foam inside of the stainless steel mesh (after the faces were bonded to the core structure), on rectangular specimens with dimensions: thickness = 2 mm, width = 15 mm, span length = 120 mm.
Static and dynamic three point bending tests were performed on sandwich beams using a Phantom v12.1 High Speed Camera and a Digital Image Correlation system ARAMIS for strain distribution. All experimental tests were performed at room temperature (23°C) with constant crosshead speed of 0.33*10^-4 m/s for static tests and 2 m/s for dynamic tests. All tested specimens were cut from the same plate.

Key words: composite sandwich beams, static and dynamic tests, surface strain mapping, closed-cell aluminum foam, steel mesh faces.

8095 | Local web-buckling of shear-deformable laminated composite beams under shear and uniaxial compressive loads using discrete plate analysis (2. Analysis of composite beams, plates and shells)

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Local web-buckling of shear-deformable laminated composite beams under shear and uniaxial compressive loads using discrete plate analysis

Torsten Kuehn, Hartmut Pasternak and Christian Mittelstedt

This paper discusses a novel closed-form analytical approach for the local flange buckling analysis of thick-walled beams with close-profile cross-sections under shear and compression loads. The web and the flanges of the beams are assumed with symmetric stacking sequences. Based on a discrete plate analysis approach the flange under consideration is idealized as a plate that has two rotationally restrained edges wherein the rotational restraints depend on the properties of the web of the beam. For the restraint stiffness that is taken to represent the remainder of the beam's cross-section, straightforward closed-form approximate solutions can be postulated. The buckling analysis as well as the calculation of the restraint stiffness is based on first-order shear deformation theory in order to account for transverse shear effects as they become relevant in moderately thick composite laminates. In order to derive a closed-form solution for the critical buckling load, adequate sets of shape functions are postulated for the buckling deflections as well as for the rotations of the laminate cross-section in the buckled state. The buckling condition is then derived from the principle of minimum elastic potential of the laminated plate in the buckled state. It will be shown that the employed shape functions allow for a very reliable determination of the local buckling modes of the flanges of composite beams and the corresponding critical buckling loads in a fully closed-form analytical approximate manner.

8171 | FE analysis of CFRP-strengthened timber finger-joint (2. Analysis of composite beams, plates and shells)

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The aim of this work was to study the mechanical behavior of timber beams externally reinforced using CFRP under bending test. Experimental and predicted results are presented. Numerical simulations based on the Cohesive Zone Model (CZM) are presented in order to allow for accurate description of the progressive damage of the bond-lines up to final failure. The numerical and measured in terms load-displacement response results in addition to the failure modes are compared. It was observed that the obtained results show that the proposed formulation can efficiently capture the global response with acceptable accuracy.

8208 | Composite Concrete Elements Reinforced by Perforated Steel Sheets; Corbel Approach (2. Analysis of composite beams, plates and shells)

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The current European road network and concrete bridges in particular have suffered in the past few decades serious and increasing damages, due to e.g. insufficient maintenance, incorrect calculation assumptions, change in use, constructional mistakes, environmental influences, etc. As engineering structures are designed in planning and execution according to current regulations and state of the art, the maintenance of such structures constitutes a serious problem for engineers. Although the addition of new reinforced concrete layers is a common practice to increase the shear capacity of a structural element, the objective of the paper is the development, optimization and assessment of an innovative steel reinforcement in form of a planar reinforcing element embedded in concrete, replacing common reinforcing bars. Through an optimization procedure, the dimensions and the distance of perforations on the steel sheet were decided, so that the load transfer through the initial crack formation is ensured with a simultaneous high exploitability of the reinforcement. The bond between the two materials constituting the composite element is investigated. Of great interest is the behavior of the structural concrete element formed within the main perforations of the steel sheet, which is assumed to act as a corbel. Analytical formulations are applied and the results are compared to 2D and 3D finite element models.

8344 | EFFECTS OF ENVIRONMENTAL CONDITIONS ON THE MECHANICAL PROPERTIES OF PULTRUDED GFRP (2. Analysis of composite beams, plates and shells)

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Composite materials have many advantages, such as high tensile strength for a low density and no corrosion susceptibility, which make their use attractive in civil engineering. Bending tests have been carried out to evaluate the effects of various environmental conditions on the long-term mechanical properties of GFRP coupons. The coupons were cut from pultruded profiles. Specimens were tested as-received and after aging in distilled water or salt solutions at room temperature and in distilled water at 75oC, for different immersion times. The Young's modulus, failure load, failure strength and vertical displacement were determined for bending parallel to the 0o fibers orientations. Both strengths and Young´s moduli were generally decreased with environmental aging, while the vertical displacements were increased.

8597 | Variable kinematics models for buckling and vibration of multilayered panels (2. Analysis of composite beams, plates and shells)

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Linear vibration and buckling of multilayered panels are analyzed by means of a variable kinematics approach to construct refined 2D models. We refer to a Unified Formulation for the construction of a large variety of 2D models. Classical higher-order displacement-based models as well as advanced mixed formulations based on Reissner's Mixed Variational Theorem are considered. In the latter case, the transverse stress field is modeled independently from the displacement field. The full 3D constitutive law is retained in all models whose kinematics is capable of correctly resolve the Poisson effect. A Navier-type solution is used to solve the resulting 2D problem for orthotropic, simply-supported panels. No approximation is made for the curvature terms of shell geometries. Plates are special cases of shells with zero curvature.
Bifurcation buckling is addressed by means of a linearized stability analysis of in-plane loaded plates and of axially loaded cylindrical shells. Geometric non-linearities are introduced by referring to the Green-Lagrange finite strain measure and the consistent work-conjugate stress measure is employed which uses constant tangential moduli. By combining the geometric stiffness matrix related to an initial stress state with the linear stiffness matrix, the influence of membrane initial stress states on the vibration response is investigated.
A systematic analysis of the model kinematics on the response of multilayered panels under membrane loading is thus proposed. Laminated as well as sandwich structures are addressed. It is shown that refined models are required for capturing the local response induced by the strong geometric and constitutive heterogeneities of sandwich structures.

8625 | Damage characteristics of unidirectional carbon fabric/epoxy composite laminate subjected to lightning strike (2. Analysis of composite beams, plates and shells)

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This study investigates the damage response of unidirectional carbon fabric/epoxy composite laminates subjected to an artificial lightning strike. The strike with amplitude voltage 50kV (45kA) and 30kV (25kA) are inflicted on two stacking sequenced ([452/02/-452/902]s, [302/02/-302/902]s) UD carbon fabric/epoxy laminates. Damage characteristics are evaluated using image processing technique, ultrasonic scanning and field emission scanning electron microscope. The results showed that the damage shape and evolution on the laminate specimen greatly influenced by voltage of the strike and stacking sequence. Intense ablation followed by a blow-off impulse can be observed on the surface of the specimen when it is inflicted by 50kV-voltage strike, the damage shape for specimens with 30° on the surface layer presented a cross form with notable fiber blow up and resin deterioration in the fiber direction while a center hole damage shape was demonstrated for the 45° sample. Besides, only impulse damage can be observed in the 30kV situation

and a rhombus damage shape can be seen for both sample cases. Ultrasonic scanning showed that the UD carbon fabric/epoxy laminates present good impact resistance with damage penetrated only through 2~3 layers depth. The nylon binder vertical to the fiber direction of UD carbon fabric influenced dramatically both the state and mechanism of the damage from the simulated lightning strike.

8630 | Shape Control of Flexible Beams Laminated with Liquid-Crystalline Elastomer actuators (2. Analysis of composite beams, plates and shells)

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When Liquid-crystalline elastomers (LCEs) are illuminated by ultraviolet or visible light, the LCEs can produce large deformation, such as reversible contraction and expansion, and even bending. LCEs can convert light energy directly into mechanical work (the photomechanical effect) with the aid of photochemical reactions. As LCEs are the materials having both properties of liquid crystals (LCs) and elastomers, the LCEs can be made as the soft actuators which could play an important role for novel applications in micro-drive and shape control. This paper gives the study in the shape control of flexible beams using LCE actuators. The mechanical properties of LCE actuators, such as photo-induced force and moment, are studied first. The deflection equations of simply supported beam and cantilever beam laminated with LCE films are derived respectively. According to the deflection expressions, the shape control of beams laminated with LCE films is analyzed using mathematical simulations. Simulation results show that the shape of beams laminated with LCE films can be controlled by light with different intensities.

8641 | the effective flange width calculation for box girder bridges with varying flange thickness (2. Analysis of composite beams, plates and shells)

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In box girder bridges, the stresses are actually not uniform through the width of the flange due to the action of in-plane shear strain in the plate, which is the so-called "shear lag". In order to make the elementary beam bending theory still applicable to the box girder bridge, an appropriate reduced uniformly stressed effective flange width is used to replace the actually acting flange width, which not only takes the shear lag effects into account, but also makes the design easier and simplified. Most of the design codes have different specifications on the calculation of the effective flange width of box girder bridges based on different philosophies of simplification and different compromise between accuracy and simplicity. In this paper, three usually used methods for the calculation of the effective flange width are studied from the point of views of computing efficiency and accuracy. The study is carried out based on the three dimensional finite element models of a three-span continuous prestressed concrete box girder bridge and a special steel-concrete composite box girder bridge with corrugated steel webs. Both bridges have varying flange thickness and the effect of the variation of the flange width on the effective flange width is also studied. The method with the best computing efficiency and accuracy is then suggested for the further study of effective flange width based on the results of the analysis.

8644 | A new displacement based plate model accounts for transverse shear stress free conditions and transverse normal strain (2. Analysis of composite beams, plates and shells)

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A new displacement model is proposed for analysis of functionally graded (FG) plates which ensures top and bottom transverse shear strain free conditions as well as non zero transverse normal strain along thickness of the plate. Proposed displacement model TOT8 is formed by blending of two plate theories from Reddy (Reddy, 1984) and Kant (Kant and Swaminathan, 2002).

The theoretical displacement based model presented herein incorporates plate deformations which account for the effects of transverse shear deformation, transverse normal strain/stress and a nonlinear variation of in-plane displacements with respect to the thickness coordinate.
The equations of equilibrium are obtained using principle of minimum potential energy (PMPE) and solutions are obtained in closed form using Navier's technique.

Analytical formulations and solutions are presented for the static analysis of all sides simply supported FG plates under static transverse load based on TOT8. The comparison of the present TOT8 results with 3D elasticity solutions and results from other higher order theories available in the literature shows that present TOT8 predicts the displacements and the stresses more accurately.

8649 | A BEAM ELEMENT FOR PC BOX-GIRDER BRIDGES WITH CORRUGATED STEEL WEBS (2. Analysis of composite beams, plates and shells)

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The PC box girder bridges with corrugated steel webs are one of the promising concrete–steel hybrid structures applied to highway bridges. However, the mechanical analysis of these structures has always been a challenge for engineers, since the classical Euler-Bernoulli and Timoshenko beam theories are not applicable to study the stress and deflection of them as the shear deformation in the corrugated steel web becomes large. Furthermore, the torsion

effects are very different for them because of the different transverse and in-plane flexural strengths of the individual plates. Some studies have been done for girders under pure torsion or pure bending, but practical bridges are subjected to bending and torsion simultaneously. Besides, the beam elements such as Beam188 or189 in ANSYS cannot be used for analyzing the behavior of this type of bridge under both bending and torsion because they cannot model the “accordion effect” of the corrugated steel webs. What's more, the 3-D finite element analysis can simulate the “accordion effect” of the corrugated steel webs more accurately but has poor computing efficiency.
so in this paper, an efficient beam element with 7 degrees of freedoms is developed to analyze the PC box girders with corrugated steel webs, taking account of both the bending and torsion. Based on the assumptions that the corrugated steel web carries no axial stress and its normal stress is negligible, the formula to calculate the axial and tangential displacements of an arbitrary point in the cross section of the box girder are deduced first. After the warping function of the cross section is introduced, the formula to calculate the normal stress and shear stress under constraint torsion are developed based on the equilibrium and compatibility conditions, and finally the differential equations of equilibrium are built for the PC box girder with corrugated steel webs under constraint torsion. Based on the assumptions that in the beam element the bending and torsion are not coupled and the warping function are derived by quadratic Hermit interpolation and torsional angles are determined by solving the geometrical equation with the warping functions known, the equation to calculate the stiffness matrix is gotten after the warping function of the cross section is solved from the homogeneous differential equation of equilibrium. The precision and computation efficiency of this beam element is verified by a numerical example.

8663 | Program ANSLACOP – Analitical solution of bending problem of layered composite plates (2. Analysis of composite beams, plates and shells)

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Anisotropic composition of layered composite plates requires "more accurate" mathematical and calculation models. By applying the Layerwise theory we can cover a wide range of problems of layered composite plates with arbitrary arrangement of layers through the plate thickness.

The analytical method of solving bending equations in the Layerwise theory is based on the assumed displacement field in the form of the double trigonometric Fourier's order. The analytical solution can be used as a test solution for solutions obtained by using numerical methods, including finite element method.

For Partial Layerwise theory, the paper present the equations of bending for layered composite plates and the algorithm for calculation of deflections and stresses in an arbitrary cross section of a simply supported rectangular plate loaded with distributed load (uniformly and sinusoidally). On the basis of the algorithm presented in this paper, author has prepared program called ANSLACOP (ANalytical SOlution of LAminated COmposite Plates) in FORTRAN, whose structure will be presented in the paper. It is presented that the solution obtained by using this program very quickly converges depending on the adopted number of members of double trigonometric order.

8664 | Analysis of influences at layered composite rectangular plates obtained using the program ANSLACOP (2. Analysis of composite beams, plates and shells)

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Closed solution to the problem of bending for laminated composite plates in the Layerwise theory is obtained by using double trigonometric Fourier's order.

This paper will present results and analysis of results obtained by program ANSLACOP (ANalitical SOlution of LAminated COmposite Plates) created by author of this paper. Program is based on assumptions given in Partial Layerwise theory. For the calculation of shear stress in the xz and yz planes semi-analytical method was used based on the conditions that must be fulfilled.

The paper will present changes the deflection in the middle of a simply supported rectangular plate depending on plate thickness, number and arrangement of the layers and types of loads. Also in results will be shown in pre-defined characteristic points of a simply supported rectangular layered composite plate for , i stresses depending of the number of layers, the thickness of the plate and load type. Based on analysis of results conclusions are derived and presented at the end of the paper.

8752 | LAYER WISE ANALITYCAL SOLUTION FOR FREE VIBRATION ANALYSIS OF COMPOSITE PLATES AND PLATES ASSEMBLIES (2. Analysis of composite beams, plates and shells)

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Multilayered composite structures are increasingly being used in aircraft and other industries. In the past, the use of composite materials was mostly confined to secondary and generally small or non-load carrying structures such as aircraft ailerons, fins and rudders which make use of thin laminates. The situation has changed over the years and fibre-reinforced material have steadfastly made their way to primary structures, therefore much thicker laminates are used.

The technique generally used to model a laminated composite structure, is based on the classical lamination theory (CLT) which assumes that the entire laminate behaves as though it is a single layer that has equivalent properties obtained by the superposition of all single layers. Probably for this reason the theory is also called equivalent single layer (ESL) theory. Since the multilayer structure is reduced to an equivalent single layer, traditional classical plate theories, such as Kirchhoff plate theory (CPT), or Reissner-Mindlin (first order shear deformation theory, FSDT) can thus be used to investigate the static and dynamic behaviour of laminated plates. Although ESL theory based on FSDT is reasonably accurate to describe the macro behaviour of multilayered structures, for thicker plates (which are often required for primary structures) more advanced theories are needed.

This has led to the development of the so-called layer-wise (LW) theory. In LW theory, each single layer can be modelled individually using classical plate theory, FSDT or higher order theory. Carrera’s Unified Formulation (CUF) is one of the most powerful and accurate methods to analyse laminated plates using layer-wise theory.

The main limitation of CUF is that the closed form analytical solution is only possible for plates that are simply supported all round, i.e. on all four sides,

otherwise solution of the equations of motion must be sought numerically (e.g. finite element method). This can be computational demanding for thick laminates due the high number of variables (at least 3 for each interface through the thickness for each node).

In this paper the equations of motion of a plate based on CUF layer wise formulation are solved analytically to produce solutions to free vibration analysis of plates with different boundary conditions. Any number of layers can be solved automatically, i.e. a method to simultaneously solve a generic number of coupled second order differential equations automatically is presented and employed.

The method is validated against results in the literature for simply supported composite and sandwich plates. It is subsequently used to produce benchmark solutions for other boundary conditions which will be compared with FE solutions obtained by NASTRAN.

Subsequently to the development of the analytical solution, the dynamic stiffness matrix of a strip element is presented. This paves the way to the possibility of analysing more complex plate assemblies (such as stiffened panels) in closed form solution, quickly, accurately and efficiently.

8757 | Effect of Boundary Conditions on Nonlinear Vibrations of Variable Stiffness Composite Plates (2. Analysis of composite beams, plates and shells)

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Modern fiber placement machines allow the manufacturing of laminates with spatially varying stiffness properties (Variable Stiffness laminates), and thereby offer the possibility to exploit the tailoring potential of composite structures. Thin-walled structures in advanced aerospace applications are often subjected to high dynamic loading and are therefore susceptible to vibrate at large amplitudes. In the present contribution, specific characteristics of the nonlinear, large amplitude vibration behavior of Variable Stiffness plates and in particular the effect of various types of boundary conditions on this behavior are studied.

A finite element based reduced order approach for nonlinear vibration analysis of plate and shell structures is employed for this purpose [1]. The approach makes use of a perturbation method that gives an approximation of the amplitude-frequency relation of the structure. After the determination of the linear natural frequency and corresponding vibration mode, the perturbation approach yields the initial curvature of the amplitude-frequency relation with a modest additional computational cost.

Recently, a new p-version finite element that uses a First-order Shear Deformation Theory was presented [2]. This element includes geometrical non-linearity and has been used successfully in investigations on the differences between the geometrically non-linear vibrations of Variable Stiffness Composite Laminates and traditional plates [2, 3].

The finite element integrated perturbation approach is compared with the p-version finite element approach and both approaches are further verified and validated by a comparison with standard (h-version) general purpose Finite Element program results for specific well-characterized Variable Stiffness composite plates. The two approaches will be used to investigate the influence of various types of boundary conditions on the nonlinear vibration behavior of Variable Stiffness plates.

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8759 | Efficient Models for Initial Post-Buckling Analysis of Variable Stiffness Curved Panels (2. Analysis of composite beams, plates and shells)

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Fiber placement technology has made it possible to automate the manufacture of complex composite structures. The built-in steering capabilities can be exploited to produce laminates with spatially varying stiffness properties, known as Variable Stiffness laminates. Both experimental and numerical researches have shown that significant improvements in structural performance can be achieved, particularly in the case of buckling, if Variable Stiffness designs are adopted.

In [1], the post-buckling behavior of Variable Stiffness (VS) plates was studied using a Finite Element implementation of Koiter’s initial post-buckling theory. This perturbation approach was employed to compute post-buckling coefficients, which are used to make a quick estimate of the post-buckling stiffness of flat VS plates and to establish a reduced-order model. In addition, the post-buckling analysis of Variable Stiffness plates was carried out using this reduced-order model, and the potential of the approach for application within optimization was demonstrated.

Recently an alternative method for computing the initial post-buckling response of Variable Stiffness cylindrical panels, based on the differential quadrature method, was presented [2]. Integro-differential governing and boundary equations governing the problem, derived with Koiter's theory, are solved using a mixed generalized differential quadrature (GDQ) and integral quadrature (GIQ) approach. The formulation was validated against benchmark analytical post-buckling results for constant stiffness plates and panels, compared with non-linear Finite Element analysis for Variable Stiffness panels, and the efficiency and potential for use within an optimization context were shown.

In the present work, the two approaches [1,2] are used to obtain relevant design information for Variable Stiffness curved panels by systematically investigating the relationship between pre-buckling stiffness, buckling load, and post-buckling stiffness for various types of Variable Stiffness configurations. The physics of the behavior is explained on the basis of the pre-buckling, buckling, and second-order deflection fields, further illustrating the advantages of the initial post-buckling approach in nonlinear buckling analysis.

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8820 | Improving Structural Damping of Composites by Viscoelastic Inclusions (2. Analysis of composite beams, plates and shells)

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Lightweight composite structures in a wide range of applications, including aircraft, wind turbines, land vehicles, mining, and marine structures, are required to demonstrate certain damping characteristics to mitigate vibration induced damage, noise and harshness, and acoustic signature. Incorporating constrained viscoelastic layers in composite laminates has proven to be an effective passive solution to enhance the damping response of structures without the need of more complex active systems. However, this structural arrangement leads to considerably lower mechanical properties (particularly stiffness) than the un-modified composites. The utilization of viscoelastic inclusions dispersed in the matrix is an alternative technique to increase the damping capability of the structure without significantly compromising its overall static strength. However, the information available in the literature on this topic is scarce, particularly in relation to the effect of the inclusions on static strength, fatigue performance, and overall structural damping properties of the composite material.
The present study aims to characterise the mechanical behaviour of laminated carbon-epoxy composites embedded with cork granules, which are a viscoelastic type material. The influence of the cork granules on the static mechanical properties of the carbon-epoxy laminate was assessed using tensile and flexural tests. Fatigue tests were performed to investigate the inclusion-induced stress concentration on the fatigue endurance. The damping behaviour of this hybrid material within the 0 to 5kHz frequency range was characterised using modal analysis approach utilising a laser vibrometer. The loss factors for both plain and hybrid specimens were determined using the half-power bandwidth method. Results show that the cork granule inclusions can significantly increase the loss factor at frequency range between 2kHz and 3.5kHz without compromising either the static strength or fatigue endurance. On the basis of high damping without excessive stiffness reduction, the inclusion of viscoelastic particulates prove to be a promising alternative to the constrained layer technique.

8850 | Three-dimensional Elastic Static Analysis of Sandwich Composite Plate Considered Imbue Layer Effects (2. Analysis of composite beams, plates and shells)

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Based on theory of elasticity, three-dimensional elastic static properties of a simple-supported sandwich composite plate considered the imbued layer effects were studied in this paper. The imbued layers caused by bonding adhesive of the plate were considered as functionally graded layers. It was supposed that elastic modulus was graded through the thickness following the exponential-law, while the Poisson’s ratio was a constant. According to the governing equations of the theory of three-dimensional elastic plate, the computational formulae of displacements and stresses, which exactly satisfied the governing equations and the simply supposed boundary conditions at four sides of the plate, were derived. The corresponding coefficients were determined on the basis of the continuity of different layers. Finally, the displacements and stresses of plate were given by substituting the coefficients back to the formulae.

8885 | Vibration of thin-walled laminated composite beams having open and closed sections (2. Analysis of composite beams, plates and shells)

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The use of thin-walled beam like slender structures made of laminated compose materials is found in many engineering applications such as helicopter rotor blades, construction industry, long wind turbine blades and few other situations. The behavior of these structures can be accurately predicted by a detailed finite element model using 3D/shell elements but the computational demand of such model will be extremely high. In order avoid this problem, a group of researchers tried to model these structures with one dimensional beam elements which will drastically improve the computational efficiency but the major challenge is to formulate such beam element that will be able to capture all effects and their couplings found in these complex composite structural system. It has drawn attention of a number of researchers which made this topic an active area of research in recent years. The studies carried out so far can be divided in two broad groups based on the technique used to determine the constitutive matrix of the bean element or beam cross-section stiffness. This is derived analytically in one approach whereas the other approach needs a two dimensional finite element analysis of the beam section to evaluate this constitutive matrix. The second approach is relatively more general because it can also be applied to beams having solid sections but the analytical approach, which is used in the present study, may be attractive due to relatively less complex as well as computationally involved specifically for thin-walled composite beams.

In this paper, an efficient beam element is developed to study the vibration characteristics of thin-walled composite beam having open section (I section) and closed box section. The formulation can accommodate any stacking sequence of the individual walls and consider all sorts of coupling between torsion, bending (bi-axial) and axial deformation. The effect of transverse shear deformation of the walls and out of plane warping of the beam section is taken into account where the warping can be restrained or completely free. In order to avoid some issues in the finite element implementation, Lagrangian interpolation functions are used to represent all deformation modes except the torsional deformation where Hermetian interpolation functions are used. Numerical examples are solved by the proposed element and the results (vibration frequencies) obtained are validated with those available from literature and/or detailed finite element analysis using a commercial code (ANSYS). The results show a very good performance of the proposed model.

8946 | A fully discretised nonlinear finite strip formulation analyses of thick viscoelastic plates subjected to time-dependent loading (2. Analysis of composite beams, plates and shells)

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A semi-analytical finite strip method was developed for the analysis of thick viscoelastic plates by using continuous harmonic function series that satisfies the boundary conditions in the longitudinal direction and piecewise interpolation polynomials in the transverse direction. The higher order shear theory of plate was used to obtain the sufficient formulation of thick plates. The mechanical properties of the material are considered to be linear viscoelastic by expressing the relaxation modules in terms of Prony series. A recurrence formulation was used to evaluate the entire deformation history that requires only the storage of the displacements from the previous time step only. The finite strip procedure based on the virtual work principle was used to derive the stiffness and geometric matrices. The out-of-plane load is used for deriving the initial deformation of plates and the nonlinear finite strip procedure is used to evaluate the critical load of viscoelastic plates in different times of loading.
A comprehensive parametric study was conducted where the maximum deflection of the thick viscoelastic plates subjected to time-dependent loads was calculated. The effect of the plate thickness on the maximum deflection and critical load of viscoelastic plates was also evaluated. The results indicated that the critical buckling load of the plate decreases with time when the relaxation modulus decreases. The results was verified using the other plates theory with thin thicknesses. Moreover, by using the higher order shear deformation theory of plates, the buckling factor of viscoelastic plates depends on the plate thickness at each time of loading which contracts with thin plates.

8958 | EFFECTS OF TEST SET-UP ON THE INDUCED INTERNAL TORQUE IN FOUR-POINT BENDING OF THIN LAMINATES (2. Analysis of composite beams, plates and shells)

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When using test coupons to predict the behavior of larger laminate components, it is important to ensure that the internal loading in the coupon is identical to that of the physical structure. In laminates, this process of determining internal loading is not straightforward because of the coupling between different modes of deformation, such as bending and twisting. The physical supporting structure prevents the laminate from deforming naturally, which induces additional internal loads. In order to accurately predict the stresses in the laminate, the total internal load consisting of both the induced loading as well as the externally applied loading must be considered. In this study, finite element simulations are used to predict the magnitude of the internal torque generated when angle ply laminates are loaded in 4-point bending. This test can represent the typical internal load distribution of thin structures in bending such as skin-stringer panels in aerospace applications. In the traditional 4-point bend test of angle ply laminates, the internal torque is the largest of the induced loads due to the bending-twisting coupling. In this paper, the ratio of the induced torque to the applied moment is presented for eight, 4-ply [+/-]s carbon-epoxy layups with respect to the d16 and d66 terms from their laminate compliance matrices. These graphs represent the first step in creating a series of design tables for predicting the internal loads for a variety of support and load configurations. Three features of the traditional 4-point bend test set-up that affect the magnitude of the induced torque have been studied: the load introduction method, the coupon width and the distance between the supports and loading noses. The first load case is the transversely clamped condition consisting of pairs of rollers which “sandwich” the laminate at both the support and loading positions. This fixture is typically used for fatigue testing when reverse loading is required and prevents the coupon from twisting about the longitudinal axis. The second load case is the simply supported condition which uses single rollers to load the coupon from the top and support the coupon from the bottom. In this case, the coupon is free to lift off the supports. In most physical assemblies, the surrounding structure will provide constraint that lies somewhere between these two cases.

The transversely clamped case produces a linear variation of torque with respect to the d16/d66 ratio because the twist in the coupon is fully resisted by the simulated ideal boundary condition. Even when the coupon width is varied, this linear relationship still holds true for the transversely clamped case. In general, the magnitude of the induced torque increases with increasing coupon width until a ratio of 1:1 between the width and the central gauge length has been reached. Coupons with a ratio of 1:1 can be scaled in size, and it was shown that a [20/-20]s laminate with central regions of 50 x 50mm and 1000 x 1000 mm both have the same internal loads. There is no change to the amount of torque induced when the distance between the supports and the loading noses are changed. This implies that for the transversely clamped case, the locations of the supports and loading noses could be adjusted to reduce the problems associated with large midspan deflections, while still maintaining the same internal load state.
For the simply supported case, the linear relationship between the torque and the d16/d66 ratio is not produced because less torque is generated when the coupon is able to lift off the supports. Increasing the distance between the supports and the loading noses also generated less torque as the longer spans allow the coupon to deform more freely. However, when the width of the coupon is increased, the simply supported case starts to behave more like the transversely clamped case.

8960 | BEHAVIOR OF R.C. COLUMNS CONFINED WITH CFRP AND SUBJECTED TO ECCENTRIC LOADING (2. Analysis of composite beams, plates and shells)

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The objective of this study is to investigate experimentally the effectiveness of FRP confined system to strengthen RC columns subjected to eccentric loads. Therefore, an experimental program including eight rectangular RC columns is set-up and tested under eccentric compression load in one hand to evaluate the suggested strengthening technique applied to strengthen RC columns using wrapping Carbon Fiber Reinforced Polymer CFRP sheets and in the other hand to study the effect of the eccentricity on the strength and ductility. Two type of confinement was applied in this study: fully confinement FC and partially confinement PC. Compared with the control ones, the strengthened columns showed an improvement in the obtained strength and ductility. The improvement in the compressive strength of the strengthened columns under eccentric loading is so pronounced as for that under concentric loading, particularly for higher eccentricity. Regardless to the type of confinement, partially wrapped or fully wrapped, the gained strength increased as the eccentricity increased. Moreover, the author suggested a modified analytical model to predict the effective FRP hoop strain. The predicted results obtained according to the modified model showed a reasonable approach to the results obtained experimentally

8963 | ANALYSIS OF STRENGTH DEGRADATION OF LATTICE COMPOSITE FUSELAGE SECTION CONTAINING RIBS WITH DELAMINATION (2. Analysis of composite beams, plates and shells)

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In frames of the FP7 ALaSCA project, it has been proven that the lattice structure has high potential (up to 20%) in weight saving of a future civil aircraft fuselage section in comparison with metal and composite structures with conventional semi-monocoque layout. However, the aircraft structure should meet the durability requirements during long-term operation. The main problem of providing the durability of composite structures is degradation of properties of composite materials due to climatic and impact factors.
One of the main objectives of investigations of lattice composite fuselage structures in frames of the FP7 PoLaRBEAR project is providing high durability of the structure during long-term operation. To attain the objective, the investigation of degradation of properties of the lattice composite fuselage structure with damaged ribs is carried out in frames of the PoLaRBEAR project. The investigation contains three consecutive tasks:
1 Investigation of reduction of load-bearing capability of lattice ribs with initial delamination;
2 Investigation of strength degradation of fuselage lattice structure containing the ribs with initial delamination;
3 Formulation of constraints and recommendations for lattice structure manufacturing technologies and for parameters of the lattice structure protection system providing minimum strength degradation.
The results of solving the first task have been presented at the 4th EASN Workshop and included:
o models and methods for the numerical estimation of strength properties degradation of the ribs with delamination,
o numerical validation of the methods,
o investigation of influence of the rib and delamination parameters on degradation of the rib strength.
The models and methods for the numerical estimation of strength properties degradation of the ribs with delamination proved to be reliable and it can be used to solve the task of investigation of strength degradation of fuselage lattice structure containing the ribs with initial delamination. This work presents the results of solving the task.
The algorithm for estimation of strength degradation of the lattice composite fuselage section containing the damaged ribs was developed on the basis of the technique for the numerical estimation of the ribs strength properties degradation. The parametrical finite-element model of the lattice fuselage structure with delaminated ribs was developed.
Analysis of influence of delamination in the lattice rib on the fuselage section strength properties was carried out based on the results of parametrical investigations on developed parametrical models.
The results of the investigations will be used for determination of parameters of protection system for the lattice ribs of composite fuselage section with advanced reliability.

8971 | Vibration Analysis and Genetic Algorithm Optimization for Control of a Composite Structure with Piezoelectric Elements Subject to Impact (2. Analysis of composite beams, plates and shells)

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As a baseline for treating flexible beam attached to central-body space structure, the generic problem of a cantilevered Euler-Bernoulli beam with piezoelectric actuator attached as appropriate along the beam and its control is solved in great detail. For comparative study, three generic configurations of the vibration of the combined beam and piezoelectric elements are solved, utilizing Euler-Bernoulli theory by both analytical and numerical methods. Selected configurations of the beam and piezoelectric elements are investigated, and three different control systems are investigated, PPF, PID and LQR, and assessed. Some preliminary results are illustrated in the extended absract. Based on the advantage of the Linear-Quadratic-Regulator, a generic control system have been designed using piezoelectric actuator to control the vibration of an elastic cantilevered beam subject to impulsive disturbance. The equation of motion for the system is elaborated using energy principle and full-state observer Linear-Quadratic-Regulator controller has been selected as the vibration control tool. To avoid iterative choice of Q and R in the LQR, Genetic Algorithm optimization scheme has been incorporated. Preliminary results was considered to be satisfactory, and further extension will be developed for more complex systems.
Next, impact resilient structures which are of great interest in many Engineering Applications varying from civil, land vehicle, aircraft and space structures are considered. For this purpose the impacted panel structure is considered and modeled as a set of Mindlin plates bonded together to represent a generic engineering structure. Utilizing analytical and computational approaches as well as considering progress in material science and technology, this work looks at a generic composite beam and plate structure subject to impact loading and carry out analysis and numerical simulation. The first objective of the work is to develop a computational algorithm to analyze flat plate as a generic structure subjected to impact loading for numerical simulation and parametric study. The analysis will be based on dynamic response analysis. The second objective is to utilize the computational algorithm for direct numerical simulation, and as a parallel scheme, commercial off-the shelf numerical code is utilized for parametric study, optimization and synthesis. Through such analysis and numerical simulation, effort is devoted to arrive at an optimum configuration in terms of loading, structural dimensions, material properties and composite lay-up, among others. Preliminary results for impact of GLARE composite plate has been assessed to be satisfactory and robust, and will be further extended.

9012 | NONLINEAR FREE VIBRATION ANALYSIS OF CLAMPED CIRCULAR HYBRID LAMINATED COMPOSITE PLATE (2. Analysis of composite beams, plates and shells)

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Nonlinear free vibration of symmetric circular fiber metal laminated (FML) hybrid plates is investigated. Considering the Von Karman geometric nonlinearity, the first order shear deformation theory (FSDT) is used to obtain the equations of motion. For the first time, five equations of motion of circular

FML plates are derived in terms of plate displacements. The obtained equations are simplified for analyzing the first mode of symmetric circular plates. Using Galerkin method, five coupled nonlinear partial differential equations (PDEs) of motion are transformed to a single nonlinear ordinary differential equation (ODE) which is solved analytically by multiple time scales method, and an analytical relation is found for the nonlinear frequency of these plates. The obtained results are compared with the published results and good agreements are found. Moreover, the effects of several parameters on linear and nonlinear frequencies and the free vibration response are investigated

9013 | Nonlinear vibration analysis of rectangular magneto-electro-elastic thin plates (2. Analysis of composite beams, plates and shells)

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Nonlinear free and forced vibration of a transversely isotropic rectangular magneto-electro-elastic thin plate with simply supported boundary conditions and

closed circuit electro-magnetic boundary conditions at top and bottom surfaces of the plate is studied for the first time based on the thin plate theory along

with the von Karman's nonlinear strains. The partial differential equation of motion is transformed to an ordinary differential equation by using Galerkin

method. A perturbation method is used to solve the obtained equation analytically and a closed-form solution is obtained for the frequency response and

nonlinear frequency of a rectangular magneto-electro-elastic plate. The results are compared with the available results. Numerical examples are carried out

to show the effects of several parameters on the nonlinear behavior of these plates.

Keywords: Magneto

9024 | Predicting Mechanical Behaviour of Tidal Turbine Blade Made of Composite Materials Using Finite Element Code (ANSYS) (2. Analysis of composite beams, plates and shells)

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The emerging field of ocean energy devices is naturally turning to composite materials due to their noncorrosive properties in the seawater environment as well as their high specific strength and stiffness. Composite materials are ideal candidates for manufacturing of turbine blades since they have longer fatigue life than many conventional engineering materials; tidal turbine blades are subjected to pressure, bending and cyclic loads from sea water currents and waves which ultimately cause failure. However, limited information is available regarding durability of composite materials in a sea water environment. Also prediction of failure modes and how these are affected by design remains a challenge in the development of tidal turbines. In this study we have combined experimental analysis and finite element analysis incorporating failure modes to determine the loci and extent of failure in a composite tidal turbine blade.

Initially static mechanical characteristics of two types of composite materials were examined according to ES BN ISO 14125; standard laminate and sandwich structures were compared. It was observed that although the ultimate strength of glass fiber reinforced epoxy is lower than the other composites tested, the stiffness of this composite is higher. Static mechanical tests on sandwich composite structures showed that decreasing the thickness of the core and number of layers will result in better mechanical properties as expected. Three-dimensional finite element analyses were then carried out to determine the stress, strain distributions and deflection contours of a test sample in the static mechanical tests to predict failure of the composite, to interpret the experimental results and to examine the failure modes of the specimens. Comparison between experimental and analytical results showed that there is a good compatibility between FEA and experimental results at lower loads in the load displacement curve of the static test. Deviations at high loads highlight the effects of defects created during the test. Various failure criteria were employed for failure prediction and failure mode identification and it was found that the major failure modes in the static mechanical test of composite materials are related to fiber tension and compression.

Considering results from quasi-static mechanical tests, fatigue tests following the ES BN ISO 13003 standard were performed on glass fibre reinforced epoxy resin and lower density sandwich structures via a fatigue rig with the capability of conducting tests in a sea water environment. Comparison between S-N curves resulting from fatigue tests indicates that Glass fibre epoxy resin has a flatter S-N curve than sandwich composite structures which is a result of the higher fatigue life of the glass fibre reinforced epoxy resin. Static flexure tests were also performed on composite specimens after different periods of fatigue testing to determine the degradation of their mechanical properties. SEM and light microscopy in conjunction with nanoindentation were used in order to analyze the failure mechanisms and it was found that interfacial debonding between fibers and matrix, resin cracking, and fiber breakage are the main failure mechanisms as expected.
In order to evaluate the mechanical behavior of a composite tidal turbine blade, a full blade was modeled in the ANSYS finite element software using materials properties determined from experiment. By doing static structural analysis on the blade, it was found that tidal turbine blades made of fiber reinforced epoxy resin shows a better mechanical performance than sandwich composites. Finally ANSYS Composite Pre-post and ANSYS n Code design life was deployed for investigation of the mechanical behavior of tidal turbine blades made of composites in which the static behavior and fatigue life of different blade designs can be predicted. Optimization of design by this method will be discussed.

9068 | EXPERIMENTAL TESTS OF SANDWICH COMPOSITE STRUCTURES IN FOOTBRIDGE DESIGN PROCESS (2. Analysis of composite beams, plates and shells)

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The advantages of glass fibers reinforced polymer (GFRP) composite make this material very attractive among specialists of various industries, including bridge designers. It is estimated that today in the world there are nearly a thousand of bridges, the construction of which is made wholly or partly of GFRP. Most of them are small span structures formed of thin-walled beam-type elements. In Poland, the current interest in using GFRP materials for the construction of bridges is not large, but noticeable. There are known a few cases of catalog structural composite parts application in bridge constructions. As representative examples two pedestrian bridges can be given: the truss footbridge in the Group Sewage Treatment Plant in Łódź made of composite profiles connected by metal elements and the arch bridge over the road S11 in Gądki with built-in a light deck made of composite panels.

The basis of the work – a pedestrian and bicycle bridge made entirely of composite sandwich structure – is being currently in the design phase. The project is supported by the National Centre for Research and Development, Poland (Fobridge research project No. PBS1/B2/6/2013) and realized by the consortium: Gdansk University of Technology (leader), Military University of Technology in Warsaw and the company ROMA Co. Ltd. The subject of the study is to elaborate architectural, material and construction design of pedestrian footbridge spans, made of composite materials. The structure of the considered spans will be of sandwich type with PET foam core and with outer lining surfaces made of glass fibre reinforced polymer laminates. The simple supported 12-16 m length spans are intended to be applied over two lanes roadways, four lanes double roadways and six lanes double roadways.

The standard design process requires the development of concepts, material selections, identification of material properties, numerical simulations, strength calculations and serviceability analyses. This procedure may be supported by experimental and numerical validation tests, which are particularly important in the case of advanced material and technology applications. The considered footbridge will be a U-shape shell sandwich type structure. The cooperation of PET foam core with outer lining surfaces will be crucial for its load bearing capacity. This issue has been subjected to a more detailed analysis. To recognize the problem a research program containing the experimental and numerical bending tests of sandwich plates has been developed.

The aim of the paper is experimental investigation of sandwich composite material. The test samples of cross-section dimensions 90x74 mm were prepared with three different foam density cores. The main components of the GFRP laminate were vinylester resin and four layers of glass fibre quasi-balanced knitted fabrics in the following orientation [(0/90),(+45/-45)2,(0/90)]. The experimental programme included quasi-static compression, three-point bending, four-point bending tests and dynamic tests with an impulse excitation. The research was concentrated on the effect of the influence of the foam core density on obtained results of stiffness, stability, failure modes and dynamic characteristics.

9071 | Validation tests of full scale footbridge sandwich segment (2. Analysis of composite beams, plates and shells)

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The purpose of the general study is to design a single span footbridge made of composite materials, with the assumption of manufacturing whole structure in infusion process.
The designed structure with U-shaped cross-section is sandwich type, shell construction with high-strength skins made of glass fiber reinforced polymer (GFRP) laminates and core made of PET foam. A footbridge of 12-16 m span length is intended to be applied over two lanes roadways or railway, additionally two spans of summary length 32 m is also possible.
The standard design process requires the development of concepts, material selection and numerical simulations to calculate strength, strain and deformation. While designing advanced structures made of unconventional materials such as the analyzed footbridge it is particularly important to expand analysis.
In this paper validations tests of pedestrian bridge segment are presented. Experimental tests were conducted on full cross-section scale element made with length reduced to 3 m. The width of the structure and the height of the barrier were assumed according to polish law regulations. The width were assumed as 2,5 m for pedestrians and cyclists traffic and the height of barrier as 1,3 m, because of the possibility to install the construction over a railway.
The aim of experimental tests conducted on validation segment is to check the correctness of numerical simulations with experimental studies. Several test were performed. Firstly the loading on bridge plate simulating crowd loading were applied. Then bending of vertical walls of cross section were caused. Afterwards compressing the top of walls were performed to check whether the handrail were going to buckle.
While test conducting several measurement points were assumed. Strains in those points were measured by strain gauge, displacements by inductive sensors, additionally the applied force were measured by extensometer.
Numerical model was performed using four nodes single and multilayered shell elements and eights nodes solid elements. Material constants were assumed based on previous experimental tests conducted for laminate and for foam separately. Firstly, numerical model were used to calculate and estimate forces and structural response. Finally, after conducting validation tests the numerical model was updated.
The study is supported by the National Centre for Research and Development, Poland, grant no. PBS1/B2/6/2013.

9082 | Hygro-thermo-elastic behavior of composite plates by the higher shear deformation theory (2. Analysis of composite beams, plates and shells)

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Key words: Hygro-thermo-mechanical beahavior, Higher Shear deformation theory, Laminated composite plates, anisotropy

The aim of this work is the study and the modeling of the hygro-thermo-mechanical behavior of thick plates subjected to mechanical and hygro-thermal bidirectional loading.

A new hygro-thermo_mechanical model is developed and validated in this study. This paper develops an analytical solution for investigating the thermo-mechanical behavior of laminated composite plates under static loadings. The higher-order shear deformation theory are considered in the current work. We use in our modeling theory of shear deformation higher-order (HSDT) that uses a parabolic variation of transverse shear deformation through the thickness. The constitutive equations are written based on the displacement , temperature and humidity fields in transient mode, in case of desorption.. The stress distribution depends on the deformation pattern chosen, both for the case of mechanical loading, the thermal loading and hygroscopic loading when the plates are subjected to temperature variations in the three directions of space, and to transient moisture variation.

9161 | Numerical study of the static deflection of a sandwich beam in the complex material (2. Analysis of composite beams, plates and shells)

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This paper presents a numerical study of the static bending of a honeycomb sandwich beam composed of four aluminum skins, two magnetorheological elastomer cores and one honeycomb core. In order to adapt the rheological properties depending on the conditions of the work environment, the beam is subjected to a permanent magnetic field. First, we experimentally determined the rheological properties of the elastomer charged to 30% of iron particles with and without the influence of the magnetic field. Secondly, it was numerically evaluated the static response of the simulated sandwich beam with Abaqus computer code. The results clearly show the significant benefit of using these adaptive structures in different industrial areas to control and improve the mechanical properties.

9185 | An analytical method for free vibration analysis of functionally graded sandwich beams under initial thermal loading (2. Analysis of composite beams, plates and shells)

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This article presents an analytical method to predict exactly the natural frequencies of functionally graded sandwich beams subjected to initial thermal loadings. Material properties are taken to be temperature–dependent. The formulation is based on a new simple parametric shear deformation beam theory (SPSDBT) which allows a systematic assessment of a large number of derived beam models by changing its parameter value. In addition, the present refined theory accounts for transverse extensibility, provides a parabolic distribution of the transverse shear strains through the thickness and satisfies the stress-free boundary conditions on the top and bottom surfaces of the beam. With help of variational methods, equations of motion are easily derived. A simple analytical approach is adopted to solve the system of ordinary differential equations and closed-form characteristic equations are derived for predicting the natural frequencies of the vibrating system for different classical boundary conditions. Numerical examples are obtained for both thin and thick sandwich beams for a given temperature range.

9191 | Bending deflection of sandwich beams considering local effects (2. Analysis of composite beams, plates and shells)

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In general the sandwich structures are designed as panels that carry bending loads. The bending stiffness is characterized by the slope of the variation curve between the applied force and the vertical displacement of the point of application of force. This vertical displacement is often associated with the vertical deflection of the sandwich structure. In this regard, based on the Timoshenko beam theory, Allen proposed an equation for the total deflection at the mid-section of a sandwich beam loaded in 3-point bending, which was generally accepted. This equation assumes that in the loading plane the vertical deflection of the neutral axis is the same as the vertical displacement of the point of application of force. In reality there are very few cases in which this condition is valid. In the case of bending of sandwich beams with flexible cores (e.g. foam, cork) and thin faces, the variation curve of the applied force and vertical deflection can be easily affected by the occurrence of some local effects such as indentation or core damage.
Considering this, within this paper is presented a method to determine the bending deflection of sandwich beams considering the local effect given by the load applied as concentrated force or distributed on a certain length of the beam. The method is based on Timoshenko's theory for highlighting the local effect given by the applied load, adapted for sandwich structures. In contrast to High Order Sandwich Panel Theory (HSAPT), this method approach the bending deflection maintaining compact the sandwich beam, is easy to apply and accurately estimate the variation of bending deflection along the cross-section.

9210 | A multilayered plate theory with transverse shear and normal warping functions (2. Analysis of composite beams, plates and shells)

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A multilayered plate theory which takes into account transverse shear and normal stretching is presented. The theory is based on a seven-unknowns kinematic field with five warping functions. Four warping functions are related to the transverse shear behaviour, the fifth is related to the normal stretching. The warping functions are issued from exact three-dimensional solutions. They are related to the variations of transverse shear and normal stresses computed at specific points for a simply supported bending problem. Reddy, Cho-Parmerter and (a modified version of) Beakou-Touratier theories have been retained for comparisons. Extended versions of these theories, able to manage the normal stretching, are also considered. All these theories can be emulated by the kinematic field of the

present model thanks to the adaptation of the five warping functions. Results of all these theories are confronted and compared to analytical solutions, for the bending of simply supported plates. Various plates are considered, with special focus on very low length-to-thickness ratios: an isotropic plate, two homogeneous orthotropic plates with ply orientation of 0 and 5 degrees, a [0/c/0] sandwich panel and a [−45/0/45/90]s composite plate. Results show that models are more accurate if their kinematic fields (i) depend on all material properties (not only the transverse shear stiffnesses) (ii) depend on the length-to-thickness ratio(iii) present a coupling between the x and y directions.

9221 | Experimental Testing of Bridge Deck Slabs Reinforced with Basalt FRP (2. Analysis of composite beams, plates and shells)

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The implementation of Basalt Fiber Reinforced Polymers (BFRP) in bridge decks supported on girders, where deflection is not an issue, has the potential to offer an efficient solution that is corrosion resistant, durable and cost effective. However, due to the lack of research studies conducted on this material, the current FRP design guidelines do not encompass sufficient specifications to describe and regulate it design and utilization. Therefore, in this paper, the flexural behavior of Lightweight Concrete (LWC) bridge decks, reinforced with BFRP reinforcing bars, was studied. The research program included experimental testing of four LWC bridge deck specimens reinforced with BFRP reinforcing bars. The cross section of the specimens was 18 x 8 in. (450 x 200 mm) with a length to height ratio (L/H) equal to 10. The purpose of testing program was to study the structural behavior of bridge decks supported on girders, in addition to the pre-cracking and post-cracking behavior till the failure of the specimens. Two of the specimens were simply supported with a span length of 6.67 ft (2.03 m); and were reinforced with 5 BFRP bars of diameter 0.625 in. (16 mm) and 5 BFRP bars of diameter 0.5 in (13mm) at the bottom, respectively. The ratio of the bottom to the balanced reinforcement areas were 4.7 and 3.0, respectively. Top reinforcement consisted of 5 BFRP bars of 0.375 in. (10 mm) for both specimens. Two additional specimens were continuously supported with two spans of 8.67 ft (2.64 m) each and were tested for positive and negative moment capacities. The two continuous specimens were reinforced with 5 BFRP bars of diameter 0.625 in. (16 mm) and 5 BFRP bars of diameter 0.5 in. (13 mm) at the bottom with equal to 4.7 and 3.0, respectively. The specimens were reinforced at the top with 6 BFRP bars of 0.625 in. (16 mm) diameter and 6 BFRP bars of 0.5 in (13 mm) diameter, respectively. The test results showed good correlation with ACI 440.1R specifications. The nominal moment capacities (Mn) were accurately predicted by the specifications of the ACI 440.1R (2006), however the ultimate moment capacities (ϕ Mn) were conservative due to a lower strength reduction factor (ϕ).

9285 | Influence of elastic coupling and anisotropy on uncertainty quantification in the aeroelastic response of idealized composite wings (2. Analysis of composite beams, plates and shells)

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Composite materials are increasingly employed to achieve efficient aeroelastic design of aircraft structures. However composite laminates are prone to severe uncertainties due to the properties of their base materials and complicated manufacturing process (Sriramula and Chryssanthopoulos, Compos Part A, 2009). Such uncertainties may strongly affect the dynamic behaviour (Arora et al., JSV, 2009) and the aeroelastic response (Manan and Cooper, J of Aircraft, 2009) of composite laminates. Nowadays, it becomes possible to obtain accurate representations of uncertainty due to tolerances in fabrication (Uhart et al., ESTIA report, 2014) or due to global uncertainty in measurement for entire layups (Sepahvand and Marburg, Mech Syst and Sign Proc, 2015). Based on these statistical models, efficient stochastic approaches can then be employed to compute the probability density function of the aeroelastic variable of interest (e.g of the flutter speed or the amplitude of limit cycle oscillations). For instance, Scarth et. al. (Compos Struct, 2014) used a polynomial chaos approach to propagate material, fiber angle and ply thickness uncertanties in the flutter speed of an idealized composite wing, employing Tsai's lamination parameters to reduce the number of uncertain parameters for a number of symmetric example laminates.
In the present work, probabilitic aeroelastic flutter will be examined in response to stochastic elastic properties of a 2-D laminated lifting surface in an incompressible flow. A simple Rayleigh– Ritz structural model is coupled with a low-order unsteady aerodynamic model to compute the linear flutter speed. Both statistical and non-intrusive spectral projection approaches are examined as a possibility to avoid direct use of Monte Carlo-type methods. In particular, we take into account the influence of uncertainties on the complete elastic behaviour of the composite laminate, that is to say not only the effect of anisotropy in bending but also the effect of elastic coupling.
In addition, we aim to deal with a realistic stochastic representation of the laminates by assessing all important sources of parametric uncertainties. In order to avoid the computational burden associated to the large number of random variables, the polar method (Vannucci, Meccanica, 2005) is used to model composite layup with material behaviour invariants, thus resulting in a dramatic reduction of the stochastic dimensions. Moreover, an efficient non-intrusive stochastic spectral projection method (Chassaing et al., JSV, 2012), based on a piecewise generalized Polynomial Chaos basis, is employed to deal with the highly nonlinear response of the flutter speed to the input uncertain parameters.

9388 | Full bandgap for in-plane waves in thin plates: numerical modelling and experiment (2. Analysis of composite beams, plates and shells)

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We show the existence of a full bandgap for in-plane waves in an locally periodic thin plate. The structured plate is constructed by machining a grid of grooves in a rectangular plate; the final result is a plate with two thicknesses with high contrast. The theoretical band structure, on the one hand, was calculated using the plane wave expansion method applied to the classical theory of in-plane vibrations in thin plates (in two dimensions). For the locally

periodic plate finite elements were used. The experiments, on the other hand, were realized using acoustic resonance spectroscopy and electromagnetic-acoustic transducers. The agreement between experiment and theory is excellent for the first bandgap if an effective parameter, that takes into account the effect of the non-uniform elastic depression in the boundary between the two thicknesses, is used.

9477 | Stresses Around Various Holes in Composite Laminates using Stroh formalism (2. Analysis of composite beams, plates and shells)

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Using Stroh formalism, a general solution for stresses around various shapes of holes in symmetric laminates under In-plane loading has been presented in this paper. This is achieved by using Savin's mapping function in a generalized form and introducing the arbitrary biaxial loading condition into the basic equations of Stroh formalism. This is a one stop solution for all kinds of in-plane loading on symmetric laminates as well as isotropic plates with any shape of cutouts. The results are obtained by introducing the various parameters such as mapping function constants for holes, biaxial load factor and load angle for loading conditions, laminate geometry, angle for fiber orientation, materials constants for isotropic and anisotropic into the MATLAB programe. The type of loading, material properties, laminate geometry and fiber orientation have significant effect on the location of maximum stress around the hole. The results obtained by this solution for holes such as triangle, rectangle, ellipse and circle in graphite/ epoxy [0/90]s laminate under x-axis loading have been validated with ANSYS software. It is noticed that the results from ANSYS software have good agreement with the present solution.

9503 | Meshless natural neighbor Galerkin method for nonlinear analysis of composite laminates (2. Analysis of composite beams, plates and shells)

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A meshless natural neighbour galerkin approach for geometricaly nonlinear analysis of laminates is presented. The C^0 natural neighbor interpolation function is implemented for geometric nonlinear analysis. The third order shear deformation theory [1] is adopted for laminate analysis. The geometric nonlinearity is based on the von K$\grave{a}$rm$\grave{a}$n's assumptions. The nonlinear static and dynamic analysis is carried out with step loading and Newton-Raphson iterative method. The natural neighbour Galerkin method [2] has distinct advantages of geometric flexibility, like in meshless method. The compact support and the connectivity between the nodes forming the compact support are performed dynamically at the run time using the natural neighbor concept. By this method the nodal connectivity is imposed through nodal sets with reduced size, reducing significantly the computational effort in construction of the shape functions. Smooth non-polynomial type interpolation functions [3] are used for the approximation of inplane and out of plane primary variables. The use of nonpolynomial type interpolants has distinct advantage that the order of interpolation can be easily elevated through a degree elevation algorithm, thereby making them suitable also for higher order shear deformation theories. The evaluation of the integrals is made by use of Gaussian quadrature defined on background integration cells. Numerical examples are presented to demonstrate the efficacy of the present numerical method in calculating deflections, stresses and natural frequencies in comparison to the Finite element method, and other meshless methods available in the literature.
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9554 | Free vibration analysis of simply supported composite sandwich beams with a graded lattice core (2. Analysis of composite beams, plates and shells)

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Consider a composite sandwich beam with laminated facesheets and a graded lattice core, whose mechanical properties are gradually changed in the length direction. A new theoretical model was proposed to investigate the free vibration behavior of the graded lattice core sandwich beam. The core of the studied beam is divided into some sub-layers and the mechanical properties in each sub-layer are assumed to be constant. Combined with the boundary and continuous conditions, the problem can be turned into a group of linear algebraic equations. Then, the natural frequencies and mode shapes of composite sandwich beams can be obtained by solving these equations. The influences of material properties and geometric parameters on the free vibration behaviors of composite sandwich beam are analyzed. The predictions of vibration parameters of the beams, such as the natural frequencies and mode shapes, are compared with experimental values.

7027 | Programmable cellular solids (3. Auxetic materials and structures)

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Advanced programmable materials with the ability of reversible, real-time control of moduli and topology can be used to manufacture the energetically efficient and multifunctional morphing structures of the future. Furthermore, these capabilities in solids can find significant application in advanced mechanical components, protective structures and biomedical devices. Here, we propose a novel concept for controlling the linear and non-linear elastic properties of cellular structures via electromagnetically triggered mechanisms in the cellular solid. Three structural systems with orthotropic material properties were proposed and studied numerically, experimentally and analytically. Using the proposed concept, the elastic modulus can be controlled over 2 to 4 orders of magnitude. The Poisson ratio of the isotropic structure can be varied from 0 to 0.5 continuously. The adjustments over nonlinear elastic (i.e. buckling) behavior of the structure are achieved by activation of supplementary cell walls in the lattice through electromagnetic actuation. Magnetic actuation will hamper the first symmetrical buckling pattern of the structure and force the structure to buckle according to a higher buckling pattern with smaller sinusoidal wavelength in the cell walls. The uniaxial buckling strength of the structure was tuned over 2 orders of magnitude.

6884 | One-step synthesis and characterization of nanocomposite based on carbon nanotubes/aluminum and their reinforcement properties (4. Poster Session)

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A nanocomposite based on carbon nanotubes/aluminum (CNT/Al) was one-step prepared by DC arc discharge under a mixed atmosphere of argon/acetone. Synthesis was performed by arc plasma on high pure graphite rod, filled by aluminum powder as anode and aluminum plate as cathode. Discharge conditions of 85 A and 20 V were used at a pressure range of 375 to 750 Torr. The CNT/Al nanocomposite was characterized by Scanning Electron Microscopy with Energy Dispersive Spectroscopy; Transmission Electron Microscopy; Thermogravimetric Analysis; X-Ray Diffraction; Raman Spectroscopy and Laser Diffraction Particle Size Analysis. The results showed CNT and carbon nano-onions filled with Al_4C_3, agglomerate sizes distributions range of 4.85 to 10.71 µm, inner diameters of 10 nm to 25 nm for multi walled carbon nanotubes with wall numbers of 5 to 10 and single walled carbon nanotubes were also obtained at ~6.0% wt representing a high yield at ~95% wt of CNT and metal particles in the nanocomposite.

6931 | A numerical simulation of the strength and stiffness of hollow cylindrical composite structures (4. Poster Session)

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The object of the investigation was a cylindrical structure made of sandwich composite with facesheets from filament wound glass fibre and polyvinylester resin and a core from recycled paper hexagonal honeycomb impregnated with polyvinylester resin.
The aims of the study were: to verify experimentally the numerical models of materials and sandwich structure for the investigation of the strength and stiffness of hollow cylindrical structures; using verified numerical model to determine the optimal geometrical parameters which ensures the stiffness and strength properties with the largest efficiency of fibre reinforced plastic volume usage of cylindrical structures.
Using experimentally obtained data of materials properties and the finite element (FE) code LS-DYNA the numerical FE model of sandwich structure was designed. To verify the FE model three different tests were performed. In the first step the verification of the numerical material model by simulating the uniaxial tensile test of facesheets has been performed. The numerical results of elastic behaviour showed good agreement with experimental stress – strain curve.
The verification of sandwich structure model was performed by simulating three points bending and the compression of hollow cylinder tests. In both the numerical and experimental investigations the force and deflection were measured and compared. During the ring compression tests the core failure was followed after debonding as in three point bending test. Debonded zones of tested specimens coincided with the FE simulation results.
The verified model allowed investigation of the stiffness and strength of cylindrical structures and determination of the optimal geometrical parameters.

7088 | Numerical-experimental failure analysis of composite columns with open cross-sections under uniform compression (4. Poster Session)

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The short thin-walled columns with top-hat cross-sections, simple supported on both ends under uniform compression were considered. The columns were made of carbon-epoxy laminate. Experimental studies of limit states and FEM numerical simulations were conducted. The non-linear buckling problem was calculated for structures with initiated geometrical imperfections, the amplitude of which was 0.1 of the column's wall thickness. The finite element analysis was performed using the commercial software suite Abaqus. The geometrically non-linear problem was solved using the incremental-iterative Newton-Raphson method, which allowed to calculate post-buckling states of the compressed composite columns until their failure. The composite material's failure was evaluated with the Tsai-Wu tensor criterion, based on the experimentally measured limit values of the composite material. The composite's failure was defined as the load corresponding to meeting the failure parameter in the first ply, while the limit load was defined as the load corresponding to the meeting of the Tsai-Wu failure criterion in all plies of the laminate. The numerical and experimental results show good agreement, which confirms the suitability of the designed simulation models for analyzing the problems of stability and load capacity of thin-walled composite structures.

7090 | Failure analysis of thin-walled composite channel section column (4. Poster Session)

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The paper presents results of a numerical and experimental analysis of post-critical and limit states of a thin-walled channel-section simply supported columns under axial compression. The columns was made of carbon-epoxy symmetrical composite prepared with a pre-preg technology using 8 layers of unidirectional band. The research was lead as the FEM numerical analyses and experimental tests in post-buckling and limit states, as well. The problem of non-linear stability of thin-walled columns was solved using high deflections. The numerical computations were performed with the incremental-iterative Newton-Raphson method, which allowed us to examine the structure's post-buckling equilibrium path in the function of load. The composite material's failure load was determined with the Tsai-Wu tensor criterion. In the simulations we used limit parameters of the composite material as determined in the experiments. The applied failure criterion allowed us to determine the critical load of the composite's first ply, denoted as failure initiation load Pf(ini)-FEM. In addition, the critical load of all plies was assumed to correspond to the limit load Pf-FEM, which is when the column loses its total load capacity. The high agreement of the experimental and numerical results proves the suitability of both the designed numerical models and of the applied Tsai-Wu criterion for estimating the composite's failure.

7095 | Continuous Basalt Fiber as Reinforcement Material in Polyester Resin (4. Poster Session)

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Industry is always striving to find new and better materials to manufacture new or improved products. With this context, energy conservation, corrosion, sustainability and other environmental issues are important factors in product development. Basalt fibers are a new natural material produced from igneous rock which can provide high strength relative to weight. The objective of this project was to examine whether a composite material made of polyester resin reinforced with basalt fibers, could be used for engineering structures. The project was based on a basic research of material properties where specimens made of basalt fibers in polyester resin were constructed and tested according to the ASTM standards. Three types of test were performed: Uniaxial tensile test, compression test and in plane shear test. The results of the material testing indicated that basalt fibers can be used as reinforcement material in polyester resin, to create a composite structural material with acceptable engineering properties.
The results were compered E-glass fabrics in epoxy resin. The sum of ultimate tensile strength of both directions (longitudinal 0° and transverse 90° direction) became 19.3% stronger in basalt fabric than the E-glass fabric. The ultimate tensile strain in the basalt fabric became more then 50% higher than in the E-glass fabric.

7622 | EVALUATION OF THREE-POINT BENDING FRACTURE TESTS OF SELECTED CONCRETE – PART I: MECHANICAL FRACTURE PARAMETERS (4. Poster Session)

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The relationships between durability parameters of selected cement-based composites and parameters which quantify content of microcracks, respectively resistance to their stable and unstable propagation is examined within the project of the Grant Agency of the Czech Republic "Evaluation and prediction of the durability of the surface layer of concrete". Present research is aimed especially at the determination of the transport characteristics of the concrete cover layers determined by the water and gas permeability methods. These so-called "durability parameters" are completed especially with the fracture parameters (e.g. fracture toughness and energy) and basic physical and mechanical properties of fresh and hardened concrete.
In this paper authors focus attention on mechanical fracture parameters obtained from records of three point bending fracture test on concrete specimens with central edge notch. Total ten sets of specimens were tested. Three specimens at the age of 28 days were tested in each set. Concrete of each set of specimens was different in dosage of Portland cement CEM I 42.5 R and amount of used superplasticizer. The effective crack extension method was used to evaluate the load–deflection diagrams. Resistance to stable and unstable crack propagation, which is evidently connected with durability of material, was quantified using double-K fracture model.

7683 | EVALUATION OF THREE-POINT BENDING FRACTURE TESTS OF SELECTED CONCRETE – PART II: RESULTS OF ACOUSTIC EMISSION METHOD (4. Poster Session)

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Mechanical properties and their characteristics in accordance of quantity and loading type enable to dimension significant construction parts and to determine their reliability, which determine so-called limiting state. A limiting state is a condition of a structure beyond which it no longer fulfils the relevant design criteria.
The relationships between durability parameters of selected cement-based composites and parameters which quantify content of microcracks, respectively resistance to their stable and unstable propagation is examined within the project of the Grant Agency of the Czech Republic "Evaluation and prediction of the durability of the surface layer of concrete". Present research is aimed especially at the determination of the transport characteristics of the concrete cover layers determined by the water and gas permeability methods. These so-called "durability parameters" are completed especially with the fracture parameters (e.g. fracture toughness and energy) and basic physical and mechanical properties of fresh and hardened concrete.
In this paper authors focus attention on acoustic emission parameters obtained from records of three point bending fracture test on concrete specimens with central edge notch. Total ten sets of specimens were tested. Three specimens at the age of 28 days were tested in each set. Concrete of each set of specimens was different in dosage of Portland cement CEM I 42.5 R and amount of used superplasticizer.
Acoustic Emission Method is considered quite unique among the non-destructive testing methods. In contrast to other Non-destructive methods, however, Acoustic Emission Method is usually applied during loading, while most others are applied before or after loading of a structure. Following these

arguments, and according to the way in which the signals are recorded, Acoustic Emission is correctly described as non-destructive. On the other hand, Acoustic Emission is often used to detect a failure at a very early stage, long before a structure completely fails.

7813 | Finite Element Analysis of the Effects of Polymer Shrinkage on Composite Fracture Toughness (4. Poster Session)

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Experimental results have shown that polymer composites with high fracture toughness tend to have high fatigue wear resistance. In this study, we are trying to understand if the residual stress stored in the matrix due to polymerization shrinkage during curing has any effect on composite fracture. A multi-scale finite element model (FEM) has been developed to study the interaction between the crack and the reinforcing particles. In this model, crack nucleation and propagation and the effect of particle/matrix/interphase material properties can all be characterized by cohesive elements and their traction-separation behavior. The advantage of this methodology for modeling fracture behavior is that macroscopic fracture criteria are not needed. A 3-point bending macro-scale FEM serves to calibrate the deformation gradient of the study zone in front of the crack tip. A microscopic unit cell model was used to simulate the crack propagation. Three types of interphase were compared: (1) matrix and particle bonded without interphase, (2) matrix and particle bonded with a silane interphase, and (3) matrix and particle bonded with a beta-peptide (high deformation) interphase. Three residual strains, -2, -4, and +2% and their effect on fracture toughness were examined, even though in reality a positive strain would require the polymer to expand during curing. Results show that different strain originating from the curing process have different effects on fracture propagation and energy dissipation rates for the composites with the three different types of interphases. For the non-bonded interphase, the crack propagates along the particle surface. For bonded interphases, the crack propagates at some distance from the particle surface.
The support of the NIH through grant DE 019885 is gratefully appreciated.

7875 | THE ULTIMATE RESISTANCE MOMENT OF REINFORCED CONCRETE BEAMS STRENGTHENED WITH CFRP (4. Poster Session)

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This paper presents an experimental study to investigate the ultimate moment resistance of reinforced concrete beams strengthened with external CFRP reinforcement. The experimental test consisted of thirty one beams. The main purpose of experimental program was to investigate the influence of anchoring of external reinforcement. Four different ways for anchoring of external reinforcement were used. The experimental results of the ultimate resistance moment and failure modes were analysed. The analysis of experimental research shows how anchoring of external reinforcement affects the performance and ultimate moment of strengthened reinforced concrete beams.

7885 | Some problems of modeling of hyperbolic heat conduction in laminates by using TAT (4. Poster Session)

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Some problems of modeling of hyperbolic heat conduction in laminates by using TAT

In the paper, two-component laminates made of homogeneous conductors, distributed as laminas along one direction, are considered. In order to analyse heat conduction, the Cattaneo law and the approach, called the tolerance averaging technique (TAT) [1,2], is used. The aim of the dissertation is deriving equations of the tolerance model of hyperbolic heat conduction.

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7892 | Simulation of process-induced failure behavior in cutting operations of hybrid FRP-metal composites by means of FEM (4. Poster Session)

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Lightweight design for high-volume production is a key factor in the process of CO2 reduction in the sector of mobility. Novel approaches towards innovative lightweight design aim to tap the potential of lightweight structures by combining both metal and fiber-reinforced plastics (FRP) in one part, thus producing hybrid structures which constitute an adequate substitution of mechanical properties at considerably lower weight.

Hybrid lightweight design offers vast opportunities of application, e.g. in aerospace engineering. However, machining operations, e.g. for rivet holes, are somewhat difficult to conduct as the individual components require contrary machining parameters. Thus, machining of hybrid FRP-metal parts often results in delamination of material layers as well as low quality processing results.

To simulate the impact of delamination and fiber breakage effects, a new three-dimensional FEM model was set up in ABAQUS. For this investigation, drilling, punching and trimming operations were taken into account. Therefore, Johnson-Cook and Hashin-Puck failure models were employed. To validate

the numerical FEM model, different tools, tool geometries and machining strategies were used. Moreover, the cutting process of the FRP-metal composite was explored in experiments to analyze fracture behavior, whereas the results were used to investigate machining accuracy. In addition the scientific findings were then used for model validation and visual process optimization as well as optimization of the FEM model for a better conformity with real material behavior.

8090 | Temperature dependence of Young's modulus of porous kaolin-based composite ceramics prepared by starch consolidation casting with different amounts of alumina (4. Poster Session)

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This work concerns the preparation of porous multiphase (composite) ceramics by starch consolidation casting of aqueous suspensions using kaolin and alumina as raw materials in volumetric ratios of 2:3 (A40K60) and 3:2 (A60K40), respectively. Potato starch has been used as a pore former and stiffening agent. After firing at 1100, 1300 and 1400 °C the samples have been characterized with respect to shrinkage, bulk density (Archimedes technique), phase composition (XRD with Rietveld refinement), apparent density and pore size distribution (mercury porosimetry). Young's moduli have been measured in the temperature range from room temperature up to 1000 °C via impulse excitation (according to ASTM E 1876-99) using high-temperature equipment (IMCE resonant frequency and RFDA 23 with furnace HT 1600). Based on the phase composition determined by XRD, literature data for mullite and alumina and estimates concerning the glass phase (content and properties) Young's moduli of the solid phase mixture are calculated. Also true densities are calculated and cross-checked with the apparent densities from mercury porosimetry. Finally, taking into account porosity and assuming a widely confirmed exponential dependence, effective Young's moduli are calculated and compared with the measured values. The results demonstrate the close correlation between phase composition and microstructure on the one hand and the high-temperature elastic properties on the other. In particular, higher alumina contents increase the Young's modulus and contribute to an improved stability at high temperatures.

8093 | Novel carbon nanostructures as modifiers of elastic and electrical properties of polyvinylalcohol composites (4. Poster Session)

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Design of novel composite materials nowadays is largely based on the synthesis of tailored nanolevel structures and their subsequent integration in the purposefully selected polymer matrices. Additives, such as graphite, graphene and carbon nanotubes, gain especial attention by considering their unique thermal, electrical and mechanical properties. It is, however, important to avoid nanofiller agglomeration during processing as well as to ensure sufficient interfacial adhesion with polymer matrix. These aims can be achieved by regulation of the interactions in the polymer matrix-nanofiller interface by purposeful covalent or non-covalent modification of the constituents of the multi-component system in situ or ex situ. Considering previously mentioned statements, the current research is devoted to investigation of the effects of organically modified carbon nanofillers on the structure and performance of polyvinylalcohol (PVOH), broadly used in industrial adhesive, textile, paper and other industries.
Graphite (G), graphite oxide (GO), reduced graphite oxide (RGO) and their organically modified (OM) counterparts have been introduced in the PVOH matrix within broad concentration range (0.1 to 5 wt.%). The nanocomposites have been obtained by means of solution casting method. Nanocomposites design and manufacturing parameters has been optimized. Especial attention has been paid to optimization of film forming behaviour of the nanocomposites. X-ray diffraction measurements, morphological characterization, thermogravimetric analysis, thermo-physical properties characterization, dielectric measurements and dynamic mechanical thermal analysis have been performed to characterize structure and some exploitation characteristics of the manufactured PVOH matrix nanocomposites.
Results of thermogravimetric analysis of the used carbon nanofillers testify that thermal stability of RGO and RGOs treated with OMs prevail that of GO. Considerable weight loss of GO between the range of 100–160°C is evidently attributed to dehydration, as well as hydroxyl and carboxyl decomposition. Considerably smaller weight losses of RGO and OM treated RGOs could testify about the fact that most of the oxygen-containing groups have been removed on GO after reduction. Besides it has been observed that diazonium salt OM appeared to be more effective in respects of thermal stability of the investigated carbon nanostructures in comparison to polyvinylpirrolidone.
Results of the structural investigations testify that diffraction peaks of the investigated carbon nanostructures after reduction are shifted to the direction of higher 2Θ values in respect to GO, testifying about the processes of removing intercalated water molecules and the oxide groups. The effect of the used OMs (either polyvinylpirrolidone or diazonium salt) in increasing interlayer space between graphene monolayers, however, is comparatively low. Nevertheless it has been observed that modification of PVOH with OM treated carbon nanostructures allow considerably increase storage modulus as well as electrical conductivity of the nanocomposites. However, it should be mentioned that the effect of OM modified GO or RGO addition to the electrical and mechanical properties of the investigated PVOH matrix nanocomposites considerably depends on the intrinsic properties of the nanofiller chosen.

8223 | Hybrid steel-polypropylene fiber for shear strengthening of reinforced high performance concrete beams with and without openings (4. Poster Session)

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The article presents the results of a research work aimed at testing the use of hybrid steel-polypropylene fiber as a strengthening solution to upgrade reinforced high performance concrete (HPC) beams with (BO1÷BO3) and without openings (B1÷B3). A total of six beams were constructed and tested under a four-point bending. Test member had a cross section of 200 x 400 mm and a total length of 2500 mm. Two square openings in each shear span were located symmetrically about the mid-point in three beams. Research was carried out with regard to the quantity and the type of reinforcement. Beams B1 and BO1 were constructed conventionally with reinforcement made of steel rods. As regards the remaining beams, instead of stirrups and compressive rods, fibre reinforcement of variable fibre volume percentage was applied. In the analysis, a non-contact system for three-dimensional measurements of strain – ARAMIS was used. The analysis of the behaviour of the beams under static load was based on the measurements of crack, deflection and strain. The test results show that the first crack shear strength and the ultimate shear strength increase significantly as the fibre content

increases. The present study indicates that hybrid fibre reinforcement can reduce the number of shear stirrups required and that the combination of fibers and stirrups may meet the requirements related to strength and ductility. The comparative analysis of the numerical results with experimental data was presented for the examples of the reinforced HPC - BO3 and B3 beams under static load. The comparison of the obtained results indicates the correctness of the assumptions and constitutive models of HPC, reinforcement steel, steel and polypropylene fiber. Numerical results of the smeared crack patterns are qualitatively agreeable regarding localization, direction and concentration with experimental results. The full nonlinear load-deformation at midspan response of the model produced compares well with the experimental response. The numerical solutions obtained for the reinforced HPC beams are coherent with the experimentally obtained results.

8225 | Experimental and theoretical investigation on shear of steel-polypropylene fiber reinforced high performance concrete deep beams with and without openings (4. Poster Session)

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The article presents an experimental-analytical investigation which deals with the behaviour and the ultimate strength of hybrid steel-polypropylene fibre reinforced high performance concrete (HFRHPC) deep beams with openings (DBO) and without openings (DB) in web tested under a three-point bending. A total of six HFRHPC deep beams of dimensions 1000 mm x 500 mm x 100 mm were tested to failure by applying gradually increased load. Simply supported conditions were maintained for all specimens. Research was carried out with regard to the quantity and the type of reinforcement. The deep beams were reinforced by vertical, horizontal, orthogonal steel bars and steel and polypropylene fibres in various arrangements. The deep beams DB1, DBO1 were constructed conventionally with reinforcement made of steel rods. As regards to the remaining deep beams, instead of the steel wire mesh, fibre reinforcement of variable fibre volume percentage was applied. The analysis of the general behaviour of the deep beams under static load was investigated. The influence of fiber content in the specimens has been studied by observing the crack patterns, failure modes and by measuring deflections on mid-span and loading point and shear strengths. In the analysis, deep beams without openings (DB) non-contact ARAMIS system for three-dimensional measurements of strain and displacement was used. A method of analysis for shear strength prediction of HFRHPC deep beams without and containing openings strengthened with hybrid fibre were studied and compared with the experimental values. The above study indicates that the quantity of web reinforcement, in the form of hybrid fibers or as steel reinforcement is the principal parameter that has an effect on the strength of deep beams.

8233 | Synthesis and characterization of nanocellulose -based bioplasticizers for preparation of medical grade PVC (4. Poster Session)

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We investigated the correlation between the time evolution of the different phase-separating morphologies and corresponding linear and transient rheological behaviors for the dynamically asymmetric PS/PVME (polystyrene/polyvinyl methyl ether) blend in which there is a large difference between glass transitions of the pure components (about 125 oC). The phase diagram was obtained from dynamic temperature sweep experiments. Phase contrast optical microscopy was employed to investigate morphological evolution of PS/PVME blends at various regions of obtained phase diagram. The sensitivity of different rheological analyses was examined to distinguish different phase separation mechanisms from each other, including nucleation and growth (NG), spinodal decomposition (SD), and viscoelastic phase separation (VPS). We found that a combination of experimental and theoretical studies of the linear and nonlinear rheology could provide satisfactory criteria to distinguish effectively samples phase separating by different mechanisms.

8298 | Novel PVA-fullerenol composite membranes: structure, transport, and thermal properties (4. Poster Session)

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Development of chemical technology using membrane processes requires the search of new membrane materials with improved physico-chemical and transport properties. One of the most promising ways for this purpose is the modification of polymers by functionalized carbon nanoparticles [1-2] because of their good dispersion. In the present research the modification of PVA by fullerenol $C_{60}(OH)_{22-24}$ are studied.

Fullerene with attached hydroxyl groups (fullerenol) is the perspective candidate due to its good solubility in water and ability to react with polymer side groups with the formation of covalent bounds that leads to the change of membrane morphology and membrane transport parameters. Structure and morphology of such hybrid membranes were investigated by X-ray analysis, atomic force microscopy and scanning electron microscopy. Thermal characteristics of PVA-fullerenol membranes were measured by thermal gravimetric analysis and differential scanning calorimetry. The transport properties of membranes were studied under separation of various binary and multicomponent mixtures by pervaporation. Sorption experiments with membranes were also conducted.

It was shown that the addition of fullerenol to polyvinyl alcohol matrix improves its transport characteristics and physico-chemical properties. These observations were explained by changes in the structure and the morphology of the membranes which are caused by fullerenol inclusion.

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8370 | Electrospun MTMS/PVDF Nanofibrous Membranes for CO2 Absorption in Membrane Contactor applications (4. Poster Session)

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One-dimensional (1-D) electrospun nanofibrous membranes are well-established materials because of their low cost, simplicity, ease of scale-up and wide range of applications. In this study, highly porous MTMS/PVDF nanofibrous membranes featuring hydrophobic fluorocarbon functional group (fluoroalkylsilane, FAS) modifications were successfully prepared using an electrospinning process, and their performance in a membrane contactor for CO2 absorption was investigated. The surface contact angle of MTMS/PVDF nanofibrous membranes submitted to three FAS modifications was approximately 144°. The as-prepared FAS-modified MTMS/PVDF nanofibrous membranes were able to prevent wetting by an amine absorbent, therefore allowing for long periods of continuous CO2 absorption over at least one day, with a CO2 absorption flux of approximately 1.0 mmol/m2s. Thus, the as-prepared FAS-modified MTMS/PVDF nanofibrous membranes are not only durable but also reusable, which indicates that the material is also promising for large-scale CO2 absorption during post-combustion process in power plants.

8374 | Composite Structure of Nb-Si-B Alloys Prepared by Spark Plasma Sintering Process (4. Poster Session)

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Ni-based superalloys, which have been extensively used for high temperature application, have made important contribution to enhance the performance of the aircraft engines and gas turbines. However, the alloys have difficulty in that the service temperature is limited to around 1150C; most advanced alloys melt at around 1350C. In this sense refractory metal-based composite materials are interesting for high temperature structural application because of their high melting temperature, good mechanical properties and enhanced oxidation resistance. Of the refractory metal-based composite materials, Nb- and Mo-based alloys have been considered as having the greatest potential for high temperature applications such as aircraft engines and gas turbines. Especially Nb-Si-B and Mo-Si-B alloy systems are attractive because they are very tough composite materials with the microstructure where very hard intermetallic compound can be uniformly distributed in the ductile matrix (Nb or Mo).
In the present work microstructural examination of the Nb-Si-B alloys at Nb-rich compositions was performed. The Nb-rich corner of the Nb-Si-B system is favorable in that the constituent phases are Nb (ductile and tough phase with high melting temperature) and T2 phase (very hard intermetallic compound with favorable oxidation resistance) which are good combination for high temperature structural materials.
The samples containing compositions near Nb-rich corner of the Nb-Si-B ternary system were prepared by spark plasma sintering (SPS) process using T2 and Nb powders. T2 bulk phase was made in arc furnace by melting the Nb slug and the Si-B powder compact. The T2 bulk phase was subsequently ball-milled to powders. SPS was performed at 1300-1500C under 34MPa for 10min, producing disc-shaped specimen with 14mm in diameter and 7mm high. Hardness tests (Rockwell A-scale and micro Vickers) were carried out to estimate the optimal composition for good mechanical property.

8528 | Alumina/LZSA Glass Ceramic Based Multilayered Ceramic Composites (4. Poster Session)

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With the aim of improving the toughness of ceramic materials, laminated composites have been successfully developed since Clegg et al. (1990) inserted weak interfaces using very thin graphite layers between silicon carbide sheets and obtained a composite that exhibited non-catastrophic fracture characteristics. The weak interface must allow the crack to deviate either by deflection or delamination; in other words, the interface must exhibit a fracture resistance that is lower than that of the matrix layer. In parallel, ceramic laminated composites with strong interfaces were developed in which the residual tensile and compressive stresses appeared in alternate layers during cooling after sintering. These composites are prepared by piling ceramic sheets produced by lamination or tape casting or by the sequential formation of layers by slip casting, centrifugation or electrophoretic deposition. The techniques may be combined to obtain a composite with the most adequate configuration. This work presents results related to the use of alumina/LZSA glass ceramic based composites to obtain multilayered ceramic laminates as a toughening mechanism of ceramic plates.

Keywords: ceramic composites, multilayered structures, toughness, interfaces, fracture mode.

8529 | The Influence of the LZSA Glass-ceramic in the Wear of Alumina (4. Poster Session)

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Alumina belongs to that class of ceramic materials which is widely applied in the production of high-tech pieces, especially where the abrasive and erosive wear are strongly demanded. The properties relative to wear of a ceramic material can be improved taking into account the characteristics of the used oxide and the manufacturing process that defines its final microstructure. The effects of several parameters on the wear behavior of alumina have been widely studied. It can be seen that the influence of grain size of alumina is a determining factor in this issue. On the other hand, the use of a specially chose glass-ceramic composition could be used to improve the sintering (liquid phase sintering) and establish residual compressive stress in the interface of alumina particles in order to improve the wear resistance. So, the aim of this work is to show results about the influence of the LZSA glass-ceramic in the wear of alumina.

Keywords: Alumina, LZSA glass-ceramic, Wear.

8575 | Polyamide/Silica Composite Membrane Applied to Separation of Aqueous Isopropanol Solution by Pervaporation Process (4. Poster Session)

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The polyamide/silica composite membrane was prepared by the interfacial polymerization technique coupled with the sol-gel process. The modified polyacrylonitrile (mPAN) membrane was immersed in the aqueous solution containing 1,3-cyclohexanediamine (CHDA) and 3-aminopropyltrimethoxysilane (APTMOS) for 5 min. After removing the redundant aqueous solution, the surface of the mPAN membrane soaking the aqueous solution contacted with the organic solution containing trimesoyl chloride (TMC) for 3 min to carry out the interfacial polymerization. The resulting polyamide/silica composite membrane was applied to the dehydration of isopropanol (IPA) by the pervaporation separation process. The effect of the APTMOS content on the pervaporation performance was investigated. Incorporating the inorganic silica particles into the interfacially-polymerized polyamide layer can effectively restrain the swelling effect of the feed solution on the polyamide and promote the separation performance of aqueous IPA solution.

8631 | Influence of the crack length on mode III results (4. Poster Session)

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Delamination failure is frequently found in composite structures. This fracture mode is produced by high interlaminar stresses due to material and geometric discontinuities when the laminate is subjected to static forces, fatigue loads or impacts.
Delamination can be produced in three different modes: I, II and III. While modes I, II and mixed I/II have been widely covered by the scientific literature and some tests to characterize these modes have been elevated to test protocols or international standards, mode III is still being studied in order to obtain a uniform and pure mode III at the crack front.
In this work, the influence of the effective crack length on a sample configuration prepared to delaminate under mode III has been studied by means of Finite Element Analysis (FE) and Scanning Electron Microscopy (SEM).
In order to perform the calculations an Ansys package was used. Samples with different crack lengths were modelled to study the influence of this parameter on the force distribution and energy released at the crack front.
The sample implemented in the model had the bottom face with all degrees of freedom restricted while a force was applied to the other sublaminate in perpendicular direction to the thickness of the laminate in order to create a scissoring delamination.
The material used to perform this study was a 32 ply unidirectional AS4/Hexcel 8552 epoxy laminate.
In order to calculate GI, GII and GIII energy release rates the Two Step procedure was followed. In the Two Step method, the crack path is modelled using pairs of coincident nodes. The forces at the crack tip are calculated in a first step when the load reaches a critical value. The imposed displacement in the sample is then held and the coupled degrees of freedom of the nodes at the crack tip are released in a second step. Displacements are then calculated in this second step. This method is similar to the VCCT (Virtual Crack Closure Technique) except for the nodes where the forces are calculated.
Different models were implemented with increasing crack length. In each model the force and released energy distribution along the crack front were calculated.
For very short crack lengths it was found that mode III was predominant. Nevertheless mode III distribution was not uniform as the applied force produced local effects due to the proximity of the load application point to the crack tip.
As the effective crack length increased, i.e. the load was applied further from the crack front, the local effects reduced, the distribution of mode III load in the crack front was more uniform, but in contrast mode II increased its influence. In this case, mode II loads were high at the sample edges. In the middle of the crack front mode III was predominant.
Fractographic observations confirm FE analyses. Depending on the crack length and observation area along the sample width, the presence of mode II and mode III topographic features were observed.

8647 | Poly(4-methyl-1-pentene) / metal-organic framework MIL-100 mixed matrix membranes for gas separation (4. Poster Session)

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The study of mixed matrix membranes (MMMs) for gas separation received considerable attention in recent years. However, there are still many uncertainties about the effect of inorganic additive on the gas separation performance, physical structure and the free volume of MMMs. In this study, we use commercial poly(4-methyl-1-pentene) as matrix and metal-organic framework MIL-100 as additive. The mixed matrix membranes with different amount of metal-organic framework MIL-100 were prepared by dry phase inversion method. The relationship between gas separation performance and characteristics of MMMs was discussed in this work. SEM image showed that MIL-100 with good affinity to polymer and well disperse in the MMMs. The permeability of MMMs increases with increasing MIL-100 loading, but selectivity decreases. Positron annihilation lifetime spectroscopy results indicated that more and bigger free volume formed due to the addition of MIL-100.

8723 | INVESTIGATION OF SOUND ABSORPTION PROPERTIES OF ENVIRONMENTALLY MODIFIED AGAVE AMERICANA FIBERS / POLYURETHANE COMPOSITES (4. Poster Session)

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In order to reduce the noise some alternative materials are produced. Generally synthetic fibre based materials are used for this applications but these materials are not friendly for the environment and human health, and they are expensive as well.
Textile fibres are fibril structured materials so they have sound absorption properties. Acoustic panels used in buildings, automotive insulation materials, covering fabrics used in concert halls are some of the application fields of these materials.
Except textile structures, porous materials used for noise control are generally categorized as fibrous medium or porous foam. Fibrous media usually consists of glass, rock wool or polyester fibers and have high acoustic absorption. Sometimes fire resistant fibers are also used in making acoustical products.
Textile fibres are fibril structured materials so they have sound absorption properties. Acoustic panels used in buildings, automotive insulation materials, covering fabrics used in concert halls are some of the application fields of these materials.
Historic ruins showed that the origin of Agave Americana L. is Africa which has hot and dry climate. Afterwards Agave Americana started to spread in North Africa, Arabian Peninsula, China and Mediterranean Region .
The Turkish name of this plant is "sari sabir" and the meaning is "yellow sword". The pedicle may grow up to 150 cm. Pipe like yellow flowers grow on the pedicle. As the flowers of the plant sarı sabır are infertile its reproduction is realized through the separation of the young buds from the plant. The plants usually have 12 to 16 leaves. Its life is around 12 years. When the plant is at the age of 4 it is considered to be grown. The leaf size of a 4 year old plant is approximately 60 to 90 cm.
Alternatively, as a natural and environmentally friendly material, Agave Americana fibres have been tested for its sound absorption properties. Besides being a hygienic material, Agave Americana fibres are a product of renewable bio-resources that makes it biodegradable.
The Turkish name of this plant is "sarisabir" and the meaning is "yellow sword". The pedicle may grow up to 150 cm. Pipe like yellow flowers grow on the pedicle. As the flowers of the plant sarısabır are infertile its reproduction is realized through the separation of the young buds from the plant. The plants usually have 12 to 16 leaves. Its life is around 12 years. When the plant is at the age of 4 it is considered to be grown. The leaf size of a 4 year old plant is approximately 60 to 90 cm .The fibers produced from Agave Americana L. are used in the paper industry, technical textiles and especially automotive industry as a results of having high mechanical properties.
In this study, Agave Americana fibres were treated with 40% sodium hydroxide by using conventional (40 minutes, 600C) and microwave energy(3and 5 minutes) methods. Composite structures were produced by using treated Agave Americana fibres as reinforcing material and polyurethane foam as matrix. Hand lay-up method were used to produce composites. Sound absorption properties of Agave Americana fibres /PU composites were investigated.

Keywords: Agava Americana fibres , polyurethane resin, composite, sound absorption

8725 | Progressive Failure Analysis of Adhesive Joints of Composite Pressure Vessels Using CZM and VBA (4. Poster Session)

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This study has conducted an analysis of the progressive failure of adhesive joints of composite pressure vessels based on changes in mechanical properties and interlaminar fracture toughness. Adhesive joint of pressure vessel was simulated using Cohesive Zone Model(CZM) provided by ABAQUS, and the values for interlaminar fracture toughness were obtained from mode I, II and mixed mode tests. Composite pressure vessel was manufactured by filament winding process, and the ply angles in finite element modeling were automatically created using the Visual Basic for Application(VBA). From the results it was found that the progressive failure analysis using the CZM and VBA could predict the failure strength for adhesive joints of composite pressure vessels produced by filament winding process, compared with the test results.

8743 | Thermodynamics calculation and analysis of nonmetallic inclusions by Ti-Mg complex deoxidation in steel (4. Poster Session)

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Oxide metallurgy is an important technique that improves steel properties through the control of inclusion size and composition. In this study, the equilibrium relationships between the oxide compounds $MgO–Ti_2O_3$ and molten iron are investigated at steelmaking temperature, 1 873 K. Using classical thermodynamics calculation to obtain the deoxidation equilibrium between deoxidizers and molten steel, and the composition of oxide inclusions, such as MgO, $MgTi_2O_4$ spinels and Ti_2O_3 are predicted by plotting of phase stability diagrams. It is also essential to know the inclusions that newly form after solidification. Accordingly, investigation on temperature dependance of stable solid oxides by the use of Ti -mg complex deoxidation method. Through the analysis of the size, morphology, and shape of the inclusion, the effects of fine oxide inclusion to steel was investigated.

8748 | Toughness Reinforcement of Low-Carbon Steel Using Finely Disperse $MgAl_2O_4$ Spinel Particles (4. Poster Session)

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In recent years, steel industry is quite competitive. Price and properties are the key factors in this marketing contest. The existence of finely dispersed $MgAl_2O_4$ Spinel Particles can induce chaotic microstructures and consequently enhance the toughness in low-carbon steels. In this study, magnesium was added into Al-killed low-carbon steel to form $MgAl_2O_4$ Spinel Particles. After certain heat treatment process, the toughness was examined by Charpy V-notch impact test. The phase constitution and microstructure of low-carbon steel were analyzed using scanning electron microscopy and electron backscatter diffraction. Results shows that the existence of $MgAl_2O_4$ Spinel Particles would conduce to the impact absorbed energy of the steels raising

between 10 and 15 times at 0°C, which implies the toughness of this materials have been greatly improved.

Keywords
Spinel Particle, Toughness, microstructures, Low-carbon steel

8761 | Aluminum/SiC/Nickel-Coated Graphite Hybrid Composite Structures (4. Poster Session)

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New composite structure for high performance tribological applications have been one of the major incentives for the development of aluminum-based metal matrix composites (MMCs). MMCs have received attention because of their improved specific strength, good wear resistance, higher thermal conductivity than ceramics, lower coefficient of thermal expansion, etc. Traditionally, lubricant externally added plays an important role in reducing wear in the application of wear resistance materials. However, self-lubricating materials are more desired than materials to which lubricant needs to be applied periodically, especially for wear parts difficult to be accessed, since solid lubricant contained in the former can be released automatically during the wear process and reduces wear.

8787 | EVALUATION OF NANO COATED TEXTILE SURFACE WITH IMAGE PROCESSING METHOD (4. Poster Session)

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In this study, the canvas cotton fabric coated with fluorocarbon based nano coating material. The effects of coating thickness, the condensation time and temperature on the water repellency characteristics have been investigated. A classical method which named Spray water repellency test method has been applied to test samples for the evaluation of water repellency.
Also the water repellency of examples has evaluated with the image processing method on a computer and compared with Spray test method. The differences between the two methods have found out.

Key Words : Nano coating, Image Porcessing, Spray Test.

8809 | Influence of nano TiO2 on selected fire properties of beech plywood (4. Poster Session)

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Nanotechnology is currently the fastest growing discipline of science, which, according to forecasts, will be a priority direction of development of science and technology in the world in the coming years, having huge economic potential in the economy. Nanotechnology is considered a key technology of the future. Currently it is used widely in different sectors of the economy. The use of nanoparticles, due to their small size, can improve the properties of traditional sponges and the creation of new multi-sealers for wood and wood-based materials. In addition, durability, ease of application and low cost efficiently tend to focus on the new possibilities of nanotechnology in the impregnation of fire protection. The result of the increased interest in nanotechnology, perceived as a new direction of development of the flame retardants, are numerous studies conducted around the world. The present article is a literature review, describing the latest achievements of scientific - research works in the area of reducing the flammability of structures made of wood and wood-based materials that are being conducted around the world, as well as in Poland, including The Main School of Fire Service. Results presented in present paper show an overview of the possible use of nanoscience and nanotechnology in the reduction of flammability of wood and wood-based materials. The work will include the results of testing the flammability of beech plywood with the addition (in the adhesive) TiO2. Research will be carried out on the cone calorimeter at 30 and 50 kW/m2 external heat of fluxes.

8901 | Functional properties of photoactive composite materials received by polymer impregnation of indoline spirooxazines in supercritical carbon dioxide. (4. Poster Session)

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Photochromic properties of indoline spirooxazines (ISO) containing of nafto- anthro- and phenanthro groups (SNO, SAO и SPO),which were introduced into thermoplastic polymers: polycarbonate (PC), polyvinyl chloride (PVC), and copolymer of vinylidene fluoride with tetrafluorethylene (fluoroplast-42, F-42) in the supercritical carbon dioxide (SCCD) medium were investigated. Spirocompounds are the most important class of photochromic compounds due to its significant photochemical stability and high efficiency of phototransformations.
It is shown that functional properties of ISO molecules introducing in polymer matrices in SCCD medium, depend on the nature of the ISO molecules, chemical structure of the polymer matrices and SCF impregnation conditions. The maximal concentration of ISO introduced in thermoplastic polymers by supercritical fluid (SCF) impregnation were of 3-5% mass.
It is known, that ISO were passed from initial colorless and nonplanar form (A) into the colored (merocianin, planar) form (B) under photoirradiation. The form B wasn't stable at usual conditions. But the SCF-impregnation of PC, F-42, PVC spirocompounds was resulted in conformational rearrangement of spirocompounds with the stabilization of ISO merocianin (coloured) forms.
The form in which ISO has stabilized in matrix depended on polymer structure. In particular, in PE matrix all ISO were only in the initial form A, in PC matrix ISO were in the forms A (SNO, SAO, SPO) and B (SAO, SPO). All ISO which have entered in F-42 matrix in SCCD medium were only in the new form. We have denoted it as form Bx. The initial form A and two coloured forms B and Bx for all ISO were found in PVC after SCCD impregnation. The maximal amount of ISO which could enter into polymer in SCCD medium depended on linear size of ISO molecules and physical state of polymer. For

example degree of impregnation (α) of polymers, for which SCCD temperature (90C) higher than glass-transition temperature Tg (F-42 and PVC), was higher as compared with α for PC (Tg~ 150C).
It was shown that the forms B and Bx entered in SCCD in PC, F-42 and PVC matrix were stable under normal conditions and in photo and thermal treatment. Probably such stabilization was connected with donor-acceptor complexes formation between polar fragments of B form and polymer. In the case of PC such fragments could be bis-phenol groups and in F-42 or PVC halogen groups played this role. We supposed that the formation of such stable complexes was possible due to strong swelling of the polymers in SCCD medium which provided the introduction of ISO in polymer. Ability of SCCD to be completely removed from the matrix after the end of impregnation was prevented the return of the ISO molecules in the initial nonplanar state.
We carried out the investigation of the stability of the SAO colored forms in polymer matrices and researched the methods for transition of ISO colored forms to other colored or colorless states. It is found that the SCCD impregnation of polymer matrices (PVC and F-42) with SAO in the presence of the aromatic electron-donating compounds (EDC), such as toluene and dibutyl phthalate, can lead to change of forms of SAO that are stabilized in polymer matrices.

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8980 | Filament winding of complex axisymmetric geometries: numerical simulation and fabrication using geodesic and non-geodesic paths (4. Poster Session)

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Filament-winding faces up limiting fabrication inconveniences when designing geodesic trajectories, so models for non-geodesic paths have been developed. This research aims to establish, to solve and to validate a non-geodesic winding, generic, mathematical model that contributes either to wind complex shapes, or to solve common filament-winding disadvantages, on the basis of an integrated strategy looking to take advantage of the benefits of composites despite the limitations of the filament-winding process. By parameterizing the surface of the mandrel, and expressing it in terms of its curvatures, the stability criteria that describes the slippage tendency of the fiber tow over the surface of the mandrel is established, and a general path equation can be formulated. A numerical tool is developed so as to predict the evolution of the filament-winding angle of the fiber tows placed over the surface of two non-cylindrical, generic, axisymmetric geometries: a convex and a concave one. Experimental validation is carried out by filament-winding these geometries using a five DOF machine. Results show that it is feasible to wind complex geometries with good accuracy.

9048 | Finite Element Investigation on Load-Stress Experiment of Homogeneous GaN Nano-Bridge (4. Poster Session)

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The development of stress-strain response during the load-deflection to GaN Nano-Bridge is analyzed by the finite-element analysis under the assumption that the Young's modulus and Poisson's ratio of GaN nano-bridge are 355 GPa and 0.183 at room temperature, respectively. The FEM consists of 5377 elements and 5579 nodes. The quadratic quadrilateral elements defined by 8 nodes were employed for the GaN nano-bridge, and the three rigid line elements were used for the indenter.
The assuming elastic modulus was measured by strain energy methods for point-loads on simple support beam models, under the guidance of linear elastic beam bending theories during the loading process.
A two-dimensional finite element model showed that a positive agreement between principal stresses varies in a beam by experimental observation and stress contour versus indentation depth by numerical simulation. This method could also be applied on the wide range of nano-materials to identify the mechanical response.

9053 | Fabrication and Analysis of Mechanical Property of Al-Si/SiCp + Al-Mg MMC bi-reinforced with Ti whisker by Powder Metallurgy (4. Poster Session)

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Al-Si alloy fabricated by powder metallurgy is widely used for vehicle components because of their high wear resistance and near-net shape manufacturing ability. Additionally, Al-Si alloy has high potential for increasing mechanical property by adding ceramic reinforcements. Unfortunately, there are several problems in this manufacturing and reinforcing process. At first, clusters and pores between ceramic reinforcement and Al-Si matrix can be formed because of low wettability of Al-Si matrix. These clusters and pores decrease mechanical property of final products. Secondly, dense oxide layers on the surface of Al matrix powder decrease sinterability and mechanical property of final products. Because of above problem, there are limitations for adapting reinforced Al-Si alloy manufactured by powder metallurgy to wide field.
The aim of this study is reinforcing Al-Si matrix powder by adding SiC particles, Al-Mg alloy powder and Ti whisker. To place the SiC reinforcement inside of Al-Si matrix particle, gas atomizing technique was used for manufacturing Al-Si/SiCp composite powder. Ti whiskers were added to Al-Si/SiCp powder for structural reinforcing and enhancing mechanical property of the Al-Si matrix. Ti metal whisker reinforcement can react with Al-Si matrix and avoid the forming of clusters and pores like ceramic reinforcements. Al-Mg alloy powder was blended for fracturing dense oxides layer on the surface of Al-Si/SiCp powder and Ti whisker. Mg elements can react with aluminum oxides and titanium oxides and reduces these oxides. During reduction reaction, dense and homogeneous oxide layer reacts with Mg elements and forms reactant locally at the surface of each powder. Al-Mg alloy powder forms liquid phases during sintering, which spreads between each particle. Because of formation of the liquid phases of Al-Mg alloy, reaction of reduction can occur on the all surface of each powder. Blended powder was densified with hot-press technique for efficient sintering. The reaction between each powder and the effects of each powder on the reinforcing the matrix were mainly analyzed.
The upgraded properties in Al-Si/SiCp + Al-Mg MMC bi-reinforced by Ti whisker will be discussed in detail.

Keywords: Aluminum, Titanium, Powder metallurgy, Metal matrix composites, Mechanical property

9055 | Analysis of Wear Properties of Hot-Pressed Al-Zn-Mg-Cu Metal Matrix Composite by Adding Al-Si/SiCp Composite Powder (4. Poster Session)

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Al-Zn-Mg alloy is widely used in the field of aerospace or automotive due to higher strength than those of other Al alloys. In case, the Al-Zn-Mg alloys are manufactured by powder metallurgy, there are difficulties in densifications because of their high strength. Additionally, Al-Zn-Mg alloys show poor wear resistance because of low fatigue resistance. Because of these problem, Al-Zn-Mg alloy products manufactured by powder metallurgy is generally used after anodizing or coating treatment and these process cause increase of production cost.
In this study, Al-Si alloy powder which has low melting temperature relative to Al-Zn-Mg alloy was added in Al-Zn-Mg powder as binder to enhance the sinterability. In addition, SiC particle was added in Al-Si alloy powder to increase mechanical and wear property. However, in case of mechanical blending, cluster and pore can be formed because of low wettability between Al-Si alloy powder and SiC reinforcement. These cluster and pore causes decrease of sinterability and mechanical property. To solve these problems, Al-Si/SiCp powder was fabricated by gas atomization for placing the SiC particle inside of Al-Si metal particle and added to Alumix 431 powder. Blended powder was sintered by hot press and wear property of sintered body was analyzed with two variables; vertical load and linear speed. Furthermore, wear behavior compared with sintered body with Alumix 431 powder manufactured by same sintering condition for analysis of effect of Al-Si/SiCp.

Keywords: Aluminum, Metal matrix composite, Powder metallurgy, Wear property

9094 | Relationship between microstructural features and laser slope efficiency of reactive-sintered Nd3+:Y3A5O12 optical ceramics (4. Poster Session)

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Nd3+:Y3A5O12 (Nd3+:YAG) transparent ceramics is a perspective material for diode-pumped solid-state lasers due to good thermo-mechanical properties and wide possibilities to design active media and dopant distribution for optimal pumping architectures. Achieving a high structure quality and optical homogeneity of transparent ceramics enables effective lasing in ceramic gain. Advanced manufacturing technologies, such as solid-state reactive sintering of well dispersed nanopowders, provides single-phase ceramics with narrow grain boundaries which are transparent for light [1]. Thus, residual pores act as light scattering centers in optical in phase-pure optical ceramics, so controlling the porosity is a challenge for obtaining high laser slope efficiency. According to previous studies [2], a volume fraction of pores lower than 0.0001 % is required to approach Nd3+:YAG ceramics the single crystal laser slope efficiency. The aim of this work was to study relationships between manufacturing conditions, porosity and laser parameters of 4 at. % Nd3+:YAG transparent ceramic.
The influence of sintering conditions on the porosity and optical losses of Nd3+:YAG ceramics obtained by solid-state reactive sintering has been studied. Relationship between residual porosity and laser slope efficiency has been found. Residual porosity of optical ceramics was studied by non-destructive method of optical microscopy [3]. The average pore diameter and volume fraction of pores was obtained for series of Nd3+:YAG samples obtained at different sintering time (0.5-12 hours) at fixed temperature. Optimal sintering conditions of Nd3+:YAG ceramics possessing porosity of 0.0035 vol. % and laser slope efficiency of about 30 % have been determined. Further reducing the porosity of Nd3+:YAG ceramics by one order of magnitude is necessary to obtain laser characteristics comparable to that of single crystals.

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9101 | Effects of magnesium on the nitridation behavior of aluminum particles (4. Poster Session)

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We investigated the effects of Mg on the nitridation of Al particles in an Al–Mg powder bed. From the transmission electron microscopy and electron energy loss spectroscopy analyses, we found that two types of reaction layers were formed on the surfaces of the Al particles during the early stages of nitridation of the Al–Mg powder bed. Compared to pure Al particles, those with added Mg exhibited faster initiation but no enhancement of nitridation.

9116 | The fabrication of polyamide/polyacrylonitrile composite hollow fiber membranes via interfacial polymerization

for pervaporation (4. Poster Session)

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The advantages of membrane separation system include high selectivity, small footprint, energy saving, and the ease of operating and scaling up. Therefore, in this study, we investigated the pervaporation performances of aqueous alcohol solution through polyamide (PA)/polyacrylonitrile (PAN) composite hollow fiber membranes. Trimesoyl chloride (TMC) and various amine monomers such as 1,6-hexanediamine (HDA), ethyldiamine (EDA), diethyltriamine (DETA) and tetraethylpentamine (TEPA) were used to fabricate PA/PAN thin-film composite hollow fiber membranes via interfacial polymerization on the outer surface of PAN hollow fiber membranes to investigate the effect of chemical structure of amine monomer on the pervaporation performances. The pervaporation performances of aqueous alcohol solution were enhanced as increasing the amine number of amine monomer during interfacial polymerization. The positron annihilation spectroscopy (PAS) experiment showed the S parameter of PA/PAN thin-film composite hollow fiber membranes decreased with increasing amine number of amine monomer during interfacial polymerization. The PAS results were well consistent with the experimental results of pervaporation.

9171 | The simulating study of piezoelectricity on an GaN nanorod under applied lateral forces (4. Poster Session)

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Nano-materials with excellent piezoelectricity have been positively studied for the nano-generator applications. In this work, we used commercial FDTD software package (COMSOL Multiphysics) to simulate the electrical properties of an GaN nanorod under applied lateral forces. Voltage distribution in a deflected GaN nanorod and current values by connecting an external resister and a nanorod are calculated from the simulation. We demonstrate that the external resistance can significantly affect the current value extracted from the deflected nanorod, but also the voltage distribution in the nano-rod is changed. The influence to the electrical properties of the deflected nanorod due to external resistance is well discussed in this work.

9196 | Alkali resistance of GFRP reinforcing bars slightly damaged by high temperatures (4. Poster Session)

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Alkali resistance of GFRP reinforcing bars slightly damaged by high temperatures was evaluated through a long-term accelerated test. Tensile and short beam shear tests were conducted on bare GFRP bar specimens. The bar specimens were exposed to 120°C and 200°C for several minutes and then immersed in alkaline solution of pH 12.6, which is similar to the alkalinity of concrete, for several months. Since the temperature and time applied is not significant compared to those applied in experimental program conducted by other researchers, only minor damage occurred on surface region of GFRP reinforcing bars. Specimens unexposed to high temperatures also were tested for comparisons. Residual tensile and inter-laminar shear strength and stiffness were measured and compared. In results, the bars slightly damaged by high temperatures underwent more degradation in tensile and inter-laminar shear strength than the thermally undamaged rebars. Scanning electron microscope images showed that the fine cracks and resin matrix damage on the surface due to exposure to high temperatures facilitated alkali penetration, thereby resulting in rapid performance degradation.

9381 | A RMVT analysis of laminated composites (4. Poster Session)

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This paper considers the analysis of laminated composite plates and shells by the RMVT (Reissner-Mixed Variational Theorem). The equations of motion are obtained by a symbolic program. Then the fundamental nucleo is used to automatically generate a MATLAB code to analyse the plates and shells, with a layerwise type of configuration.

The results obtained show clearly an accurate approach for this kind of materials and structures.

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9552 | Dynamic analysis and control of laminated soft core sandwich panels with active piezoelectric elements (4. Poster Session)

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In this paper we present a finite element model for the analysis of sandwich laminated plates with a soft core and composite laminated face layers, as well as piezoelectric sensor and actuator layers. The model is a generalisation of the element developed by Araujo et al. [1] for active and passive damping of soft core sandwich plates, where the transverse compressibility of the core is included. The model is formulated using a mixed layerwise approach, by considering a higher order shear deformation theory (HSDT) to represent the displacement field of the compressible core and a first order shear deformation theory (FSDT) for the displacement field of the adjacent laminated face layers and exterior piezoelectric layers. Control laws are implemented and the model is validated for free and forced vibrations with results from the literature [2,3,4] and the effect of the core transverse compressibility is

assessed on modal damping and frequency response.

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9582 | The Influence of Residual Stresses on the Micro-Crack Propagation Direction (4. Poster Session)

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Residual stresses are introduced during the fabrication process - produced by the sintering due to mismatch of coefficients of thermal expansion, and the understanding of the effects of residual stresses on the material response is important. The aim of the present work was to develop a two-dimensional finite element model to analyze the influence of residual stresses on micro-crack behavior of ceramic-based particulate composites. The maximum tangential stress criterion (MTS) was used to predict the direction of the crack propagation, in the framework of linear elastic fracture mechanics. The modeled material was a Low Temperature Co-fired Ceramic (LTCC), containing alumina particles embedded in a glass matrix. The effect of the volume filler fraction (VFF), micro-crack length and loading on the micro-crack propagation was investigated. The conclusions of this paper can contribute to a better understanding of the propagation of micro-cracks in particulate composites.

8021 | Investigation of mechanical behavior of a bone plate made of bioresorbable phosphate glass fiber reinforced PLA composite (5. Bio-inspired design of composites)

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Metals and their alloys are commonly used to fabricate internal fixation devices to fix the bone fractures. Metallic prostheses have much higher elastic moduli than that of bones which cause stress shielding and results in bone atrophy. Also metallic prostheses generate high stresses at cortex which disturb the blood supply to the bone and may cause bone re-fracture after removal of metallic prosthesis. Moreover, these metallic prostheses may cause other problems when exposed to the human body fluid such as corrosion, poor fatigue life, release of metallic ions, loosening of implant, incompatibility with magnetic resonance imaging and computed tomography and so on. Also a second surgery is required to remove the metallic prosthesis after healing of bone fractures which lead to pain, blood loss and additional operation cost. Completely bioresorbable composite prostheses have four main advantages over metallic implants: (i) the material properties can be tailored to match the properties of bone according to the site of application, (ii) second surgery for removal of implant is not required, (iii) gradual stress is transferred at the fracture site to stimulate the healing tissue and (iv) bioactive material enhances the healing rate and drug can be loaded to prevent any infectious disease. Moreover, completely bioresorbable composites give the solutions of other problems associated with metallic prostheses.
Poor mechanical properties of completely bioresorbable composites were a challenge for weight bearing long bone fractures. This was recently overcome by using phosphate glass fibers (PGF) which are bioresorbable and bioactive and, give excellent initial material properties. PGF are brittle, has high Young's modulus (60-70 GPa) and high degradation rate which cannot be used alone as fracture fixation devices. Therefore, polymers are used to make PGF reinforced polymer composites. Polylactic acid (PLA) is well known polymer which is extensively used for medical devices. PGF and PLA are known as biocompatible and completely resorbable materials.
In this study, PGF/PLA completely bioresorbable composite bone plates were fabricated with appropriate fiber volume fractions to meet the Young's modulus of bone. An appropriate initial Young's modulus of composite bone plate was determined for successful healing. Homogenous bone plate and functionally graded material (FGM) bone plate made of PGF/PLA composite were fabricated to achieve the different bending stiffness. These bone plates were assembled with the bone fragments and a fracture gap was created to simulate the real fracture conditions. The fracture gap was filled with the material of equivalent average Young's moduli of healing tissue at different healing time points (estimated using FEA) and the bone plates of different bending stiffness were assembled with artificial bones. Real loading conditions after surgery (10%, 200% and 300% body weight for 0-8 weeks, 9-12 weeks and 13-16 weeks during abnormal and normal walk of a patient) of tibial bone were applied to the simulated bone.

8915 | Bio-mimetic Nanostructure Self-assembled from Phage Fusion Proteins and Au@Ag Heterogeneous Nanorods (5. Bio-inspired design of composites)

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Bio-mimetic Nanostructure Self-assembled from Phage Fusion Proteins
and Au@Ag Heterogeneous Nanorods

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Molecular self-assembly is the spontaneous organization of individual molecules into well-defined structures through the non-covalent bond, which forms biological complex and exists ubiquitously in living organisms. Viruses of different sizes and shapes are the typical self-assembling biological systems

which are composed of proteins and polynucleotides. To date, many viruses were disassembled and the purified coat proteins were available to be reassembled with nonviral materials to form functional virus-like particles. However, their practical applications were restricted due to lacking of specificity. Phage display technology offers a promising way for discovering target ligands towards specific tissue, cancer cells or other biological components. Landscape phage library, as the excellent extension of phage display technology, was generated by fusing random octapeptides to all 4000 copies of the phage major coat proteins. As a result, the landscape library is available for identifying target peptides in a high-throughput fashion.
In this talk, we report a novel multifunctional phage-mimetic nanostructure, which was prepared by layer-by-layer self-assembly of Au@Ag heterogenous nanorods (NRs) with rhodamine 6G, and specific pVIII fusion proteins. Au@Ag NRs, first being applied for photothermal therapy (PTT), exhibited excellent stability, cost-effectivity, biocompatibility and tunable NIR absorption. The fusion protein was isolated from phage DDAGNRQP specifically selected from f8/8 landscape phage library against colorectal cancer cells in a high-throughput way. Considering the definite charge distribution and low molecular weight, phage fusion proteins were assembled on the negatively charged NR core by electrostatic interactions, exposing the N-terminus fused with DDAGNRQP peptide on the surface. The fluorescent images showed that assembled phage fusion proteins can direct the nanostructure into cancer cells. The nanostructure was more efficient than gold nanorods and silver nanotriangle-based photothermal agents and was capable of specifically ablating SW620 cells. The prepared nanostructure would become an ideal reagent for simutaneously targeted optical imaging and PTT of tumor.

Keywords: biomimetic nanostructure, Au@Ag heterogeneous nanorods, specific phage fusion protein, phage display, photothermal therapy

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9022 | Bioinspired 3D Nanotube Composite Surfaces for Implant Applictions (5. Bio-inspired design of composites)

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Majority of biological materials have hierarchical structure that induce unique properties during the function of such biosystems. Here, we report that three dimensional (TiO2) nanotubes can be fabricated that mimic the overall structure of the bone materials. These 3D TiO2 nanotubes are fabricated using a cost effective technique and obtained using eco friendly chemicals and materials. We have demonstrated good control over the processing parameters to obtain nanotubes with controlled geometrical features and chemistry. Our electrochemical results show a superior resistance for such 3D morphologies over other
structures. We also have demonstrated that such 3D nanotubes can be used as an effective media for drug loading and targeted drug release at the site if inflammation and infection when used as biomedical implants.

9054 | DESIGN OF COMPOSITE PARTICLE BOARD FROM WASTE GROWING MEDIA MUSHROOMS TO MAKE SPEAKER BOX (5. Bio-inspired design of composites)

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This study is make of the speaker box that be designed by composite particle board made from waste mushroom growing media. Mushroom growing media waste is one of the types of agricultural waste and have huge numbers and accumulate, because every few months, after crop harvest mushrooms, it will use the new planting medium, so long planting medium thrown away and is generally only used for solids in the cliff area to widen the area plengsengan. Therefore utilized waste mushroom growing medium mixed with polyester resin and natural adhesives (glue copal) for to be made of particle board and then performed design and manufacture to be made box speakers that have undergone the tests.

Manufacture of particle board composite of mushroom growing media waste using hot press machine and tests were conducted laboratory tests (density, moisture content, thickness swelling after water soaked, supple firmness (dry), firmness bending (wet), firmness pull perpendicular to the surface , and firmness pull screws), mechanical testing (bending and tensile) and acoustic testing.

The final results showed that the higher density particle board shows a better acoustic properties, but the modulus of rupture produces a low value, because rigidity increasing particle board.

Keywords: Speakers box, composite particle board, mushroom growing media waste, polyester resins, natural
adhesive (glue copal)

5455 | A Double-Composite Rectangular Truss Bridge and its Joint Analysis (6. Composite structures in civil engineering)

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A novel composite tubular truss bridge has been proposed and designed. A double-composite section including concrete slab and concrete-filled rectangular chords was specified to enhance the global and local performance. Perfobond rib (PBR) was installed in the truss girder's joints. Investigation of the effect of PBR in concrete-filled tubular joint was elaborated. Comparison has revealed that concrete-filled tubular joint with PBR have much higher constraint capability than joints without PBR. Fatigue performance of the joint with PBR installed was improved which was found through analysis of the stress concentration factor of joint. Since the ease of construction of rectangular truss, innovative concept of structural design, the new composite tubular truss bridge is of technical significance in highway bridge construction.

6384 | The Possibility of Enhancing Some Mechanical Properties of Ferro-Cement Mortar by Waste Plastic Fibers (6. Composite structures in civil engineering)

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Development countries like Iraq suffered from high quantities of solid waste such as empty beverage plastic bottles. This type of waste formed one of the serious environmental pollution resources. The main aim of this research is to study the effect of adding Waste Plastic Fibers (WPF) on the mechanical properties of ferrocement mortar. Waste plastic resulting from cutting plastic beverage Polyethylene Terephthalate (PET) bottles by electrical shredder machine, which is used to cutting paper, was added with different volume ratios of fibers to cement mortar, and these percentages were (0.5%, 1.0%, 1.5%). Reference mix was made for comparative reason. The following tests were made to investigate ferro-cement mortars mechanical properties as followed: compressive strength, flexural strength and density.
Results showed that, the compressive strength slightly decreased with an increasing in WPF content. The lowest value of compressive strength in (14, 28 and 56) days was (37.1 MPa) for (Vf=1.5%) at (14) days test age. The range of decreasing was between (1.1-12.2) percent with respect to reference mix. Flexural strength increased with increased of the waste plastic fibers volume. The highest value of flexural strength in (14, 28 and 56) days was (8.22 MPa) for (Vf=1.5%) for (56) days age. The range of decreasing of flexural strength in (14, 28 and 56) days were between (2.27-16.67) % with respect to reference mix.

6388 | CFRP Rehabilitation of Degraded Steel CHS under Combined Bending and Bearing (6. Composite structures in civil engineering)

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To rehabilitate damaged or sub-standard steel pipelines, techniques uthe lightweight, high strength and corrosion resistance of carbon fibres reinforced polymers (CFRP) composites have been proposed. This paper presents experimental results for two series of CFRP strengthened and rehabilitated model box girders under quasi-static large deformation 3-point bending. The first series was for rehabilitation of 31 artificially degraded Circular hollow Section (CHS) beams with limited corrosion repaired using externally wrapped sheets. The extent of corrosion along the pipeline was in the range of Lc/Dn=1.0 to 3.0, where Lc=length of corrosion and Dn is the nominal diameter of the pipe. The second series represents rehabilitation of 12 degraded CHS beams with full corrosion along the length of the pipe. The extent of corrosion along the pipeline in this series was Lc/Dn =8.0. The main parameters examined in this paper were the section and member slenderness and the type and number of the CFRP sheets. The section slenderness examined in this paper was in the range of D0/t =20.32 to 93.6. The CFRP sheets were wrapped around the section in the longitudinal and transverse direction with a sufficient overlap. The results show that the combined flexural and bearing strength of the CHS can be significantly increased by adhesively bonding CFRP. Expressions for the bearing strength and plastic moment of the composite section were obtained by means of an equivalent thickness approach.

6686 | Bridge safety and maintenance management tools using Fiber Reinforced Polymers (FRP) (6. Composite structures in civil engineering)

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Meeting the expected increase in freight demand by increasing the number or the weight of trucks will be detrimental to bridge longevity. Also, additional repetitive loading may cause fatigue cracking in these bridge superstructures and limit the bridge service life. This increases the bridge cost due to the accelerated required maintenance to keep structures at an acceptable level of service too.

Maintaining the safety and serviceability of deteriorating highway bridge networks necessitates suitable bridge maintenance management system (BMS) tools to maximize cost effectiveness. Predicting the lifespan of a strengthened bridge using FRP laminate is one of the bridge management main tools. The FRP and the resin long-term performance have a direct influence on the long–term performance of the strengthened structural members and the lifespan as well. However there is a lack of information about these materials' mechanical properties. Thus, numerous experiments have been conducted to detect those of the epoxy resin materials used in the FRP strengthening and maintenance. Moreover, Finite Element Analysis (FEA) models using the ANSYS software to simulate the unstrengthened and FRP strengthened prestressed concrete bridges of different spans with the original and aged properties of construction and retrofitting materials were developed. These models aim to develop a bridge performance chart for the capacity of the bridge with and without strengthening interventions as a BMS tool.

6726 | Reinforcement of cement mortars through recycled nylon fibers (6. Composite structures in civil engineering)

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The present paper investigates on structural uses of recycled nylon fibres obtained from waste fishing nets. The presented study is focused on the employment of recycled nylon fibres as tensile reinforcement for cementitious materials such as mortars, plasters and concretes. We characterize the tensile behavior of both unconditioned fibers, and alkali-cured fibers, in order to assess their resistance to chemical degradation. We also conduct compression and bending tests on fiber-reinforced mortar specimens, on establishing comparisons with the response of the unreinforced material. We analyzed different volume fractions of nylon fibers and different fiber aspect ratios. We observe marked increases in tensile strength (up to 54%) and the switching from brittle to ductile failure of the material response, due to the addition of recycled nylon fibers to the mix design. The study is completed by a rich review of available literature results, which highlights the high potential of recycled nylon fibers for the reinforcement of sustainable construction materials.

6873 | Effects of CFRP Retrofitting on Impact Response of Shear-Deficient Scaled Concrete Beams (6. Composite structures in civil engineering)

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Current experimental work studies low-velocity impact response of reinforced concrete beams with initial static shear failure. Specimens have scaled geometry and material properties preserving physical similarity with full-scale members and have external carbon fiber reinforced polymer (CFRP) sheets. Study inspects layup effect on deflection, material strain, accumulative damage, and impulse capacity during lifetime impacts. Skins are unidirectional and cross-ply full wet layups. Drop weight collides six simply supported beams, three pairs, repeatedly at mid-span location with kinetic energy equal to static collapse. Tests gather reliable and robust data revealing notable stiffness and strength recovery within skin attachment. Fibers restrain shear cracks, reduces deflection and improves acceleration, especially for cross-ply wrap. Acceleration frequency contents of unidirectional and cross-ply retrofits is stable around first and third fundamental modes respectively, beside excessive frequency content aberration occurred in intact samples. Rebar yields for all retrofits, but concrete crushes only in cross-ply retrofit. Peak absorbed impulse attains for unidirectional retrofit, which the horizontal strain of web is high and the shear strain is low for load repeats. Stiffness recovers for initial impacts and then starts degrading due to rupture of horizontal fibers in cross-ply retrofit, but provided stiffness is stable for unidirectional retrofit during all impacts.

6964 | Testing and Deployment of FRP Material in Bridges (6. Composite structures in civil engineering)

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A summary is presented on 20 years of testing and deployment of FRP materials in bridges in Kentucky. The field applications range from: (1) the “Clear Creek” bridge that was constructed in 1996 using two 610 mm (24 inch) deep hybrid glass/carbon I-girders; (2) a bridge deck in 1997 that is partially reinforced with glass FRP (GFRP) rebars; (3) a suspension bridge constructed in 1999 and having a 420 ft. long GFRP superstructure; (4) a spread box prestressed concrete beam bridge constructed in 2001 and having a concrete deck reinforced entirely with 10 mm (3/8 inch) diameter carbon FRP rebars; (5) a three span prestressed concrete bridge retrofitted for shear using carbon FRP (CFRP) fabric in 2001; (6) a four span reinforced concrete bridge slab on girder retrofitted for flexure using CFRP laminates in 2004 ; (7) repair of reinforced concrete bridge pedestals using CFRP fabric in 2006; (8) a retrofit of the ends of prestressed concrete I-beams using CFRP fabric; (9) retrofit of two multi-span bridges using high strength steel wire fabric in 2007; (10) retrofit of bridge pier using 3-D CFRP fabric in 2010; (11) strengthening of a steel girder bridge using ultra high modulus CFRP laminates bonded to the steel girders in 2010, and strengthening of five deteriorated and/or impacted bridges from 2011 to 2014. A discussion of the lessons learned along with recommendations will also be presented.

7149 | Mechanical properties of FRP anchors for masonry and concrete strengthening (6. Composite structures in civil engineering)

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This work presents an investigation of the mechanical properties and the influence of FRP anchors in debonding phenomena. The characterization of these reinforcement techniques, the analysis of the the adhesion between the composite and the substrate, and the efficiency of the system are presented.
FRP materials are widely used for retrofitting masonry and concrete buildings. Failure is mainly due to debonding from the substrate, for load values lower than the tensile strenght of the composite.
In order to reduce debonding phenomenon anchors in FRP materials was proposed in the literature. A large experimental campaign was performed and analytical and numerical analyses were developed to study the stresses and strains distribution and the load transfer mechanism.
The anchor system is constituted by carbon or glass fiber fixed into the block or fanned out on the substrate surface with an epoxy resin. Tensile tests were carried out on the and several pull-out tests were performed on specimens where the reinforcement system was applied with various configurations on substrates with different mechanical and geometrical properties.
The main failure modes were the collapse of the connector, of the substrate block or the anchor slippage. The experimental results showed the influence of the substrate characteristics, but also of the methodology of application and the volumetric reinforcement ratio.

7150 | Out-of-plane strengthening of masonry panel with fabric reinforced cementitious matrix (FRCM) systems (6. Composite structures in civil engineering)

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Fabric Reinforced Cementitious Matrix (FRCM) composites are used for strengthening concrete or masonry structures. The system is composed of a dry fiber grid embedded in a cementitious matrix. FRCM are particularly indicated in the reinforcement of historical masonry buildings due to the higher compatibility with the substrates, reversibility, vapor permeability and durability to external agents.
The mechanical properties of these materials are investigated and the out-of-plane behaviour of a masonry panel reinforced with FRCM is investigated. This topic is particularly interesting because the earthquake events recently occurred showed that a lot of damages occurred to structures and people are correlated to the collapse of internal masonry walls. The aim of this research is the study of the efficiency of this strengthening system and of its out-of-plane behavior.
Two types of FRCM materials were investigated: the first made with a PBO fabric, the second with a mesh composed by PBO and glass rovings. These systems are applied on medium-scale panel made with clay bricks and light hollow bricks.
The failure mode showed a collapse due to the development of cracks in the cementitious matrix and slippage or tensile failure of the fiber grid. FRCM system presents a more ductile failure mode when compared to the brittle failure of organic matrix FRP systems.
The experimental results were compared with the analytical formula proposed by the US standards.

7577 | Verification of bonding performance of FRP hybrid rebar (6. Composite structures in civil engineering)

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During the last two decades, fiber reinforced polymer (FRP) reinforcing bars for concrete structure has been extensively investigated and a number of FRP bars are commercially available. However, major shortcomings of the existing FRP bars are its high initial cost and low elastic modulus compared to conventional steel bars. The main objective of this study using the concept of material hybridization is to develop a viable hybrid FRP bar for concrete structures, especially for marine and waterfront concrete structures.
The purpose of the present study is to coat esin using a glass fiber to steel rebar. By this hybridization, the tensile strength of steel rebar is improved and also to make high corrosion resistance. For the effective use of this hybrid FRP rebar, the bonding performance between concrete and outer surface of hybrid FRP rebar, and between glass fiber and steel rebar is very important. So, for the optimum bonding performance between glass fiber and steel rebar, we considered various types of surface condition of steel rebar. In this paper the results of experimental tests related to bonding performance of hybrid FRP rebar is discussed.

7694 | Static behaviour of GFRP pultruded profile-concrete composite beams (6. Composite structures in civil engineering)

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Abstract

Glass fibre reinforced polymer (GFRP) are being increasingly used in buildings construction as they offer several well-known advantages such as high strength to weight ratio, chemical resistance or ease to installation. However, their low stiffness and the induced instability phenomena limit their use. One of the solutions consists in associating GFRP pultruded beams with concrete slab in order to increase their stiffness and to decrease the risk of instability. Numerous studies showed the effectiveness of this innovative hybrid beams through bending tests under different loadings.
In this study, we investigate the behavior of composite – concrete structures connected by means of studs or bonding. The material characteristics were first determined by means of tension or compression tests. The interface properties were also using push-out tests and provided for instance the average ultimate shear strength. Those results were used to design two composite-concrete composite beams, one connected by means of shear studs, the other one by epoxy bonding. Both those beams and the same GFRP profile without the slab were statically loaded up to failure. Their behaviors and measurements were analyzed and compared. They show the interest of the slab on the failure load and on the failure mechanism. Furthermore, bonding connection allowed a greater stiffness than shear studs connection and a stress distribution at the GFRP profile – concrete interface limiting the risk of cracking.
Existing models from literature are finally used to simulate the behavior of the three beams. Numerical results are compared to measurements showing their enough accuracy to predict the displacements and the state of stress in that new type of hybrid beams.

Keywords: GFRP pultruded profiles - Hybrid beams – Push-out tests – Bending tests – Bonding connection

7699 | FIRST EXPERIMENTAL RESULTS ON THE MECHANICAL BEHAVIOUR OF “PULTRUDED” BEAMS REALIZED BY BONDING MODULAR PLATES (6. Composite structures in civil engineering)

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The pultruded elements, especially beams, are now used for the construction of various civil engineering opera (bridges and footbridges) but what slows their spread on large scale is a poor economic attractiveness as well as a number of uncertainties that still remain on the their mechanical properties (fire resistance, deformability, delayed response to the viscosity of the resin, instability). Given the great interest of the international scientific community towards adhesive joints, the authors of this work have started an experimental campaign, followed by a numerical one, aimed at characterize mechanics of pultruded double-T beams obtained by bonding modular pultruded plates each other. In particular, in this work the first experimental results related to four-point bending tests on a priori pultruded beams and a posteriori pultruded beams (obtained by bonding pultruded plates) are presented and compared. The experimental results demonstrate the feasibility of the project.

7760 | Influence of chosen parameters on ductility of two chord battened steel-concrete columns (6. Composite structures in civil engineering)

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Column ductility is one of the most important parameters of structures subjected to unexpected overloads, load reversals, impacts, earthquakes and structural movements due to foundation settlement. Structural ductile members are capable of dissipating large amounts of energy by undergoing large deformations before failure, hence providing early warning to the occupants of the building and sufficient time for taking preventive measures. Previous analyses conducted by the authors suggest that except for the type of a column (steel, reinforced concrete, composite steel-concrete) applied measure of ductility, as well as other factors such as used materials, loading and boundary conditions, have also significant influence on column's ductility.

In this paper, division for a column pre-buckling and post-buckling ductility is introduced and various parameters concerning this division are presented. Based on own experimental research on two-chord composite steel-concrete columns, influence of different loading conditions (application of the force through the steel shapes only or through the concrete part of the cross-section), concrete strength and steel fiber reinforced concrete usage on the pre-buckling ductility is evaluated. In order to complement the research, a numerical model in ABAQUS was created, which takes into account all material (steel plasticity and concrete damage and plasticity) and geometric (contact and changes in a geometric configuration during analysis) nonlinearities.

The results reveal beneficial effects of using fiber reinforced concrete and through the steel shapes loading on the pre-buckling ductility of the investigated composite columns.

7790 | Design, Modelling and Numerical Testing of 5-Box GFRP Shell Footbridge (6. Composite structures in civil engineering)

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The study concerns design, modelling and numerical testing of a composite bridge for pedestrians and cyclists, of 16.60m span length and 2.56m usable width, intended for use over main roads with two-lane carriageways. Architecture, a structural solution and a manufacturing technology of the footbridge are original. The footbridge satisfies a condition of easy and quick assembly / disassembly.
The footbridge superstructure is a 5–box shell girder, made of E-glass / vinylester laminates. Quasi-balanced bidirectional stitched fabrics of 800g/m2 weight are used. The superstructure consists of three main shells formed in the infusion technology and adhered together. Composite cross members adhered to the shells are applied. A longitudinal profile of the footbridge has a triangular shape.
The railing consists of steel columns with handles, polycarbonate plates and wood handrails. There are used plate–screw connectors for connecting steel columns with the bottom shell of the superstructure. Bearings are designed using the vertical / horizontal anchors and support composite plates adhered to the bottom shell. The polyurethane pavement is used.
Load schemes and design criteria for the footbridge are adopted in accordance with Eurocodes and with the recent authors' paper. Seven load capacity limit states and four serviceability limit states are considered. Based on design of GFRP composite pressurized containers, the strength condition is developed, taking into account material tests, chemical resistance, effect of temperature, and durability. The strength condition is checked at the Gauss points of laminate layers according to the Hashin–Fabric failure criterion.
Numerical modelling and simulation of static processes and modal analysis in reference to the footbridge is performed using the FE code MSC.Marc 2010. A geometrical model of the system is made using the Catia v5r19 programme and the Generative Shape Design environment. The FE mesh was made in the Altair HyperMesh 11.0 environment. A homogenized layer of laminates is modelled as a linear orthotropic elastic – brittle material. Elastic and strength constants related to a single layer are determined experimentally at temperature of 20°C, in accordance with the relevant standards.
Global static and dynamic analyses of the footbridge are carried out for the shell model of the object. Influence of ply sequence variants on the displacement and the effort states as well as on the modal characteristics of the footbridge is analysed.

7930 | Tribological properties and a wear model of aluminium alloy matrix composites. (6. Composite structures in civil engineering)

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Aluminium based metal matrix composites are well known for their good wear resistance, high specific strength, stiffness and hardness. They have found applications within the aerospace, military but especially in the automotive industries. This paper presents the results of tests as regards the application of a mixture of particles in aluminium matrix (AlSi12Cu2Ni2Mg4) composites, in which the mixture of types of ceramics SiC were applied. The target of the research was to determine the tribological properties as well as the phenomena, and mechanisms which accompany the tribological wear of composites with under dry friction conditions. Tribological investigations were carried on a pin-on-block tester. Based on the performed tribological tests, microscopic observations and profilographometric measurements, an attempt of presenting a model mechanism of wear for the SiC-particle reinforced composite under dry sliding conditions was made. The model refers to consecutive wear stages: from the running-in to established interaction. It presents characteristic friction-related effects, such as: pullout of the reinforcing particles, plastic deformation of the matrix, abrasive wear of the cast iron sample and crushing of the particles during interaction. Moreover, differences in the wear nature, resulting from the sizes of investigated particles, were presented.
A model of the composite with particles sized up to 50 m, involves four stages:
Stage I: initial interaction – the cast iron surface rests on the protruding (after polishing) reinforcing particles. Initial ploughing of the cast iron surface (running-in).
Stage II: due to "adjustment" during the running-in process, the contact area of interacting surfaces increases. At this stage, decrease and stabilisationof the friction coefficient are observed. Irregularities on the surface of cast iron counter sample interact with the reinforcement and the matrix, which results in their gradual abrasive wear.
Stage III: this stage should be divided into two types: A and B. For the A type, the reinforcing particle pullout and intensification of the wear process due to its additional interaction with the friction surfaces are observed. As a result, the particle may be embedded in the cast iron surface, which leads to increased abrasive wear of the composite, or it may freely move between the interacting surfaces. The moving particle may scratch any of the interacting surfaces or cause plastic deformation of the unreinforced parts of the matrix. Over time, the particle crushes and is eliminated. In the case of B type, the reinforcing particle is pressed into the matrix. This may result in adhesion of the composite matrix part to the cast iron, which leads to pullout or plastic deformation of the matrix identified as "smudging" on the friction surface.

Stage IV: it can be described as a return to the normal interaction following the previous stage disturbances. The characteristic effects for this stage are: gradual smoothing of the composite surface due to plastic deformation of the pullout-affected area and exposure of further reinforcing particles due to abrasive wear of the matrix.
The effects observed during the III and IV stages should be considered as typical of the set friction characteristics; they occur cyclically due to material wear during operation.

8027 | The study on the properties of polymer concrete with various curing temperature for application to rail slab track with reduced rolling noise generation (6. Composite structures in civil engineering)

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The cement concrete has been widely used as the material of construction and civil engineering, as it has proper mechanical properties. However, there were several problems such as high noise, vibration through floor and railway due to its low damping ratio, which would make train passengers less comfortable and generate noise pollution during train running. Nowadays, the polymer concrete has been widely used to replace with cement concrete because it has the possibility to reduce the vibration/noise problems. In this paper, the mechanical/dynamic property of polymer concrete was investigated to reduce the vibration/noise problems on rail slab. The polymer concrete was fabricated with the different curing temperature and different mixing ratio of the epoxy resin/aggregate. To observe the curing reaction between the epoxy resin and curing agent with respect to the curing temperature during the curing process, the in-situ curing monitoring of the polymer concrete was performed by measuring the dissipation factor of the epoxy resin using the dielectric sensor. Also, the viscosity of epoxy resin with different curing temperature was measured using the viscometer. The compressive and flexural strength of the polymer concrete were measured using tensile test and 3-point bending test with respect to the curing temperature and the mixing ratio of epoxy resin/aggregates, respectively. Also, the frequency dependent variation of the polymer concrete stiffness and damping were obtained by impact vibration tests to characteristic the vibration control capability. The bonding state of cured epoxy resin was observed using scanning electron microscope (SEM). From the study, the polymer concrete with the weight fraction 20 wt% of the epoxy resin and 80 °C curing temperature exhibited the appropriate property for the noise/vibration reduction and mechanical properties compared to the cement concrete.

8539 | Effect of the inherent eccentricity in single-lap direct-shear tests of FRCM composites (6. Composite structures in civil engineering)

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Investigation of the bond between fiber reinforced composites and the substrates onto which they are applied is of critical importance to understand their failure mechanisms. The bond behavior can be studied using different experimental test set-ups; the most commonly used are the single- and double-lap direct-shear tests, and the small-beam test. In single-lap direct-shear tests the presence of an eccentricity between the pulling and restraining forces leads to a mixed Mode-I – Mode-II fracture process at the interface. The effect of a small loading angle was investigated by some authors and was found to be negligible for long composite bonded lengths (Yao et al. 2005). In this paper single-lap direct-shear tests conducted on fiber reinforced cementitious matrix (FRCM) composite-concrete joints were used to investigate the eccentricity effect on the composite bond behavior. FRCM composite strips with the same bonded length were applied to concrete blocks of different lengths. The use of an optical technique known as Digital Image Correlations (DIC) allowed for studying the strain field on the surface of the bonded composite. The results obtained from FRCM composites with the same bonded length applied to concrete blocks of different lengths provided similar results confirming that the eccentricity effect is negligible for long bonded lengths.

Yao, J., Teng, J.G. and Chen, J.F. (2005). Experimental study on FRP-to-concrete bonded joints. Composites: Part B, 36, 99–113.

8672 | NEW AND EMERGING COMPOSITE TECHNOLOGIES FOR CIVIL INFRASTRUCTURE (6. Composite structures in civil engineering)

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There is an increasing interest in the application of fibre reinforced polymer (FRP) composite materials in civil, marine and mining infrastructure. The many advantages of FRP include low energy consumption, low cost, light weight, and good specific mechanical properties. Being lightweight, these materials are easy, fast and economic to install as it requires minimal handling and reduces energy in transportation. They also have superior durability resulting in reduced maintenance requirements. Consequently, an increasing range of structural components and systems made from FRP are now available.

Despite its many advantages, the acceptance of FRP has been limited due to lack of standards and design. New techniques involving fibre composite materials into construction have noticeably failed to meet expectations by the owners because of the lack of appropriate design guidelines. Thus, it is important to investigate the behaviour of new and emerging FRP systems in order to gain a detailed understanding of their structural performance and to give end-users confidence on the quality and reliability of these new materials. When this is achieved, it could help expedite the implementation of FRP in civil infrastructure through a more functional and economical design.

This paper presents the on-going research, developments and applications of new and emerging composite technologies for civil infrastructure. These include sustainable bridge girders, pile rehabilitation and composite pile systems, boardwalks and walkways, railway sleepers, strengthening and retrofitting of existing structures, and other innovative technologies utilising the unique advantages of FRP materials.

8693 | Flexural strength and ductility of reinforced and partially prestressed concrete sections with corrugated steel web(s) (6. Composite structures in civil engineering)

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Prestressed concrete bridges with corrugated steel web(s) have emerged as one of the promising bridge forms. This structural form provides excellent structural efficiency with the concrete flanges primarily taking bending and the corrugated steel webs taking shear. In the design of this type of bridges, especially those with flanges made of high-strength concrete and those with the requirement of earthquake resistance, both the flexural strength and ductility need to be carefully examined. Evaluation of these safety-related attributes requires the estimation of full-range behaviour. In this study, the full-range behaviour is evaluated by means of a nonlinear analytical method which uses the actual stress-strain curves of the materials and considers the path-dependence of materials. In view of the different behaviour of components and the large shear deformation of webs with negligible longitudinal stiffness, the assumption that plane sections remain plane may no longer be valid. The interaction between shear deformation and local bending of flanges may cause additional stress in flanges, which is considered in this study. The numerical results obtained are compared with experimental results for verification. An extensive parametric study is undertaken to clarify the effects on strength and ductility of various parameters such as the grade of concrete, the grade of non-prestressing steel, the reinforcing index, the partial prestressing ratio, and the degree of prestressing. From the numerical results, the flexural strength and ductility are investigated and some design recommendations are obtained.

8724 | Free formaldehyde and internal bond in composites from eucalyptus and bagasse (6. Composite structures in civil engineering)

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The use of natural fibers in composites manufacturing is ancient, although its industrial application is low due to the costs of adapting the industrial process, the lack of information and its availability in the market, despite its importance and applications, in particular, in developing countries. In this context, the generation of plant fibers, such as agricultural waste, is related to (i) the characteristics of the production process and its shredding, (ii) the selective and restricted market conditions, (iii) the perishability stage of the natural products and (iv) the limited information available for their destination and use.
Considering these aspects, it is desirable that institutions that develop research related to science and technology in agricultural resources submit work proposals that contribute to the resolution of questions regarding the use of these resources in a sustainable way, with improved yield potential and quality improvement of products generated by the agricultural bases industry, thus allowing increased competitiveness in this market segment.
Under laboratory conditions, the bagasse particles were mixed with eucalyptus fibers for composites with up to 25% sugarcane bagasse (increasing increments of 5%) and two levels of urea formaldehyde resin (13% and 16%). The internal bond properties of the panels showed satisfactory average values for the design of a new product and mostly attended the current specifications. The application of 16% UF resin, compared with 13% UF resin, reflected in better physical and mechanical properties and the mean of the assays totally met NBR 15316 (2009) norm. Furthermore, the lowest content of free formaldehyde was detected in composites with higher percentage of sugarcane particles. The results indicate that the composite of eucalyptus particles and sugarcane bagasse fibers (in percentages of 5-25%) present technological properties that meet the standards and feasible production possibilities in the existing industrial conditions.

8726 | DEVELOPMENT OF AFT BULKHEAD OF THRUST-REVERSING DEVICE OF AIRCRAFT ENGINE FROM POLYMER COMPOSITES (6. Composite structures in civil engineering)

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Today fibrous polymer composite materials (PCM) are widely used in aviation industry all over the world. Composites are used not only in the airframe, but also in manufacture of aircraft engines parts and components. Generation of new materials, improvement of manufacturing technologies and development of numerical simulation methods allows to expand the range of application of PCM in aircraft engines – not only for light loaded shells but for load-bearing parts. One of such parts is the aft bulkhead of thrust-reversing device of aircraft engine PD-14.
Thrust reverser systems are featured on many jet aircraft to help slow down just after touch-down, reducing wear on the brakes and enabling shorter landing distances. Reverse thrust is located behind the fan cowl doors and combined with an exhaust nozzle. It consists of fixed and movable parts. The fixed part is the cascades located between forward and aft frames and bolted with them.
The form of frame is non-closed "U"-shaped ring. The loads on frame are transferred from the cascades through bolted joints. The weight of metallic frame is about 17 kg without taking fastening details into account. The application of composites (carbon-fiber reinforced plastic in particular), for the engine frame will provide considerable weight savings.
We developed the numerical model of the frame. Stress and strain fields in the frame under various conditions of loading were obtained with ANSYS software using this model. The mechanical properties of materials were found experimentally. The aims of numerical simulations are the selection of reinforcement scheme based on technological feasibility and the development of manufacturing conception.
Numerical simulation of manufacturing processes also was carried out. Thus, RTM process and laying-out of material plies procedure were realized with PAM-RTM and Fiber-SIM software.
Finally optimal reinforcement scheme providing technological effectiveness and satisfying to service conditions of engine was selected.
The next step of this work will be the manufacture of full-size specimen for mechanical test to verify the results of numerical simulation. The possibility of usage of strain gages and piezo sensors in test will be considered.

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Project No. 14-01-96020: “Experimental and theoretical studies of the mechanical behavior of composite materials with optical fibers and piezo materials”

8728 | Strength and confinement of SFRC – an experimental study (6. Composite structures in civil engineering)

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Strength and confinement of SFRC – an experimental study

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An experimental study was carried out with the aim of examining the structural behaviour of steel fibre reinforced concrete (SFRC) and the influence of volume fraction (Vf) on the bi-axial state of strains due to axial compressive loads as well flexural strength. In particular, the study has focused on investigating the confinement provided by the steel fibres. This was achieved by measuring strains both axially (i.e. compressive) and laterally (i.e. tensile) on prism SFRC specimens as well as the applied axial compressive stresses. The experimental programme comprises tests which were carried out on cube, prism and beam specimens in order to establish the compressive strength, axial and lateral strains, and flexural load-deflection curves; respectively. For each set of specimens, tests were carried out using varied steel fibre contents, namely: one plain and three steel fibre volume fractions (0.5%,1% and1.5%). So for the cube specimens, three cubes of size 100mm * 100mm * 100mm were studied for each volume fraction totalling twelve specimens. Similarly, two prisms of size 100mm * 100mm * 300mm were tested for each volume fraction totalling eight specimens and two beams of size 100mm * 100mm * 500mm were adopted totalling eight specimens. The steel fibres used in the experimental study were hooked-end DRAMIX RC-65/35-BN steel fibres with length 35mm and diameter 0.55 and a corresponding aspect ratio 64. The fibres were added to a standard concrete mix of proportion 1:2:3 with a water-cement ratio of 0.55. The specimens studied did not have any other form of reinforcement added such as steel bars.
For the cube specimens, it was found that there was a gradual increase in the compressive strength values in line with the increase in volume fraction of steel fibres added to the concrete mix. The average percentage change in cube compression strength was found to be 1.5%, 4.4% and 16.5% for Vf = 0.5%, 1.0% and 1.5%; respectively. Thus, it can be concluded that although there was a consistent increase in strength, it was only the higher dosage of Vf = 1.5% that has resulted in a practical increase. Crucially however, the prisms bi-axial strain results show that the ultimate axial compressive strains increase as the fibre amount is raised demonstrating that the fibres improve the post-peak softening response (with ultimate strains as high as 0.006 compared to 00.0035~0.004 found in plain concrete prism specimens). The increase was consistent even with the lowest amount of fibres of Vf = 0.5%. It was also interesting to find that the lateral tensile strains were gradually reduced as the fibre dosage was increased showing that the fibres enhance the confinement (in the orthogonal direction to the applied compressive load). This can only be captured by measuring both axial and lateral strain rather the common uni-axial testing approach. Considering the crack patterns of the specimens, it was also observed that the addition of fibres has led to a reduction in crack propagation. The experimental study on beams revealed that the addition of steel fibres enhanced the flexural strength to the beam. The percentage increase in the load-carrying capacity for the beams was 90% with Vf = 0.5%, 133% with Vf = 1.0% and 250% with Vf = 1.5%, which is quite considerable. Additionally, there was also a consistent enhancement in ductility (and corresponding energy absorption capacity) as fibre dosages were increased. The addition of fibres also helped arrest the crack propagation and made the SFRC beams stiffer in comparison with their plain concrete counterparts.

Keywords: concrete, steel fibres, shear

8730 | Experimental investigations on steel fibres as shear reinforcement (6. Composite structures in civil engineering)

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Experimental investigations on steel fibres as shear reinforcement

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An experimental study was carried out examine key structural reposes of steel fibre reinforced concrete (SFRC) beams with shear links. This comprises compressive, tensile and shear strengths as well as ductility and energy absorption capacities. A key issue assessed is whether the use of steel fibres can result in a significant reduction in conventional reinforcement without compromising ductility and strength requirements set out by the design codes. In this respect, the spacing between shear links was relaxed while steel fibres were added to see whether or not the loss of shear strength can be compensated for in this way. This is particularly useful in situations where the shear reinforcement required can lead to congestion of shear links, for instance in seismic design. The experimental programme comprises tests which were carried out on cubes under compressive force, notched cubes under splitting tensile force and beam specimens with two different spacing values between shear links, namely: 45mm and 90mm. Additionally, four variations of fibre volume fraction were also considered in the study, which were Vf = 0%, 1%, 2% and 3%. One beam was tested for each link spacing and volume fraction and a further beam was tested at a spacing of 30mm and Vf = 3%, thus totalling nine beam specimens. Cube compressive test and split tensile test was performed to determine the compressive and tensile strength of the concrete mix with different steel fibre content. Two cube specimens were tested in compression for each volume fraction totalling eight and similarly eight cubes were examined under tensile splitting loads. The dimensions of the beams were 100mm * 100mm * 500 mm and the dimensions of the cubes were 100mm * 100mm * 100mm. The steel fibres used in the experimental study were hooked-end DRAMIX RC-65/35-BN steel fibres with length 35mm and diameter 0.55 and a corresponding aspect ratio 64.
For the cube specimens, it was found that there was a linear increase in the compressive strength values in proportion to the increase in volume fraction of steel fibres added to the concrete mix. The average percentage change in cube compression strength was found to be 7%, 20% and 25% for Vf = 1%, 2% and 3%; respectively compared to the specimen with no fibres. It was also found that the tensile splitting strength (representing the residual tensile

strength) also increases with the addition of steel fibres indicating that the fibres at these high dosages are active in bridging the orthogonal cracks. The experimental study on beams revealed that the addition of steel fibres enhanced the shear strength of the beam. Crucially the experiments has shown that the relaxation of shear link spacing from 45m to 90mm (i.e. by 100%) can be compensated for by adding steel fibres at Vf = 1% or above. Initially, when the spacing was relaxed and no fibres were added, there was a drop of ~10% in load-carrying capacity. When fibres were added at Vf = 1% (with relaxed spacing of 90mm), this has resulted in an enhancement of 5% of the strength compared to the specimen with link spacing of 45mm and no fibres (i.e. control specimen). The enhancement increased to 15% and 33% when fibres with Vf = 2% and 3% were added, respectively, compared to the control specimen. The addition of fibres also helped arrest the crack propagation. The studies provided insight into how the steel fibres can help reduce congestion of shear links.

Keywords: concrete, steel fibres, volume fraction, shear strength

8771 | Structural behaviour of concrete wide beams strengthened with overlay UHPC material (6. Composite structures in civil engineering)

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Reactive powder concrete (RPC), also commonly known as Ultra-High Performance Concrete (UHPC), is a relatively new type of high strength concrete (HSC) in the construction industry. UHPC offers excellent structural properties, such as ultra-high strength of more than 150 MPa, high fracture toughness, high ductility and better durability. Because of its superior properties, UHPC is suitable as an advanced material for reinforced concrete (RC) structures subjected to severe mechanical loading such as blast and impact.
Recently the use of UHPC has been extended into the rehabilitation of concrete structures. The basic concept is to use UHPC to strengthen parts of the structure where the outstanding properties of UHPC can be fully exploited. The resulting configuration consisted of composite structural elements combining UHPC and conventional RC. So far the rehabilitated structures has demonstrated significant improvement on the overall structural resistance and durability. The findings are very promising, it indicated the great potential of UHPC applications and the technology is possible for either cast in-situ or precast applications using conventional standard concreting equipments.

8797 | IMPROVEMENT OF AXIAL FLEXIBILITY AND STRENGTH OF WEB-FLANGE JUNCTIONS OF GFRP PULTRUDED I-BEAMS (6. Composite structures in civil engineering)

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In past few decades, the interest in using pultruded fiber reinforced polymeric (PFRP) composites in construction applications has grown rapidly. Several research studies were conducted and focused on the performance of PFRP beams, columns and frame structures. The results of the majority of previous studies highlighted a major problem associated with the deficiency of the off-the-shelf, unidirectional open-web pultruded profiles. In this regards, a common conclusion was drawn by many researchers; that is: the inherent structural deficiency of commercially produced unidirectional PFRP profiles, especially at the flange/web(s) junction(s) that lacks fiber continuity. The lack of fiber continuity creates a ″resin-rich″ zones at the junctions that were shown to be responsible for rapid degradation of both axial and rotational stiffness as well as the strength of the majority of PFRP profiles.
Another related problem is the use of incorrect framing connection details, currently being used by industry. Such connection details mimic those associated with steel structures. This approach ignores both the anisotropic and the viscoelastic nature of composites as well as the aforementioned inherent junction deficiency that, in most cases, lead to a greater risk with regard to the safety, reliability and economic aspects of such structures.
In recent years, several programs on optimizing pultruded composites have been initiated. For example Davalos et al. presented an approach for flexural analysis and design of pultruded beams. This approach involved computational procedures for utilizing fibre volume fraction of the constituents, ply stiffness and panel laminate engineering constants. Over the past two decades or so, a number of studies focusing on the performance of PFRP connections and frame structures have also been reported. Some of the pioneering studies on PFRP frame structures were reported by Mosallam et al. presenting the results of a comprehensive theoretical and experimental program to evaluate both the short- and long-term behavior of PFRP structures subjected to both quasi-static and sustained loading.
Other relevant studies related to this topic have been also proposed by Turvey and Zhang and Borowicz and Bank. Due to the critical impact of the web-flange junction local failure on the structural behavior of pultruded composites that are being currently used by the construction industry, it is necessary to develop techniques to detect such type of potential localized failure. Leung et al. developed a fiber optic based technique to detect delamination at the web/flange junction of a GFRP I-beam.
Finally, the authors of this paper have recently presented the results of a multi-phase comprehensive joint research program between University of Salerno, Italy, and the University of California, Irvine, USA. In particular, load-displacement (P-δ) and moment-rotation (M-θ) relations have been developed in order to accurately model and in order to establish design limit-state of PFRP structures, necessary to predict the local and global responses of PFRP structures.
The aim of this study is to suggest simple detail to improve the structural behavior of web/flange junction of GFRP I-beam. In particular, the performance of various stiffening elements will be evaluated by means of an experimental investigation that the authors are going to conduct at the Materials and Structural Testing Laboratory (LMS) of the Department of Civil Engineering of the University of Salerno. The experimental results will be also compared with the numerical ones obtained via a 3D finite element analysis.

8847 | Beam-to-column bolted connections between GFRP pultruded tubular members: Experimental tests and numerical modeling (6. Composite structures in civil engineering)

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This paper presents experimental and numerical investigations about the structural response of beam-to-column bolted joints between glass fibre reinforced polymer (GFRP) pultruded members. This study was developed in the scope of the CLICKHOUSE project, which aims at developing a prototype of an emergency house made of composite materials. In this prototype, the connections between GFRP members (as well as between these and the other construction elements) are intended to have an expedite assembly and disassembly process.

The GFRP profiles used in the experimental tests have square tubular cross-section with 120 mm of height/width and 10 mm of wall thickness. The beam-to-column joints comprised a 1.16 m long column connected to a 1.00 m long beam. The connections tested were materialized by means of tailor-made connection parts made of steel plates positioned inside both the beam and the column. Three experimental series were testeds: (i) a connection in which the beam is fixed with two bolts per flange; (ii) a connection with the beam fixed with four bolts per flange; and (iii) a connection in which the beam is fixed with one bolt per web. The frame connections were subjected to static monotonic tests by applying a transverse load to the beam. The results were analysed in terms of moment vs. rotation curves, stiffness, strength and failure modes.

The numerical investigations consisted of simulating the experimental tests with three-dimensional finite element (FE) models. The numerical models were developed in ABAQUS commercial package. A classical isotropic material model was adopted for the steel plates and the bolts, whereas for the GFRP an orthotropic elastic behavior was considered. For all surfaces the contact behavior was simulated using small sliding with normal and tangential behavior. Geometric non-linear analyses were performed. The results of the experimental tests were used to calibrate and validate the numerical models, which were then used to evaluate the strain and stress fields in the joints.

8944 | Application of Lattice Composite Technologies to Aircraft Primary Structures (6. Composite structures in civil engineering)

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Current composite materials in frames of “Black metal” aircraft primary structures do not allow to obtain significant weight decrease for these structures as compared with state-of-the-art metallic analogues. Besides, a number of principal problems concerning long-time operation of aircraft still can not be solved for these structures without significant weight expenses.

At the same time, there has been an encouraging experience associated with the so-called “pro-composite” structures made of unidirectional composite elements that led to a significantly improved weight efficiency of aerospace structures. One of the successful examples of real-life pro-composite structures are the space structures having lattice topology and manufactured by wet filament winding. Such lattice interstage adapters for the Russian heavy launcher Proton-M have demontrated real weight reduction up to 50% as compared to metallic ones. This successful experience became the basis for the investigations dedicated to adaptation of lattice composite technologies to development of primary structures of perspective civil aircrafts.

Aircraft structures have a number of specific problems, which are not typical for space structures. The main of these problems are:
- combined loading, including significant shear forces, bending and torsion;
- requirements of long-term operation, including durability and damage tolerance;
- requirements of maintenance and repairability.

In the presented work authors suggest the following solutions of the problems of adaptation of lattice technologies to aircraft primary structures:
1. Application of novel pro-composite structure concept for composite airframes based on the principle of division of the primary structure into two main elements:
- High-strength grid of composite ribs – for taking external forces and moments.
- Elastic internal skin – for pressurizing and transferring loads from pressurizing to the grid.

Application of this structure concept allows bearing the combined external loading by the means of unidirectional composite ribs only, i.e. by tension and compression of composite elements along the fibers, while the skin acts as a pressurized membrane and can be lightweight.
2. Development of protection system for load-bearing composite ribs.
In order to assure long-term and safe operation for composite primary aircraft structures, the load-bearing elements must be protected from impacts and environmental factors. Such protective systems can be effectively realized for lattice structures due to the topology of the load-bearing grid, which allows to protect the ribs with slight weight penalty.
3. Multilevel repair concept.
Repair concept for lattice composite structures includes several different scenarios of repair depending on type and extent of damage.

In this work some results of development of lattice composite airframes are presented. The investigations have shown that the lattice composite primary structures demonstrate about 10-15% weight saving in comparison with metallic and “Black metal” analogues for a number of airframes, including cylindrical and oval fuselage structures, panels for “flying wing” aircraft concept and some other aircraft structures.

8966 | Eccentric compression performance of laminated bamboo column (6. Composite structures in civil engineering)

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This study investigated the influence of eccentricity ratio upon behaviour of laminated bamboo column specimens under eccentric compression. The load-strain and load-deflection relationships are obtained from column tests, and the detailed failure modes for all specimens are reported. The test deformation curves for the columns can be expressed as the sine half-wave line no matter how much the eccentricity is and the strain across the cross-section of the laminated bamboo column is linear throughout the test process. The ultimate load values decrease with the increase of the eccentricity ratio. How the eccentricity ratio influencing the strains for the four side surfaces have been described. An equation for calculating the eccentricity influencing coefficient of laminated bamboo columns is proposed. The calculation results obtained from the equations give a good agreement with the test results.

8983 | Seismic Behavior of ECC/RC Composite Frame (6. Composite structures in civil engineering)

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Engineered cementitious composites (ECC) is a special type of high performance fiber reinforced cementitious composites featuring significant tensile ductility and multiple cracking. An ECC/RC composite frame in which normal concrete both in beam-column joint zones and column roots in the ground floor was substituted with ECC, was proposed to relax the requirement of transverse reinforcement in the joint core and to improve the seismic performance of the frame. In theory, as the shear capacity and ductility of ECC are higher than those of normal concrete, the lateral capacity, ductility, and energy dissipation capacity of frame can be improved by the substitution of concrete with ECC in the beam-column joint zones. The seismic behavior of an ECC/RC composite frame was evaluated through the pushover analysis, and its seismic behavior was compared with those of reinforced concrete frame and ECC frame. Results indicated that the use of ECC in the frame could reduce the distribution range of plastic hinges, decrease the inter-story drift with relatively large plastic deformation, and mitigate the earthquake damage.

9000 | NONLINEAR MICROMECHANICAL MODELING OF TUFF STONE MASONRY FOR DYNAMIC RESPONSE ANALYSIS (6. Composite structures in civil engineering)

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Masonry is a composite material made of prismatic elements (i.e. stones, bricks or blocks) and mortar or dry joints. Masonry assemblages are typically used to form load-bearing or partition walls, as well as vaults, domes and retaining walls. Different computational strategies are currently available to simulate mechanical behavior of masonry structures, but experimental data are needed to assess the accuracy of numerical and analytical models.
In this study, a micromechanical finite element (FE) model is proposed for tuff stone masonry, which has been used from ancient times to the present for construction of buildings and infrastructures (e.g. arch bridges and water distribution networks). The arrangement of stones was set up according to the running masonry bond scheme. The micromechanical modeling approach allowed the authors to distinctly simulate the behavior of stone units and mortar joints, as well as their interaction. The FE model was developed within LS-DYNA computer program to predict masonry response to quasistatic, dynamic and even impulsive loads such as blast and impact. Material properties and volumetric stress-strain behavior of constituents (i.e. stones and mortar) were properly defined by means of laboratory test results. The nonlinear micromechanical FE model was then calibrated to get an effective reproduction of the experimental behavior of masonry specimens under different load patterns, hence assessing its numerical robustness. A satisfactory experimental-numerical comparison in terms of force-displacement diagrams and crack patterns was found. Local limit states associated with different failure modes of masonry constituents were statistically characterized for each load pattern. Finally, the influence of material properties was assessed. This investigation was first based on a sensitivity analysis where material properties were changed according to statistical variability from experimental evidence. Then, a stochastic FE analysis was carried out by simulating material properties in compliance with discrete and continuous probability models. That procedure accounted for the actual inhomogeneity of masonry constituents. Key masonry properties such as peak resistance and ultimate displacement were statistically characterized, evaluating the propagation of material uncertainties to the macroscopic level. The micromechanical model presented in this paper will be used for dynamic response analysis of masonry walls subjected to blast loading.

9009 | Research on the FRP deck panel for road bridge application (6. Composite structures in civil engineering)

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The growing need of durability enhancement for road bridge decks has recently caused the big impulse for research on new, durable, lightweight and easy to handle bridge decks, made of advanced materials, f.e. FRP (fibre reinforced polymers). Therefore, in the frame of UE 7FP, three structural solutions of sandwich FRP bridge deck have been elaborated, produced and tested under static load. On the base of initial test results the stiffness, load carrying capacity and dynamic behaviour of panels have been estimated and the best solution for further research has been chosen.

The best solution, i.e. panel fabricated by VARTM manufacturing technique, has been tested in full scale to estimate its behaviour under service, ultimate as well as dynamic load. The panel fulfilled the required criteria for ultimate capacity, serviceability and safety, therefore its application in prototype bridge construction is planned. The detailed FEM model of the panel was also elaborated and after validation against the test results, it is planned to use the FEM model in designing of the real bridge application. The structure, production technology and main test results of the full scale panel as well as FEM validation procedure will be presented in the paper.

9145 | Research on the Constraint Effect of GFRP Grid Beam Filled with Concrete (6. Composite structures in civil engineering)

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Abstract: Many studies have shown that comparing with the conventional reinforced concrete beam GFRP-concrete composite beam can reduce dead weight and improve durability by placing concrete and GFRP in the compressive and the tensile zone respectively. In this paper, the concept of GFRP-concrete beam is taken a step further, by combining the rectangular pultruded GFRP box with concrete slab which is restrained by GFRP grids to improve the bearing capacity, simplify the engineering and speed up construction. The finite element analysis software ABAQUS is the main tool in this research. To a better simulation, cubic concrete restrained by GFRP was designed in several sizes to ensure the constitutive relation of confined concrete. During the research, models of plain concrete slabs and concrete slabs with grids on the top are taken into comparison, to verify the existence of constraint effect. Additionally, different grid sizes of the beams are simulated, with a steady purpose of determining the proper size of the grids, which would maximize the effect of constraint. Besides these, several frequently-used strength grades of concrete are also taken into account. This study shows that the grid constraints can effectively improve the ultimate flexural capacity of the beam.

Key words: Composite beam; Constraint effect; GFRP; Grid; Concrete; Sizes; Bearing capacity.

9169 | RESIDUAL STRENGTH TESTING IN PULTRUDED FRP MATERIAL UNDER A VARIETY OF TEMPERATURE CYCLES (6. Composite structures in civil engineering)

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This research evaluates the effects of various temperature cycles on the compression behaviour of pultruded fibre reinforce polymer (FRP) samples. The performance of the temperature affected samples are then compared with samples not subjected to the temperature cycles in order to evaluate the effects of temperature on both the load compression achieved and any surface or material degradation as a result of the temperature cycles. The analysed FRP samples were physically characterized by a very low slenderness value in order to avoid potential material instability as a result of successive high temperature cycles on the compressive strength. Strain-gauges were used to evaluate any local deformation of the samples both in the direction of the pultruded fibres and orthogonally to them.

9208 | Reinforcement of old masonry structures by advanced composites materials : experimental analysis and modelling. (6. Composite structures in civil engineering)

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Reinforcement and strengthening of historical masonry is of highest importance for preserving the world build heritage. The present paper focuses on the strengthening of limestone masonry by advanced composite materials adapted to the aesthetics and economical challenges. Thus, two strengthening techniques are studied, the first one using textile reinforced concrete (TRC), and the second one near surface mounted (NSM) FRP glass bars. Orthotropic and non-linear characteristics of the masonry require a multi-scale experimental analysis, in order to get the parameters adapted to the forecast of the mechanical behaviour.

In order to study the interactions at the level of the joint when shear loading prevails push-out and pull-out tests were realized. Push-out tests, under varying lateral confinement loads, allowed to establish a generalized law for the behaviour of the mortar joint and the joint/stone interface in shear. Pull-out tests on small masonry prisms reinforced by NSM- FRP bars allowed to quantify the effect of the reinforcement on the local mechanisms. Totally twelve specimens were tested, six for eaxh configuration.
Diagonal compression tests performed on real scale masonry walls allowed to analysis the interaction between masonry and TRC or NSM reinforcement. For each reinforcement configuration six walls were tested. Global and local mechanical parameters were analysed such as, global stiffness, strength, local strain field, etc. Correlation was made between the results of small and real scale specimens.

Experimental campaign was accompanied by a research of adapted analytical models found in the literature to describe the mechanical parameters as a function of the observed phenomena and material characteristics.

9220 | Design of Retrofit CFRP System for Pier Caps of I-88 Bridge over Fox River (6. Composite structures in civil engineering)

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A detailed structural capacity analysis of the cantilevered segments of the pier caps and spandrel caps on the I-88 Bridge over the Fox River in Ogden, Illinois was performed. The intent of this analysis was to investigate whether the bridge retains sufficient structural capacity after intermittent severing of rebar during construction. Cracks were observed over the critical sections over the cantilevered portion of the pier and spandrel caps. The structural analyses included the flexural and shear capacity of the cantilevered portion of the pier and spandrel caps.
As a result of this analysis, it has been determined that the cantilevered portions of the pier and spandrel caps on the westbound I-88 bridge over the Fox river retain sufficient ultimate flexural capacity and experience live load deflections within the range permitted by AASHTO. However, the intent of the retrofit system is to provide additional strength capacity to bring the flexural strength to its original design. In light of that, it was decided to design a full structural retrofit CFRP system of the pier caps given the intent of the crack control provision and issues.
In addition, a full retrofit to alleviate architectural cracking in a substructural element, blocked from public view, and protected from moisture by both deck and girders, can be considered acceptable. An epoxy injection and sealant application treatment on those pier caps was sufficient to prevent future problems caused by service level flexural cracking in the pier and spandrel caps.

9222 | BEHAVIOUR OF CONCRETE FILLED DOUBLE SKIN CIRCULAR STEEL TUBES IN AXIAL COMPRESSION (6. Composite structures in civil engineering)

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Experimental tests were conducted on 32 concrete filled double skin circular tube (CFDSCT) columns. The CFDSCT columns were loaded in axial compression until failure. The parameters that were varied were the lengths, diameters of outer steel tubes and strength of the outer steel tubes. The lengths that were tested ranged from 1.0 - 2.5m, in increments of 0.5 m. The CFDSCTs of 1m lengths failed by a combination of overall buckling and yielding of the steel tubes. All the other columns failed by overall buckling due to their larger slenderness ratio. The provision of concrete filled tubes (CFTs) in SANS 10162-1 and Eurocode 4 (EC4) were adjusted in order to determine the compressive resistance of these structural elements. A comparison of the test results and the proposed formula shows that the proposed formula predicts the test results well.

9299 | Experimental study on shear resistance evaluation of perfobond strip without penetrating rebar (6. Composite structures in civil engineering)

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A perfobond strip is widely used as the shear connector in various steel-concrete hybrid structures and in designing the perfobond strip, it is important to understand its shear resistance. In this study the shear resistance of perfobond strip without the penetrating rebar is investigated experimentally by employing the simple push-out specimen. As a result, the design formula is proposed for evaluating the shear resistance of the perfobond strip taking into account the dimensions of concrete block and the thickness of the perfobond plate as well as the perforation size, and the concrete compressive strength. In addition, the limit of the concrete block size effect and the influence of the location of the perfobond plate in concrete block on the shear resistance are also investigated in this paper.

9307 | On the structural design of the Portable Temporary Mataf Pedestrian Bridge (6. Composite structures in civil engineering)

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This paper presents the structural design of the Temporary Mataf, two-story composite walkway-bridge in Mecca, Saudi Arabia. This bridge is connected through several access ramps to Grand Mosque and Al-Umrah gates.
The application of this Structure is to provide the comfort of the current capacity of the worshipers even while the Grand Mosque is under the construction. Therefore, this project has alleviated crowd density of worshipers, increased the capacity of the pilgrims and provides a shorter period of Tawaf.
In order to design an ultra-lightweight, highly stiff and large span structure for the simple, fast and safe erection, ring structure is constructed from carbon fiber reinforced composite components with steel connections. Moreover, the access ramps are built from Carbon fiber pillars and steel beams. Whole structure can be removed and reconstructed as needed without the use of heavy machines which is the important feature according to the flow of the pilgrims in the Mataf area.
Furthermore, investigation of Vulnerability of this lightweight structure to the dynamic loads and the study of the structural interacting behavior of the steel connection and carbon fiber reinforced composite members are depicted in this paper.

9337 | Design of structural columns using composite systems (6. Composite structures in civil engineering)

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Composites systems are used more and more in structural civil engineering applications. Due to high specific stiffness and strength, corrosion resistance and durability, they may be used in new structures, in internal reinforcement of new concrete structures (replacing steel rods), new hybrid systems, in rehabilitation and reconstruction, in repairing and strengthening of old structures and in seismic performance optimization.
Besides a state of the art review of composite systems in civil engineering applications, the paper will present a new conceptual construction, including the design for columns to support plates for a petrol station.
The following aspects are considered:
• Customer's users requirements, including codes and standards
• Development of concept
• Materials selection using CES EDUPACK®
• Analysis of manufacturing procedures comparing advantages and disadvantages, particularly in pultrusion process
• Structural design, including bonded and bolted joints
• Numerical simulation using finite elements (ABAQUS®)
The columns structural design followed the design rules of a manufacturer of pultruded profiles FIBERLINE®, considering the anisotropic properties of the composite system. It will be discussed the design of the cover, the main structure and the support columns. The profiles used are W cross section, U, I and round cross sections. Structural loading considers also effects of snow and wind.
Finally, after the materials selection procedure, a glass fibre reinforced epoxy system has been chosen.
The paper will also present a design methodology for structural applications of columns.

9371 | Structural Behavior of RC Beams Strengthened with NSM Steel Bar: Experimental and Numerical Investigation (6. Composite structures in civil engineering)

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Due to hostile environmental conditions, faults in design, change in requirements and extend the design life may require strengthening or rehabilitation of existing reinforced concrete (RC) structures. Near surface mounted (NSM) technique incorporating steel bars is an effective for strengthening of RC beams under flexural loads. An experimental program and nonlinear finite element modeling (FEM) were carried out to explore the performance of RC members strengthened with NSM-steel. The experimental investigation comprised of three types of total nine RC beams with rectangular cross-section: (i) one unstrengthened beams, (ii) four beams strengthened with single groove NSM-steel bar and (iii) four beams strengthened with double groove NSM-steel bars. Four-point bending tests were performed up to failure of RC beams strengthened with different ratios of NSM reinforcement. Nonlinear material behavior of plain concrete, main and strengthening reinforcement are simulating applying pertinent constitutive models. Flexural failure modes, concrete compression, tension steel and NSM reinforcement strain, cracking behavior on strengthening are reported and discussed based on measured load, deflection and strain data. The experimental and numerical results show good agreement. A parametric studies were carried out the effect of NSM groove and reinforcement, effectiveness of NSM-steel technique and ductility on the structural response. The test results shown that NSM-steel significantly

increase the stiffness as well as the flexural strength (up to 84%) of RC beams.

9377 | Synthesis of composite lightweight concrete using palm oil clinker and oil palm shell as coarse aggregate (6. Composite structures in civil engineering)

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During the last decade, to ensure less destruction of natural resources, it is being popular to recycle the waste materials from the industries. Hence, the construction industries can get alternative building materials for producing green lightweight concrete. In Malaysia, palm oil producing industries are responsible to produce huge amount of solid wastes. It is possible to synthesis the lightweight aggregate concrete using solid waste namely oil palm shell (OPS) and palm oil clinker (POC) from the palm oil producing industries. Some attempts of previous studies were to use OPS, some were to use POC separately. Each concept has some advantages and disadvantages. In this research, OPS and POC were used together as a coarse aggregate to improve the mechanical properties of concrete. To achieve this purpose, normal coarse aggregate was fully replaced by POC and OPS in the lightweight aggregate concrete. This concrete was named as oil palm shell and palm oil clinker concrete (PSCC). Attempts have been made to fix the optimum mix ratio of OPS and POC in concrete for better performance. The proportions of OPS and POC mix are varied from 40% to 70%. Mechanical properties of PSCC including workability, density, compressive strength at different ages, splitting tensile, flexural strengths and modulus of elasticity have been evaluated. The results revealed that PSCC has the extensive potential to perform better as green lightweight aggregate concrete. It will solve the problem of solid waste management as well.

9549 | Parametric study of net section failure of pultruded connections with three-dimensional finite element approach (6. Composite structures in civil engineering)

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The results of a three-dimensional finite element study of the net section dominated failure behaviour of pultruded open-hole specimens are presented. Computer models are developed using the general-purpose software Abaqus. Several issues are addressed in the study with respect to the notched plate geometry: (i) thickness of plate, (ii) transverse centre-to-centre spacing of holes (gauge), and (iii) distance from the centre of the hole to the nearest edge. The analytical results provide information on basic performance and the effects of these parameters on strength and damage tolerance performance, thereby furthering the current understanding of pultruded plate-to-plate connection behaviour under static loading. Based on the results, design recommendations for minimum edge distance and gauge spacing for bolts are given.

6288 | Chiral separation using membranes coating with different chiral polymer materials (7. Innovative Applications)

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Separation of chiral compounds enantioselective composite polymer membrane was prepared by using co-polymerizing interfacially a mixture of different chiral compounds (amino acids, chiral metal complexes and drugs) and piperazine with trimesoyl chloride in-situ on polysulfone ultrafiltration membrane. The chemical composition of composite membrane was determined by ATR-FTIR, scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM) and X-ray Fluorescence Spectroscopy. High-performance liquid chromatography analysis was carried out using a chiral HPLC apparatus equipped with Chiral Chrompak-CR (+) column. The optical resolution of α-amino acids was performed in pressure driven process. The effect of operating pressure, permeation time and feed concentration on the performance of membrane was studied. The proposed schemes assume a new concept of excipient, which are not only inert ingredients but they have eligibility to separate different enantiomers. Keeping in view the pharmacological and chemical aspects of a specific enantiomer there is great need for efficient separation process. Our studies will be fruitful in the area of separation of enantiomer by using polymer composite material as support.1-3
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6301 | Design of a Lightweight Composite Sandwich Panel Semi-Trailer Deck (7. Innovative Applications)

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In road haulage the empty weight of a vehicle is a significant contributor to fuel consumption and resulting CO2 emissions. The application of lightweight materials in design is one avenue that needs to be explored in reducing the carbon footprint of road freight vehicles. There are very few regulations which determine the structural design of typical road freight semi-trailers, providing large scope for innovation in design. A lightweight composite sandwich panel has been designed to replace existing hardwood deck materials used in semi-trailers transporting grocery goods. The lightweight sandwich deck, comprised of woven e-glass fibre / polyester face sheets and a balsa core, is calculated to be approximately 200kg (40%) lighter than lightest existing birch plywood based deck. The lightweight composite sandwich panel has been shown to have comparable stiffness and strength to existing deck materials. A cost-driven design approach is employed to ensure cost competitiveness against existing materials. Future work will involve fitting a demonstrator of the composite sandwich deck to an existing trailer.

6380 | Organic/inorganic composite fibers for x-ray protection applications (7. Innovative Applications)

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Composite fibers containing an organic and an inorganic component are used for the production of plain textiles for x-ray protection applications. The production of the composite fibers is performed by the lyocell-process, while combining the organic cellulose fiber with an inorganic component as x-ray absorber. Adequate x-ray absorbers are non-soluble compounds of heavy chemical elements, which have to be non-toxic. The actually prepared composite fibers contain the x-ray absorbing compounds bariumsulphate, bariumtitanate, bariumzirconate and bismutoxide. Composite fibers with an inorganic content of 40 weight-percentage were realized and in first investigations the preparation of yarns and fabrics is started. Investigations are performed with monochromatic x-radiation of photoenergy 8 keV and x-radiation of full spectra up to photoenergy of 80 keV. The significant reduction of x-ray transmission is possible by such produced woven and non-woven materials. Especially effective for x-ray protection are the combination of different x-ray absorber and the use of double layer woven textiles.

7761 | Consolidated Fiber Placement - The lay-up of consolidated unidirectional fiber tapes (7. Innovative Applications)

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Automation will be the key factor for the increasing use of composite technology in all industrial areas. Some automated technologies (like ATL and AFP) are already used in the manufacturing process of large composite components. However, there are still problems during manufacturing which could not be resolved completely yet. Furthermore, the drawbacks of the cooling chain and the expensive autoclave process deter the use of composite technology in some industrial areas. The aim of this study is to demonstrate the suitability of a new manufacturing approach regarding the automated fiber placement. The bonding of consolidated fiber tapes allows for an optimal utilization of the fiber properties and eliminates typical manufacturing defects. In order to show the automated processing of the consolidated tape, a rudimentarily placement unit was developed. The unit takes the changed material properties into account and verifies the use of consolidated fiber tape for an automated process.

7762 | Consolidated Fiber Placement - A new approach in composite manufacturing (7. Innovative Applications)

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High tolerance requirements during fiber placement bear specific challenges – especially the problem of fiber deviation has to be mentioned. Furthermore there are long process times for the global process, caused by fiber preparation and matrix-curing. To ensure highest quality composites with a high grade of fiber parallel structures, a new production process for an economic production of large structures is proposed. Therefore, the bonding of unidirectional, pre-consolidated fiber tows to a load-specific global structure is investigated. With this approach, the fiber embedding is temporally decoupled from the fiber layup process. By producing a structure from optimally aligned fibers and with a hedged bonding process, an increase of the manufacturing-rate and quality is possible.
To prove a general suitability of this approach, initial basic investigations were carried out. Those will demonstrate if an adhesively fixed prepreg structure can compete with a pure prepreg structure. Reference samples of pure prepreg and adhesively fixed prepreg samples with different adhesives were made. For a second sample series, the prepreg-surfaces of the adhesively fixed samples have been pretreated with different methods before bonding. Finally, pressure-tests, 4-point-flexure tests and interlaminar-shear-strength test have been carried out with all samples. All test results have been compared with the reference sample.
The investigation led to very promising results and motivates to further pursue this approach.

7795 | Experimental study on mechanical behavior of FRP reinforced 3D printed elements (7. Innovative Applications)

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To enhance the mechanical properties of structural elements produced using three dimensional printing (3DP) techniques, and study the reinforcement provided by glass fiber reinforced polymer (GFRP) sheets wrapped around and adhered to the elements, axial compression experiments were conducted on circular columns, including four reinforced and one control element. Additionally, four-point bending tests were conducted on four reinforced beams and one control beam. These experiments mainly studied the influence of the number of GFRP sheets and reinforcement methods on elements' failure characteristics, bearing capacity, and ductility. The research results indicated that changing wrapping the columns in GFPR changed the failure mode from brittle to ductile, and markedly improved the peak loads (by 1427.2%~1792.0%) and largest compression deflections (by 833.9%~1171.3%) depending on the number of layers and reinforcement details. Additionally, the mechanical behavior of 3D printed beams with GFRP sheets adhered to the bottom was improved greatly, as bearing capacities were increased by 179.6%~538.8% and flexure deflections at the midspan were increased by 40.8%~225.8% depending on the number of layers and reinforcement details. However, the failure characteristics of 3D printed beams were affected by different reinforcement details.

7821 | Carbon fiber/thermoplastic bipolar plate-carbon felt electrode assembly for vanadium redox flow batteries (VRFB) (7. Innovative Applications)

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The vanadium redox flow battery (VRFB) is a promising energy storage system (ESS) which can decrease the risk of power outage by storing electricity

energy at non-peak time, and using at peak time. Among various ESSs, the VRFB is one of the safest and most flexible systems due to its unlimited capacity, non-explosiveness, and infinite lifetime.
Since the compaction pressure on the carbon felt electrode (CFE) inside the stack is relatively small, the electrical contact resistance between the CFE and bipolar plate (BP) largely affects the cell efficiency. In this work, a carbon fiber/thermoplastic composite BP-CFE assembly has been developed to decrease the contact resistance between the BP and CFE by embedding the CFE into the thermoplastic matrix of the carbon fiber composite BP through diffusion process to decrease the electrical contact resistance. To evaluate the performances of the BP-CFE assembly, the area specific resistance (ASR) and gas permeability were measured. Also the acid aging tests were performed to verify the stack reliability. Finally, the performances of the BP-CFE assembly were measured and compared with those of the conventional bipolar plate during the charge/discharge cycles of a VRFB stack.

7838 | Carbon elastomeric composite bipolar plate for high temperature PEM fuel cell (7. Innovative Applications)

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The carbon/epoxy composite bipolar plate (BP) is being substituted for the brittle graphite bipolar plate commonly used for the proton exchange membrane fuel cell (PEMFC) due to its high strength and high stiffness, and easy manufacturing. However, the harder surface of carbon/epoxy composite compared to graphite, requires coating of expanded graphite to decrease the area specific resistance (ASR), which is contributed much by the electrical contact resistance between the BP and compliant carbon electrode felts.
In this work, elastomeric materials are applied for the matrix of carbon composite BP to decrease the surface hardness of BP without coating of graphite. Silicon rubber, which is a high viscous and high temperature elastomer, was employed for the BP of a high-temperature PEMFC (HT-PEMFC) as a matrix of the carbon composite bipolar plate. The impregnation method of silicon rubber into the carbon fibers of up to 70 % volume fraction was developed. To increase further the electrical conductivity and strength of BP, conductive nano-particles were mixed with the silicon rubber. The thermo-mechanical and electrical characteristics of carbon elastomeric BP were investigated with respect to carbon fiber volume fraction, nano particle concentration and environmental temperature.

8128 | Effect of solid waste addition on the properties of soil-cement based composite (7. Innovative Applications)

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The possibility of reuse of solid wastes obtained of different industrial activities (eggshell waste and welding flux slag waste) as an alternative raw material for producing soil-cement based composite for civil construction was investigated. To prepared soil-cement based composite containing solid waste, the mixtures of soil, ordinary Portland cement, and solid waste (up to 30 wt.%) were uniaxially pressed and cured during 28 days. The effect of solid waste addition on the technical properties (water absorption, apparent density, and compressive strength) of soil-cement based composite was evaluated. The surfaces of fractured specimens were observed via confocal microscopy. The results showed that the amount of solid waste addition had an effect on both technical properties and microstructure of soil-cement based composite. It found that up to 15 wt.% of welding flux slag waste and up to 30 wt.% of eggshell waste could be added into the soil-cement based composite material.

8552 | Lightweighting road freight semi-trailers through the application of composites in trailer decking. (7. Innovative Applications)

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In road haulage the empty weight of a vehicle is a significant contributor to fuel consumption and resulting CO2 emissions. The application of lightweight materials in semi-trailer design is one avenue that needs to be explored in reducing the carbon footprint of road freight vehicles. There are very few regulations which determine the structural design of typical road freight trailers, providing a large scope for the use of composites in creating an innovative lightweight design. To achieve a targeted 30% weight reduction in trailer mass, structural design tasks have been split into two broad areas; applying composite solutions for specific sub-components and adopting a 'clean-slate' approach in the design of a whole trailer chassis. Preliminary work identified conventional hardwood-based trailer decking as a sub-component that is particularly suited lightweighting.

A novel test method has been developed to characterise the indentation wear failure of trailer decking caused by repeated loading of nylon cage wheels typically used in grocery haulage. Experience of industrial partners indicated this to be the critical factor in the failure of existing trailer decks. The method has taken into consideration a wide range of both static and fatigue load cases.

The test method has been applied to pultruded glass fibre reinforced polyester (GFRP) decking, commonly used on footbridges bridges, to show that it can also be suitable for use in trailers used for grocery haulage. The pultruded GFRP decking is in the order of 30% lighter than the lightest existing birch plywood based deck, highlighting the very encouraging potential for the use of composites in lightweighting trailer decking.
The lessons learned from the indentation wear study were also used to develop a lightweight composite sandwich panel deck, comprised of woven GFRP face sheets and a balsa core. This sandwich panel decking is calculated to be approximately 40% lighter than the lightest existing decking. However, the highly cost-driven nature of the trailer industry dictates that use of pultruded GFRP decking is the most prudent first step to introducing composites into trailer decks.

9063 | DOW Automotive Systems 2K Polyurethane Technology: From catalyst and prepolymer technology to vehicle manufacturing (7. Innovative Applications)

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There is increasing integration of composite parts into modern vehicles design due to light weight vehicle requirements. The application of adhesives technologies for their assembly is considered the most promising joining technology and aims at optimized production processes, improved crash performance and long term durability of the manufactured vehicle. Two component polyurethane structural adhesives are designed for these demanding automotive applications to enable light weight construction for significantly reduced CO2 emissions, fuel consumptions and reduced air pollution. Polyurethane chemistry offers flexibility for tailor made adhesive technologies.
Special pre-polymers were developed in order to offer superior thermal modulus stability, excellent adhesion to challenging substrates like coated metals, Carbon Fiber Reinforced Plastics (CFRP) for structural applications and thermoplastics for outer panel bonding. Highest bulk elongation combined with high young´s modulus provides stability as well as superior energy absorption under crash conditions. Tailor made catalysts technologies enable long working times combined with fast curing and strength built-up to enable maximum flexibility for the vehicle manufacturing process.

The article gives an insight into the chemistry of 2K polyurethane adhesives, provides an overview of the DOW Automotive Systems 2K polyurethane adhesives portfolio, lists applications in the area of composite bonding and provides an outlook for the future of structural adhesive assembly of composites in the automotive industry.

9192 | FEM Analysis of a Tailored B-Pillar using composite materials (7. Innovative Applications)

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Energy efficiency of car body structures includes, in addition to the obvious aspect of fuel consumption, an ultra-high level of passenger safety. However, with traditional manufacturing processes, an acceptable level of passenger safety results in an increased car body weight. In this context, the ongoing demand towards innovative solutions is getting very high. The realization of high strength properties and, at the same time, improved structural weight could be achieved through different tailoring routes. Nevertheless, the state of the art application of these tailoring routes is mostly limited to metals. In this study, an FE model is developed through which an optimization of the thickness profile and the stacking sequence can be realized by using composite materials in the proposed FE model of an existing B-Pillar geometry.

9213 | Rapid Isothermal Stamp Forming Processing Approach of Newly Developed High Performance Thermoplastic Matrix Composites (7. Innovative Applications)

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While aligned fibre thermoset matrix composites have been extensively used in structural applications over the past 30 years, thermoplastic matrix composites (TPCs) are only beginning to penetrate into structural applications, chiefly in aerospace. One driver for this is ready potential for rapid, cost-effective processing and high manufacturing volumes [1-3], in addition to inherent reprocessibility [4]. Additionally, TPCs exhibit relatively high fracture toughness and superior damage tolerance performance when compared to similar structures made of untoughened epoxies [3, 4]. These attractive features of TPCs are being offset with some drawbacks due to their high melt viscosity property which requires them to be processed at high temperature and pressure [5]. It is known that the high viscosity of thermoplastics often leads to poor wetting and impregnation of fibre during processing. This means that the common manufacturing techniques applied for thermoset composites are not feasible for thermoplastic composites. . Therefore there is a need to develop an alternative processing routes which not only able to achieve uniform resin distribution, complete fibre impregnation and good consolidation throughout the structures but also capable of rapid manufacturing cycle suitable for high volume manufacturing

One of the research area at WMG is examining the use of rapid isothermal and traditional non-isothermal stamp forming processes for this purpose using newly devoloped high performance/high temperature thermoplastic composite materials. In this study, unconsolidated and unwetted pre-form materials are being moulded using the novel rapid isothermal processing approach and the quality of the moulded components are compared with the ones moulded with traditional forming process. The effect of forming pressure, temperature and time are investigated in order to establish optimised processing parameters.

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9401 | Gasket-integrated carbon/silicone elastomer composite bipolar plate for high-temperature PEMFC (7. Innovative Applications)

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The primary components of proton exchange membrane fuel cell (PEMFC) systems are bipolar plates, end plates, membrane electrode assemblies (MEAs), gas diffusion layers (GDLs), and gaskets. The PEMFC composed of many components induces sealing problem of the stack, which affects the fuel efficiency, reliability, and maintenance costs of the system. Conventional PEMFCs are sealed with numerous elastomeric gaskets to seal the stack, which increases the manufacturing and assembly costs.
To reduce the assembly time and to increase the sealing reliability without the use of gaskets, a gasket-integrated carbon/silicone elastomer composite bipolar plate is developed. Silicone elastomer is employed rather than conventional glassy thermoset or thermoplastic polymers for the matrix of the composite bipolar plate, where the silicone elastomer works as gaskets due to its resilience. The mechanical and electrical properties of the developed carbon/silicone elastomer composite are investigated at both room temperature and operating temperature of high-temperature PEMFCs (HT-PEMFCs). The sealability of the gasket integrated composite bipolar plate is tested.

9486 | Development of the gasket-integrated elastomer composite bipolar plate for high-temperature PEMFC (7. Innovative Applications)

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To reduce the assembly time and to increase the sealing reliability without the use of gaskets, a gasket-integrated carbon/silicone elastomer composite bipolar plate is developed. Silicone elastomer is employed rather than conventional glassy thermoset or thermoplastic polymers for the matrix of the composite bipolar plate, where the silicone elastomer works as gaskets due to its resilience. The mechanical and electrical properties of the developed carbon/silicone elastomer composite are investigated at both room temperature and operating temperature of high-temperature PEMFCs (HT-PEMFCs). The sealability of the gasket integrated composite bipolar plate is tested.

9575 | Manufacturing of the carbon/phenol composite bipolar plate for PEMFC with hot rolling process (7. Innovative Applications)

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The bipolar plate is a major component to determine the cost, volume and performance of the PEMFC (Polymer Electrolyte Membrane Fuel Cell) stack. Carbon composite/epoxy has been considered as a potential material for bipolar plate due to its high mechanical properties, electrical conductivity and corrosion resistance. However, the long curing time of epoxy matrix under high pressure still remains an obstacle for mass production.
In this study, a continuous process using hot rolling for the carbon/phenol composite bipolar plate has been developed for mass production. To accelerate the curing reaction of the phenolic resin, p-toluene sulfonic acid catalyst was used. The temperature and pressure for high speed hot rolling process were optimized with cure monitoring using the differential scanning calorimetry (DSC) and dielectrometry. The area specific resistance (ASR) and mechanical properties of the carbon/phenol composite bipolar plate were measured with respect to the cure temperature, pressure and rolling speed. It was found that the composite bipolar plate produced by the optimized hot rolling process satisfied the department of energy (DOE) targets.

7840 | Optimized lifetime estimation model for composite textile used for façade cladding (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Lifetime estimation is a delicate subject especially for materials used in extreme environments. In this study, we present an optimized lifetime estimation model for textiles. These textiles are composite materials made of a core of PET woven fibers coated with PVC; this core is then protected with a film or with another coating. An accelerated ageing protocol was developed in the laboratory for these materials. The ageing was made in harsh conditions with high level of temperature in a basic medium. Then, mechanical and physical properties were monitored to understand the degradation mechanism and to evaluate the degree of ageing.Finally, an optimized lifetime estimation model was developed. This model allows the control of pH and temperature parameters and reduces the number of tests and conducted operations.

This paper presents the studied material and its properties. Details of the experience design and the ageing protocol are exposed and explanations on how the optimized method could give accurate life time estimation, through the temperature and pH control, are discussed.

Key words: composite material; accelerated ageing; hydrolysis; building; durability; textile.

7903 | Numerical studies of the coupling between water absorption and mechanical state based on the free volume theory (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Nowadays, in a difficult energy context, oceans represent a huge potential through the exploitation of tidal turbines, offshore wind turbines and waves' energy conversion systems. In order to improve global performances of such structures, a mass reduction is needed. Consequently GFRP and CFRP are premium choices due to their good specific properties. However, polymers interact with the environment. Indeed, they absorb moisture which leads to an ageing of the material. This interaction may lead to a premature damage of the structure. The knowledge of the water absorption effects and the changes of the mechanical properties through time are crucial to predict long term behavior of marine structures. To model water absorption, the well-known Fick law is often used assuming constant parameters of diffusion. However, some experimental results on specimens under mechanical loadings have highlighted dependency of the diffusivity to the mechanical strain field. Indeed, an increase of the diffusivity is observed when samples are under tension while a compression induces a decrease of the diffusivity. To explain/model this phenomenon, the free volume theory can be used. Diffusion parameters depend on the internal strain field and thus evolve according to both space and time. Finite element simulations are performed to solve coupled water absorption problems. Numerical analyses of hydrophobic fiber-reinforced composites depicted at the microscopic scale are presented.

7907 | Validation of a generic tool of kinetic simulation of polymer ageing (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Since the early 2000s, the EDF R&D team of polymers is interested in the study of the multiscale analysis aging of polymers (at the molecular, macromolecular and macroscopic levels) used in nuclear power plants, such as cables, pipes or paintings [1-4]. This understanding of the mechanisms of aging allows, among others, to develop a universal approach for life time prediction or monitoring the aging of these materials on-site. The establishment of structure/property relationships remains the major problematic in any non-empirical approach for lifetime prediction.
The objective of the present work is to present the first step of this approach which is the development of a generic tool of simulation of aging kinetics and its validation on different ethylenic polymers (EPDM and PE).
The approach taken to establish the physical model validation of polymer aging consists in: First, the integration of a system of non-linear differential equations derived from an established mechanistic scheme for describing the polymer ageing process in the simulation code. Then, the comparison of chemical experimental results [1,5] (obtained by FTIR spectrophotometry in a transmission mode to deduce changes in concentration of thermal degradation products) and numerical resolution (obtained both with Matlab software and the new simulation tool). The results show a satisfactory agreement between theory and experiment in a wide temperature range. Thus, this new developed simulation tool is validated on well-controlled tests and allows us to take with confidence the next step of our approach for lifetime prediction, i.e. the prediction of macromolecular and macroscopic changes of polymer and the proposed methodology is conceptually applicable to other types of polymer.
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7973 | On The Long-term Behavior of Glass Fiber Reinforced Polyester Pipes (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Thanks to light weight, high strength and stiffness and good corrosion resistant, glass reinforced polyester (GRP) pressure pipes are widely used for water transmission. Since they are subjected to internal pressure and other service loads during their service lifetime, they need to satisfy requirements for long-term hydrostatic pressure. An experimental procedure for obtaining pressure class of GRP pipes on the basis of long-term behaviour is very time consuming and costly that sometimes take about 2 years for collecting required data. Then, obtained results are extended to 50 years.
A modeling procedure is developed to obtain residual strength of pipes after 50 years taking into account creep phenomenon. The modelling procedure is constructed on the basis of simulating creep in a single ply and then it is extended to laminates of pipe wall configuration. A progressive modelling consisting of stress analysis, failure evaluation and material properties degradation is developed. Stress analysis is performed using FEM. Material degradation rules for both gradual degradation over the time and sudden degradation upon failure occurrence are developed. This phase includes both stress analysis executed using finite element modeling and also material degradation properties with respect to the time. As a case study, the developed modeling procedure is conducted for predicting long-term behavior of a specific GRP pipe. A comparison between real experimental data and theoretical modeling is presented.

8031 | Species diffusion in textile composite materials (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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The employment of textile composites is foreseen for the next future for the realisation of aircraft structures since these materials may exhibit high resistance to impact and shock loads, high specific stiffness/strength and good fatigue performances. When high temperature applications are concerned, for structures exposed to aggressive environments, degradation and ageing issues must be taken into account and species diffusion mechanism and kinetics within the materials should be known.
Species diffusion in textile materials may present specific issues related to the complexity of the diffusion path, which is directly related to the complexity of the composite microstructure, and exhibit anisotropic behaviour at the meso/macroscopic scale.
All these issues are at the origin of complex behaviour, coupled with mechanics, which is in turn responsible for material degradation, onset and propagation of damage.

To tackle these issues coupled experimental/numerical approaches must be employed. Models are useful to interpret experiments, to predict behaviour, to design accelerated tests, for design and optimisation of structures.
The present paper discusses specific items related to probing and modelling species diffusion in textile composite materials, namely:

- providing experimental evidence of material ageing under exposition to the environment,
- discussing models containing the explicit representation of the microstructure, which are useful to identify the complex of diffusion path taking place in these materials,
- discussing efficient methods for rapid identification of the diffusion properties at the meso/macroscopic scale.

8044 | Towards a strain rate and water ageing sensitive constitutive modelling: Effects of strain rate and water ageing upon the properties of epoxy resin matrix for composites (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Composites structures, due to their many advantages, are being increasingly utilised in industrial applications where high performance and high reliability are required. In the case of composites for marine structures, subjected to underwater explosion, the effects of ageing upon the strain rate dependent response of these materials must be considered in the design. As virtually no information of this type has been reported in the open literature to-date, in this study, the following challenges have been addressed: (i) the degradation of mechanical properties caused by water absorption and salinity; and (ii) the corresponding strain rate behaviour.
In this paper, the result of investigation upon an epoxy system, commonly used as a matrix in composites for marine applications, has been presented. Compression and tensile tests have been performed at a variety of strain rates (1E-3 - 1E+3 s-1) after subjecting the samples to a range of wet environments (pure water and saline solutions). Thus obtained results demonstrate detrimental effects of ageing upon mechanical properties such as their apparent elastic moduli, yield stress at all strain rates considered in this study.
This observation and quantification provides the basis for the development of constitutive models for predictive numerical simulations of the response of aged composite structures to underwater explosion.

8103 | Structural deformation assessment of glass fibre reinforced polymers subjected to hygrothermal ageing (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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This paper deals with the effects of hygrothermal ageing on the structural properties of glass fibre reinforced polymers. Short-term temperature and moisture superposition promote the degradation process providing with information regarding the long-term behaviour of such materials. In this study, specimens were immersed in distilled water at 25oC, 40oC, 60oC and 80oC for a period of 8 months. In all stages, gravimetric measurements were conducted following their water uptake gain. Bulk moisture diffusion coefficients in the 3 different directions were acquired via the examination of selectively shielded samples. In addition, the deterioration of the tensile and shear mechanical properties was evaluated after pre-described exposure time intervals. At the same time intervals, Dynamic Mechanical Thermal Analysis (DMTA) tests were carried out in order to follow the ageing process. Last but not least, Impedance spectroscopy was employed in order to enhance our understanding of the behaviour of such materials when exposed to hygrothermal ageing.

8113 | A numerical method to deal with stochastic transient uncoupled hygro-elastic problems: application to glass fiber reinforced polyamide composites (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Nowadays, composite materials are often used in structural design for various engineering applications thanks to their good mechanical properties coupled to their lightness. Those materials are presently more and more used by the car industry for the manufacturing of structural components such as center pillars or car floors. During their life-service, these components are submitted to harsh environments which, coupled to classic mechanical loadings, may lead to a premature aging of the structure. Among these various aggressive phenomena, water absorption is of first importance since the involving

hygroscopic swelling may activate or worsen a damage mechanism.
In this work, we thus focus on the impact of water absorption on structural components made of glass fiber reinforced polyamide composites for which resins can be very hydrophilic. The diffusion model is the classical Fick's law and the mechanical problem is solved under a linear elasticity assumption. The first step of the study was to conduct experiments in order to quantify the diffusion parameters (diffusion tensor and maximum moisture absorption capacity). Several composite specimens were thus submitted to the same well-controlled humid environment and gravimetric measurements enabled to quantify the water mass gain with respect to time. However a quite large dispersion was observed on the identified diffusion parameters. A stochastic study seemed necessary in order to well apprehend the uncertainties on the various output fields such as local water content or stress fields. Here is the purpose of the present work.
We adopt a parametric vision of the uncertainties which leads to a probabilistic model based on independent random variables. These random variables help in the modeling of parameters such as the water diffusion coefficient tensor, the maximum moisture absorption capacity or the hygroscopic expansion tensor. We focus on the propagation of uncertainties through the proposed physical model governed by stochastic partial differential equations. Several methods are available to achieve this task depending on the probabilistic quantities one seeks to obtain (Monte-Carlo methods, reliability analysis etc.). Among them, the spectral stochastic methods is a good candidate in order to get an explicit solution with respect to the basic random variables modeling the diffusion coefficients for instance. They consist in representing the random solution on a suitable approximation basis. Several choices are possible for the definition of stochastic approximation spaces and we propose to use the most commonly employed known as generalized polynomial chaos for which approximation bases are composed of multi-dimensional orthonormal polynomials depending on the input random variables. For the computation of the coefficients of the polynomial chaos expansion, which are the unknowns of the stochastic problem, the spectral methods can be divided into two families: the intrusive techniques, such as Galerkin projection, and the non-intrusive techniques such as L2-projection or regression methods. In this study, we only propose to use the latter family which only requires the numerical solution of a finite set of deterministic boundary value problems and thus allows to use classical finite element softwares.
The efficiency of the proposed method is shown using numerical examples. We conduct different analyses at the macroscale (the scale of the composite) for which we focus on various local and global stochastic quantities of interest. The impact of uncertainties associated with the input parameters on the outputs response is finally discussed.

8291 | Experimental and numerical study on ice-induced damage of cement based composites. (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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The paper presents the experimental and theoretical study on the concrete degradation induced by low temperature. The experimental part considers the change of microstructure and the properties of concrete due to cyclic freezing of water. The degradation of internal structure was recognized by means of multicycles mercury intrusion porosimetry test. The total open porosity, pore size distribution and contribution of ink-bottle type pores was investigated for virgin cement mortar and after 25, 50 and 100 cycles of freezing test. Moreover the change of capillary suction coefficient due to cyclic freezing of water was investigated. The results of those tests indicate that the narrower thoughts between larger pores are broken by crystallization pressure. It is manifested by the enlargement of the arbitrary pores volume, usually of diameter 100 nm – 10 □m. Consequently, the capillary suction coefficient increases with the progress of ice-induced damage. We also analyzed the relation between the microstructure and the intrinsic permeability for concrete exposed to the cyclic freezing of water. The change of intrinsic gas permeability for virgin concrete and concrete after 50, 100 and 150 freezing cycles was investigated using the Cambureau method. The theoretical part considers the development of mathematical model of coupled heat and water transport in deformable porous materials accounting for the kinetics of water phase change. The mathematical model consists of three governing equations: mass balance of water molecules, energy balance of multiphase medium, momentum balance equation, which describes mechanical equilibrium of porous materials. Additional equation defines the kinetics of water solidification which is describes by ODE. The material parameters obtained during experiments are used to complete the mathematical model. The crystallization pressure was determined as the volume average of Everett's equation, calculated using the parameters describing evolving microstructure, obtained using mercury porosimetry test. The nonlocal approach was utilized to calculate the damage of concrete due to cyclic freezing of water. The four PDEs, which make the mathematical model, were solved using the standard numerical techniques: finite differential method – time derivative, finite element method – space derivative, Newton-Raphson method to linearize the set of nonlinear equation. Such a complex model, which takes into account, the interaction between the stress induced by the water solidification and changed of microstructure due to crystallization pressure allows for the reliable modelling of ice-induced damage of concrete.

8735 | Durability of Adhesively Bonded CFRP/Steel Joints in Civil Engineering Applications (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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Many civil engineering structures are subjected to deterioration due to aging and exposure to harsh environments. Strengthening and repair of existing structures using adhesively bonded CFRP laminates has attracted a great deal of attention in the past two decades. However, concerns about the durability of adhesively bonded joints, exposed to different environmental conditions, still hinder their widespread application in steel structures. Numerous studies have been conducted to evaluate the short-term behaviour of steel members bonded with CFRP laminates. However, comparably very little is done on the environmental durability of the bond between CFRP materials and steel surfaces when it comes to civil infrastructure. Aspects such as loading conditions, material characteristics, exposure environment, and manufacturing process for civil infrastructure are different from those in other industries and prevent direct application of existing knowledge in other fields in structural engineering applications. This paper, presents the state of the art on durability of CFRP/steel joints. Important influencing factors on the durability of adhesively bonded joints are addressed and different damaging mechanisms are discussed. Moreover, a short description of different testing methods and standards regarding the experimental assessment of such joints is given. Finally, various durability-related predictive analytical and FE modelling methods are reviewed and suggestions are given for future work.

8802 | Durability of cemeny and geopolimer composites (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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A low emission of CO2, a fast increment of resistance and high values of resistance constitute evident advantages of the geopolymeric binders over the Portland cement binders. Most probably, these features will not be used very soon. It is only legal regulations that put limits to carbon dioxide emission that will contribute to the “green” geopolymeric concrete technology being implemented on a wide scale in the production of concrete. This paper describes current physical and mechanical properties, which new concretes and cements materials should obtain. Very important problem of CO2 emission was also mentioned. According to European restrictions, which are one and only regulations implemented on such a large area, presented data shows deficit of similar regulation in other places in the world. Mainly paper focuses on selected features of new geopolymer material. It compares with new technological mortars made of classical clinker cement and nano-cement modified by polymers. The mechanical properties like shrinkage, compressive and tensile strength were tested. Additionally materials were tested to obtain information about their durability. In that case the impact of high temperatures were tested. The properties were tried to be received by specially prepared tests, which could be compared to natural situation, in which this construction materials could work. In case of high temperature test samples were cubic bricks. They were exposed to temperatures and condition that could appear in real fire.

9083 l Behaviour of a composite laminate [θm/90n]s cracked and aged in absorption (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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The variational model is used to evaluate the behavior of the longitudinal stiffness for a cracked and aged laminate in different environmental conditions, case of absorption. The results were compared with the experimental results and show that this model is quite interesting to study the interaction between transverse cracking and delamination.
This comparison shows that the variational model gives a good approximation for the behavior of the longitudinal stiffness . On the other hand the model of transient absorption Tsai, was chosen for the hygrothermal model .The model takes into account the effect of aging at the fiber level and matrix for a variable concentration. versus time called study the behavior of composite material cracked under the temperature and moisture effect. The results show that the hydrothermal environment has a significant effect on the behavior of the mechanical properties of the material and the number of cracked and uncracked folds.

9289 l Accelerated Ageing of Pultruded Fibre Reinforced Polymers: Physical and Mechanical Characterization (8. Durability and Ageing of composite materials (Marco Gigliotti, ENSMA, France))

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The lack of reliable data to assess the effect of environmental aging on Pultruded Fibre Reinforced Polymer (PFRP) components is a crucial barrier to exploitation of such an advanced material in Civil Engineering structures [1]. This weakness manifests itself in design by the need for sever knock-down factors to make allowances for material degradation [2].
This paper presents experimental findings of a characterization study on the understanding of material property changes with exposure to hot /wet environment. In this work, an ‘off-the-self’ pultruded glass FRP plate was investigated at a coupon level. To that respect, samples cut from the same flat sheet were examined in terms of moisture diffusion and the subsequent deterioration of mechanical properties that moisture ingress induces after prolonged aging.

Out of 476 coupon specimens cut from the plate 448 were fully immersed in distilled water at the four constant temperatures of 25, 40, 60 and 80°C, in order to accelerate the moisture kinetic and hydrothermal effects. Batches of five specimens per temperature and at ages of 28, 56, 112 and 224 days were tested under compression and shear for material properties. Equivalent batches with a notch were used to determine bearing strengths. For each temperature moisture uptake measurements and mechanical properties are therefore measured.

Experimental testing revealed that moisture diffusion is promoted with temperature increase. It was also found that both increased temperature levels and prolonged exposure time of hygrothermal aging induced a reduction in the mechanical properties of the composite plates. The understanding of the relationship between the mechanical property retention and hygrothermal aging is completed with the development and of a computational analysis platform that is to be employed for the design of composite structures in the framework of DURACOMP project (EPSRC - Providing Confidence in Durable Composites).
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6972 l Effects of Fiber Reinforced Plaster on The Earthquake Behavior of Masonry Buildings (9. Dynamics of Composite Materials)

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The objectives of our study were to experimentally investigate earthquake behavior of masonry buildings whose walls were strengthened by using fiber reinforced plaster. To this end, Polypropylene and steel fiber was added to the traditional plaster at certain proportions determined by pre-trials. Then, one story, single span masonry building specimen was plastered with traditional, steel-fiber or polypropylene added plaster. Each specimen was subjected to a powerful earthquake for 8 times on a shaking table. The specimen plastered with a traditional plaster was regarded as control and its earthquake behavior was compared to that reinforced by fiber plaster. Steel fiber or polypropylene addition significantly increased rigidity, displacement ability and energy consumption ability of specimens as compared to control. The suggested reinforcement method was proven to strengthen masonry buildings in a fast, reliable and economical way. Moreover, it can easily be adapted to any masonry building without causing any negative impact.

7048 | Semi Impregnated Micro-Sandwich structures - SIMS - investigation on impact behaviour and damaging process
(9. Dynamics of Composite Materials)

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Lightweight is one of the main leading target for the new design of automotive vehicles in order to decrease both the fuel consumption and, strictly related, the GHG emissions. In this perspective the use of composite material in substitution of the traditional steel is one of the main path.
Within thin sandwich structures, that contains long fiber composite skins and low-cost fleece core, porosity often remains within the fleece while the non-woven fleece needs to be completely wetted and bonded by the matrix in order to obtain the desired stiffness. In the current study, a novel material developed and proposed by DELTAtech company is considered. Material characteristics with particular attention to its impact behaviour and damaging process is investigated.
The material has been developed in such a way that the amount of resin impregnation has been controlled during polymerization to obtain also some dry fibers in the final product. Such Semi impregnated micro-sandwich structures (SIMS) can exhibit very high toughness due to the deformation mechanism in the dry regions of the nonwoven fleece. In particular the fiber in the dry regions can slide respect to each other without showing a neat fracture so such mechanism causes high level of failure strain of the material and high level of energy adsorbtion during the deformation.Obtained results confirm that the proposed material indeed have a potential for automotive application.

8030 | Nonlinear Dynamic Characteristics and Optimal Control of GMM-SMA Composite Laminated Beam Subjected to Axial Stochastic Excitation **(9. Dynamics of Composite Materials)**

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Nonlinear dynamic characteristics and optimal control of giant magnetostrictive material (GMM)-shape memory alloy (SMA) composite laminated beam subjected to axial stochastic excitation are studied in this paper. Nonlinear differential items are introduced to explain the hysteretic phenomena of both the SMA's strain-stress curves and the GMM's strain-magnetic field intensity (MFI) curves, and the GMM's constructive relationships among strain, MFI, and frequency are obtained by the partial least-square regression method. The nonlinear dynamic model of GMM-SMA composite laminated beam subjected to axial stochastic excitation is developed, and the probability density function of the system's dynamic response is obtained. The system's stochastic stability is analyzed, and the conditions of stochastic Hopf bifurcation are given. The conditions of noise-induced chaotic response are determined by the stochastic Melnikov integral method, and the fractal boundary of the system's safe basin is provided. The reliability of the system is discussed, and the probability density of the first-passage time is obtained. Finally, the optimal control strategy is proposed by stochastic dynamic programming method. The numerical and experimental results show that the stability of the system varies with parameters, and stochastic Hopf bifurcation and chaos appear in the process; the area of the system's safe basin decreases when the intensity of the noise increases, and the boundary of the safe basin becomes fractal; the reliability of the system is improved through stochastic optimal control, the area of safe basin of the system increases, and the first-passage time is delayed. The result is helpful for the application of GMM-SMA composite laminated structures in MEMS.

8991 | Shake-table tests and numerical simulation of plastered masonry-infilled steel frames with openings **(9. Dynamics of Composite Materials)**

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This paper presents the experimental tests of 1/3 scaled, one storey, one bay masonry-infilled steel frames on a shake-table. Two types of infilled frames were considered: one with central door opening and another without opening. Each type was tested in variants of unreinforced plaster and plaster reinforced with a PVC mesh. Masonry elements made of autoclaved lightweight concrete were used. The tested specimens were exposed to the series of artificial accelerograms with gradually increasing amplitude. The artificial accelerograms were chosen to match the elastic response spectra. Characteristic displacements, accelerations and strains, as well as structural deformations and crack patterns in the masonry were observed during the test. Test results show the efficiency of the PVC mesh in a plaster by reducing the crack zones in it. Also, the specimens without opening exhibited a better performance than those with the central door opening. Afterwards, a developed numerical model for nonlinear dynamic analysis of planar structures composed of concrete, steel, masonry and plaster was used to simulate the performed tests. Fairly good agreement is observed between experimentally determined and numerically obtained results.

9143 | Structural analysis of flexible composite structures moving in space using finite element method **(9. Dynamics of Composite Materials)**

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Lightweight structures are used in several applications, such as aircrafts and aerospace structures. Dynamic analyses of flexible composite structures are presented in this paper using high order shear deformation finite element theory. The motion of the structures in space has been divided into large and small motion. The effects of rigid body motion, relative motion, coriolis motion (Gyroscopic effects) and centripetal motion have been taken into consideration in the element derivation. The coupling effect of large and small motion on the kinetic and strain energies has been introduced to define the mass matrix, stiffness matrices and finite force vector. A finite element programming package was designed employing the developed element and to easily accommodate any future developments. Several case studies have been investigated and package results were compared with published theoretical and/or experimental results. Parametric investigations have been carried out with some cases, and the results proved that the package can be a useful tool for the design optimization of the motion of flexible structures in space.

6989 | Fabrication of silicon carbonitride-covered boron nitride/Nylon 6,6 composite for enhanced thermal conductivity by melting process (10. Electro-thermal properties of composite materials)

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The surface-treated boron nitride (BN) particles were prepared with polysilazane (PSZ) by using a dip-coating method to fabricate a thermally conductive interface material. PSZ-BN particles were generated by crosslinking of PSZ on BN and heat treatment of the formed PSZ-BN at 800°C to convert PSZ-BN to SiCNO-BN. The SiCNO-BN particles were fabricated with Nylon 6,6 by using an extruder and injection molding method. The interfacial adhesion between the BN particles and the Nylon 6,6-based matrix was enhanced by surface treatment of the BN particles. The surface-treated boron nitride/Nylon 6,6 composites exhibited thermal conductivity ranging from () to (), which is higher than that in the case of loading with pristine BN/Nylon 6,6 composites at the same weight fraction. The tensile strength and tensile modulus increased from 59.13 MPa and 1.67 GPa with the use of pristine BN to 69.15 MPa and 2.10 GPa with incorporation of 20 wt% SiCNO-BN into the Nylon 6,6 composite.

7655 | Nanocomposite Based Solid Polymer Electrolytes (10. Electro-thermal properties of composite materials)

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Nanocomposite solid polymer electrolytes (SPE's) are developed using synthesized acrylate copolymer with the blending of ionic salt and nanofillers. The acrylate copolymer is synthesized using emulsion polymerization technique utilizing the monomer mixtures of methyl methacrylate (MMA), butyl acrylate (BA) and acrylic acid (AA). In the nanocomposite SPE's formulation two different types of amphoteric oxides namely silver (I) oxide (Ag2O) and silicon (IV) oxide (SiO2), selected from the periodic table grouping of transition metal and non-metallic, respectively were studied for its effect on the properties. These were done using the analytical techniques of electrical, structural, surface hydrophilicity etc. The two developed systems exhibit ionic conductivity of 10-4 and 10-5 S/cm respectively for SiO2 and Ag2O based SPE's. The improvements in ionic conductivity were observed as results of the intimate polymer-nanofiller interaction induced by the nanosized particles having high surface active sites. This interaction will impose to the increase in the amorphous fraction of SPE's upon doping with the nanofillers, which was evaluated using the X-ray diffraction technique. Apart from the above discussed properties, the developed systems were also found to exhibit appreciable surface adhesiveness which is beneficial to achieve good interfacial contact with the rough surface electrode. Other excellent properties such as high heat resistance, less subjection to hydrolytic attack, improved aging factor etc. are also observed for the systems. All the properties possessed by the SPE's enable it to be a potential electrolyte material to support energy applications such as batteries, supercapacitor etc.

7702 | The effect of a photo-initiators and an acrylate monomers on the electrical resistivity of UV-curable silver adhesives (10. Electro-thermal properties of composite materials)

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In this study, low electrical-resistivity, UV-curable silver adhesives were prepared, and we investigated the effect of mixing urethane acrylate with different types and contents of photo-initiators and acrylate monomer on the electrical resistivity of the UV-curable silver adhesives. The UV-curable silver adhesives had faster curing times and lower curing temperatures than thermally-cured silver adhesives, which saved processing time and energy. However, their electrical resistivities usually were greater than those of thermally-cured silver adhesives. This was due to the fact that their content of silver particles was greater, resulting in their resisting UV light and decreasing the degree of crosslinking in the UV-curable adhesives. These results indicated that the potential applications for these UV-curable silver adhesives were limited. Therefore, in order to prepare UV-curable silver adhesives that had low electrical resistivity, we investigated the use of photo-initiators, such as 2-methyl-4′-(methylthio)-2-morpholinopropiophenone (MMTPP), phenylbis(2,4,6-trimethylbenzoyl)phosphine oxide (PTMBP), 1, 2-diphenylethanedione (DPED), benzil dimethyl ketal (BDK), benzoyl peroxide (BPO), and terephthaldicarboxal-dehyde (TTDD); we also studied acrylate monomers, such as acrylic acid (AA), 2-hydroxyethyl acrylate (HEA), pentaerythritol triacrylate (PTTA), and dipentaerythriol pentaacrylate (DPTTA), which affect the electrical resistivity of UV-curable silver adhesives. Prior to our work, no research had been conducted to investigate the effect of photo-initiators and acrylate monomers on the electrical resistivity of UV-curable silver adhesives. The different degrees of crosslinking and the conversion of UV-curable silver adhesives by different types and contents of the photo-initiator and acrylate monomer were demonstrated using Fourier transform infrared (FTIR) spectroscopy, which was in effect be electrical resistivity of composites.
The results indicated that 46 wt% of urethane acrylate mixed with 46 wt% of HEA and 8 wt% of MMTPP was ideal when the adhesive contained 70 wt% of 3-um, flake-shaped silver particles, which have a low electrical resistivity at 2.3×10–4 ohm•cm.

7775 | Structure of Reinforcing Filler Network Determined by On – line Measurement of Electrical Conductivity of the Polymer / Carbon Black Composite (10. Electro-thermal properties of composite materials)

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Electrical conductivity of composites of polymeric insulating matrix filled with electroconductive filler depends on a formation of conductive filler network, leading to a pronounced increase in conductivity at certain filler concentration called percolation threshold. Obviously, any change of the conductive network due to the external influence should result in a change of electrical conductivity. Thus, the changes in electrical conductivity resulting from either mechanical deformation or a change of volume due to e.g. temperature change can be used for monitoring the current state of the physical reinforcing network formed by the filler.
The principle described above was used to investigate the behavior of either vulcanized rubber or thermoplastic polycaprolactone filled with electroconductive reinforcing carbon blacks. The effect of a decrease of elongation at break in the electrical percolation threshold region is demonstrated on composites with either thermoplastics (polycaprolactone, polyethylene, polypropylene) or rubber matices, both filled with conductive filler. The effects during deformation are investigated by online measurement of conductivity during mechanical deformation. Conclusions from changes in electrical conductivity regarding the decay or reforming of the conductive network have been done and compared to the mechanical responses of the material during uniaxial tensile deformation, as indicated by stress – strain curve, or during cyclic deformation characterized by hysteresis curves. In the latter stage, regeneration of the conductive network during stress relaxation measured at constant nonzero deformation followed by recovering after release the mechanical stress was also considered.
The changes of electrical conductivity were found to be far away from simple monotonous increase / decrease during deformation. On the contrary, rather complicated dependences with several extremes on the conductivity vs deformation curves were observed. In most cases, the extremes appearing in dependencies of electrical conductivity on strain occur at the same deformation region as typical parameters derived from stress – strain curve. Some of them are related to Hookean part and inflex point on the stress strain curve of filled rubbers. Yield point for composites with thermoplastic matrices also corresponds with typical course of the electrical conductivity dependence on strain. By such a way, the measurement of electrical conductivity of composites during uniaxial deformation can indicate changes in filler physical network contributing to reinforcing effects in composites. Cyclic deformation with constant or rising amplitude contributes to better understanding of more complicated mechanical responses e.g. related to Payne's effect.

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7785 | ANALYTICAL, EXPERIMENTAL AND NUMERICAL APPROACH OF STORAGE AND LOSS MODULI OF FIBRE REINFORCED EPOXY COMPOSITES AND THE INFLUENCE OF THE INTERPHASE (10. Electro-thermal properties of composite materials)

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In this work an attempt was made to correlate analytical, experimental and numerical results for the dynamic moduli of Fibre Reinforced Composites (FRC). A theoretical approach for the prediction of the storage and loss modulus based on the theory of elasticity gave their values which were compared with the experimental values obtained from dynamic experiments carried out on glass fibre and epoxy composites [1-4].
Then a numerical approach was performed via the Finite Element Method [5] in order to calculate the dynamic moduli and also the glass transition temperature by taken into consideration the frequency and the temperature factors that influence the moduli of the composite. The study can be performed either by keeping constant the frequency and varying the temperature or by variation of the frequency under constant temperature. Finally the storage and loss modulus have been calculated at the interphase region between the matrix and the fiber using analytical, experimental and numerical methods.

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7836 | Influence of the filler particles on Polymer Electrolyte Membranes (10. Electro-thermal properties of composite materials)

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Present work mainly focused on synthesis of TiO_2 nano-particles and their influence on Solid Polymer Electrolyte membranes. Nano-Composite Polymer Electrolytes (NCPE) films: [80PEI: 20Li $(CF_3SO_3)_2$] + nano- sized particles of TiO_2 filler materials have been reported. NCPE films have been casted by solution cast technique. Solid Polymer Electrolyte (SPE) composition: [80PEI: 20Li $(CF_3SO_3)_2$], were identified as one of the high conducting films in an earlier study with room temperature conductivity (□rt) ~ 2.77×10^{-5} S/ cm, has been used as Ist-phase host matrix and the filler particles as IInd-phase dispersoid. NCPE films exhibiting highest room temperature conductivity, referred to as Optimum Conducting Composition (OCC), has been identified from the filler particle dependent conductivity studies. An enhancement of conductivity approximately an order of magnitude in the room temperature conductivity resulted. NCPE membranes with TiO_2 content: 4 wt. (%) exhibited optimum room temperature conductivity (σ) values ~2.5×10^{-4} S/cm . The phase identification and materials characterizations on NCPE OCC film have been performed using XRD, FESEM, FTIR and DSC/TGA techniques. The ion transport property has been characterized in terms Electrochemical Impedance Spectroscopy (EIS) and ionic transference number i.e. total (tion) and cationic transport number (t+). These ionic parameters have been determined experimentally using combine ac/dc techniques. The temperature dependent conductivity measurements have also been carried out to compute activation energy (Ea) by least square linear fitting of Arrhenius plot: 'log □-1/T'. The electrochemical properties of the NCPE films based Li/LiFePO4 batteries have been studied by Linear Sweep Voltammetry (LSV), Cyclic Voltammetry and Charge/Discharge performances.

8071 | Thermal conductivity enhancement of vertically aligned long nanotube carpet reinforced thermoset composites (10. Electro-thermal properties of composite materials)

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Fiber reinforced thermoset materials are more and more used for satellite structure manufacturing. Beside their in plane structural properties, advanced designs are requiring increased thermal and electrical conductivity, as well as damage tolerance against meteoritic impact. The main material weak point is related to the low properties of the interply polymer matrix.

In order to enhance these properties, carpet like vertically aligned carbon nanotubes (VACNT) are investigated as reinforcing solution of the thermoset resin system. The synthesis of the carpets is done by Aerosol-Assisted Chemical Vapor Deposition on quartz substrates. The process allows to produce multiwalled nanotubes with a length up to 3.5mm and a volume fraction up to 20% . These carpets are in a second step densified with an aerospace qualified epoxy resin using liquid infusion process.

After machining and polishing, thermal and electrical properties are measured at the reinforced film level on nano-composites with increasing carbon nanotube volume fractions. Through the thickness conductivity was investigated parallel to the nanotube orientation using the laser microflash method.

As expected, results show an improvement of these properties, much higher than that is usually reported for dispersed nanotube reinforced composites. Thermal conductivity increases by a factor 100 when comparing the non-reinforced epoxy (0,19 W/m/K) to for the 12% volume fraction reinforced 50 nm diameter long nanotubes (22 W/m/K). Results show also that the thermal conductivity increases when, for the same level of CNT density, the nanotube diameter increases from 25nm to 50nm. More over a high temperature annealing (at 2000°C) of the nanotubes before resin infusion, has a strong effect on thermal conductivity. As a matter of fact, high temperature graphitization results in higher organization of the nanotube graphene walls.
Finally same general trend was observed for the electrical conductivity values of the reinforced nano-composites.

8072 | Novel method of metal – oxide glass composite fabrication for use in thermoelectric devices (10. Electro-thermal properties of composite materials)

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The usability of potential thermoelectric material for both heat generation and cooling is determined by various parameters: Seebeck coefficient (α), electrical conductivity (σ) and thermal conductivity (κ). All of them are combined in a dimensionless figure of merit: ZT=α2Tσ/κ [1]. The higher is the Seebeck coefficient and electrical conductivity of material and the lower is thermal conductivity, the better is the material from the thermoelectric applications point of view. Although oxide glasses exhibit some of the lowest lattice thermal conductivities, they also have very low electrical conductivity. In order to make oxide glasses useful for thermoelectric devices they should be modified to obtain a kind of 'phonon-glass electron-crystal [2]. Such composite materials can be obtained by heating oxide glasses in a hydrogen atmosphere. This is called a reduction process. This procedure causes the reduction of metal ions and the formation of metal grains both in an amorphous glass matrix and on the glass surface. If a certain critical grain concentration is achieved, the electron tunneling between the grains becomes possible. Further reduction leads to the connecting of metal grains and to the formation of continuous, metallic layer on the surface of the glass. Thus an increase in the surface electrical conductivity, even of several orders of magnitude, is observed [3].
If a glass sample is ground to obtain a powder and then this glass powder is reduced, it is possible to fabricate a metal-oxide glass composite. This kind of material can even have better thermoelectric properties, because of higher phonon scattering on grain boundaries and, as a result, lower thermal conductivity.
In this work some results indicating a possibility of applying reduced oxide glasses (containing Bi, Te and Sb) in thermoelectric devices will be shown.

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8640 | Highly conductive polymer/metal/CNT composite fiber prepared by melt-spinning process (10. Electro-thermal properties of composite materials)

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Composite fibers from polymer/metal/CNT are prepared by melt spinning process for high electro-conductivity. Fiber is the re-spotlighted form of complex materials because of its flexible and easy transform benefits. In addition, the fibers granted electrical properties have a high potential to achieve ideal smart textile. They show high conductivity having help from conducting materials such as metals and carbons. These hybrid composite fibers are generally fabricated by wet spinning, electro-spinning, and solution-spinning, and they are applicable to electrical device. In the polymer/metal composite, metal acts as conductor to transport electrons in polymer matrix. The fibers that contain large amounts of metals show higher electrical conductivity. Metal arrangement in orientated polymer is also major factor to have high electrical property because only connected metals can flow the electrons. Disconnected metals are unable to act as the electron path, therefore, it is important to control the metal positioning in matrix for preventing aggregations or separations. However, controlling the metal position is very difficult in large scale process practically. Melt spinning is the most difficult process to control the accurate mixing ratio, regulation, and well dispersion, therefore, it is hardly used to fabricate high performance conductive fibers. However, it is the essential process to produce bulk scale because it facilitates fast and low cost process. In our research, the method for fabricating the highly electro-conductive fiber is attempted through the melt spinning process. In first, compact screw of 11mm diameter is used to mix polymer with metal. It helps well mixing between melted polymer and metal powder because the smaller space between screw threads has a good influence on the mixing property. The other trial is using carbon nanotubes(CNTs) as an electron bridge between metal powders. It is judged that CNT network is easy way to connect un-contacted metal powders. CNT functionalization is also processed to enhance electrical performance of conductive fibers. As a result, highly conductive fiber from polymer/metal/CNT is obtained successfully. It is confirm that degree of dispersion of our composite is largely increased comparing to that of others manufactured by melting process. In addition, the electrical conductivity is enhanced according to whether CNT is added or not. It is expected that our attempts are fundamental researches to produce the highly electrical conductive fiber in bulk scale.

8655 | Laser Flash Analysis of Thermal Conductivity in Non-Homogeneous Polymer-VANT Composites (10. Electro-thermal properties of composite materials)

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High thermal conductivity (TC) is one of most important feature among many other superior properties of carbon nanotubes (CNTs). However, there is a large scatter in the TC absolute values reported for single wall (SWNTs) and multiple wall (MWNTs) nanotubes as well as a divergence between theoretical estimations and experimentally observed values [1]. The scatter is further larger in TC of polymer (PM)-CNT composites. In the report we analyze the origin of the scatter.
In this work, TC was measured by Laser Flash Analyzer (LFA) (NETZSCH LFA 457 MicroFlash apparatus in accordance with standards ASTM E-1461) in pure epoxy resin (ER), pure array of vertically aligned CNTs (VANTs) and in composites ER/VANTs and, for the first time, ER/HANTs (horizontally aligned CNTs). An arrays up to the area of 25 cm2 and with the height up to 3mm of the VANTs forest can be deposited routinly, using permanently injected catalyst (PIC) version of pyrolytic chemical vapor deposition (PCVD) [2]. A large enhancement of the TC by a factor 10 to 16 was achieved in ER/VANTs composite, reaching TC κ = 3.2 to 4.2 W/(m K), which is comparable with the TC of pure VANTs forest. The enhancement is much weaker in ER/HANTs composite, in correspondence with a large anisotropy of heat transport parallel and perpendicular to the CNT channel. The analysis of the experimental data includes the anisotropy of heat transport within CNTs, the waviness and defectness of the MWNTs, and a huge disproportion in heat transport via VANTs and via polymer matrix.

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8674 | Effect of SiC particles on dielectrically properties of epoxy reinforcement by (bi-directional) glass fiber (10. Electro-thermal properties of composite materials)

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In this research the dielectric properties of the epoxy composites were characterized as a function of a frequency, "weight fraction, particle size" of fillers. Composite plates were prepared by incorporating fiber glass and SiC Particles of 0.1μm, 3μm, 40μm diameter sizes at 10, 20, 30 and 40 percent weight in epoxy matrix. The experiments were performed to measure the dielectric constant and electrical conductivity in range (10-2000) KHz.
The result showed that the dielectric constant decrease smoothly with an increase of frequency. An increase of them was also observed with an increase of weight fraction, particle size. Also, the a.c electrical conductivity showed an increase both with an increase of frequency, weight fraction and with an increase of particle size.

8676 | Thermal properties of ZnO/ ZnO-MgO-Al2O3-SiO2 glass-ceramics composites using LTCC process (10. Electro-thermal properties of composite materials)

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LTCC(Low Temperature Co-fired Ceramic) process is suitable for firing the ceramics with electrode materials of low melting point, such as silver, gold and copper at low temperature(1000°C<). Therefore, the LTCC process has been used to electronic application, and many LTCC systems were studied from the view point of dielectric constant, thermal properties and micro-structures.
LED is the semiconductor device for being widely used from the illumination for the car backlight. LED has the advantage including the small size, long lifetime, energy-saving and power consumption, and etc. when comparing with the other emitting device [1]. But the heat generated in LED device cause the life reduction of the device, so it need to emit the heat quickly outward to avoid heat accumulation in LED device. To solve this problem, recently, glass/ceramic composites substrate which use Al2O3 with high thermal conductivity (40W/mK) or various compositions has the high thermal conductivity was carried out.
In this research, the glass/ceramic composite was designed through LTCC process using the ZnO and ZnO-MgO-Al2O3-SiO2 glass, obtain the high thermal conductivity. The composition of the in the glass system, ZnO filler rate and sintering temperature were determined as the experimental factors. The microstructure observation and DTA analysis need to evaluate the composites.

8720 | Investigation of the Thermal Insulation of Polyester Microfiber and also Polyester and Acrylic Fabrics Coated with White Tuff Stone Powder with Different Particle Size (10. Electro-thermal properties of composite materials)

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In this study; polyester microfiber, polyester and acrylic fabrics were coated with white tuff stone (Alacatı stone) having different particle size, the thermal insulation properties of samples having different size of white tuff stone and different types of fabrics were evaluated. It was concluded that, the white tuff stone coated fabrics can be used in building textiles in order to increase the thermal insulation properties.

Key words: White Tuff Stone, Thermal Insulation, Coating, Polyester Microfiber Fabric, Polyester and Acrylic Fabric.

9205 | Numerical and experimental study of thermal energy storage of phase-change materials based on high-density polyethylene filled with micro-encapsulated paraffin wax (10. Electro-thermal properties of composite materials)

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This paper focuses on the experimental and numerical study of the storage and release of thermal heat during melting and solidification of phase change material (PCM). Shape-stabilized phase change materials (PCM) based on high-density polyethylene (HDPE) mixed with micro-encapsulated paraffin wax were prepared and investigated for application in thermal energy storage. The distribution of the capsules within the HDPE matrix was uniform without any tendency towards agglomeration. A Transient Guarded Hot Plate Technique (TGHPT) based on heat flow and temperature measurements was employed to determine the thermophysical properties and the latent heats of these phase-change materials. These experimental results have been simulated using numerical Comsol® Multiphysiques 4.3 based models with success. The results of the experimental investigation compare favorably with the numerical results and thus serve to validate the numerical approach.

9206 | Computational homogenization for the thermo-mechanical analysis of phase change composite materials (10. Electro-thermal properties of composite materials)

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The ability of Phase Change Materials (PCM) to store thermal energy makes them a central technology for energy supply in the future, since energy storage could contribute to efficient energy use, enables the use of renewable energy sources etc... In the present work a computational homogenization method is proposed to compute the thermo-mechanical behavior of composites structures with phase change materials. The computations were performed on composite based on High Density Polyethylene (HDPE) filled with microencapsulated paraffin wax. The capsules are assumed spherical with uniform size distribution. A representative elementary volume is identified for the material and the effective parameters (Young modulus, Poisson ratio, thermal conductivity) are derived through a Finite Element computational homogenization framework, thereby establishing the link between micro and macroscale of the composite. The Heat latent phase change of the paraffin was modeled by the effective heat capacity method. The simulations have been performed using the Comsol Multiphysics 4.3 based models with success. The expected difference of behaviors of the composite structure corresponding to the solid and liquid phase state of paraffin wax have been highlighted. The comparison of the results of simulations with available experimental data at different temperatures above and below the melting temperature of paraffin permit to validate the computational homogenization approach adopted.

9399 | Bi-layer Rectifying Characteristics of SrTiO3-δ/La0.9Hf0.1MnO3 n-n Heterojunction (10. Electro-thermal properties of composite materials)

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We report the fabrication of n-SrTiO3-δ/n-La0.9Hf0.1MnO3 bi-layer heterojunction on SrTiO3 (STO) substrate by pulsed laser deposition method. X-ray diffraction and electron backscattering diffraction measurements prove the single crystal property and [001]-orientation for both SrTiO3-δ and La0.9Hf0.1MnO3. High-resolution transmission electron microscope image of the interface between the two layers indicates that the great crystal property and film qualities. This heterojunction showed an excellent rectifying property in a wide temperature range from 20K to 300K, and the most significant part of this heterojunction is the leakage current is quite low. The diffusion voltage and junction resistance as functions of temperature has also been studied.

The epitaxial LHMO film was deposited by using pulsed laser deposition (PLD) technique with a XeCl excimer laser machine (λ=308 nm). And The epitaxial SrTiO3-δ film was covered on the LHMO layer also by the PLD in situ using a single crystal SrTiO3 target with ultrahigh vacuum. The crystal structure was determined by the X-ray diffraction (XRD) with Cu Ka radiation as well as Electron Backscattered Diffraction (EBSD). The current-voltage behavior of the SrTiO3-δ/LHMO junction was measured at various temperatures by using traditional two-probe method.

It is widely reported that oxygen-deficient SrTiO3-δ films are typical n-type semiconductor materials，and Hf-doped LaMnO3 is also n-type material. The observed rectifying property in the SrTiO3-δ/LHMO bilayer film strongly suggests the formation of n-n junction between LHMO and oxygen-deficient STO.

5762 | FE MODELING OF CONTINUOUS RC BEAMS STRENGTHENED WITH FRP PLATES (11. FRP reinforced concrete structures)

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This paper presents a simple uniaxial nonlinear finite-element model (UNFEM) able to investigate the behavior of continuous reinforced concrete (RC) beams flexurally strengthened with externally bonded fibre reinforced polymer (FRP) strips and plates applied in positive or negative moment regions. The proposed UNFEM follows a displacement–based approach and can accurately estimate the ultimate load and the corresponding failure mode of strengthened continuous RC beams subjected to any type of loading. A twenty one-degree of freedom element is suggested with layer-discretization of the cross-sections. Realistic nonlinear constitutive relations are employed to describe the stress-strain behavior of each strengthened beam components. The finite element model is based on nonlinear fracture mechanics. The interfacial shear and normal stresses in the adhesive layer are presented using analytical uncoupled cohesive zone model with a mixed-mode fracture criterion in positive or negative moment regions. Both maximum positive or negative moments and plate end failure modes are considered.
Numerical simulations and experimental measurements are compared with some tests available in the literature. The numerically simulated responses agree remarkably well with the corresponding experimental results.The results using the proposed UNFEM are compared with the available empirically formulae in the literature. The major feature of the proposed UNFEM is its simplicity.

6352 | High Performance Fiber-Reinforced Concrete Columns for Sustainable Bridge Construction (11. FRP reinforced concrete structures)

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This paper presents an experimental/analytical investigation of the performance of pre-fabricated bridge columns constructed from ultra-high strength concrete and reinforced with glass or carbon fiber rebars and carbon fiber full wrapping. The aim of this form of construction is to present a highly durable structurally efficient rapid form of construction for bridges sub-structures in aggressive environments. Slender circular columns were tested under monotonic axial compression up to failure. Experimental variations included the type of FRP reinforcement, namely, glass or carbon fiber, longitudinal reinforcement ratio, number of CFRP wraps and slenderness ratio. Experimental results have shown promising capabilities of the proposed design and the results were used to build and validate a finite element model for the tested specimens. The model was then used to conduct an extensive parametric study on untested design configurations. The paper finally presents a set of design charts for the proposed form of construction.

6435 | Behavior of Reinforced Concrete Structures Strengthened with Prestressed Near Surface Mounted CFRP Reinforcements: Experimental Study (11. FRP reinforced concrete structures)

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The aim of this study is to investigate the effectiveness of strengthening RC beams with non-prestressed and prestressed CFRP bars/plates to increase the monotonic flexural strength of the beams. Twenty-one RC beams were fabricated. One beams were not strengthened and acted as control to simulate an existing structural member. The other beams were divided into groups that were strengthened with prestressed CFRP bar without MI(mechanical interlocking) (BB series), prestressed CFRP bar with MI (BBM series), prestressed CFRP plate without MI (BP series) and prestressed plate with MI (BPM series). The prestress level is from 0% to 50% of the CFRP bar/plate tensile strength. The test results showed that strengthening the RC beams with NSM CFRP bars/plates increased both the monotonic flexural strength. An increase in the yield and ultimate load of 27%~40% and 42~65% was achieved, when the beams were strengthened with non-prestressed CFRP bars/plates compared to the control beam. Also, the flexural stiffness of the strengthened beam was slightly enhanced that of the control beam. When the beams were strengthened with prestressed CFRP rod (10%~50%), considerable improvements in the cracking, yield, and ultimate loads were achieved as well as the flexural stiffness (serviceability).

6436 | Reinforced Concrete Beams with Unbonded Prestressed Carbon Fiber Reinforced Polymer Plates (11. FRP reinforced concrete structures)

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Carbon fiber reinforced polymer(CFRP) materials were primarily used in the aerospace and defense industries rather than the civil engineering field because of the prohibitively high cost of the raw materials and manufacturing processes. However, according to the need for both maintaining and upgrading civil infrastructures in all parts of the world and the well-known advantages of CFRP composites, diverse efforts are being made to reinforce the deteriorated concrete structures with CFRP materials. In most cases wherein the concrete structures are strengthened using externally bonded CFRP reinforcements, the full use of CFRP reinforcements is not possible. It is because premature debonding failures occur from the interface between concrete and CFRP reinforcements. However, prestressing allows the use of a greater share of CFRP materials. Most studies on the prestressed CFRP reinforcements focused on the verification of the flexural strengthening effect of the reinforced concrete members. In this study, however, the effects of the unbonded CFRP reinforcements on the strengthened beam with different prestress levels were examined. A flexural test was conducted with six reinforced concrete beams, and CFRP plates were used as the CFRP reinforcements. The main test variables included diverse prestress levels and anchorage systems. Based on the test results, the failure mode, load-deflection relationship, elastic and plastic energy and strain variance of the concrete

6531 | Numerical Simulation of the Fatigue Bond Behavior of Near surface mounted (NSM) FRP reinforcement (11. FRP reinforced concrete structures)

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This paper presents a three-dimension finite element model for direct pullout test of near surface mounted reinforcement using the general purpose FE software ANSYS. Combination elements and a theoretical local bond stress-slip relationship are employed to simulate bond between FRP and concrete. Numerical simulation of the specimen under monotonic load is carried out firstly. Previous experimental results in the literature are selected to verify the obtained result.
With the verified model, an approach of fatigue analysis is proposed, which is capable of predicting the fatigue life and debond development history of the

NSM reinforcement system. Furthermore, some parametric studies have been done. The influence on fatigue life and debond history of several variables, concrete strength, FRP rod diameter, and bonded length, was investigated.
Approach of fatigue calculation proposed in this paper can be easily modified and applied to a more refined NSM FRP reinforced system FE model for further simulation.

6718 | Creep and Multiple loading behaviours of CFRP- concrete bonded systems (11. FRP reinforced concrete structures)

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Carbon fibre reinforced polymer (CFRP) is used extensively in retrofitting civil structures. It has superior properties for many structural applications. The external bonding system uses epoxy resin to join CFRP and concrete and is required to endure many combinations of factors during its service life. Permanent and transit loads are commonly imposed on the bonded system and these loads may change structural performance in short- and long-term applications. The study of strain response (creep) in permanently-loaded samples at different load levels is essential to understand system behaviour under service conditions. Multiple loading and unloading routines may have significant effects on the functioning of the system. To investigate the effect of permanent loading at different levels, a single-shear lap test was selected. Purposely-designed and fabricated loading frames were used to apply the required service load levels. Long-term strains at selected locations were monitored for the entire period of testing. The samples were unloaded and reloaded to previous levels for an additional period. The consequences of repeated loading to higher stresses were also investigated. Strain and permanent deformation due to high stresses were examined up to failure. photogrammetry was used to analyse 2-D strain fields during loading-unloading stages throughout ultimate shear-lap testing.

6872 | Shear Response Characteristics of Scaled Reinforced Concrete Beams Wrapped with CFRP Sheets (11. FRP reinforced concrete structures)

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Response characteristics and cracking behavior of semi-deep reinforced concrete (RC) beams with dominant shear failure mode is experimental inspection target in current study. Externally bonded carbon fiber reinforced polymer (CFRP) sheets apply as retrofits. Effects of fiber orientation as unidirectional and cross-ply skin patterns on ultimate load carrying capacity, strain distribution and failure ductility are examined in detail. Specimens consist of six simply supported beams with scaled geometry and material properties preserving physical similarity with intact designed prototype with three-point monotonic loading. Study targets include changes in compressive and mid-span web concrete straining values considering tensile steel rebar and CFRP skin deformations. Results disclose major shear strength and failure ductility enhancement within retrofits. Stacking orientation affects rebar yielding corresponding deflection and controls hardening regime during deformation process of structure. Composite stabilizes cracking rate in web zone, protects continuity and waives initial catastrophic shear collapse. Straining of compressive concrete block and tensile rebar are expressed primarily for unidirectional orientation. However, global strength and stiffness are enhanced well when the skin was in cross-ply form. Premature necking and rupture of steel stirrups embedded in concrete is postponed after concrete crushing for all retrofitted beams preserving structural stability.

7557 | Evaluation of the new CAN/CSA-S806-12 Provisions for the Torsion Design of Concrete Beams with FRP Reinforcement (11. FRP reinforced concrete structures)

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Recently, the Canadian Standards Association proposed a torsion design provisions for the case of beams reinforced using fiber reinforced polymer (FRP) within the Canadian standard for the Design and construction of building structures with fiber-reinforced polymers (CAN/CSA-S806-12). The purpose of this study is to evaluate these provisions. In this study, an experimental database from four different studies with a total of 24 concrete beams reinforced with FRP bars and stirrups, tested under torsion, is compiled. The torsion design provisions of the CAN/CSA-S806-12 were used to calculate the strength. The predicted strength was compared with that measured during testing. The comparison showed that, with the exception of bonded FRP stirrups, the design code is conservative. However, improvements for the case of adhesively bonded FRP stirrups are required.

7571 | Structural performance of HPFRC beams reinforced by hybrid pre-stressed GFRP bars and steel strand (11. FRP reinforced concrete structures)

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The present study investigates the structural behavior of I cross section beams flexurally reinforced by hybrid prestressed steel strand and GFRP bars, and made by of high performance fiber reinforced concrete (HPFRC) beams in order to eliminate steel stirrups, since this reinforcement is the most susceptible to corrosion in this type of structural elements. Combining prestressed GFRP bars of relatively low elasticity modulus, but immune to corrosion (positioned with a small concrete cover), with prestressed steel strand (with higher concrete cover to avoid corrosion) a good compromise in terms of reinforcement effectiveness, ductility, durability and cost competitiveness can be obtained. The steel strand aims also to assure the necessary flexural strengthening of the beams if GFRP bars becomes ineffective in case of fire occurrence. The paper focuses on the results obtained in an experimental study of I shaped cross-sectional beams flexurally tested under monotonic and fatigue loading conditions. The main structural parameters such as deformation, crack spacing, crack width and ductility under both ultimate and serviceability conditions are examined.

7580 | The Issues Related to Flexural Behaviour of FRP Prestressed Concrete Beams (11. FRP reinforced concrete structures)

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In the recent years a vast of experimental work with non-metallic reinforcement is being widely used to explain a comprehensive structural integrity of composite material as an alternative for construction industry purposes. The objective of this research was to experimentally investigate issues and concerns related to flexural behavior of concrete beams internally prestressed with fiber-reinforced polymer (FRP). Together with the strength characteristics, the effect of prestressing force, prestressing reinforcement ratio on corresponding deflection and cracking distribution has been mainly governed by the stress-strain laws of reinforced concrete. The experimental results are compared to theoretical estimates from formulas available in U.S. and European codes and recommendations.

7620 | Optimization of FRP Hybrid Bar Design for Tensile and Bonding Performance (11. FRP reinforced concrete structures)

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“FRP Hybrid Bar” has recently developed by Korea Institute of Civil Engineering and Building Technology (KICT) to overcome the low elastic modulus of glass-fiber-reinforced polymer (GFRP) to be used for reinforced-concrete (RC) structures built in a corrosive environment. The concept of FRP Hybrid Bar is to combine basically two different materials, including steel and GFRP. In this case, steel and GFRP provide high elastic modulus and high tensile strength, respectively. Two type of FRP Hybrid Bar were introduced: 1) FRP crust with steel core; 2) FRP bar with steel wires dispersed over the cross-section. E-glass fibers and unsaturated polyester resins were used for FRP Hybrid Bar by Braidtrusion (i.e., Braiding + Pultrusion).

Various tests, including tensile, bonding and corrosion tests, have been conducted and showed its potential feasibility. As a result of primary tests for the first prototypes, tensile and anti-corrosion performance has improved significantly in comparison with GFRP and steel rebars, respectively. However, bonding strength has showed relatively low in comparison with steel rebar. The main objective of this study is to improve the first prototypes on bonding strength as well as tensile performance, and corresponding tests are examined in this study.

7690 | Sandwich panels with thin-walled high performance concrete layers (11. FRP reinforced concrete structures)

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Sandwich panels, exhibit an attractive choice for modern building envelopes. The application of two thin facings made of high performance concrete and a core of polymeric rigid foam can highly enhance the load-bearing capacity of the sandwich panel providing a low weight at the same time. An additional prestressing with pre-tensioned CFRP (Carbon fiber reinforced polymer) tendons enables long spans. The use of TRC (textile reinforced concrete) or UHPC (ultra-high performance concrete) with high uniaxial compression strengths leads to a reduction in concrete usage and the realization of slender panels.
In general sandwich panels with concrete facings are assembled by cutting slabstock foams, which results in fine dust covering the cutting edges harming the bond quality to the concrete facings. Additionally air inclusions may occur during concreting the sandwich panels. In order to overcome these issues, i.e. to achieve a homogenous bond quality, the core foams made of polyurethane (PU) are foamed in pack between the concrete layers made out of TRC or UHPC. This prevents unbonded parts in certain areas and makes various shapes of cross-sections possible. In addition the set-up of non-metal connectors made of CFRP or GFRP contributes to ensure the composite action without acting as a thermal bridge. These connectors are capable to withstand stresses evoked by shrinkage of the concrete on one hand and temperature loads on the other hand. At the same time the stiffness and load-bearing capacity of sandwich panels can be increased by the application of these connectors.

The innovative composite material TRC takes into account the advantages of high-strength fine-grained concretes and open-meshed textile reinforcements, which are mainly made of alkali-resistant glass (AR-glass) or carbon fibers. Due to the non-corrosive behavior of the textiles, the required concrete covers can be minimized resulting in filigree and lightweight concrete structures. By using TRC as facing of sandwich elements, the overall wall thickness can be halved.

Sandwich panels with UHPC facings were developed exhibiting a folded cross-section and pre-tensioned with CFRP tendons. Hence a high stiffness and load bearing capacity of the sandwich element were enabled.

This paper reports on the experimental investigations on the load-bearing capacity of sandwich panels with varying connector types, foam cores, concrete mixture, pre-stressing forces and cross-sections subjected to tensile and shear forces as well as bending action.

7693 | FRACTURE ENERGY APPROACH ON BOND PERFORMANCE OF CFRP/CONCRETE COMPOSITES EXPOSED TO SALINE WATER (11. FRP reinforced concrete structures)

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Life expectancy of externally bonded Carbon Fiber Reinforced Polymer (CFRP) composites highly hinge on ageing conditions as the epoxy adhesive bond between CFRP and concrete is immensely susceptible to numerous environmental exposures. Ageing mechanisms under environmental conditions such as temperature fluctuations, chemical degradation, creep, fatigue and moisture directly affect on long-term durability of CFRP/Concrete composites. It is vital to scrutinize the long-term performance of such systems since many CFRP applications can be perceived in outdoor structures. A series of accelerated environmental testing was conducted on CFRP strengthened reinforced concrete beams exposed to combined effects of sustained loading and artificial ageing of beams comprising saline water immersion. A finite element model was developed to forecast the interface deterioration with exposure period after exposure to saline water. Strength-based and fracture-based models were also implemented to determine the interface bond

strength of CFRP/Concrete composites. Comparison was made to identify the best theoretical approach to quantify the interface bond degradation.

Keywords : CFRP, ageing mechanisms, saline water, sustained loading, fracture mechanics, bond strength

7719 | RC beams strengthened with NSM GFRP rods (11. FRP reinforced concrete structures)

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Near Surface Mounted (NSM) technique which uses fiber reinforced polymer (FRP) rods inserted into grooves on concrete covers appears a promising technology to increase the flexural and shear capacity of reinforced concrete members. The availability of strengthening with NSM Glass-FRP rods depends on many factors linked to materials - dimensions of the rods used, type of GFRP material employed, rods' surface configuration, groove size, etc. – and to effects of reduction of adhesion between concrete and GFRP rods due to cracked concrete under loading.
Occurrence of damage in a reinforced concrete element leads to changes in its dynamic response just like RC beams strengthened with NSM GFRP rods. An investigation has been developed to evaluate the experimental vibration changes of RC beam strengthened with NSM GFRP rods respect a RC beam with steel reinforcement. In this paper experimental tests on RC beams strengthened with NSM GFRP rods that include both static bending tests, measuring static parameters until failure for beams, and dynamic tests based on frequency values in the case of free-free ends are described. Comparison between experimental and theoretical data and the analysis of frequency changes due to damage for bending cracks and decrease of adhesion permit to discuss the actual behaviour of RC beams strengthened by NSM GFRP and to assess the availability of this technique of strengthening.

7729 | Concrete Compression Struts Strengthened using Carbon Fiber Reinforced Polymers (CFRP) (11. FRP reinforced concrete structures)

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As traffic loads rise and bridge infrastructure ages, it is becoming increasingly necessary to repair or strengthen existing bridge members. Externally applied Carbon Fiber Reinforced Polymer (CFRP) materials have been used extensively to repair and strengthen reinforced con-crete structures. Strengthening concrete members using CFRP is a cost-effective and rapid retro-fit technique, which can be implemented while members are in service. Moreover, CFRP materi-als offer additional benefits over traditional materials because of their high strength-to-weight ratio, corrosion resistance, and limited architectural impact. Previous tests of strengthened full-scale I-girders showed significant differences in the shear-strength contribution of anchored CFRP strips used in uni-directional or bi-directional layouts.
Concrete panels were used to examine the influence of various layouts of uni-directional and bi-directional CFRP strips. The panels were loaded to produce bottle-shaped compression struts similar to those in the webs of beams. The effects of the amount of CFRP material used, the inclination and layout of CFRP strips relative to the direction of cracking were studied through the panel tests. The tests highlighted the most critical parameters influencing the effec-tiveness of CFRP materials in strengthening the concrete panels.

7740 | A mechanical model for predicting the stress-strain response of FRP/SMA reinforcing bars for concrete structures (11. FRP reinforced concrete structures)

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Despite many advantages concerning the corrosion resistance and the high strength to weight ratio compared to conventional steel reinforcement, the use of fiber reinforced composite materials in the form of pultruded bars for reinforced concrete structures is still limited by many performance factors mainly concerning the lower ductility of the final structural member.

The loss of ductility is due to the linear elastic behavior (up to failure) of FRP which leads to less energy dissipation in comparison with structural members reinforced with steel bars, where energy dissipation is reached through large plastic deformations.

As a consequence, structural applications where high energy dissipation or high damping ratio is expected or required are still not practical.

A possible response is represented by so-called “hybrid composites”, where fibers with different size, modulus of elasticity and ultimate strain limit are combined. The constitutive behavior, which is nonlinear, depends on the gradual rupture of the internal fibers at different strain levels. As it easy to realize, a ductile response is achieved only through permanent damage.

With the aim of improving the ductility and damping performance of concrete structures reinforced with FRP internal bars, recent studies are focused on the behavior of innovative bars composed of common fibers (glass/carbon) embedded in a polymeric matrix in combination with super-elastic shape memory alloy (SMA) wires. Based on the results of these studies, the use of FRP/SMA bars seems worthy of being extensively studied.

With a look at this research field, the present work deals with a 1-D mechanical model able to capture the main features of the constitutive behavior of FRP/SMA bars, including the time-dependent interaction between fibres, wires and the resin simulated via appropriate rate-dependent cohesive interfacial laws. A finite element approximation is also derived with the aim to perform numerical simulations.

7756 | THE SHEAR BEHAVIOUR OF FULL-SCALE REINFORCED CONCRETE T-BEAMS STRENGTHENED USING BI-DIRECTIONAL CFRP STRIPS AND CFRP ANCHORS (11. FRP reinforced concrete structures)

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The shear performance of full-scale reinforced concrete T-beams strengthened bi-directionally with Carbon Fiber Reinforced Polymer (CFRP) material was studied. Although CFRP materials have high tensile strength, the ability to utilize their strength is limited by debonding failure of the CFRP strips from the concrete surface. In order to prevent or at least delay this debonding, CFRP anchors were used to provide an alternative means of transferring forces from CFRP strips to the concrete. T-beams that had 14-in. wide webs and a depth of 24 in. were tested. Four tests were conducted on full-scale specimens to examine the effect of the bi-directional layout of CFRP on the shear capacity. All specimens were designed using ACI-318-11 provisions with transverse steel spacing of 10-in. and a shear span-to-depth ratio of 3. Test results indicate a significant increase in shear strength due to the bi-directional application of CFRP strips with CFRP anchors. An interaction between the concrete contribution Vc and the CFRP contribution Vf to the shear strength was observed.

7809 | THE INFLUENCE OF THE MATERIAL TYPE OF THE REINFORCEMENT ELEMENTS ON THE ETS SHEAR STRENGTHENING EFFECTIVENESS OF RC BEAMS (11. FRP reinforced concrete structures)

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In the past years a new shear strengthening technique designated as Embedded Through-Sections (ETS) has been developed. According to this technique, holes are drilled through the beam section with a desired inclination, and bars of steel or composite material are introduced into these holes and bonded to the concrete with adhesive materials. Technical alternatives based on the ETS technique can be adopted when the concrete cover has not enough bond and strength to guarantee a strengthening effectiveness for the Externally Bonded (EBR) and Near Surface Mounted (NSM) techniques. The ETS bars mobilize in fact the beam's concrete core that in general is the less damaged zone of a beam, improving the bond performance of the strengthening system. Previous experimental programs have demonstrated that the ETS technique significantly increases the shear resistance of beams and slabs, being capable of transforming a brittle shear failure mode into a ductile flexural failure mode. An experimental program composed of reinforced concrete (RC) T-cross section beams shear strengthened with steel and CFRP bars according to ETS technique was carried out to assess the influence of the material of the ETS bars on the strengthening effectiveness of this technique. This program is formed by asymmetric three point beam bending tests with a total length of 2650 mm, and beam's cross section height of 400 mm. The percentage of existing stirrups (ro,1,s= 0.1% and ro,2,s= 0.17%), the percentage of the ETS reinforcement ratio, the interaction between ETS bars and existing steel stirrups, and the inclination of the ETS bars with respect to the longitudinal axis (vertical and 45°) were also variables investigated in this program. The experimental program is described in detail and the main results are presented and discussed.

7810 | Bond analysis of Fabric Reinforcd Cementitious Mortar (FRCM) to concrete (11. FRP reinforced concrete structures)

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Due to their favourable properties such as light weight, high strength, corrosion resistance, ease and speed installation, fiber reinforced composites are, today, widely used as strengthening system of existing reinforced concrete structures. The most used systems are made by composite fabrics or laminates embedded in an epoxy adhesive (Fiber Reinforced Polymer, FRP). Although the use of epoxy has proven to give excellent performances both in terms of bonding and resistance to environments, some drawbacks exist. The epoxy resin, in fact, has low permeability, diffusion tightness, poor thermal compatibility with the base concrete, poor fire resistance, susceptibility to UV radiation and low reversibility.
To avoid some of these problems, cement based composite systems consisting of fiber reinforced composites in form of grid or meshes and a cementitious bonding agent can be used (Fabric Reinforced Cementitious Mortar, FRCM).
The occurrence of debonding is one of the most interesting structural aspect that characterizes the mechanical behaviour of strengthened reinforced concrete beams. Debonding phenomena, as well-known, are strongly depending on the load transfer mechanisms at the concrete/matrix interface. As outlined earlier, the load transfer mechanisms are different for FRCM and FRP systems. In the FRP system, in fact, the bond between resin and reinforcing fibres is very strong and slips at the interface fibres/matrix are avoided; in addition, the resins impregnate a concrete thickness that is involved in the resisting mechanisms. On the contrary, in the FRCM system large slips at the fibres/cementitious interface take place and the load transfer mechanisms make active only at the interface concrete/cementitious matrix.
The analysis of the bond FRCM to concrete becomes, then, essential to define accurately relationships useful for the evaluation of the structural response of FRCM strengthened reinforced concrete elements.
The paper is devoted to the analysis, both experimental and theoretically, of the bond between a cement based fiber reinforced strengthening material and the concrete substrate. Results of tests on concrete specimens strengthened with the PBO-FRCM system, made by PBO (short of Polypara-phenilene-benzo-bisthiazole) fiber meshes embedded into a cementitious mortar (FRCM, Fabric Reinforced Cementitious Mortar), are presented and discussed. Tests were carried out varying both the bond length, the amount of the strengthening system and the outer surface conditions of the concrete substrate. Obtained results furnish useful information i) to determine the loss of bond between the PBO-FRCM system and the concrete, ii) to define the failure modes and iii) to evaluate both the influence of outer surface conditions of the concrete substrate and mechanical and geometrical parameters on the loss of bond PBO-FRCM-to-concrete. Test results were, then, utilized to calibrate a local bond-slip relation. A comparison between experimental results and theoretical predictions of the bond-slip law PBO-FRCM–to-concrete is, finally, presented and discussed.

7862 | Anchoring element for prestressed FRP reinforcement – functionality and design (11. FRP reinforced concrete structures)

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Fibre-reinforced polymers (FRP) used as inner reinforcement in concrete members are, especially in the case of members exposed to demanding

environmental conditions, regarded as a better alternative to steel bars due to their resistance to corrosion, their nonmagnetic behaviour, and also their very good strength to weight ratio. One of the disadvantages of FRP reinforcement is its lower modulus of elasticity (especially in the case of commonly-used GFRP reinforcement, which is one of the most widespread types of FRP reinforcement used in the world today). This leads to lower stiffness and thus to greater deflections of structures, and can also cause early propagation of cracks. The paper deals with the possibility of eliminating this problem by prestressing the reinforcement. It is especially focused on the description of the behaviour of the anchoring area of the own developed anchoring element, which is based on the creation of an additional spreading area in the anchorage zone of prestressed reinforcement by casting.

The anchoring system is based on the creation of an additional spreading area in the anchorage zone of prestressed reinforcement. This area allows the efficient transfer of prestressing force into the surrounding concrete. Thus, the anchoring length is significantly shorter than the normal necessary bonded length of straight tendon. The area is created by attaching one or more anchoring rollers manufactured from a special polymer compound (made up of a special mixture which is injected into a removable form and thereafter hardened) with a larger diameter than the diameter of the reinforcement. The diameters, lengths and also number of rollers are variable. It is simple to implement, both in the preparation as well as their subsequent implementation either in the factory (for pre-stressed elements) or in-situ (for additionally prestressed elements).

The theoretical part of the development of the anchoring system was aimed at the derivation of simplified forms of equations that are easy to use in design practice. The goal of the presented analytical solution is to describe the dependence of the anchored force on the slip of the embedded prestressed reinforcement, and also to quantify the prestressing loss due to the slip in the reinforcement/anchor and anchor/concrete interface. The behaviour of the anchoring area is described by using the stiffness parameters of its individual components.

The functionality of the anchoring system for prestressing reinforcement has been verified through a series of pull-out tests. Different anchoring element lengths were tested – anchor lengths of 40 mm, 50 mm and 70 mm were tested as a "single anchor element", and an anchoring element with a length of 30 mm was tested in series (two elements in the anchoring area). A comparison of data from numerical and analytical calculations of the anchoring area with data obtained from experiments is also carried out in the article.

Acknowledgment: The research is realized in the co-operation of two workplaces: Department of Concrete and Masonry Structures of Faculty of Civil Engineering at Brno University of Technology and PREFA KOMPOZITY Corp., which deals with the research and development of the fibre composites, among others. The results were obtained with the financial support of the Ministry of Industry and Trade project TIP TI FR 4/159. This article was also supported by the Ministry of Education, Youth and Sport through project CZ.1.07/2.3.00/30.0005.

7881 | Characterisation of microstructural evolutions in high alumina refractory castables reinforced with carbon fibers **(11. FRP reinforced concrete structures)**

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The high alumina refractory castable composites were prepared from calcium-alumina aggregate, calcium aluminate cement, reactive alumina, microsilica, dispersive chamotte and carbon fibers. Green, dried and fired at different temperatures samples were characterized by XRD, FT-IR, SEM/EDS and mercury intrusion porosimetry. Moreover, bulk density, open porosity, modulus of rupture (MOR) and cold crushing strength (CCS) of investigated castables were carried out. The result showed that the physical properties of high alumina refractory castables and their microstructure can be improved using the carbon fibers addition.

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7938 | Pseudo-Ductile Behavior of FRP-UHPFRC Composite Girders **(11. FRP reinforced concrete structures)**

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This paper is a part of a comprehensive study aimed at developing sustainable composite girders for bridge applications. The girders are composed of I-shaped fiber reinforced polymers (FRP) girders and precast Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC) slabs. Bolt shear connectors with or without epoxy bonding were used to transfer the horizontal shear force from the UHPFRC slab to the FRP girder. Test variables included two types of bolt shear connectors (vertical and inclined) and two types of FRP plates (CFRP and GFRP), which were bonded to the soffit of the FRP girders. Eight large-scale composite girders and two control girders were tested under four-point flexural loading. Three composite girders were composed of full-length precast UHPFRC slabs. The other five girders were made up by twelve precast UHPFRC segments, which were connected by either high strength mortar or epoxy adhesive. The results indicated that the FRP-UHPFRC composite girders with the bonded FRP plates and the composite girders with the inclined bolt shear connectors showed a pseudo-ductile behavior. The use of mortar connections resulted in more ductile behavior than that of the epoxy connections. The developed FRP-UHPFRC composite girders exhibited high flexural-strength-to-weight ratio, high durability, and satisfactory ductility. These girders can provide a promising and sustainable solution for structures subjected to severe environmental conditions and accelerated bridge construction.

8047 | Multi-objective weight and cost optimisation of hybrid composite-concrete beams **(11. FRP reinforced concrete structures)**

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The construction industry currently lacks floor solutions for renovations which are lightweight and easy to install. To meet these needs, composite materials can be introduced as a lightweight structural material. However, despite their high mechanical capacity to weight ratio the practical use of composite materials in construction remains rather limited, the relatively high cost often being mentioned as the most restricting factor. To tackle the need for the minimisation of both the cost and the mass, a multi-objective size optimisation procedure was developed and applied on hybrid composite-concrete beams which are the loadbearing elements of a lightweight floor system.

The used Non-Sorting Genetic Algorithm (NSGA-II) results in a Pareto front which represents all efficient solutions, for which none of the objective functions (mass and cost) can be improved without degrading the other. All Pareto optimal solutions are sets of variables which allow the user to decide which of these solutions is the most appropriate compromise between mass and cost for any given situation.

The optimisation algorithm facilitates the study of the influence of different parameters such as the span and the concrete class on the weight and cost of the beams. As such, this study gives an insight in the future possibilities of using lightweight hybrid beams for floors. Obtained results indicate a major weight reduction up to 50% by using hybrid composite-concrete beams instead of traditionally steel reinforced concrete beams.

8052 | Experimental and numerical assessment of two FRP-based strengthening systems for earthquake damaged precast reinforced concrete wall panels (11. FRP reinforced concrete structures)

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Abstract. This paper presents a part of an experimental program conceived to study the behaviour of precast reinforced concrete wall panels (PRCWP) subjected to seismic action. The wall specimens having an as-built narrow door opening were tested under simulated seismic action and then they were repaired, retrofitted or rehabilitated and retested. The experimental part presented here shows the possibilities of using FRP materials for strengthening the PRCWP, namely EBR-CFRP strips alone, or combined with NSM-CFRP plates.Theproposed solutions considered the followings: the restoration of the shear resistanceof one wall and the increase of the shear resistance for the other one. The experimental results validate the retrofitting solutions, indicating the good performance of the elements achieved through FRPs in terms of load bearing capacity, stiffness degradation and energy dissipation capacities.

Keywords: experimental tests , numerical study , FRP, earthquake, shear wall, seismic behaviour

8110 | Fracture Resistance of Concrete Column-Slab Connections Strengthened with Pre-stressed Carbon Fibre Plates (11. FRP reinforced concrete structures)

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Fibre reinforced plastics (FRP) have been used widely in civil engineering in order to improve the ultimate response of structures. However, there is concern about their contribution to the structure ductility, which is critical in the application of this technology. This paper presents a theoretical method to predict the fracture resistance behaviour of FRP poststrengthened column slab connections. The model takes in consideration the mixed-mode debonding failure at the interface of concrete and FRP plates due to dowel action and the size effect. The influence of the bridging stresses provided by the fracture process zone (FPZ) at the tip of a fictitious fracture is examined. The effect of various material and geometric parameters on the resistance curve and toughness of the hybrid structure is discussed, based on the numerical results from the developed theoretical model. The results provide a useful insight into the strengthening/toughening and the design of FRP plate/concrete slab structures.

8141 | LONG-TERM PERFORMANCE OF BASALT FIBER-REINFORCED POLYMER (BFRP) REINFORCING BARS (11. FRP reinforced concrete structures)

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This paper presents an experimental study that investigated the physical, mechanical, and durability characteristics of newly developed Basalt-fiber-reinforced polymer (BFRP) bars used as internal reinforcement for concrete structure. To perform durability study, specimens were exposed to an alkaline solution (pH=13) for 3 and 6 months at elevated temperatures of (60 o C) to accelerate the environmental conditioning effects. Thereafter, the properties were assessed and compared with the unconditioned reference values. The test results showed that the properties of the conditioned BFRP specimens affected by the accelerated time and temperature in alkaline solution. The physical and mechanical properties, however, achieved the minimum requirements of CSA S807-2010 and ACI 440-2008 to be used as internal reinforcement. To provide engineers with more confidence in using BFRP bars, for safe and economic reinforced concrete structures in aggressive environments, more experimental tests for durability issues and full-scale structure element testing are urgently needed.

8149 | Shape optimized struts made of ultra-high performance concrete (11. FRP reinforced concrete structures)

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In July 2010 the Deutsche Forschungsgemeinschaft launched Priority Program 1542 „Concrete Light. Future concrete structures using bionic, mathematical and engineering formfinding principles". The main objective of this Priority Program is to develop mechanical fundamentals, engineering models and construction principles for the realization of new, free formed, light concrete structures in the future. Besides a structural concept that follows the flux of forces and bionic principles, those „lighter" structures shall be realized by using innovative materials, like ultra-high performance con-crete

(UHPC), carbon-fiber-reinforced polymers (CFRP) and textile reinforcement.
One of the altogether 17 subprojects within Priority Program 1542 entitled “Shape optimized filigree rods made of UHPC and non-corrosive CFRP-reinforcement for variable three-dimensional trusses” is currently processed at the Chair of Concrete Structures of the Technische Universität München. The basic idea of this research project is to resolve the commonly built massive, compact concrete bearing structures, which are mostly characterized by plane surfaces, rectangular geometries and an irregular material utilization, and create filigree truss supporting structures in accordance with the principle „form follows force“ instead. Thus besides weight reduction and a higher transparency, a more balanced utilization of resources can be achieved. For the truss supporting structures a modular construction method, including a prefabrication of the components strut, prestressed tie and con-nection joint element and an assembly at the construction site, is aspired. Possible fields of applica-tion are areal three-dimensional supporting structures, such as light roof supporting structures, but also two-dimensional trusses with primarily uniaxial load transfer, such as long-span roof trusses.
Among other things, the intended realization of filigree, concrete truss supporting structures requires the development of struts as slender as possible. Especially because of the high compressive strength, but also due to the excellent properties concerning durability, UHPC is the appropriate ma-terial for this purpose. One focus of research concerning the struts is on the shape optimization in longitudinal direction. Hence extensive numerical analyses using the software “optiSLang“ and the finite element program “ANSYS” were carried out in order to determine the optimal shape of struts subjected to concentric and eccentric compression loads for varying lengths and support conditions. Furthermore, it was experimentally examined to what extend the cross-sectional capacity in highly stressed areas of the struts can be increased by an embedded CFRP confining reinforcement. Thereby, a reasonable confining reinforcement as well as the short-term mechanical behavior was determined by compressive tests on cylindrical UHPC-specimens with a confining reinforcement of varying geometry. In addition to this, the influence of long-term loads on the confined specimens was studied by creep tests with varying loading levels. Based on these experimental investigations and the theoretical shaping analyses mentioned above, shape optimized struts were produced and com-ponent tests were carried out with variation of the parameters strut length and load eccentricity. The results from these tests were verified by physically nonlinear ANSYS-analyses. Finally, general de-sign principles for shape optimized struts can be developed on the basis of the experimental findings in conjunction with numerical analyses.

8180 | Influence of recycled aggregate on bond behaviour between recycled aggregate concrete and fibre reinforced polymer bars (11. FRP reinforced concrete structures)

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The construction industry is using natural resources and disposing of construction and demolition wastes in very large quantities. The environmental and economic impacts of both these practices may be considerable. Many policies aimed at increasing reuse and recycling are being promoted by governments. The use of recycled aggregate concrete (RAC) is one way to reduce the energy and available natural resources consumption, thus solving some of the problems in construction engineering. Special concern exists on the possible reduction of mechanical properties of hardened concrete, mainly attributed to the unknown origin of the recycled aggregates and to the existence of old mortar.

In designing reinforced concrete (RC) structures, bonding between reinforcement and concrete is a relevant aspect. Bond behaviour between natural aggregate concrete (NAC) and steel rebars has been studied for years, and numerous investigations on the bond between this conventional concrete and fibre reinforced polymer (FRP) rebars have been carried out. For the latter, the literature reveals that surface treatment and mechanical properties of concrete, among other aspects, are determinant in the bond performance.

Given the great economic and environmental benefits of recycling of concrete and the efforts of construction industry to promote the use of plastic reinforcement, research on the combination of RAC and FRP rebars is of main concern.

This paper presents the results of an experimental campaign on the study of the bond between RAC and FRP rebars. The experimental programme consisted in 48 pull-out tests. Three different concrete grades (low, medium and high), four recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 20%, 50% and 100%), and two types of FRP rebars with different surface configuration (i.e. spirally wounded and ribbed) were combined. The replacement ratio or RCA was termed as the recycled aggregated replacement percentage to the total coarse aggregates by weight, and the origin of the recycled aggregates was unknown.

Results of present experimental campaign confirm the tendency of higher bond strength being developed in pull-out test with larger concrete grades, irrespective of the RCA replacement percentage and FRP bar surface configuration.

For low concrete grades, bond behaviour greatly depends on concrete properties. Therefore, replacing natural aggregate with recycled aggregate would be counterproductive. This is confirmed by experimental results, which show a decrease in bond strength for any RCA replacement percentage. However, for medium to high concrete grades, bond behaviour is less dependent on concrete properties and more dependent on bar surface configuration. Therefore, the addition of RCA in medium and high concrete grades produces a lesser decrease in bond strength, showing even some increases in bond strength for a given combination of bar surface, concrete grade and RCA replacement.

The study of the effect of bar surface configuration reveals that for ribbed bars the best bond performance after RCA substitution is obtained for a 20% of replacement. For larger replacement percentages, experimental compressive strength of hardened concrete stabilizes or even decreases, thus affecting bond performance. However, for spirally wounded bars the largest benefits in bond were obtained for a 50% replacement. In this case, the mechanical properties of hardened concrete are not highly decisive because bond strength does not depend on concrete shear strength.

8219 | Aspects of bond behavior for concrete beam strengthened with CFRP-NSM (11. FRP reinforced concrete structures)

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The Near Surface Mounted (NSM) technique has been used in recent years for the strengthening of reinforced concrete beams. It involves the insertion of strips or rods of carbon fibers reinforced polymers (CFRP) in grooves made previously in the concrete cover of corresponding surfaces, filled with epoxy adhesive for fixation. In order to characterize the laminate and rods to concrete bond behavior, pullout-bending experimental investigation was performed. In order to evaluate the influence of the bond strength, the concrete strength and the strengthening configuration and type on the pullout load-carrying capacity, bonding stress, rigidity and mode of failure, a parametric study was carried out based on pullout-bending tests. The influences of these parameters on the bond behavior between the three materials (concrete, epoxy adhesive and CFRP) were evidenced and discussed.

Keywords: Beam, NSM, CFRP, epoxy, bond, failure.

8295 | Steel-CFRP Composite Bars as Shear Reinforcement for RC T-Beams (11. FRP reinforced concrete structures)

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The present study investigates experimentally the shear behavior of reinforced concrete (RC) T-beams with the conventional steel stirrups and innovative hybrid bars: steel stirrups hybridized with carbon fiber reinforced polymer (CFRP). In addition to the advantage of protecting steel stirrups from corrosion, the objective of the study is to determine the effect of the innovative steel-CFRP composite stirrups on the various aspects of RC T-beam behavior with emphasis on load-carrying capacity, deformation profile, crack distribution and propagation, and failure mechanism. Test results obtained from four beams, two served as control samples reinforced with conventional steel stirrups and the others were with the innovative stirrups, showed that shear behavior of RC beams with the innovative stirrups would be improved, where shear strength could be increased and beam ductility is enhanced. On the other hand, the same amount of CFRP used were applied as internal shear reinforcement for additional two beams. It is found that the integrity of the structural element could not be guaranteed in the ultimate stage when steel stirrups are replaced with CFRP strips.

8606 | Discrete crack modeling of side face FRP-strengthened concrete beam (11. FRP reinforced concrete structures)

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Shear strengthening can be carried out in concrete structures by external fibre reinforced polymer (FRP). In the present investigation, a new fracture mechanics model is developed to model side face of strengthened concrete beam by external FRP. Discrete crack is simulated by a spring element with softening behavior ahead of the crack tip to model the cohesive zone in concrete. A truss element is used, parallel to the spring element, to simulate the energy dissipation rate by the FRP. The strain energy release rate is calculated directly by using a virtual crack closure technique and then, the crack propagation criterion is presented. The results are found acceptable when compared to previous experimental results and ABAQUS software data. It is observed that the length of the fracture process zone (FPZ) increases with the application of FRP in side face at the same load in comparison with that of the control beam.

8615 | Chloride Resistance of Engineered Cementitious Composites containing Palm Oil Fuel Ash (11. FRP reinforced concrete structures)

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The influence of palm oil fuel ash (POFA) inclusion on the chloride resistance of engineered cementitious composites (ECC) were experimentally investigated. Different ECC mixes with varying POFA content and water-binder ratios were used. The results show that the mechanically pre-loaded POFA-ECC specimens exposed to chloride solution remain durable. The results also indicated strong evidence of self-healing of micro-cracked POFA-ECC specimens, which can still carry considerable flexural load. The chloride permeability test (RCPT) reveal that the total charge passed was gradually reduced with the inclusion of higher amount of POFA. The results presented in this study provide a preliminary database for the durability of cracked and uncracked POFA-ECCs under chloride environment or/and combined mechanical loading.
Keywords: Chloride resistance.Palm oil fuel ash. Engineered cementitious composite

8617 | Textile based lightweight shell in hybrid prefabricated construction (11. FRP reinforced concrete structures)

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Modern architecture is increasingly dominated by the tendency to design buildings in an organic way. However, the implementation is often highly difficult, because the material and technologies which are currently available are expensive. Shells made from fiber reinforced plastic with filament reinforcement are flexible and have an excellent surface quality. However, the formwork construction for unique elements is complex. This makes an implementation difficult. Therefore, it is necessary to develop suitable, reusable shell systems for an efficient production of individually designed concrete lightweight elements.
The new technological approach uses flexible, multilayered shell elements, consisting of glass fiber reinforced plastic (GFRP). They permit a targeted adjustment of curvature states, utilizing the anisotropic structural behavior. As permanent formworks, these flexible moldable elements are combined with textile reinforced fine grained concrete. This results in a hybrid material which consists of GFRP and textile concrete and combines high strength properties and formative characteristics. The hybrid material combines high tensile strength and flexural strength, surface quality, durability and resource efficiency.
By means of experiments and calculation, different curvature states were determined in different multi-layered GFRP-laminates that are used as flexibly moldable shell elements for the production of free-form composite elements. The adjustment of defined curvatures is achieved by using multi-layered

GFRP shell elements with low flexural strength, which can be produced location-independently and combined in various ways. Normally, the curvature states of the multi-layered GFRP-laminates result from temperature load and traction due to anisotropic structural behavior. For this purpose, material properties were determined, with regard to fiber orientation and layer structure of asymmetrical GFRP shell components. Furthermore, an analytical and numerical calculation, based on the classical laminate theory, was conducted.
In addition, an analysis of the composite action between permanent GFRP formworks and textile concrete was conducted, and an interlayer for the mechanical coupling und thermal decoupling of the composite components was developed. At the same time, the components were adjusted with reference to stiffness and linear coefficient of thermal expansion.
By means of the interlayer that were developed, a composite of permanent GFRP shell and textile concrete was implemented successfully. In this way, the amount of work was reduced, while at the same time the mechanical properties of the lightweight elements increased, compared to textile concrete components. Thus, the material compound system, consisting of permanent GFRP shell construction and textile reinforced fine grained concrete, permits the location-independent implementation of any free-form surface, according to the principle “form follows force”. This facilitates the production of thin-walled (and therefore light) shell support structures made of GFRP textile concrete, with concrete of excellent quality of the highest face concrete class.

8639 | Use of prestressed CFRP strips for flexural strengthening of RC slabs with the NSM method (11. FRP reinforced concrete structures)

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Use of carbon fiber reinforced polymers (CFRP) is one of the fastest developing area in civil engineering industry. Composite materials found adoption in rehabilitation of reinforced concrete (RC) structures in numerous applications displacing conventional strengthening due to their abundant advantages. Apart from the exceeding bearing capacity of structural elements, the requirements posed to constructions especially in serviceability limit state enforce an improvement in service conditions like decrease in existing deflections or reduction of crack width. Near surface mounted (NSM) method assuming use of narrow strips glued in longitudinal grooves made in the concrete cover is the most effective way of flexural strengthening of RC specimens with composite materials. NSM method is characterized by the limitation of premature debonding frequently observed in strengthening with externally bonded (EB) FRP strips and high strengthening efficiency ratio. Despite of all advantages, strengthening by non-prestressed CFRP strips affects only flexural resistance of concrete members but does not influence on serviceability limit state conditions. Moreover, passive strengthening does not fulfill tensile strength of CFRP strips, what has been previously reported in the literature.
Novel experimental program conducted at the Lodz University of Technology is the complementation of the previous tests carried out on RC slabs strengthened with NSM CFRP strips applied as prestressed and non-prestressed. Promising results of former research induced authors to continue the undertaken topic. The general assumptions of tests remained unchanged like specimens dimensions, cross-section and loading method. The difference included CFRP reinforcement ratio, number of pre-tensioned strips and effect of specimens pre-loading. Elements with the 6000 mm clear span and cross section dimensions of 220 mm high and 500 mm wide were tested under six point static bending. Bottom tensile steel reinforcement of the slabs consisted of four steel bars with the nominal diameter of 12 mm (ρs=0.49%). Four bars with the diameter of 8 mm were used as compressive longitudinal steel reinforcement. All specimens were strengthened with 1.5 mm thick and 20 mm wide CFRP strips with a difference in a number of applied and prestressed strips. In NSM12A member the combination of one prestressed and two non-prestressed CFRP strips was applied. The NSM12B and NSM12BL specimens were strengthened with the two pre-tensioned CFRP strips without any additional non-active CFRP reinforcement. NSM12A and NSM12B members were strengthened and tested under their dead load equal to 25% of the yield strength of reference specimens. NSM12BL slab was tested under preloading level corresponding to 60% of the yield strength of the nonstrengthened member.
Encouraging results of tests carried out on slabs strengthened with prestressed narrow CFRP strips is presented in this paper. The purpose of the test was verification of strengthening effectiveness and examination the influence of doubling pre-tensioned strips on terms of serviceability limit state. The practical aspect of research was to review the effect of pre-tensioning CFRP strips on the pre-loaded RC specimens, which refers to strengthening of existing overloaded structures. For pre-tensioning narrow CFRP strips, author’s novel prestressing system adapted to strengthen structural RC elements in existing constructions was used.

8646 | Full-range behavior study of FRP-to-concrete interface for pull-pull bonded joints (11. FRP reinforced concrete structures)

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External bonding of fiber reinforced polymer (FRP) composites has become a popular technique for strengthening concrete structures all over the world. The performance of the interface between FRP and concrete is one of the key factors affecting the behavior of the strengthened structure. The bond behavior is related to specific bonded joint. However, there are few studies concerned about pull-pull bonded joint at present, and theoretical study is not profound yet, comparing with that of pull-push one. This paper presents an analytical solution for the debonding process in such an FRP-to-concrete bonded joint model. A realistic bi-linear local bond-slip law is employed. Based on rigorous and complete theoretical derivation, six possible failure processes has been identified. The bond length and the relation between geometrical and material parameter are the key factors governing these failure process. Letters E (elastic), S (softening) and D (debonding) are used to describe the states of the interface from the left to the right. The six possible failure processes (FP) will be FP1: The interface experiences the E, E-S, E-S-D, S-E-S-D and S-D stages; FP2: The interface experiences the E, E-S, S-E-S-D and S-D stages; FP3: The interface experiences the E, E-S, S-E-S, S-E-S-D and S-D stages; FP4: The interface experiences the E, E-S, S-E-S and S stages; FP5: The interface experiences the E, S-E-S, S-E-S and S stages; FP6: The interface experiences the E, S-E-S, D-S-E-S-D and S-D stages. Expressions for the interfacial relative slip, shear stress distribution, as well as normal stress in the FRP plate and the load-displacement response are derived for different loading stages, whose accuracy is verified by FEM numerical simulation. While the solution is developed with particular reference to FRP-to-concrete bonded joints, it is also applicable to similar bonded joints made of other materials (e.g. FRP-to-steel bonded joints).

KEY WORDS: FRP, bonded joint, pull-pull, interface, bond-slip model, softening
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8661 | Experimental study on BFRP prestressed concrete beams under cyclic loading (11. FRP reinforced concrete structures)

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In this study prestressed concrete beams reinforced with non-metallic reinforcement under cyclic loading are being investigated. Experimental study on fatigue of BFRP reinfocement and fatigue prestress loss of internally prestressed concrete beams were completed. Main focuses of this research were on concrete beam cracking and deflection changes during the cyclic or repeated loading and determination of fatigue load-life relationship (S-N).

8668 | FATIGUE BEHAVIOR OF CFRP-STRENGTHENEDREINFORCED CONCRETE BEAMS (11. FRP reinforced concrete structures)

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Existing experimental studies conducted to date showed that the reinforced concrete (RC) beams strengthened with carbon fiber-reinforced polymer (CFRP) plates have a significant improvement in bending capacity. However, many of the existing studies on FRP strengthened RC beams are limited to monotonic loading conditions. In this paper the experimental results, both from literature and in-house tests are investigated to establish an analytical model that describes the degradation in flexural stiffness of the beams under fatigue loading. Existing power-law expressions from “S-N” curves for concrete, steel and FRP are investigated to propose a new power-law expression addressing the composite response of the FRP strengthened RC beams. Validation of the analytical model and proposed power-law expression was made through the collected experimental database.

8673 | Impact Response of Concrete filled FRP-Steel Tubes (11. FRP reinforced concrete structures)

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Concrete filled FRP-steel tube is a composite structure made of the concrete-filled steel tube with externally wrapped FRP sheet. This is a promising structure with various advantages in construction and mechanical performances, such as improving the plastic issues of FRP tube structure as well as the corrosion resistance of the steel tube, etc. The dynamic response of concrete filled FRP-steel tubes under the impact loading was investigated in this study. 11 column specimens with the same cross-sectional area but different lengths were tested on a drop weight system. These specimens include 8 concrete filled CFRP-steel (carbon fiber reinforced polymer) tubes, 2 concrete filled GFRP-steel (glass fiber reinforced polymer) tubes, and 1 concrete filled steel tube as a baseline material. The impact force, acceleration, deflection, strain and the damage were measured and recorded. Test results show that the additional wrapping of FRP on concrete filled steel tube is effective in resisting impact loading, thus reducing the overall beam deflection and absorbing more energy compared to the ordinary concrete filled steel tube. The effect of GFRP reinforcement is better than the CFRP ones, since the GFRP one absorbed more energy and created smaller deflection though higher impact force. Results of damage pattern of FRP show that CFRP exhibited brittle behavior and experienced more severe damage. Finally, Increasing the layer of FRP and the axial compressive load could also reduce the impact deformation due to the enhancement of the overall integrity and general stiffness. The proposed concrete filled steel tube with FRP concept offers significant advantages on the impact performance compared with conventional concrete filled steel tube.

8679 | FRP Shear Strengthened Concrete Beams Exposed to Marine Environment (11. FRP reinforced concrete structures)

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Deterioration of aging civil engineering infrastructures, due to loss of material properties, exposure to aggressive environment or increase in loading requirements, demands drastic measures for repair and rehabilitation. The use of advanced composite materials, such as carbon fibre reinforced polymer (CFRP), is gaining tremendous popularity and interest in the strengthening and rehabilitation of reinforced concrete (RC) structures. These techniques offered many advantages like high strength to weight ratio, high corrosion and environmental degradation resistance and easy to handle during construction. Many researchers have conducted experimental and analytical studies on the structural behaviour of FRP strengthened RC members. Short-term laboratory test results of FRP application demonstrate that improvement in flexural or shear strength is possible with this material. However, there is little comprehensive research done on the long term durability of FRP strengthened RC members under aggressive environments, such as exposure to corrosive chemicals, moisture and seawater that commonly encountered in chemical or wastewater treatment plants and marine structures. So far, all studies on the long term durability effect are purely devoted to the case of flexural strengthening. There is a lack of experimental studies look thoroughly the performance of shear strengthening under this extreme environmental condition. Shear failure is brittle and sudden, any potential failure due to deteriorate of FRP performance will be catastrophic and should thus be avoided at all time. The main purpose of this research is to investigate experimentally the corrosive environments on the behaviour of CFRP shear strengthened RC beams and on the interfacial bond between the fibre and the concrete. Corrosive environment are commonly encountered in our marine structures, where in splash (tidal) zone that frequently subjected to repeated wetting and drying by seawater. The experimental work will be conducted in laboratory condition through wetting and drying cycles of saltwater in order to simulate this marine environment.

8680 | New Analytical Optimised Truss Model for FRP Shear Strengthened Concrete Beams (11. FRP reinforced concrete structures)

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Majority of research and application carried out using FRP as reinforcing material, has been devoted to the case of flexural strengthening. Shear strengthening, on the other hand, are rather limited and still under investigation. Current shear design approaches of externally bonded FRP strengthened concrete structures are analogous to internal stirrups, which is based on the well known 45-degree truss analogy. Three concerns may appear due to the use of this analogy: (1) overestimating the shear strength and unrealistic representation to the actual stress distribution, (2) deviation on the orientation of current strengthening scheme in relation to the actual stress distribution, (3) neglecting of direct relationship between internal stirrups and external FRP, and failing to capture the influencing parameters and interaction that exists in between them. This research proposal is intended to explore thoroughly the abovementioned concerns and resolve it by develop a new analytical model.
The objectives of this study are (a) to formulate a new analytical truss model that based on the optimization of Strut-and-Tie Model (STM) for FRP shear strengthened T-beams with stirrups, (b) to investigate the relative shear contribution (stiffness proportional) of the optimised STM models for internal stirrups and externally bonded FRP, (c) to define an interaction framework between externally bonded FRP laminate strips with shear influencing parameters, such as stirrup ratio and a/d ratio.

8702 | RELIABILITY-BASED PARTIAL SAFETY FACTORS FOR CONCRETE GIRDERS STRENGTHENED WITH CFRP (11. FRP reinforced concrete structures)

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Fiber reinforced polymer (FRP) fabrics and laminates have been extensively used as externally bonded reinforcement (EBR) aiming at strengthening concrete structures. When compared with other techniques, e.g. epoxy-bonded steel plates or concrete overlays, this technique exhibits several advantages, such as: easy installation, low weight, and reduced thickness. The growing interest in this reinforcing material led to the development of new design guidelines for reinforced concrete structures strengthened with FRP, being fib bulletin 14 and ACI 440.2R-08 those most wide-spread used. Given that this technology started to being used just two decades ago, there are issues that still need to be addressed. In this scope, how to attain in FRP design the same level of confidence reached in current construction materials, such as concrete or steel, is particularly relevant.
It is expected that the use of FRP in bridges, as an EBR, with the goal of restoring or upgrading its original strength, will assume increasing importance. In fact, during the last decades, most developed countries made strong investments in their highway networks, including the construction of bridges, where prestressed concrete girders were largely adopted. The deterioration of some of these structures, due to environmental attack combined with low maintenance, inadequate structural materials, low quality construction, poor design and/or detailing, overloading, accidental actions, or simply change of the structure's use, led to the need of finding fast and effective means of strengthening, as those provided by FRP applied as EBR.
Most studies on the performance of FRP applied as EBR focus on the deterministic behaviour of structures, through both experimental studies and numerical analyses. However, the reliability analysis of these systems is a critical tool for the development of semi-probabilistic based design codes. But the fact is that this approach has received little attention, in particular in what regards the strengthening of existing structures.
This paper assesses the flexural safety of deteriorated prestressed concrete girders strengthened with carbon FRP (CFRP) applied as EBR. A set of bridges with three spans, which are representative of bridges built in the last two decades, was analysed. The reliability of the girders was computed using the First Order Reliability Method (FORM), considering the uncertainty of the most relevant parameters: the tensile strength of the pre-stress steel, the tensile strength of the ordinary steel, the ultimate strength of the CFRP laminates, the traffic loads, and the uncertainties of the models adopted. The reliability index and the importance of CFRP in the probability of failure were computed. Moreover, a set of reliability-based partial safety factors was determined and these were compared with those proposed in the above-mentioned design guidelines. Finally, the basis for a reliability assessment of prestressed girders strengthened with CFRP applied as EBR was established, aiming at supporting the definition of a semi-probabilistic safety assessment European code for this type of elements.

8791 | Experiments of AMS Fiber Cementitious Composite and Reinforced Concrete Beams (11. FRP reinforced concrete structures)

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Keeping step with the growth of new material technologies, several researches about the applications of high performance fiber-reinforced concrete composites have been interested in the field construction of building and civil structures in order to improve structural characteristics. Recent concrete and composite structural members have been required to have more high-ductile, high-performance, and high-durable characteristics.
Like synthetic fibers which were used to apply to have high ductile after cracking in fiber cementitious composites, well known as strain-hardening cementitious composites (SHCC), steel fibers were used to mix with concrete in order to renovate their brittle characteristics as well as strength. Steels used in construction fields were generally a crystalline metal in which crystal was formed when liquid metal was cooled. Crystalline steels are fundamentally an anisotropic, so that the mechanical characteristics are differ from the crystal direction. Therefore, steel fibers in crystal are too weak in corrosion and too heavy to get suitably disperse into fresh cementitious mixtures and to get suitable mechanical characteristics of fiber cementitious composites.
Amorphous micro-steel (AMS) is manufactured by rapid cooling process of liquid pig iron at the bottom of a furnace that don't make crystalline grain boundaries. Therefore, AMS is solely isotropic like liquid characteristic in solid, called as a liquid metal, so that AMS has high strength and toughness with relatively lightweight in mechanical characteristics as well as high durability against corrosion.

The current research is firstly an attempt to newly manufacture AMS fiber reinforced cementitious composites and to present their appropriate mixing design varying with the amount of AMS fibers. Secondly a series of flexural tests of reinforced concrete composite beams applying with AMS fiber cementitious composites has been carried out in order to evaluate the structural characteristics of AMS fiber cementitious composites in terms of capabilities of crack control under bending or shear cracked regions as well as enhancements of load carrying capacities of the beams.

From material and mechanical test, such as slump flow test, compressive strength test, direct tensile test, and shear transfer test, with AMS fiber length of 15 mm and 30 mm, it was known that 1.0 ~ 1.25 % fiber volume fractions were suitable for the AMS fiber cementitious composites. From four-point beam tests, reinforced concrete composite beams applying with AMS fiber cementitious composites exhibited excellent enhancements in control of bending and shear cracks to compare with conventional reinforced concrete beams.

Acknowledgements

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8881 | Development Length of Spliced GFRP Reinforcing Bars in Normal and Self-Consolidated Concretes (11. FRP reinforced concrete structures)

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Abstract: The bond characteristics and develppment length of reinforcing bars are the most critical issues in the design of reinforced concrete structures. The resisting mechanisms under bending, shear, and torsion are related to the development of adequate bond. Limited research work was conducted to investigate the bond behaviour and development length of spliced FRP bars when self-consolidated concrete (SCC) is used. Thus, in this study, the bond behaviour and development length of spliced glass fiber-reinforced polymer (GFRP) reinforcing bars in SCC and normal concrete beams was investigated. The beam specimens measured 4300-mm long × 250-mm wide × 400-mm or 600-mm deep. The specimens were tested under monotonic loading over a clear span of 4.0 m up to failure. The test parameters were: (i) reinforcement type (GFRP and steel bars); (ii) concrete type (SCC and normal concretes), (iii) the splice length (20 db and 40 db where db is the bar diameter; and (iv) beam height (400 or 600 mm). The SCC and the normal concrete beams showed similar behaviour and the same failure mode. The test results revealed that the bond behaviour of the GFRP bars in SCC and normal concrete is significantly affected by elastic modulus of the reinforcing bars. Besides, the effect of splice length on the bond strength in SCC and normal concretes is not linear.

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8882 | Laboratory Characterization and Durability Evaluation of Basalt Fiber-Based FRP Reinforcing Bars (11. FRP reinforced concrete structures)

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This paper presents the mechanical, durability, and microstructural characterization of newly developed basalt-fiber-reinforced-polymer (BFRP) reinforcing bars exposed to concrete environment under accelerating conditions. Reference BFRP bars were first characterized and the measured properties were compared to GFRP bars. BFRP bars were then exposed to alkaline solution at 50°C during 1000 and 2000 hours to accelerate the effect of the solution and to simulate the concrete environment. The measured direct shear, interlaminar shear and tensile strengths of the bars before and after exposure were considered as a measure of the durability performance of the specimens. In addition, Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC) and Scanning Electron Microscopy (SEM) were used to characterize the aging effect on the BFRP reinforcing bars. The results revealed that even at high temperature (60oC), the change in direct shear strength is not significant. On the other hand, interlaminar shear and tensile strengths of BFRP bars are affected by the time of immersion in alkaline solution showing that the fiber/matrix interface can be affected by aging.

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9038 | Research and application on prestressed variable bond carbon fiber plate - R.C.beam composite structure (11. FRP reinforced concrete structures)

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First the concept of variable binding carbon fiber plate - R.C. composite beam in this paper has been outlined, and then describes the test and research on the composite structure, present the advantages about the variable binding carbon fiber plate composite beam. Finally three engineering application examples of composite structure of prestressed carbon fiber plate variable binded on R.C. beam have been stated.

9080 | Interfacial Bond-Slip Behavior of Near Surface-Mounted FRP Plate in Concrete (11. FRP reinforced concrete structures)

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In this paper, a stress transfer mechanism between near surface-mounted (NSM) fiber reinforced polymer (FRP) plate and concrete was investigated and a reliable analytical procedure for it was presented by using bi-linear bond-slip model simulating the bond behavior of NSM FRP plate.
As a result, critical values in the bi-linear model such as maximum shear strength, slip at that time and failure slip at the initiation of softening de-bonding were suggested for being used in the differential equation considering the interfacial characteristic between NSM FRP and concrete. Also, it was found that the bond-slip behavior could be suitably predicted by using the proposed procedure even in the case of various bond lengths from the comparison with bond test result.

9091 | Seismic resistance of GFRP reinforced concrete columns (11. FRP reinforced concrete structures)

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In an effort to evaluate the feasibility of GFRP bars and spirals as internal reinforcement in columns, an extensive research program is underway at the University of Toronto. Seventeen 356 mm diameter concrete columns have been tested under simulated earthquake forces which included constant axial load and cyclic lateral displacement excursions. Nine columns contained GFRP longitudinal bars and spirals while eight had longitudinal steel bars and GFRP spirals. Selected results from this group of specimens will be presented in this paper highlighting the ability of GFRP reinforcement in providing large deformability of columns. In addition to the moment vs. curvature response and shear vs. deflection behaviour, a number of ductility parameters related to curvature, displacement, and energy dissipation are used to evaluate the performance of specimens. Due to their linear elastic behaviour until rupture at a strain of approximate 0.02, GFRP spirals provided continuous confinement to the columns which displayed excellent deformability. Columns reinforced with longitudinal steel and GFRP spirals showed higher stiffness and larger shear and moment capacities compared to the columns which contained GFRP longitudinal bars.

9111 | 1. EFFECT OF LONGITUDINAL REINFORCEMENT DETAILS ON REHABILITATION STRATEGY AND SEISMIC PERFORMANCE OF FRP-REPAIRED COLUMNS (11. FRP reinforced concrete structures)

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Recent damaging earthquakes provided powerful reminders of how vulnerable we all are to the forces of nature. Even in an advanced industrial nation, built environment is still quite susceptible to natural disasters. A significant amount of damage has been observed to a number of bridges and buildings. To restore an earthquake-damaged community as quickly as possible, a well-prepared repair, reconstruction, or replacement strategy is most essential. Hence, this study aims to identify the effect of longitudinal reinforcement details on the performance of FRP-rehabilitated bridge columns. Two reinforced concrete bridge columns with improper details of longitudinal and/or transverse reinforcement were examined under the effect of constant axial compressive load and increasing lateral cyclic loading. Residual deformation, as a post-earthquake recoverability index, and damage level of both samples were considered to assess the probability of quick restoration of structure functions after a seismic action. Test results showed that column with lap-splice reinforcement exhibited inferior performance where column strength showed rapid degradation after yielding and its deformation capacity was limited; however, quick restoration is possible through a suitable rehabilitation technique. On the other hand, expensive repairs or even complete replacement of damaged column could be the decision for the column with confinement failure of the flexural plastic hinge region. After that, designed external basalt fiber reinforced polymers (BFRP) jacket guaranteeing the required enhancement in the inelastic performance was applied for both damaged columns. Test results of repaired columns confirmed that post-earthquake recoverability of structure is dependent on the reinforcement details within the plastic hinge zone. In addition, short lap-splice could be adopted as a seismic-performance-controllable tool.

9136 | Locking Method of Prestressed Sand-Coated Basalt-Glass Fibre Reinforced Polymer Anchor Structure (11. FRP reinforced concrete structures)

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The durability problem of anchor rods used to reinforce slopes can be solved by substituting fiber reinforced polymer(FRP) bars for steel bars. The FRP bar has a small elastic modulus，and therefore should be prestressed in order to limit the deformation of the reinforced slope during its service stage. This paper applied the grating sensing technology to monitor the bond behavior of sand-coated GFRP anchor rod under cyclic prestressing. The results showed that prestressing of the sand-coated GFRP anchor rod resulted in the damage of the anchor rod-mortar interface bonding，and the effect of repeated loads frequency on the bonding can be ignored，only the surcharge load is significant；The damage in bonding of the anchor rod-mortar interface is only dependent on the surcharge load，and not on the service load；The shear force of the anchor rod is provided by the bonding force and friction，with the bonding force generated at the initial stage，and then changes into friction at later stage；The damage in bonding resulting from the amplitude load on the anchor rod can make the anchor structure loose；The over tensioning load of the prestressed anchor rod structure must exceed the service load to an extent in order to ensure a stable anchorage force in the servicing stage.

9144 | Study on Flexural Performance of GFRP Grid and Concrete Composite Beam (11. FRP reinforced concrete structures)

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Many research about FRP-concrete composite beam/floor system haven been done and showed that these system can not only prevent chemical corrosion in harsh environment but also ease the problem of FRP structures which lack of ductility. This paper presents the numerical results of study on solution for beams with combination of glass fibre reinforced polymer (GFRP) pultruded profiles box and concrete which confined by GFRP grid, with shear connection and sticky sand contact. In this paper, theoretical derivation of the flexural capacity formulas and effects of various parameters upon flexural capacity of GFRP-concrete composite beam systems were studied. Firstly, mechanical analysis was conducted by elastic and plastic theory stress of this cross-section for composite beam. Secondly, formulas of ultimate anti-bending flexural capacity were established. Finally, the formulas were then

used to analyze the effects of cross-section parameters under three kinds of neutral axis location. The results show that concrete strength and neutral axis location have important effects on carrying capacity of the composite beam. GFRP profile can be fully utilized and the structure can have a higher carrying capacity when the position of the neutral axis is right at the bottom of the concrete.

9148 | Experimental Calibration for Tensile Strength Estimation of Circular GFRP Rebar (11. FRP reinforced concrete structures)

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Owing to the non-corrosiveness of the materials of which it is made, the FRP reinforcement emerges as a structural member that can replace advantageously the steel reinforcement in reinforced concrete structures. Unlike the steel reinforcement, the mixing of two heterogeneous materials for the fabrication of the FRP reinforcing bar results in a tensile strength change depending on the diameter of the rebar. The tensile characteristics of the FRP rebar are often evaluated by the rule of mixture (ROM) using the properties of linear elastic materials. Even if the ROM predicts accurately the elastic modulus of the FRP rebar in general, it has a tendency to overestimate its tensile strength. Therefore, this study intends to propose a modified ROM formula based upon the tensile test results of hollow GFRP rebar to predict accurately the tensile strength of the FRP reinforcing bar. Tensile tests for GFRP rebars of 19 mm diameter with four type hollow section in its center of cross section were performed. The tensile strengths for various diameters of hollow section were compared with that of GFRP without hollow section and used to modify the ROM. Parabolic stress distribution due to shear lag was assumed to evaluate the tensile strength of GFRP rebar. From the test results of GFRP rebars with and without hollow section, a modification factor of 64.8% was obtained for good estimating the average tensile strength of GFRP rebar with a diameter of 19 mm.

9214 | Experimental and Numerical Investigations of Punching Shear Strength of GFRP Reinforced Two-Way slabs (11. FRP reinforced concrete structures)

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Punching shear usually occurs in reinforced concrete slabs subjected to concentrated loads due to development of an internal arching action within the system of slab column joint. Recently the application of FRP in reinforced concrete structures has been increasing significantly due to its attractive properties, such as high tensile strength, lightweight, corrosion resistance, and simplicity of fabrication and formability.
This study program has been conducted to investigate the punching shear behavior of concrete members reinforced with GFRP reinforcement. Eight specimens are to be cast in lab within two categories of reinforcements such as GFRP and equivalent steel reinforcements. Three major factors which are studied, ultimate load, crack patterns, and strains in the concrete surfaces. Also this paper presents results of non-linear finite element formulation of all tested specimens reinforced with GFRP bars to study their effectiveness under service and ultimate limit states. The accuracy of the non-linear finite element analysis is to be demonstrated using independent test results conducted by other researchers. The behavior of the GFRP reinforced slabs were compared to that of the conventional slab reinforced with steel reinforcement. In addition a comparison between flexural and punching shear design concepts for FRP concrete slabs is presented.

Key Words: Punching Shear Strength, GFRP Reinforcement, Two-way Slabs, and 3D finite element modeling.

9228 | Durability of CFRP Bonding System for Strengthening Steel Structures in Natural Tropical Climate (11. FRP reinforced concrete structures)

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Carbon Fiber Reinforced Polymer (CFRP) material has been focused of many researched for strengthening structures recently. Excellent properties of CFRP including light weight, high tensile strength and corrosion resistance caused it to be a desirable material in rehabilitation of existing structures. Previous studies indicated bonding of CFRP plate to the structural elements was a successful technique to increase the mechanical properties. Generally, this method increased the flexural strength and stiffness of the beams considerably. Nevertheless, one of the main limitations of using this technique is the durability of CFRP bonding system against various environmental conditions. This study evaluates the durability of CFRP plate and bonding system after exposure to tropical climate which is a harsh severe environment. High temperature and humidity combined with the ultraviolet of the sun and heavy raining are the specification of this environment. For this purpose, CFRP and adhesive coupons were prepared and subjected to this specific exposure for 8 months. Then the coupons were tested at specific intervals. The study found that CFRP was quite durable material and the change of properties was negligible. However, the adhesive was influenced significantly. The adhesive properties improved at the beginning, but degraded eventually at the end of conditioning.

9344 | Increased the ultimate flexural capacity of concrete beam by using AFRP (11. FRP reinforced concrete structures)

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Using of FRP plate for strengthening and increasing flexural capacity of concrete beams have been extensively common. The possibility of plate debonding should check for compute the ultimate capacity and delaying the premature failure of these beams. In this study, Aramid fiber reinforced concrete beams in the usual way and four-point bending tests were performed on the samples .The result of tests showed premature failure phenomenon. On the based on the results, theoretical method was presented which reinforced cover on these beams caused delay premature failure phenomenon.

KEYWORDS: AFRP, reinforced beam, premature failure phenomenon

9346 | Premature fracture of concrete beam strengthening by FRP plates, Introduction of variety of models, and comparison of presented theoretical model with experimental results (11. FRP reinforced concrete structures)

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Externally bonded of FRP laminates for strengthening and increasing flexural capacity of concrete beams have been extensively common. The possibility of laminate debonding should investigate for determining the ultimate capacity of these beams. This article includes two parts. In the first part the phenomenon of premature fractures and details of debonding of laminate/concrete are explained and relevant theoretical model are introduced. In the second part, with using empirical results that obtained by researchers, accuracy of presented model by researcher that is able to predict of failure load at the time of premature fracture is investigated.
Keywords: fracture of beams, flexural capacity, advanced composites, debonding, studies and empirical

9469 | Analysis of 2D-Solids with Internal Friction and Tensile Resistant Membranes (11. FRP reinforced concrete structures)

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In the last few years the technical use of composites is attracting an increasing attention in the field of Civil Engineering.
Their application concerns both new structures, generally made up of pultruded shapes, and the strengthening of existing constructions because of change of use, inadequate initial design, deterioration or new earthquake resistance requirements.
Although they are more expensive than traditional materials such as concrete and steel, they offer a number of advantages. Their lightweight means they are cheaper and easier to transport and install; inherent corrosion resistance of composites not only increases their durability but it reduces the need for maintenance throughout the structure's life.
Actually a big spread out of researches linked to the adoption of composite materials, and, in particular, of Fibre Reinforced Polymers (FRPs), can be recorded in the field of rehabilitation and strengthening of the monumental heritage, usually made of masonry material: typical applications are structural adaptation or improvement of historical constructions for seismic purposes, structural reinforcement of masonry constructions, either for repairing already formed cracks or for preventing the formation of unilateral hinges that can result in the activation of collapse mechanisms in masonry patterns such as arches and vaults, or for reducing the stress in masonry panels, thus, increasing the loading capacity of the wall.
In the paper a theoretical procedure about the deformation process –up to the collapse condition- of a masonry panel subjected to an increasing quasi-static force is developed and the relevant results are compared with those deriving by the experimental tests on some masonry panels built at the Laboratory of Materials and Structural Testing of the University of Naples "Federico II". Moreover in order to evaluate the benefits induced by the application of carbon fibre strips, other experimental are developed after enwrapping the lower part of the masonry structure with mono-directional FRP strips.

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5484 | Dynamic stress intensity factors for several moving cracks in a non-homogeneous orthotropic plane (12. Functionally graded materials and structures)

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This paper provides a theoretical investigation of the behavior of multiple moving cracks in a non-homogeneous orthotropic plane under anti-plane deformation. The distributed dislocation technique is used to carry out stress analysis in a non-homogeneous plane containing moving cracks under anti-plane loading. The Galilean transformation is employed to express the wave equations in terms of coordinates that are attached to the moving crack. Finally, the solution of a moving screw dislocation is obtained in a non-homogeneous plane by using the Fourier transform. The stress components reveal the familiar Cauchy singularity at the location of dislocation. The solution is employed to derive integral equations for a plane weakened by several moving cracks. Numerical calculations are performed to show the effects of material properties and the speed of cracks propagating on the stress intensity factors of crack tips.

6734 | Uncertainty quantification on free vibration of functionally graded shells (12. Functionally graded materials and

structures)

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This paper presents uncertainty quantification approach for free vibration analysis of functionally graded shells. Stochastic natural frequencies are obtained by utilizing metamodels. Global sensitivity analysis is carried out to address the influence of input random parameters on output natural frequencies. Different types of input variables are varied to validate the proposed algorithm. The aim of present approach is to reduce the sampling effort and computational cost involved. The stochastic finite element approach is utilized and statistical analysis is carried out to compare the results obtained by present surrogate model and full scale Monte Carlo Simulation. The quantified uncertainties in random variation of natural frequencies of functionally graded shells obtained are the first known results for the type of analyses carried out here.

Keywords: uncertainty quantification; functionally graded materials; natural frequency; metamodel; sensitivity analysis

6827 | MODULUS OF ELASTICITY CHANGE ON THE CONCRETE FILLED STEEL TUBE COMPOSITES (12. Functionally graded materials and structures)

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The modulus of elasticity value is a unique deformation behaviour under external loads. Material properties can be predicted according to angle and proportional limit point of elastic range. Stress and strain values are well known parameters for common materials such as concrete and steel in reinforced concrete structures. However, composite materials such as concrete filled steel tubes have different properties than concrete and steel. In this paper, effect of cross sectional shape, steel thickness and concrete compressive strength changes are studied on the concrete filled steel tubes considering the modulus of elasticity values. Circular, square, rectangular and hexagonal sections are selected with 1.5, 3.0, 5.0, 8.0 mm steel wall thickness and 3 different concrete compressive strength values. Totally 64 specimens are performed. Modulus of elasticity values of all specimens up to elastic range are compared and presented within the results of considered variables.

6915 | Free vibration of thick functionally graded beams rested on Winkler-Pasternak elastic foundation with elastically restrained edge (12. Functionally graded materials and structures)

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In this study, an improved third order shear deformation theory is employed to investigate the free vibration of thick functionally graded beams resting on the Winkler-Pasternak elastic foundation with edges elastically restrained against translation and rotation. Governing equations and boundary conditions are derived from the Hamilton's principle. The material properties of the FGMs beam vary continuously in the thickness direction according to the power law form. The linear combination of Fourier series and auxiliary Legendre polynomial function is used to obtain the natural frequencies and the corresponding mode shapes of the FGMs beams with elastically restrained edges. Comparison between the obtained results to those available in literature confirms an excellent accuracy of the present approach. The effects of parameters, such as the material properties, power-law index, span-to-height ratio and different combinations of constraints at edges on the frequency and mode shape are also investigated. Numerical results show that the mentioned effects play very important role on the frequency and mode shape. The new results can be used as benchmark solutions for future researches.

7050 | Mechanical properties of an FGM consisting of a high-alloyed CrMnNi-steel and varying Mg-PSZ content processed by asymmetric Spark Plasma Sintering (12. Functionally graded materials and structures)

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A functionally graded material (FGM) consisting of a TRIP steel matrix (TRansformation Induced Plasticity) and a varying Mg-PSZ particle reinforcement (MgO Partially Stabilized Zirconia) was sintered by Spark Plasma Sintering (SPS). The used steel is high-alloyed (16 wt.% Cr, 7 wt.% Mn, 3 wt.% Ni) and the Mg-PSZ content increases along the sample height from 0 vol.% to 100 vol.%. To densify both, the steel and the Mg-PSZ, in one sintering step is challenging due to their different melting temperatures and therefore different optimal sintering temperatures. By varying the number of graphite foil layers which are used in SPS to protect the graphite punches, it was possible to create a temperature gradient within the matrix along the sample height. Depending on the temperature gradient, local melting of the steel phase occurred. Bending tests were carried out with the Mg-PSZ layer on tensile stresses on the one hand and the steel layer on tensile stresses on the other hand. The bending strength of the FGM varied with the temperature gradient during SPS. The layers of the FGMs were investigated in matters of density and microstructure. Due to the temperature gradient, the relative density was only slightly improved and the porosity within the layers of the FGM increased with increasing ceramic content.

7313 | Influence of interface strength gradation on mechanical properties of woven glass fabric/polypropylene laminates (12. Functionally graded materials and structures)

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Recently, thermoplastic polymer composites have gained a growing interest owing to many advantages with respect to thermosets based ones as shorter processing times, improved fracture toughness and potential recyclability. However, their potentialities are still restricted by some drawbacks mainly related to the high cost of matrices and the relatively poor know-how in terms of design and manufacturing. For example, a huge amount of studies are

available about approaches to improve the damage tolerance of composite laminates based on thermosetting matrices but, at present, a relevant lack of know-how on the same topic for thermoplastic systems limits their perspectives especially for structural applications. Aside from conventional hybridization approaches, a new class of hybrid laminates were realized by grading the interlaminar polymer/fibres interface strength (IGIS). Composites were prepared by alternating glass woven fabrics with polypropylene (PP) layers, either neat and compatibilized for glass fibres by using a maleic anhydride grafted PP. Different sequences were investigated and compared by flexural and low-velocity impact tests with not graded laminates (i.e. containing only neat or compatibilized PP layers as matrix). Results demonstrated that the IGIS design allows to prepare composites with high flexural properties coupled with high impact resistance at the same time, without affecting the reinforcement configuration nor using fibre hybridization methods.

7583 | Study of a porous ceramic material impregnated with titania and silver for water purification (12. Functionally graded materials and structures)

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Although, water is available in the world, it is not always located where it is needed and may also be contaminated. In some developed countries, the infrastructure and water distribution are not good and some problems such as hazardous contamination from human origin can occur. The adequate access to clean water is responsible for health problems. Titanium oxide and silver show bactericidal characteristics and have been used to clean contaminated foods and water.

The present work investigated the photocatalytical and bactericidal effect of titania and silver deposited in a porous ceramic substrate using Escherichia Coli (E.coli) as reference pathogen. The results show that the presence of both material causes a higher bactericidal efficiency in the contemned water.

7584 | Optimization of Functionally graded plate wings against divergence (12. Functionally graded materials and structures)

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Optimization of Functionally Graded Plate Wings against Divergence
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ABSTRACT
This paper presents a model for aeroelastic optimization of composite plate wings using material grading concept. Both continuous and piecewise grading patterns have been implemented along the wing span as well as the airfoil thickness directions. The objective function is measured by maximization of the critical flight speed at which wing divergence occurs, while maintaining the total structural mass at a constant value equals to that of a known baseline design. The major aim of the study is to tailor the fiber volume fraction distribution in order to improve the wing aeroelastic performance and broaden its stability boundary without mass penalty. Various power-law mathematical expressions describing material grading have been utilized where the power exponent was taken as a main design variable. The preassigned aerodynamic parameters that are not subject to change during the optimization process are chosen to be the wing projected area, aspect ratio and chord taper ratio. The optimization problem has been formulated as a nonlinear mathematical programming problem solved by invoking the MATLab optimization Toolbox routines, which implements the sequential quadratic programming method. The mathematical model employs the classical plate and beam theories for determining elastic deformation of the wing structure and the modified strip theory for calculating the aerodynamic loads that arise from these deformations. This representation, together with classical lamination theory, allows the solution of the wing divergence problem using the exact governing differential equation and the transfer matrix method. Adequate scaling and normalization of the various parameters and variables are given in order to make the model valid for a variety of wing configurations and types of material of construction. A case study including the optimization of a composite, cross-ply, plate wing made of carbon-AS4/epoxy-3501-6 has been presented, where trends for good designs having expanded aeroelastic stability boundary under the imposed mass constraint were discussed. Results have shown that the approach implemented in this work can be efficient in producing improved designs in a reasonable computer time. Actually, the proposed model has succeeded in arriving at the optimum solutions showing significant improvements in the needed design goal as compared with a reference or baseline design.

7607 | The Combined Model of Heat Conduction in a Skeletonal Micro-heterogeneous Hollow Cylinder (12. Functionally graded materials and structures)

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This contribution deals with a stationary heat conduction problem in an infinite hollow cylinder with a non-periodic deterministic material micro-structure. The main aim is to formulate and apply the new mathematical model of the heat conduction in the skeletonal composites made of thin walls with constant width along radial axis. The regions situated between the walls are occupied by a homogeneous matrix material. It is assumed that the cross-section of the conductor represents a certain plane micro-heterogeneous structure which is, for a fixed radius, periodic along angular axis but have slowly varying apparent properties in the radial direction. Therefore, we deal here with a special case of functionally graded materials.

The fundamental heat transfer equations are based on the well-known Fourier theory and the formulation of approximate mathematical model of these composites will be based on the tolerance averaging technique, Woźniak et al. (2008, 2010) and its alteration. The fundamental concept of the modelling technique is the averaging operation and micro-macro decomposition of the temperature field. Having now the solution to the asymptotic case (smooth passage with the microstructure size in tolerance model) and using it in micro-macro decomposition of the new temperature field, we obtain a new model, which gives us more realistic temperature propagation in a microstructured media - in opposition to the tolerance model.

For the sake of simplicity, the analysis will be restricted to the problem with no external heat sources. Examples of the obtained results will be given during the presentation.

7692 | Influence of Prebuckling Deformation in Buckling Analysis of Functionally Graded Plates and Shells. (12. Functionally graded materials and structures)

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In Functionally Graded Material (FGM) plates and shells, as soon as the in-plane load is applied, it undergoes lateral displacement even though the load applied is much lower than the buckling load. This is termed as prebuckling deformation and the magnitude depends on the bending-stretching coupling in the FGM. The buckling analysis of FGM plates and shells with the prebuckling deformation included become analogous to that of plate and shells with geometric imperfection, which is a nonlinear problem. Hence the question here is buckling of plates and shells should be treated as linear or non linear. A.W.Leissa et al. [1] investigated the transverse deflection of unsymmetrical laminated plates subjected to in plane loads and concluded that the behavior is similar to isotropic plates. Metin [2] States that Clamped boundary condition are capable of supplying the necessary bending moments and twisting moments to keep the plate flat. Very few literatures are available for the influence of pre buckling deformation.
The package COMSAP was developed using Semiloof shell element by the authors[3] for linear analysis is extended to non linear analysis. The nonlinear finite element formulation is based on Green strains and Piola-Kirchhoff stresses and power law for material modeling. To investigate the influence of prebuckling, the plates and shells are subjected to inplane loads and treating them as (a)Linear buckling without curvature,(b)Linear buckling with curvature,(c) Extended Linear Buckling,(d) Non linear Buckling. The programme is validated by results available in the literature. New results are obtained for square, rectangular plates and cylindrical shells.
An FGM square plate is analyzed with three simply supported boundary conditions for various volume fraction indexes (n). The investigation shows that the non linear buckling load is less significant in the case of simply supported boundary conditions and has no effect in clamped clamped boundary conditions.Load versus displacement to thickness (w/h) ratio curve is studied for linear and non linear cases. In Linear analysis the displacement linearly increases and displacement ratio varies from 0.007 to 0.019 and in the non linear analysis the nonlinear displacement ratio varies from 0.0116 to 0.456 for n values 0.5 to 5.Rectangular plate of various aspect ratios 2, 2.5 and 3 are analyzed for simply supported boundary conditions and the results are same as square plate.
The shell is subjected to simply supported boundary conditions and clamped clamped boundary conditions for different volume fraction index (n) and various Lengths to Radius (L/R) ratios. The investigation shows that the non linear buckling load is more significant in both simply supported and clamped clamped boundary conditions. Load versus displacement to thickness (w/h) ratio curve is analyzed for linear and non linear cases. In linear analysis the displacement ratio varies from 0.038 to 0.090 and in non linear analysis the displacement ratio varies from 0.26 to 0.73 for n values 0.5 to 5.The nonlinear buckling load to linear buckling load ratio varies between 0.167 to 0.399 for simply supported boundary conditions and 0.201 to 0.440 for clamped clamped boundary conditions for L/R ratios 0.5 and 5.The nonlinearity of the displacement path is depends on the young's modulus of the constituent material for the variation of volume fraction index (n= 0.5, 0.7, 1, 3, 5)
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7696 | Thermoelastic phenomena in the transversally graded laminates (12. Functionally graded materials and structures)

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In this paper we deal with a problem of thermoelasticity in a two-phase laminate, with non-periodic distribution of the ingredients. The cells with constant thickness l are composed of two sublayers of different materials. The macroscopic properties change continuously in a direction perpendicular to laminas. Therefore, we deal here with laminates with functionally graded properties, [3]. In the analysis of various issues concerning these laminates, the same approaches are often used as for composites with periodic structures. Different modelling methods are presented in the book [3]. Unfortunately, most of the proposed equation models do not take into account the effect of the microstructure size.
In order to obtain the averaged equations, taking into account this effect, the tolerance averaging technique is applied, cf. [6,5,4], to describe various thermomechanical problems in periodic composites. This way of modelling was used in many studies to derive equations for various cases of such structures, cf. [5,4,1]. Recently, it is modified and adapted for problems of composites and structures with functional gradation of properties. Numerous examples of applications of this method can be found in [5,4,1].
Using the tolerance modelling the system of differential equations with slowly-varying coefficients is obtained, instead of highly oscillating, tolerance-periodic and discontinuous coefficients. For this purpose, the concept of a slowly-varying function, a tolerance-periodic function and an averaging operation are used, cf. [5,4,1].
Two basic assumptions are used in the modelling. The first one is the micro-macro decomposition, where it is assumed that the fundamental unknowns (e.g. - the displacement field and the temperature field) are taken as a sum of a averaged part (field) and an oscillating part. Furthermore, it is assumed that the oscillating part can be expressed as a product of the known fluctuation shape function, and the new unknown - the fluctuation amplitude. The new basic unknowns, averaged fields and fluctuation amplitudes, are assumed to be slowly-varying functions of that coordinate which parameterizes the perpendicular direction to the laminas. The second assumption is the tolerance averaging approximation, in which it is assumed that some terms are negligible small.
The main aim of this work is to obtain and apply averaged differential equations of the thermoelasticity problems of considered laminates with transversally graded properties. Substituting the micro-macro decomposition to the main equations of thermoelasticity problems, [1,2], by doing the appropriate averaging and transformations, the final equations of the tolerance model were received, cf. [2].
The tolerance model equations take into account the effect of the microstructure size. Equations of the asymptotic model are obtained by neglecting some of the terms in equations of the tolerance model and describe the thermomechanical problems only on the macro-level.
The equations of the tolerance and the asymptotic models will be applied to analyse some specific cases.

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7723 | The Importance of Sample Preparation of Wood Polymer Composites (WPC) for FTIR Spectroscopy and Thermal Analyses (12. Functionally graded materials and structures)

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The Importance of Sample Preparation of Wood Polymer Composites (WPC) for FTIR Spectroscopy and Thermal Analyses
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Using of wood polymer composites (WPC) is rapidly increasing all around the world. WPC is produced by mixing wood flour -especially obtained from wastes of wood products industry - and polymers such as low density or high density polyethylene. The major advantages of WPC are the high durability of microorganisms which can easily degrade wood and wood based materials and high resistance to water absorbancy. Therefore WPC are used in a large variety of structural and non-structural applications, especially for outdoor using such as decking, railing and fencing. On the other hand recycle and reuse of waste wood products are of both environmental and economical concerns. It seems that WPC market will continue to expand in the near future. The new WPC products are being designed for applications where long-term performance, consistent appearance, and dimensional stability are important. Before improving and submitting to the market a new material, it is very important to know its` physical, mechanical, biological, thermal and chemical characteristics. Even though wood itself can be accepted as a heterogenic material, there are many standards to understand its structure, orientation of cell layers and chemistry. On the other hand, the combination of hydrophilic natured wood and hydrophobic natured plastics leads to completely heterogenic material and has no standard to analyze the chemical structure. Having knowledge of wood polymer composite materials` chemical and thermal behavior has a great importance to improve the material to meet post consumers` requirements and to improve for new products based on them. However, FTIR spectroscopy provides rapid analysis of the complex molecules such as wood and wood polymer composites. IR spectroscopy is a very useful analytical tool to monitor the degradation of wood polymers via biological and UV light. It is an important step to prepare a homogenous specimen for obtaining accurate results in FTIR spectroscopy. On the other hand, it is also very important task to obtain a homogeneous material for the thermal analysis. So it is obvious that obtaining a homogeneous material is the most important task to have an idea of a material concerning with structural and thermal characteristics. Cryogenic grinding, also known as freezer milling, is the best way to grind the material which resistant to brittle fracture, such as thermoplastics. They are difficult to grind to small particle sizes at room temperature because they soften, become sticky and cause to plug up screens. Cryogenic grinding of thermoplastics or the material includes thermoplastics such as WPC is the excellent way to obtain homogeneous specimen to investigate the chemical structure and thermal behavior.

Key words: Wood polymer composite, FTIR spectroscopy, Thermal analyses, cryogenic grinding, homogeneous material

7789 | The effect of step-wise graded density cores on the blast resistance of polymeric foam core sandwich panels. (12. Functionally graded materials and structures)

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Polymeric foam core sandwich panels are of increasing interest in military applications due to their low density, their tailorable mechanical properties and their low radar signature. In the research presented here styrene acrylonitrile (SAN) foam core sandwich panels with glass fibre reinforced polymer (GFRP) face-sheets are subjected to 100 kg TNT equivalent charge sizes at a stand-off distance of 15 m. The aim of these tests was to compare a sandwich panel with a step-wise graded density foam core to one with a single density foam core. The step-wise graded core incorporated a low density foam sheet on the blast side, a medium density core in the centre, and a high density core on the back face. It was found that by grading the core density the panel deflection during blast was reduced, as well as the total through thickness damage observed in the sandwich panel. Each sandwich panel was 30 mm or 40 mm thick, and had 2.4 kg/m^3 face-sheets either side. The panel response was measured using 3D digital image correlation (DIC), which required two high speed cameras in order to track out of plane displacement and surface strain. The pressure loading on the sandwich panels during blast loading was measured using a pressure gauge situated on the front centre of the cubicle to record the reflected over-pressure, and a static pressure gauge was situated in free space away from the test cubicle to validate the reflected pressure recorded. The damage suffered by the sandwich panels during blast loading was found by sectioning and inspecting the panel edges for debonding between the face-sheets and core, and cracking in the foam core. Finite element simulations of the blast tests are currently being performed using dynamic fracture data collected through laboratory experiments, to accurately predict the blast response of graded density sandwich panels including damage patterns observed.

7823 | Creep Relaxation in FGM Rotating Disc with non-Uniform Profiles (12. Functionally graded materials and structures)

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Rotating discs are the vital part of many kinds of machineries. Usually they are operating at relatively high angular velocity and temperature conditions. Accordingly in practice, the creep analysis is an essential necessity in the study of rotating discs. More recently the application of Functionally Graded Materials (FGMs) in construction of rotating discs is the subject of many researches. These newly developed heterogeneous compounds enable the designer to manage the distribution of material properties and benefit their better thermo-mechanical advantages. Apart from the patterns of material distribution, the shape of a disc is another factor which controls the stress field and consequently the deformation and life expectancies. To study the effects of cross sectional profile, three different Aluminum-Silicon Carbide FGM discs with uniform, convergent and divergent cross section profiles are selected for the study.

7952 | Thermal Effect on the Modal Characteristics of FG Anisotropic Plates with Temperature-Dependent Materials (12.

Functionally graded materials and structures)

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Recently a considerable amount of work has been devoted to the investigation of isotropic and sandwich functionally graded material (FGM) structures. However, very few articles have been published with the purpose to analyse the effect of the anisotropy on the modal characteristics of FGM structures. In this respect, the present work provides a contribution aimed to partially fill the gap, coping with the analysis of free vibration of FG anisotropic plates with temperature-dependent materials in thermal environment. In particular, the material properties are assumed to be temperature-dependent by a third order function of the temperature. Moreover, not only the material properties but also the fibre orientation varies smoothly through the plate thickness.
The investigation is carried out by using advanced higher-order Equivalent Single Layer (ESL) plate theories developed within the framework of Carrera's Unified Formulation (CUF). The used theories are generated hierarchically allowing the possibility to choose the desired accuracy and the computational cost. The week-form of the governing equations are derived by using the Principle of the Virtual Displacements (PVD) and are solved by employing the advanced Hierarchical Trigonometric Ritz Formulation (HTRF). Several convergence analyses are performed in order to validate and assess the accuracy of the proposed formulation. Results in terms of natural frequencies are compared with those proposed in literature and/or obtained by using FEM software. The effect of the thermally induced loadings on the modal characteristics of the examined FG anisotropic plates is thoroughly discussed. Modal shifting/modal interchange phenomenon is investigated while evaluating the influence of several parameters. Finally, the effect of the length-to-thickness ratio, material temperature-dependence, FGM power law, volume fraction index and boundary conditions on the natural frequencies is commented.

8096 | Transient analysis of a sandwich composite beam with functionally graded syntactic foam core using a semi-analytical state space method. (12. Functionally graded materials and structures)

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In this paper, we present the three-dimensional transient analysis of a sandwich composite beam with functionally graded syntactic foam core. The semi-analytical method combines the state vector approach in elasticity based on the Eshelby-Stroh formalism, the generalized differential quadrature numerical method, and the Laplace transform with a numerical scheme for the inversion of the transform. This approach efficiently combines the advantages of the state space method for layered and functionally graded structures with the power of the differential quadrature method for different types of boundary conditions and depth-to-length ratios. The state vector approach is used to define the state variables and obtain lower order governing elastodynamic equations in terms of these state variables which include both the stresses and displacements. The thickness direction is analytically solved using the state space approach while the axial direction is numerically treated using a 2-D version of the generalized differential quadrature method. The time domain solultion is solved using Laplace transform and a numerical scheme for the inverse transform.

The face sheets of the sandwich beam are made of graphite-epoxy laminates while the core is a two-phase syntactic foam made of hollow glass inclusions and epoxy resin. Functionally graded syntactic foams (FGSF), can be obtained by either varying microballoon volume fraction or the wall thickness of the balloons in the desired direction. The second approach using a changing inclusion wall-thickness has been shown in literature to be more efficient. The core behaves as an isotropic material whose effective properties are estimated using a self-consistent homogenization scheme for multiphase composites. The properties are assumed to vary through the thickness of the core symmetrically about the mid-plane. The transient analysis is carried out for sandwich beams with simply supported and fixed-free boundary conditions. A parametric study of the response of the sandwich composite beam for dynamic loading conditions has been conducted to investigate the effects of various factors. These include the radius and wall thickness of the inclusions, ratio of face sheet thickness to core thickness, functional gradation of core and lamination scheme used. To demonstrate the accuracy of the analysis, results are compared with those obtained from finite element analysis

8121 | Ti/polymer/Ti sandwich systems for bio-applications (12. Functionally graded materials and structures)

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Most of works on metal/polymer sandwich systems for the automotive industry deal with the combination of steel and polyolefins . For these applications, there is no need to take care about toxicity, a very important aspect for biomedical devices. Sandwich systems, especially three-layered sandwiches are often produced by roll bonding. A two-component epoxy resin normally is used for the polymer-metal bonding.
Titanium/polymer (P)/titanium sandwich systems are developed, focusing on the design of their interface, the control of their mechanical properties and shaping.
The new strategy is to design the P/Ti interfaces free of an epoxy resin currently used as adhesive agent but not biocompatible. Therefore, we aim at creating adhesion between polymer and titanium sheets using polymerization initiator covalent grafting at the Ti surface followed by a cross-linking polymerization. The right combination in thickness of the single layers allows to tailor the mechanical properties such as Young´s Modulus, yield and ultimate strength close to the bone‘s behaviour, following the rule of mixture.
The results of these investigations are presented and discussed.

8122 | A new FSDT for the thermoelastic bending analysis of functionally graded sandwich plates (12. Functionally graded materials and structures)

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This paper presents a thermoelastic bending analysis of functionally graded plates (FGPs) by using a new first shear deformation theory (FSDT). This theory contains only four unknowns, with is even less than the classical FSDT. The nonlinear term of the temperature field is independent of the shape functions of the displacement field. The mechanical properties of functionally graded layers of the plate are assumed to vary in the thickness direction

according to a power law distribution. The governing equations for thermoelastic bending analysis are derived by employing the principle of virtual works. These equations are then solved via Navier-type, closed form solutions. The accuracy of the present theory is ascertained by comparing it with various available solutions in the literature.

8129 | A new trigonometric quasi-3D higher order shear deformation theory for vibrational analysis of functionally graded plates resting on elastic foundations (12. Functionally graded materials and structures)

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This paper presents a free vibration analysis of functionally graded plates (FGPs) resting on elastic foundation by using a new trigonometric higher-order shear deformation theory. The highlight of this theory is that, in addition to including the thickness stretching effect (Ɛzz ≠ 0), the displacement field is modeled with only 4 unknowns, which is even less than the first-order shear deformation theory (FSDT). The elastic foundation follows the Pasternak's model. The mechanical properties of the plate are assumed to vary in the thickness direction according to a power law distribution. The governing equations are obtained through the Hamilton's principle. These equations are then solved via Navier-type, closed form solutions. The fundamental frequencies are found by solving the eigenvalue problem. The accuracy of the current solutions can be visualized by comparing it with the 3D and other closed form solutions available in the literature.

8130 | Thermoelastic analysis of isotropic and sandwich plates by using a new trigonometric quasi-3D HSDT with 4 unknowns (12. Functionally graded materials and structures)

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This paper presents a thermoelastic bending analysis of functionally graded sandwich plates and one-layered isotropic plates by using a new trigonometric quasi-3D higher order shear deformation theory (HSDT). The highlight of this theory is that, in addition to including the thickness stretching effect (Ɛzz ≠ 0), the displacement field is modeled with only 4 unknowns, which is even less than the first-order shear deformation theory (FSDT). The plate considered is subjected to a temperature field which varies linearly through the thickness. The mechanical properties of functionally graded layers of the sandwich plate are assumed to vary in the thickness direction according to a power law distribution. The governing equations for the thermoelastic bending analysis are obtained through the principle of virtual work and solved via Navier-type solution. The degree of precision of the current solutions can be noticed by comparing it with the quesi-3D and other closed form solutions available in the literature.

8153 | A new First Order Shear Deformation Theory with Stretching for Functional Graded Materials (12. Functionally graded materials and structures)

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The optimization of a new first order shear deformation theory (FSDT) for the bending analysis of functionally graded shells is presented in this paper. The FSDT includes the stretching effect and their shear strain shape functions contain the parameters "n" that need to be selected by providing displacements and stresses which produce close results to 3D elasticity solutions. The governing equations and boundary conditions are derived by employing the principle of virtual work. Navier-type closed-form solution is obtained for functionally graded plates and shells subjected to transverse load for simply supported boundary conditions. Numerical results of the optimized FSDT are compared with other FSDT for functionally graded plates, referential solutions, and 3D solutions. The key conclusions that emerge from the present numerical results suggest that: (a) the optimization procedure is beneficial in terms of accuracy; (b) it is possible to gain accuracy keeping the unknown's constant by performing the optimization procedure shown in this paper.

8154 | A generalized quasi-3D theory for vibration of functionally graded beams (12. Functionally graded materials and structures)

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This paper presents the static and dynamic behavior of functionality graded (GF) beams using a quasi-3D theory, which includes both the shearing deformation and thickness effects of stretching. The governing equations are obtained through the Hamilton's principle. Navier solutions are developed to determine the displacements and stresses of beams for various power-law index, thickness of the skin-core-skin ratios. The numerical results are compared to those predicted by other theories to show the effects of shear deformation and the thickness of the movement and stretching stresses. Numerical examples are carried out to investigate the effect of thickness that extends in the natural frequencies.

8546 | LAYERWISE APPROACH TO ANALYSIS OF A FUNCTIONALLY GRADED CYLINDRICAL SHELL VIBRATION AND DYNAMIC BEHAVIOUR (12. Functionally graded materials and structures)

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A layer-wise finite element approach is developed to the analysis of thick functionally graded material (FGM) cylindrical shell with finite length under dynamic load. For this purpose, FGM cylinder is divided into many sub-layers and then the general layer-wise laminate theory is formulated by introducing piecewise continuous approximations through the thickness. The radial displacement field is approximated both linearly and in quadratic form, through each "mathematical" layer. The FGM shell properties are controlled by volume fraction as an exponential function of radius. The virtual work statement yields the 3-D governing equations which are then reduced to 2-D differential equations and the resulting equations are solved by finite element in the axial direction. Results are obtained in terms of the time history of the displacement and stress components with different exponents of functionally graded

material. The results for static loading and the first natural frequencies are also compared with the solutions of previous problems in the literature. In addition, the natural frequency and mean velocity of the radial stress wave propagation for different exponents of functionally graded material (FGM) are studied and compared to similar ones obtained for FGM cylindrical shell of infinite length.

8556 | Analysis of forced vibrations of annular plates made of functionally graded material (12. Functionally graded materials and structures)

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The work deals with the problem of dynamics behavior of bodies made of smart materials in which a characteristic, deterministic and microstructural construction has an influence on the macroscopic properties of the entire system. In particular, the subject of the analysis is the annular plate made of the material with functionally graded properties (FGM) [1]. On the micro-structural level the structure is constructed from two materials. In the circular direction the structure is periodic. In the radial direction the averaged properties of the structure are functionally variable. There is examined the issue of forced vibration. The starting point of the discussion is the equation of motion of a thin plate based on Kirchhoff theory.
On a microstructure level, mentioned above equation of motion includes coefficients which are described by discontinuous functions. This is caused by discrete variable nature of the analyzed structure. In order to find satisfactory solutions of the problem the tolerance averaging technique (TAT) is applied [2]. TAT has been described in many works, for example in the monographs [3][4]. The most important assumption used in the present work is the decomposition of the displacement field which define the division on average part w0 and oscillating part. The oscillating part is the product of the amplitude of oscillations VA and a-priori known shape function hA.
In conclusion, as a result of modeling procedure, partial differential equations for the unknown, slowly varying functions w0 and VA were obtained. This system contains slowly varying coefficients and can be solved by well known numerical methods.
Moreover, the paper shows selected numerical solutions obtained from the averaged model. The obtained results were analyzed on several examples for some boundary conditions and different types of vibration extortion.

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8557 | DYNAMIC MODELLING OF RECTANGULAR THIN PLATES WITH DENSE SYSTEM OF RIBS IN TWO DIRECTIONS (12. Functionally graded materials and structures)

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DYNAMIC MODELLING OF RECTANGULAR THIN PLATES WITH DENSE SYSTEM OF RIBS IN TWO DIRECTIONS

The aim of this contribution is to propose and apply the mathematical model of composite plate made of two families of thin beams which axes intersect at a right angle. It is assumed that the width of the beams can vary slowly in the midplane of the plate. Thus, we deal with composite plate that has space-varying microstructure. The generalized period of heterogeneity is assumed to be sufficiently small comparing to the measure of the midplane of the plate. At the same time, it is assumed that the microstructure length parameter is comparable to the thickness of the plate. Hence, there are proposed simplified mathematical models described by averaged equations with functional but smooth and slowly varying coefficients. The formulation of the macroscopic mathematical model for the analysis of dynamic behavior of these plates is based on the tolerance averaging technique [3]. The applications of this technique for the modeling of various dynamic problems of elastic micro-heterogeneous composites are given in papers [1], [2].

The starting point of this contribution is the direct description of the structure in the framework of the well known theory of thin plates. The modeling technique will be based on the tolerance averaging approximation and on the restriction of the displacement field. The governing equations derived from stationary action principle of the averaged Lagrangian. The obtained equations have the smooth and functional coefficients in contrast to equations in direct description which have the discontinuous and highly oscillating coefficients.

The work shows selected numerical solutions obtained from the model. The obtained results were analyzed in several examples, which are compared with the numerical results obtained from Abaqus.

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8609 | Microstructure and Nano-indentation Research of C/C composites Modified with Gradient-distributed SiC/TaC Multi-interlayer (12. Functionally graded materials and structures)

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SiC/TaC ceramic multi-interlayer were introduced into C/C composites by using chemical vapor infiltration (CVI) and distributed gradient by controlling the flow direction of reaction gas in the porous C/C preforms. The results showed that, along the thickness direction of C/C composites, the content of SiC/TaC ceramic phase and the thickness of the multi-interlayer are decreased, while the structure of the ceramic phase also changes from multi-interlayer (Region I) to composite interlayer (Region II) and then single interlayer (Region III). In Region I, the SiC/TaC multi-interlayer is composed of five interlayers: the first gray SiC layer, the second white TaC layer, the third TaC composite interlayer embedded with gray SiC particles, the forth SiC composite interlayer embedded with the white fine mosaic-like TaC phase and the fifth white TaC layer. In Region II, the ceramic phase is no longer coated on the surface of carbon fiber in the form of an interlayer, but of a cauliflower-like cluster. At last, the nano-hardness and elastic modulus of the SiC/TaC ceramic multi-interlayer in Region I were also discussed.

8624 | BUCKLING AND VIBRATION ANALYSIS OF FUNCTIONALLY GRADED SANDWICH BEAMS USING A ZEROTH-ORDER SHEAR DEFORMATION BEAM THEORY (12. Functionally graded materials and structures)

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The authors propose a zeroth-order shear deformation theory for buckling and vibration analysis of functionally graded sandwich beams. The present theory accounts a hyperbolic distribution of transverse shear stress which satisfies traction-free boundary conditions. Equations of motion are derived from Lagrange's equations. Analytical solutions are presented for functionally graded sandwich beams with various boundary conditions. Numerical results are compared with earlier works and investigated effects of the material parameter, thickness ratio of layers, span-to-depth ratio and boundary conditions on the critical buckling loads and natural frequencies.

8690 | Nonlocal effects in viscoelastic functionally graded Bernoulli-Euler nanobeams (12. Functionally graded materials and structures)

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Analysis of size-effects in nanostructures, such as carbon nanotubes, is conveniently carried out by making recourse to theoretical and computational methods of continuum mechanics. An open point in this approach consists in defining constitutive laws leading to reliable results. An effective choice was performed by J. Peddieson et al. [1] who formulated the elastic equilibrium problem of Bernoulli-Euler nanobeams with the nonlocal constitutive behavior proposed by A.C. Eringen [2]. A variational treatment for bending, buckling and vibration of nonlocal nanobeams was contributed by J.N. Reddy [3]. An innovative numerical solution procedure, based on a meshless method, was illustrated by A.J.M. Ferreira [4]. A critical review on the modeling of carbon nanotubes can be found in the recent paper by R. Rafiee [5]. Numerous investigations were done also to analyze composite nonlocal nanobeams (see e.g. [6]), due to the prominent applicative potentialities of such structures in industry. In the present treatment, the equilibrium problem of Bernoulli-Euler viscoelastic damped nanobeams is investigated. Nonlocal composite materials characterized by a Kelvin-Voigt viscoelastic model are considered. The mathematical formulation is given in terms of three constitutive parameters: Young modulus, a length scale parameter and a viscous damping coefficient. Closed-form expressions of transverse deflection and bending moment solutions are established by resorting to the technique of Laplace transform. As a new result, it is shown that the nonlocality effect can be evaluated in Laplace domain by prescribing, on a corresponding local nanobeam, a bending curvature distortion linearly depending on the transform of transverse loading distribution. Exact solutions in the time domain are evaluated by inverting the transform. Engineering applications are illustrated and new benchmarks for numerical analyses are detected.

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8741 | Functionally graded oxide glasses with nanostructural conductive surface layers (12. Functionally graded materials and structures)

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Oxide glasses, in general, are ionic conductors, however their electronic component of conductivity is very low. In order to increase the electronic conductivity it is necessary to perform a reduction process in low oxygen partial pressure atmosphere at high temperature (above 300oC). This procedure causes the reduction of metal ions present in the glass structure and the formation of metalgrains both in an amorphous glass matrix and on the glass surface. If a certain critical grain concentration is achieved, the electron tunneling between the grains becomes possible. Further reduction leads to the connecting of metal grains and to the formation of continuous, metallic layer on the surface of the glass. Thus an increase in the surface electrical conductivity, even of several orders of magnitude, is observed [1].
If the reduction process is repeated for several times in different conditions (time, temperature), it is possible to gradually form some following surface layers and, in consequence, to fabricate a functionally graded sample with various nanostructural conductive surface layers. This kind of material will present some brand new properties for various applications, for example in optoelectronic or thermoelectric devices.

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8745 | A nonlocal higher-order beam theory with application to bending, buckling, and vibration of functionally graded nanobeams (12. Functionally graded materials and structures)

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There has been increased interest in recent years in developing structural theories that have the ability to capture material length scale effects. The non-local theory assumes that the stress at a point is a function of strains at all points, at least in some neighborhood of the point, in the continuum. These theories contain information about the forces between atoms, and the internal length scale is introduced into the constitutive equations as a material parameter. In this proposal, static, bending and buckling of a functionally graded (FG) nanobeam are examined based on the nonlocal higher-order beam theory. This Eringen's non-classical model incorporates the length scale parameter which can capture the small scale effect. The material properties of FG nanobeams are assumed to vary in the thickness direction and are estimated through the Mori–Tanaka homogenization technique and classical rule of mixture. The governing equations and the related boundary conditions are derived using Hamilton's principle. Finite element model and Navier-type solutions are developed to determine the displacement, stresses and natural frequencies as well as critical buckling loads of FG nanobeams with various boundary conditions. Numerical results are presented to investigate the influences the material length scale parameter, different material compositions, skin-core-skin thickness ratios and shear deformation on the bending, vibration and buckling behaviour of FG nanobeams. Some of the present results are compared with the previously published results to validate the present formulation. The results reveals that the inclusion of the size effects results in an increase in the beam stiffness, and consequently, leads to a reduction of deflections and stresses and an increase in natural frequencies and critical buckling loads. Such effects are more pronounced when the beam depth was small, but they become negligible with the increase of the beam depth.

8867 | An Exact Solution for transient Three Dimensional Thermo-elasticity of Functionally Graded Circular Plates due to Axisymmetric Loads (12. Functionally graded materials and structures)

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In this paper, we focused on transient response of functionally graded materials under simultaneous thermal and mechanical loads. The approach towards this purpose is generating exact solution for Navier equation of transient thermo-elastic problem of three dimensional form. To this end a circular plate made of functionally graded material is considered. The thermal and mechanical loads on upper and lower surfaces are axisymmetric and the most general forms of the boundary conditions on the lateral surface of the plate are considered, where no limiting assumption is used. The material properties except Poisson's ratio are assumed to exponentially vary along the thickness direction. for the first time a full analytical method is developed, and an analytical solution for Navier equations is presented. The result therefor consists of displacement and stress fields.

8908 | Optimal Vibration control of FGM plate using piezoelectric patches (12. Functionally graded materials and structures)

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The aim of this work is to study the active vibration control of functionally plate graded (FGM) with piezoelectric actuators and sensors. In this regard, a governing equation of motion based on the classical plate theory is adopted and extended to the case of a simply supported FGM plate to obtain a space state equation, the location of piezoelectric sensors and actuators are found by using optimization approche. The material proprieties of FG plate are assumed to be graded along the thickness direction. In order to control the amplitude vibration of the plate an LQR and LQG optimal controllers has been designed and developed. The simulation studies are carried out using MATLAB and ansys.

8953 | Static analysis of porous functionally graded beams with elastically restrained ends and foundation using differential quadrature method (12. Functionally graded materials and structures)

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Static analysis of functionally graded (FG) beams with elastically restrained ends and resting on two-parameter elastic foundation under various boundary conditions is studied based on the third-order shear deformation beam theory formulation. The material properties vary continuously through the thickness direction according to a power-law distribution in terms of the volume fraction of the material constituents. Due to the possibility of the existence of imperfection inside functionally graded materials during the fabrication process, it is necessary to consider static analysis of beams having porosities in this investigation. Based on the distribution of porosities within the FG beam cross section, two different models are used to describe and approximate the material properties of FG beams with porosity phases. In order to discretize the governing equations, the differential quadrature method (DQM) in conjunction with the Hamilton's principle is used. The convergence of the method is demonstrated, and in order to validate the results, comparisons are made with the solutions for the isotropic and FG beams. By examining the results of the FG beam for various geometrical and material parameters with the inclusion of the supporting elastic foundation, the influence of these parameters, and in particular those due to functionally graded material parameters, on the normal and shear stresses distribution through the thickness direction of FG beam are studied. Also the effects of these parameters on the lateral and axial displacements are demonstrated.

8961 | Experimental investigation of slag concrete-filled steel tubular columns axially loaded (12. Functionally graded materials and structures)

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In this paper we present the axial bearing capacity of hollow rectangular section columns filled with a sand concrete. A series of tests were conducted to study the behaviour of short composite columns under axial compressive load, the cross section is of dimensions: 100x70x2 mm. A total of 24 columns were tested, as following : 8 filled with an ordinary concrete , 8 filled with a natural sand concrete was substituted completely by a crystallized slag sand concrete , and eight others have been filled with a slag sand concrete where the natural sand was partially replaced by crystallized slag sand. The main objectives of these tests were to clarify the steel specimens performance filled with sand concrete compared to those filled with ordinary concrete. The main parameters studied were: the height of the specimen (200-300-400-500) mm, and type of filling concrete. From the test results, it is confirmed that the length of the tubes has a considerable effect on the bearing capacity and the failure mode. In all tested short tubes , the failure occurred by the buckling outwards of greater outer side , followed by the smallest due to the outward thrust of the concrete , it was observed that the sand concrete improves the bearing capacity and the failure mode of composite columns.

8975 | 2. Design and Characterization of Different Structures of WC-Co FGM Fabricated Using Hot Isostatic Pressing (HIP) Technique (12. Functionally graded materials and structures)

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Abstract
Among the frequent trails to improve the mechanical properties of hardmetal, this study comes to investigate the effect of new modifications on the gradient stability and hence the mechanical properties of WC-Co functionally graded composites. Constitutive process was followed to build graded layers of WC-Co precursors with cobalt content graded from 5 wt % in the top layer to 15 wt % in the extreme layer. Moreover, Graphene additives were added in different ratios only in the middle layer of the structures to prevent the cobalt migration and gradient loses. Other parameter such as particles size, layers thickness, and sintering temperature were also changed to investigate their effect in the final gradient. Finally, the different parameters were optimized to fabricate functionally graded tungsten-carbide cobalt specimens of 2-3 mm thickness maintained the significant hardness of tungsten carbide and the moderate fracture toughness of the composite materials. Impact test, microhardness and nanoindentation test were subjected to find out the effect of the several parameters in the final mechanical properties. On other hand, EDX and SEM analysis were carried out to examine the gradient stability.

Keywords: Functionally graded material, Graphene, Hot isostatic pressing, Tungsten carbide-Cobalt, Ceramic composites

8988 | Flexural behavior of functionally graded composite beam composed of high-volume and high-strength micro-steel fiber reinforced concrete (12. Functionally graded materials and structures)

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The failure process of concrete structure is the emergence and propagation of cracks in concrete. So, from the crack-control viewpoint of delaying and preventing the emergence and development of cracks in concrete, the cement composite reinforced with high-strength micro-steel fiber was developed based on the principle of fracture mechanics. According to the design principle of functionally graded material, a functionally graded composite beam was obtained by employing the developed material in the tensile stress area of concrete structures, of which the flexural behavior was also explored. The study on the cement composite reinforced with high-strength micro-steel fiber shows that, comparing with the reference ordinary concrete, when the volume ratio of micro-steel fiber mixed in the cement composite reaches 6%, the cube compressive strength of the material was improved by 33.3%, flexural-tensile strength by 114.6%, elastic modulus by 11.9% and equivalent bending strength by 293%, indicating that the material is characterized with crack resistance and toughness enhancement. The experimental results of the functionally graded composite beam composed of the cement composite with the fiber volume ratio of 6% by 1/3 of the beam height show that, comparing with the reference ordinary concrete beam, the cracking load of the functionally graded composite beam was improved by 107.1%, yield load by 44.9% and ultimate load by 42%; the propagation of cracks in the beam was slower, and the stage of in which all the cracks emerge was pushed later; moreover, the stiffness of the beam was considerably improved, and its failure exhibited a ductile failure mode. The paper has also proposed the theoretical formula for the cracking load and ultimate load of the composite beam according to the results from the material and structural experiments, which is consistent with the experimental results.

Key words：high-strength micro-steel fiber；crack control；equivalent bending strength； functionally graded composite beam

9033 | Levy-type solution for vibration and buckling analysis of functionally graded sandwich plates based on quasi-3D theory (12. Functionally graded materials and structures)

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In recent years, there is a rapid expansion in the application of sandwich structures in aerospace vehicles, automotive and civil engineering due to their superior properties in bending rigidity, specific weight and strength. However, stress concentrations which often lead to delamination can happen due to the abrupt change in the material properties from one sheet to another. One of solutions to this problem is the introduction of the concept of functionally graded materials (FGMs) sandwich structures. Owning to the gradual transformation in the properties of FGMs, the stress concentration which is found in laminated sandwich structures is eliminated in FG sandwich structures. To broaden the applications of such structures, more accurate theories are demanded to predict their vibration and buckling responses. Quasi-3D theories, in which both shear deformation and thickness stretching effects are included, have been used to study the behaviours of composite structures including sandwich FG plates. However, as far as authors are aware, there is no work available using the quasi-3D theories accompany with Levy-type solution to investigate vibration and buckling behaviours of FG sandwich plates in various boundary conditions. In this paper, Levy-type solution for vibration and buckling analysis of functionally graded sandwich plates based on quasi-3D theory is presented to achieve closed-form solution for free vibration and buckling analysis of FG sandwich plates. Governing equations are obtained from the principle of minimum total potential energy. Numerical examples are carried out to investigate the effects of boundary condition, power law of materials, skins to skins thickness ratio on the natural frequency and critical buckling load of FG sandwich plates.

9052 | Properties of NBR Composite Material by Reinforced with Aramid Fibers (12. Functionally graded materials and structures)

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The meta-aramid fiber as the material replacing asbestos and the method of interfacial polymerization are been used to complete the aramid's surface modification. Combining with NBR, the composite material reinforced with aramid fiber have been synthesized. The structure and properties of aramid fibers before and after modification are characterized by SEM, FTIR, DSC and POM. It is novel that the morphology of modified aramid fibers is rigid-rod and the fiber has liquid crystalline properties.

9096 | Characteristics of thin films prepared from SEBS/PP/WAX composites as polyelectrolyte membranes for fuel cell applications (12. Functionally graded materials and structures)

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Polyelectrolyte membranes are critical components of fuel cells. Their properties strongly affect the performance of the cells. An ideal fuel-cell membrane should exhibit properties such as good mechanical and chemical durability, high proton conductivity at low temperatures, low fuel permeability from anode side to cathode side during operation and low cost [1]. Unfortunately, none of the membranes available at present fulfill all of these characteristics. Nonetheless, several of the commercially available membranes satisfy most of the industry requirements for fuel cells. Among them, the Nafion® is well recognized as an industrial standard membrane, and significant efforts have targeted the development of its cost-effective counterparts [2]. Polystyrene-block-poly(ethylene-ranbutylene)- block-polystyrene (SEBS), a three-block copolymer, is a potentially cheaper alternative to Nafion® owing to its abundance, low cost and its ability to behave as an elastomer and a thermoplastic simultaneously, which facilitates processing [3]. Although SEBS allows high proton conduction via the sulfonation of styrene units efficiently, difficulties in film casting of pure SEBS before sulfonation and the high swelling of sulfonated SEBS in the presence of water hinders the efforts to use it as a fuel-cell membrane [4,5]. Nonetheless, several studies observed low swelling and good mechanical properties by blending SEBS with hydrophobic polymers such as polyvinylidene fluoride (PVDF) or high-density polyethylene [6,7]. However, these studies failed to provide evidence for the stability of such blends, which consist of highly incompatible components, before and after sulfonation.

A well-known industrially produced thermoplastic elastomer SEBS and thermoplastic polypropylene (PP) blends was investigated in this study to utilize it as a polyelectrolyte membrane in fuel cell applications. Membranes were prepared by hot-press subsequent to extrusion and sulfonated by immersing into chlorosulfonic acid solution. For characterization water uptake, mechanical strength, ion exchange capacity (IEC) and proton conductivity measurements were carried out. Water uptake values and IEC values exhibited an upward behavior as the sulfonation degree increased. Proton conductivities were acquired only from 68S09M45 and 68S09M60 titled membranes at 75°C and 80°C. Conductivities were demonstrated to be between 26.2-82.2 mS/cm which are higher than Nafion 117 (37 mS/cm). Incorporation of PP into the blend composition enhanced e-modulus values. It was also found that elongation at break values and fracture stresses decreased with increasing the degree of sulfonation. This study has shown that SEBS/PP/WAX blends could be a good alternative for high proton conducting membranes for fuel cell applications.

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9123 | Free vibration and buckling analysis of FG-CNT reinforced composite quadrilateral plates resting on Pasternak foundations (12. Functionally graded materials and structures)

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This paper considers the vibration and buckling behaviors of functionally graded carbon nanotube (FG-CNT) reinforced composite thick straight-sided quadrilateral plates having CNT reinforced uniaxially aligned in the axial direction with its material properties graded in the thickness direction. The first-order shear deformation theory (FSDT) is employed in the formulation of energy functional to incorporate the effects of transverse shear deformation and rotary inertia. Using the IMLS approximation for the field variables and minimizing the energy functional via the Ritz procedure, a discretized eigenvalue equation of the problem is derived. The vibration and buckling solutions of the plates can be obtained through solving this eigenvalue problem. Convergence studies are performed to demonstrate the numerical stability of the IMLS-Ritz method. This numerical study is performed through a few selected example problems. Besides, the accuracy of the IMLS-Ritz results is examined by comparing them with the published values. Close agreement is found for the comparison study. The influence of Winkler and shearing layer parameters on the natural frequencies and buckling load factors has been investigated, by considering the composite effect of CNT distribution, side angle, plate thickness-to-height ratio, plate aspect ratio and different boundary conditions. It is evident that the effect of Winkler parameter on the vibration and buckling of composites is relatively small in comparison to the effect of shear layer parameter. Generally, an increase in elastic foundation parameters, will lead to an increase in the vibration frequencies and buckling load. The effects of transverse shear deformation are evident in the free vibration and buckling studies on the FG-CNT reinforced composites. The frequency parameter (also the buckling factor) decreases as the plate thickness ratio increases and the aspect ratio reduces. These solutions can be adopted as a benchmark solution for other numerical studies on FG-CNT reinforced composite plates.

9280 | Numerical Analysis of Functionally Graded Circular Plates with Modified Couple Stress Theory **(12. Functionally graded materials and structures)**

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Finite element models of microstructure-dependent nonlinear theories for axisymmetric bending of circular plates, which accounts for through-thickness power-law variation of a two-constituent material, the von Karman nonlinearity, and the strain gradient effects are developed. The strain gradient effects are included through the modified couple stress theory that contains a single material length scale parameter which can capture the size effect in a functionally graded material plate.
Finite element models are used to determine the effect of the geometric nonlinearity, power-law index, and microstructure-dependent constitutive relations on the bending response of functionally graded circular plates.

9295 | Differential evolution for optimization of functionally graded materials. **(12. Functionally graded materials and structures)**

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Functionally graded materials (FGM) were first proposed by Bever and Duwez in 1972 [1]. In functionally graded materials (FGMs), material properties vary continuously as opposed to those in laminated composites where such variation is discontinuous at layer interfaces. In an FGM the material properties are varied by changing the volume fractions of its constituents.

In order to better design materials, volume fraction and distribution can be tailored trough optimization techniques. In [2] volume fraction optimization of functionally graded beams is studied for maximizing the fundamental natural frequency by applying a new meta-heuristic nature-inspired algorithm called firefly algorithm (FA) which is based on the flashing behavior of fireflies. In [6] an imperialist competitive algorithm is used for the optimization of three-parameter power-law distribution of functionally graded (FG) beam. In [5] particle swarm algorithm is used for optimization of functionally graded materials. In [3] genetic algorithms and simulated annealing have been adopted to develop a multi-objective optimal design for FGM implantation design.

In the present work, differential evolution (DE) is proposed to analyze the behavior of functionally graded materials. Differential evolution is a stochastic optimization technique developed by Storn and Price [4]. Differential evolution (DE) is a simple population based, stochastic function minimizer. DE may be initialed by sampling the objective function at multiple, randomly chosen initial points. Next, DE generates new points that are perturbations of existing points by using the scaled difference of two randomly selected population vectors (mutation). Crossover is then performed to enhance the diversity of population. Finally, selection chooses population members with lower objective functions, maintaining the population size constant. The process ends when a predetermined value of the objective function is reached, or when a maximum number of generations is produced. DE can be used to find approximate solutions to problems that have objective functions that are nondifferentiable, non-continuous, non-linear, noisy, flat, multi-dimensional or have many local minima, constraints or stochasticity.

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9353 | NONLINEAR FREE VIBRATION OF FUNCTIONALLY GRADED SHELLS (12. Functionally graded materials and structures)

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Nonlinear free vibration behavior of shells occurs in many engineering applications such as air craft panels and missiles and launch vehicles. Chorfi and Houmat [1] investigated the nonlinear free vibration of a functionally graded doubly curved shallow shell using a p-version of the finite element method and concluded that the increase or decrease in hardening effect depends on the thickness ratio and volume fraction exponent. Dao and Nguyen [2] studied the nonlinear vibration of cylindrical shell subjected to axial and transverse loading using Galerkin method and observed a beating vibration phenomenon when the frequency of excitation is near to the natural frequency of the shell. Strozzi and Pellicano [3] studied the effect of material distribution on the natural frequencies and non linear response of functionally graded shells. Sheng and Wang [4] presented a simplified approach using Hamilton's principle to find the nonlinear vibration of FGM shell subjected to thermal and mechanical loads. Alijani and Amabili [5] reviewed nonlinear vibration of shells and observed that the research performed on large amplitude vibrations of shell structures, specifically for those made of advanced materials, is still far from being considered well established.

From the reviewed literature, a very few papers are available for nonlinear free vibration of thin shells. Also the available literature studied shells subjected to harmonic loading based on von Karman large deflection plate theory taking into account the transverse displacement. In this work the transverse displacement as well as inplane displacement of the FGM is considered.

Nonlinear free vibration of thin shells are carried out based on Green strains and Piola-Kirchhoff stresses, nonlinear terms of transverse and in plane displacement using semiloof element in the formulation. Convergence and validation of results are carried out to ascertain the accuracy of the present formulation. The formulation is capable of analyzing the effect of anisotropy and various shell geometries.
In nonlinear vibration of shells softening type of nonlinearity is present up to amplitude ratio 0.5 and after that mixed behavior exists and in some cases weak hardening behavior observed. The coupling of bending stretching significantly affects the strength of nonlinearity and the in plane boundary conditions. The L/R ratio has effect on frequency ratio, for short shells boundary restraints have significant effect and for long shells the effect diminishes. The bending stretching coupling effect is more predominant in the behavior of short FGM shells and hence the behavior is more complicated for amplitude ratio more than 0.5. The nonlinear behavior of FG cylindrical shell shows dissimilarity as the amplitude ratio increases the frequency ratio varies (ie decreasing and increasing) since the mode shape is not identical for different boundary conditions and L/R ratios in addition to the effect of bending extensional coupling.

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9356 | Small scale effect on response of functionally graded nano-beams to super-harmonic excitation (12. Functionally graded materials and structures)

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This article attempts to investigate the effects of small scale parameter on steady state response of functionally graded nano-beams resting on a viscous foundation to super-harmonic excitation. A simple power-law distribution is used to model the variation of material property graded in the thickness direction. The dimensionless partial differential equation of motion is derived by using Euler-Bernoulli beam theory, von-Karman geometric nonlinearity and Eringen's nonlocal elasticity theory. Governing equations of steady state response of functionally graded nano-beams excited by distributed harmonic force are found by using multiple scale method. The small scale parameter is changed between 0 to 2 nm to investigate the effects of small scale on steady state response of excited functionally graded nano-beams due to lack of information. The effects of other parameters such as index of power-law , distributed lateral load, stiffness and damping coefficient of foundation are studied on frequency-response curves of FG nano-beams as well.
The results show that with a decrease in the stiffness coefficient or with an increase in the damping coefficient, dimensionless peak response increases and frequency-response curve bends more to the right-hand side as well. It is also shown that an increase in small scale parameter and/or index of power law often increases the dimensionless peak response, although the type of loading can change the relationship between small scale parameter and the dimensionless peak response.

9361 | The nonlinear effects of gradient foam core on the natural frequency of composite sandwich panels (12. Functionally graded materials and structures)

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ABSTRACT: A gradient sandwich panel model based on a {2, 1}-order sandwich panel theory is developed. In this model, the Young's modulus of the core varies with the mass density along the thickness direction. A simple formula is employed to characterize the correlative effect of Young's modulus and mass density of the gradient foam material. This gradient sandwich panel model has been validated with the finite element code ABAQUS®. Finally, the nonlinear effects of the gradient foam core on the natural frequencies of sandwich panels based on Taylor method are investigated.

9362 | Indentation model of sandwich circular panels with gradient metallic foam core (12. Functionally graded materials and structures)

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A new analytical model is presented to predict indentation behavior of the sandwich circular panel with gradient foam cores under a spherical indenter. In the model, a displacement field of the upper face sheet of the sandwich panel is assumed to be a cosine function and plateau stresses of the gradient foam core vary with the mass density along the thickness direction of the sandwich panel. The sandwich panel is modeled as an infinite, isotropic, plastic membrane on a rigid-plastic foundation. The explicit solutions of the relation between the indentation force and maximum plastic regions of the upper face sheet are derived based on the principle of minimum work. The analytical results are validated using the finite element code ABAQUS®. The influences of the gradient foam core on the maximum plastic region, the indentation force, the contact radius of the spherical indenter and the energy dissipation of the sandwich panel are also investigated.

6719 | Durability of CFRP-concrete bonding systems under sustained load exposed to harsh environments (13. Health Monitoring Techniques in Composite Structures)

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Carbon fibre reinforced polymer (CFRP) has promising prospects in civil engineering work such as retrofitting and reinforcing structures. Although it has superior qualities for structural applications, more research is required to investigate the effects of different environmental exposures on its performance. In this research, the pre-cured CFRP plates were bonded to the concrete surface using suitable epoxy. The samples were subjected to several sets of controlled environmental conditions and loading intensities. Specially-designed steel frames were fabricated to impose the prescribed continuous single-lap shear stress on the bonded interface for the entire exposure period. The exposure factors studied were temperature cycles, relative humidity, salt content in water at different temperatures, and exposure time. Following the exposure period, the samples were released and reconditioned to the normal environment. The single-lap shear test was used to determine the ultimate bond strength. During the test process, two-dimensional strain fields were monitored by photogrammetry. The changes in the ultimate bond characteristics and maximum total slip between the externally-applied CFRP and concrete due to permanent loading, ageing, and exposure conditions were used as measures of exposure effects. The objective of the study was to understand the behaviour and the limits imposed on the bond performance due to selected exposure regimes and loading conditions.

6874 | Dynamic Damage Evaluation in Shear-Strengthened Concrete Beams by Fourier and Wavelet Methods (13. Health Monitoring Techniques in Composite Structures)

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Dynamic response features of reinforced concrete beams with dominant shear failure mode are investigated within experiments. Regarding frequencies as indicators of structure condition, dynamic content of intact and carbon fiber reinforced polymer (CFRP) strengthened specimens is extracted using fast Fourier transform (FFT) and continuous wavelet transform (CWT). CFRP applies to exterior surface in vertical-unidirectional and cross-ply orientation. Resultant deflection and acceleration records demonstrate the relationship between fiber stacking and frequency content change. Composite skin provides notable stiffness on active frequency range shift-up and peak spectrum amplitude maintain for impact repeats. Active domain in FFT spectrum is sensitive to failure type either shear or flexural. The CWT analysis ridges show a clear difference for failure types of samples. CFRP control cracking and deflection, which is also revealed as increased acceleration values especially for cross-ply wrap. Acceleration frequency contents of unidirectional and cross-ply retrofits are retained around first and third fundamental modes respectively with little deviations for impact repeats, beside excessive frequency aberration of intact beams. Effective stiffness is recovered during initial impacts and then starts degrading due to rupture of horizontal fibers in cross-ply retrofit, but provided stiffness is stable for unidirectional retrofit during all impacts.

7056 | Recent development in passive sensing for structural health monitoring applications (13. Health Monitoring Techniques in Composite Structures)

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This paper presents some recent developments in structural health monitoring (SHM) of composite panels, using in particular a passive approach for impact detection. In this type of analysis, two different features can be investigated: impact location and impact force reconstruction.
Common impact location approaches are based on the investigation of the propagation of the waves caused by the impact. The knowledge of the wave speed is usually required; as for composite materials this depends on the direction of propagation, a straightforward approach cannot be applied, being the position of the impact unknown. A novel approach based on the use of proper orthogonal decomposition of the signal collected at multiple locations, without using information about the wave velocity, is presented.
The main issue related to impact force reconstruction is the evaluation of a correct transfer function which can be used during the inverse analysis. The method presented exploits a transfer function obtained thanks to different sets of known input-output data. The results in terms of force reconstruction are better than a classic approach based on the frequency response function of the system. The method has proven to be accurate with both numerical analyses and experimental verifications.
The two methodologies presented can be coupled to develop a unique platform for online monitoring of aeronautical composite panels.

7664 | Flexural After Impact (FAI): A new criterion to evaluate the residual strength of composite materials (13. Health Monitoring Techniques in Composite Structures)

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Composite materials have been utilized for nearly four decades owing to their beneficial characteristics, such as stability, weight and high stiffness. Particularly, in the aerospace industry the use of composites is justified by reducing structural weight with consequent fuel saving and improving performance. During the service life, a composite structure is subjected to various loading conditions, which can give rise to various defects. Composite laminates are especially sensitive to low velocity impacts since even minor damage can cause considerable reduction in structural integrity. In fact, the impact energy is absorbed through remarkable internal damage mechanisms without exterior signs detectable by visual inspection. Various types of damages, like delamination, fiber-breakage, matrix cracking and fiber–matrix interfacial debonding can occur, leading to structural failure. To ensure that a damaged structure will not catastrophically fail during service life and will maintain maximum structural efficiency, it is necessary to carry out damage tolerance studies, evaluating the residual properties of the structure after impact. This study present a new criterion to evaluate the residual strength of laminate composite subject to low velocity impact loading. Low-velocity impact tests and residual strength tests are performed using an instrumented drop-weight machine and static test machine, respectively. The experiments were carried out on laboratory specimens, which are flat and rectangular composite plates. Two different stacking sequence and thickness are tested, in order to analyze the influence of these factors on the impact and post-impact response. The residual flexural strength of damaged specimens is evaluated by quasi-static and four-point bending test. The results of drop-weight impact tests and flexion after impact (FAI) tests on carbon/epoxy laminates are presented. A new criterion based on damage metrics and flexural after impact (FAI) analysis is proposed in order to correlate these factors. Thus, these results are normalized by using the project load and the metrics for damage analyses, i.e. if there is no damage in the structure, then the metric returns "zero" value. If the structure is partially damaged then the metric returns a number between one and "zero", which is related to the severity of the damage. Finally, if the structure is totally damaged, then the metric returns a value equal one. Finally, it is discussed the advantages and limitations of this criterion into the context of SHM (Structural Health Monitoring).

7771 | On the direction-dependent thermal behavior of layered structures fabricated via Fused Deposition Modeling (13. Health Monitoring Techniques in Composite Structures)

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Ever since their introduction, composite materials have dominated in a number of engineering fields as of their superior mechanical performance and lightweight in combination with the possibility of modification to meet requirements. In parallel, as technology evolved, the increasing demand for complex, customized structures has led to the innovative introduction of Additive Manufacturing methods (AM). AM attracts augmenting attention worldwide as it enables a fully automated, tool-free and fast production of complex structures with high levels of dimensional punctuality. Fused Deposition Modeling (FDM), being a rapidly developing AM technique, produces complicated parts by creating layers of material strands and depositing layer upon layer. Although typical FDM method does not produce composite structures which consist of two or more different materials as the traditional composite theory premises, a powerful connection has been reported between the orientation in which the layers in a FDM part are built and the mechanical properties of the final structure. In a similar logic, it is reasonably hypothesized that the thermal behavior of a structure fabricated via FDM may follow the respective direction-dependent pattern.

On the present work, the degree of influence of the layer orientation on the overall thermal behavior of Acrylonitrile Butadiene Styrene structures produced via FDM, as well as the efficiency of Fiber Bragg Gratings (FBG) in sensing the internal thermal strains developed, are examined. To accomplish the forenamed objectives, layered specimens were fabricated and FBG sensors were embedded in various directions relative to the specimen nominal ones. Prismatic specimens of 20 mm x 10 mm x 40 mm (width x height x length) were built. A closed chamber Stratasys Elite 3D Printer was used to generate the specimens with a raster orientation of [+45o/-45o] (criss-cross raster angle) while a MakerBot Replicator 2X was employed to build the [0o] and [90o] direction ones. In all cases, the layer thickness was selected to be 0.254 mm and the parts were built using zero air gap. The specimens, featuring multiple FBGs in planes parallel to each other, were subjected to thermal cycling in a temperature range which exceeds the glass transition temperature derived from literature. K-type thermocouples were used to monitor the temperature inside the specimen and the thermal chamber. Wavelength measurements were recorded all along the experiments and the data was used for the calculation of the internal thermal strains as a function of temperature. Finally, the coefficient of thermal expansion (CTE) was determined and its dependence on the layer orientation was evaluated for temperatures above and below the glass transition region.

7779 | Fatigue Studies in the Development of a Proof Test for Through-Life Monitoring of Bond Integrity in Aircraft Bonded Repairs (13. Health Monitoring Techniques in Composite Structures)

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This paper describes further development of the proof test method [1] developed by Baker et al for the purpose of evaluating the initial and through-life integrity of the structural adhesive bond in bonded repairs. The periodic proof testing approach is similar in principle to the NDI inspection approach of "safety by inspection" that is used to manage damage-tolerant aircraft structures. It involves thin disks of material similar to the bonded repair, installed together with the patch. These bonded repair coupons (BRC) experience the same loading and environmental exposure as the patch and can be proof tested by applying a torsion load. To be considered for aircraft applications, the technology readiness level needs to be raised through increasing its practicality and improving the test database. This paper focuses on the fatigue aspects of the test database to address whether the proof test can withstand fatigue loading and importantly, if it does, how closely the proof tests matches the behaviour of the patch.
The investigations within this study used experimental and computational approaches, the latter exploiting finite element analysis. Those investigations looked at the adhesive stress behaviour of different BRC/parent materials under static axial loading, the fatigue response of different BRC/parent materials, the stress interaction between the patch and BRCs bonded within close proximity, the comparability of adhesive stresses in the patch tip and

the BRC as well as the comparability of adhesive stresses in the patch tip and different orientations of a composite BRC, and the fatigue response of aluminium BRCs using an alternative grit-blast silane surface treatment.

References
[1] A. Baker, D. Bitton and J. Wang, "Development of a proof test for through-life monitoring of bond integrity in adhesively bonded repairs to aircraft structure," International Journal of Adhesion and Adhesives, pp. 65-76, 2012.

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7804 | Damage detection using artificial neural networks (ANN) and probability ellipse (PE) methods via Lamb waves approach (13. Health Monitoring Techniques in Composite Structures)

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This paper shows the application of Artificial Neural Networks and Probability Ellipse methods for damage detection using Lamb waves approach. The propagation data of the lamb waves are used to detect the damage in metallic and composite plates. The experimental set-up is realized with array of actuators and sensors (PCB) able to excite and record the dynamic response. A damage index, calculated from the measured wave propagation data in a reference state (baseline) and in the current state, is introduced as a determinant of structural damage. The index is a relative measure comparing the two states of the structure under the same ambient conditions. The damage index increases its intensity when the damage size increases too. Moreover, its calculation for different paths, associated with the Artificial Neural Networks or Probability Ellipse methods allow for the identification of the position and the entity of the damage. Two different panels made by either aluminum or fabric composite have been used for testing. The effect of the through the thickness damage entity (hole with diameter equal to 6mm) have been investigated for the aluminum panel while the effects of the three through the thickness damage entities (hole with diameter equal to 2.5mm, 4.5mm and 9mm) have been investigated for the composite panel. The required ANN training have been performed throughout finite elements analysis carried out on the aluminum panel by taking into account a set of damage paths. Simulations have been also performed in order to characterize the behavior of the damaged composite plate. The damage index for both simulations and tests were compared in relation to each damage size. The potential applications of these methods in developing health monitoring systems in defects-critical structures and in composite material structures are discussed.

8049 | BFRC and carbon fibers: multifunctional and smart reinforced cement materials (13. Health Monitoring Techniques in Composite Structures)

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In this work ,the attention is focused on the study of the combination of Basalt Fiber Reinforced Cements (BFRC) with carbon fibers, where the structural reinforcement is represented by the basalt fibers in epoxy resin, while the sensing element (electrically conductive phase) is made by the carbon fibers. Basalt fibers (BFs) have advantageous properties as high strength, high durability, low thermal conductivity, lower energy consumption during the production cycle, but lower electrical conductivity. Carbon fibers (CFs) are of particular interest as they are less costly, improve the electrical conductivity and enhance the mechanical properties (fracture toughness and strain capacity).

Due to the load and the strains increments of the material, the distance of conductive particles is progressively increasing allowing to record a gradual and continuous increase of the electrical resistance.

The efficiency of self-monitoring reinforced cement materials is evaluated by studying the BFRC with carbon fibers as a whole, and observing the variation of electrical resistance with the load and/or strains applied to the entire composite.

The effects of the type of fibers used (fiber volume fraction, fiber length, surface area, size, aspect ratio for carbon fibers and basalt fibers), the time of hydration and the sand-cement ratio on the electrical conductivity and self-diagnosis properties are evaluated.

To make the mortar specimens, Portland cement and standard sand, as prescribed by the UNI EN 196-1 (1996) and different geometrical and mechanical properties of the carbon fibers were used in this analysis.
To obtain a better fiber dispersion and mortar compactness, silica fume and fluidifying agent were used. The specimens were made from different mix design evaluating water-cement ratio (w/c); sand–cement ratio (s/c); silica fume-cement weight ratio; fluidifying-cement weight ratio. A standard mixing procedure was used: the specimens with the dimensions of 40x40x160 mm were cured at standard temperature for 24h.

The experimental study carried out in this work e pointed out that the addition of basalt fibers to cement mortar specimens can produce an increase of strength and that the addition of a small quantity of carbon fibers can produce a significant increase in the electrical conductivity of material. The experimental results were analyzed through the percolation theory point of view.

References: Chiarello - Zinno

8104 | Hybrid Effect of Conductive Materials on the Bending Behaviour of Concrete Beam and Self-Monitoring of Freeze-Thaw Damage (13. Health Monitoring Techniques in Composite Structures)

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The damage accumulation was studied by following the fractional change of impedance (FCI) with number of freeze-thaw cycles (N). The nano-carbon black (NCB), carbon fiber (CF) and steel fiber (SF) were added into plain concrete to produce the triphasic electrical conductive and ductile concrete. The effects of NCB, CF and SF on the compressive strength, flexural properties, and electrical impedance were investigated. The concrete beams with different dosages of conductive materials were tested for FCI and mass loss (ML). The results indicate that FCI can be used to assess the concrete damage under freeze-thaw actions. In this paper, an innovative nondestructive and self-sensing testing method is suggested. The relationship between FCI and number (N) of freeze–thaw cycles can be well fitted by a first order exponential decay function and it appears that FCI is sensitive to damage in conductive concrete caused by freeze-thaw action.

8105 | Concrete with triphasic conductive materials for self-monitoring of cracking development subjected to flexure (13. Health Monitoring Techniques in Composite Structures)

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In order to enhance the conductivity and ductility of concrete, the electrical conductive materials like nano-carbon black (NCB), carbon fiber (CF) and steel fiber (SF) were added into concrete. The influence of the NCB, CF and SF on the self-diagnosing ability to the load-deformation property and crack pattern of triphasic conductive concrete member subjected to bending were investigated. The relationship between the fractional change in surface impedance (FCI) and the crack opening displacement (COD) of concrete beams with conductive materials has been established. The results illustrated that both the conductivity and ductility of concrete are increased by addition of conductive materials clearly, and there is a linear relationship between COD and FCI.

8109 | Structural Health Monitoring of Stiffened Composite Panels Using the Damage Force Indicator Method (13. Health Monitoring Techniques in Composite Structures)

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Aerospace vehicles use stiffened composite panels extensively to sustain combined in-plane and out-of-plane loads with a light weight structure. However, skin-stiffener joint is a hot spot for damage initiation due to geometric and loading complexities. Such joints are usually located in hard-to-reach areas (e.g., inside aircraft wing box) making efficient nondestructive inspection very difficult. Structural Health Monitoring (SHM), which uses sensors and actuators integrated with the structure, is highly suitable for early identification of damage in skin-stiffener joints. In this study, we investigate an SHM method based on ultrasonic guided waves, which may be actuated and sensed by embedded or surface bonded piezoelectric patches. A damage detection algorithm known as “Damage Force Indicator (DFI) method” is employed for detecting composite skin-stiffener debond. The DFI method uses dynamic stiffness of healthy structure and measured response from the damaged structure in order to calculate the force difference between damaged and healthy structures occurring due to the damage. The DFI peaks only at measurement locations adjacent to the damage, which helps locating the damage. The dynamic stiffness of healthy structure is obtained by the wavelet spectral finite element (WSFE) method developed by the authors for guided wave propagation in composite plates (Composite Structures, 108 (2014), 341–353). WSFE is an efficient and accurate technique for high frequency wave propagation modeling in anisotropic composite structures. Transverse shear flexibility is included in the model such that the accuracy holds up to wavelengths close to plate thickness. Daubechies compactly supported scaling functions are used to approximate the partial differential wave equations for 2D composite laminates in time and one spatial dimension. Resulting ordinary differential equations are rearranged and solved for wavenumbers by assuming a harmonic solution in the transformed domain. The global dynamic stiffness matrix of the structure is formed relating transformed nodal forces and displacements. Stiffened panel is then assembled following a procedure similar to conventional finite element method and the matrix equation is solved in frequency-wavenumber domain. Major advantages of the DFI method coupled with WSFE modeling are that it does not need any baseline measurement, knowledge of input is not necessary, and it is computationally very fast, making it an ideal tool for on-line structural health monitoring. Results presented at the ICCS18 will show that the DFI based damage detection approach combining WSFE modeling of healthy structure and experimentally measured sensor data for damaged structure yields efficient damage diagnosis in stiffened composite panels.

8652 | On the Modal Acoustic Emission testing of composite structures (13. Health Monitoring Techniques in Composite Structures)

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Acoustic Emission is a well-known nondestructive testing technique which is being applied on composite structures since the sixties. It is a passive technique, and allows detecting progressive damages in structures under loading. The data analysis is often achieved in the time domain (events, counts, and hits numbers, amplitude, duration, rise time …). However, the experimental collected data (waveforms) can be transformed to the frequency domain and analyzed there, enriching then the analysis. This is the basic principle of the Modal Acoustic Emission (MAE) technique.
This communication deals so with this not-well known technique. It will start by clarifying its concept through underlying the main subtleties between MAE and the mother technique, which is Acoustic Emission. Performances and limitations of MAE will be carried out. Some cases of study on composites structures, from both literature and field experience of the authors, will be presented and discussed.

8653 | Felicity Effect and Ratio in Multilayer Composite Overlapped Pressure Vessel (13. Health Monitoring Techniques in Composite Structures)

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Composite Overlapped Pressure Vessel (COPV) is in growing use in energy field for storing gases and fluids. These structures are exposed to damages occurring from either impacts and falls or nature ageing due fatigue. For mainly safety concerns, these structures should be tested regularly. Acoustic Emission testing method is well adapted for this kind of structures. It offers the possibility to detect progressive damages during pressurization. Correlation between acoustic emission activity and damage identification is a serious challenge. In another words, to accept or reject such a structure, defect size should be assessed accurately. Basing on signal features such as events, counts, and hits numbers, amplitude, duration, rise time, etc., some criteria are established over time and experience feedback of researchers and engineers, and are currently available in national and international standards. However, these criteria are numerous and too dependent of various factors such as material, geometry, dimensions, age of the structure,… Felicity effect, which was discovered in the 80's, and used through its ratio, is one among them. A deep study has been conducted by the authors aiming to rule on the relevance of this ratio.

During this presentation, a brief story of Felicity effect, evolution of the definition of Felicity ratio and its method of assessing over time will be presented. Results gained from several experimental tests carried out on sheets and full structures (COPV) will be shown concisely and debated. The relevance of Felicity ratio as an accept/reject criteria will be discussed.

8683 | Exploring the limits of the mode shape derivatives to localize damage in laminated composite plates (13. Health Monitoring Techniques in Composite Structures)

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Damage localization in laminated composite plates is a very hot topic due to the important role that it assumes for preventing failures or breakdowns and the important use of these structures in the transport industries. The mode shape spatial derivatives are one of the most used techniques to localize damage in composite plates and other kind of structures. These derivatives are usually computed using finite differences. However, it is well-known that finite differences spread and amplify the error. The magnitude of this error is not easy to estimate, mainly because it depends on the values of derivatives of higher order than the one which is required. This error can prevent the damage localization. Recently, a new technique to estimate the error was proposed by the authors [1]. This technique is based on Ritz method and allows to choose an optimal sampling in order to minimize the error. As a result of this minimization, the damage localization is improved.

In the present work we apply this technique to different orders of the finite differences. For the same order derivative, the order of the finite difference implies the use of more points and different coefficients, resulting on different errors and therefore different results on the damage localization. The objective of this work is to explore the limits of the technique for different orders of the finite differences.

[1] P. Moreno-García, J. V. Araújo dos Santos, H. Lopes. "A new technique to optimize the use of mode shape derivatives to localize damage in laminated composite plates". Composite Structures, 108, 548-554, 2014

8686 | Damage Detection of a Prestressed Concrete Bridge with Corrugated Steel Webs Using a Moving Vehicle (13. Health Monitoring Techniques in Composite Structures)

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Prestressed concrete bridges with corrugated steel webs have emerged as a relatively new form of steel-concrete composite bridge and many of them have already been constructed around the world. However, damage may appear in such bridges due to overloading, earthquakes, deterioration, etc. Damage detection and structural health monitoring of bridges with a moving vehicle is a new technique especially for bridges with corrugated steel webs. This paper reports an experimental study of the feasibility of identifying the occurrence and location of damage from the vertical acceleration of a model vehicle moving over a simply supported prestressed concrete beam specimen with corrugated steel webs. The instrumented vehicle acts both as an exciter and sensor system. Two or three sensors are installed on the vehicle depending on whether an external sinusoidal force exciter is equipped on the vehicle. The weight of the vehicle can be varied by additional masses. When the vehicle moves from one end of the beam to the other, the vehicle and beam interacts with one another. The vibration of the beam can be acquired by the accelerometers on the vehicle. Two methods may then be used to identify the occurrence and location of damage. The first one extracts the dynamic properties of the beam before and after damage and then applies vibration-based damage detection method to identify the damage. The second method applies continuous wavelet transform to the vehicle response directly and gets the coefficients of different scales. Smoothing technique is then used on the original coefficients. Lastly, damage indicators are proposed based on the properties of the smoothed coefficients to identify the damage occurrence and location.

8713 | Fabrication of the thermoplastic composite impact sensor usable at cryogenic environment (13. Health Monitoring Techniques in Composite Structures)

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Impact damage is a major concern in the design of the polymer composite structure. Generally, impact damages which occur from inside of the polymer composite structure cannot be detected by visual inspection. Piezoelectric impact sensors and fiber bragg grating (FBG) sensors are widely applied to monitor the damage of the polymer composite structure. However, in cryogenic environment, the commercial impact sensors are easily broken by impact load due to their high brittleness. In this study, the thermoplastic composite impact sensor was fabricate by using the piezoelectric polymer film and fluoride resin which are not broken by impact damage at room temperature and tend to maintain its property under the glass transition temperature. Impact tests are performed by instrumented drop weight impact tester at various impact energies with respect to the impact mass and height. Sensitivity of the thermoplastic composite impact sensor was determined by measuring the output voltages against the impact force.

8751 | LAMB WAVE PROPAGATION IN A DELAMINATED COMPOSITE PANEL: MODELING AND TESTING (13. Health Monitoring Techniques in Composite Structures)

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Guided waves are one of the most interesting instruments for damage identification, basing on in-situ actuation and acquisition and on the possibility to correlate anomalies in wave propagation with internal damage. For this reason, they are particularly suitable for structural health monitoring (SHM) applications, where the objective is to identify possible anomalies, defects, in structures.

The delamination is the most hazardous defect for laminated composites, which could be induced during careless manufacture or a consequence of accidental impact; it appears as the debonding of adjoining plies and it plays a major role in lowering structural strength and stiffness, consequently downgrading system integrity and reliability; therefore its identification in the structures that are currently in service is required.

The wave propagation in composite laminates is complex due to the heterogeneity nature of the constituents, inherent material anisotropy and the multi-layered construction which leads to the wave mode velocity being macroscopically dependent on the laminate layup, the direction of wave propagation, frequency and interface conditions. To overcome this difficulty the Finite Element Analysis might be a flexible and efficient tool to evaluate the propagation characteristics of Lamb waves in more general cases.

In this work the interactions of guided waves with interfacial internal damage artificially reproduced in a composite panel are investigated experimentally and results are employed for correlation of those ones derived by numerical model. The final target is a validated numerical modeling procedure that could represent a powerful tool for designing and assessing effectiveness of SHM systems based on propagating ultrasonic waves generated and acquired by piezoelectric sources.

8910 | Structural Health Monitoring in composite plate using system identification (13. Health Monitoring Techniques in Composite Structures)

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Non-Destructive Inspection (NDI) and Structural Health Monitoring (SHM) play a very crucial role in ensuring safe use of structural components. NDI is an offline approach of damage detection, which involves significant costs due to the need for frequent grounding of aircraft, shutdown time, and labour involved in inspections. Therefore, techniques for continuous health monitoring are needed to identify damage in structures before occurrence of catastrophic failure using minimal time and human intervention. Polymer matrix composites are used in many engineering applications: in ships, aircraft, and pressure vessels, due to their superior specific stiffness and strength. In particular, laminated composites are susceptible to damage in the form of delaminations which may not be visible but can significantly compromise structural integrity. This research aims to develop a cost effective and reliable SHM technique for composite plates using system identification based on Eigen Realisation Algorithm (ERA). A methodology has been developed to extract the stiffness values of various elements in composite plates from their response to natural excitation using System Identification based on Eigen Realization Algorithm (ERA) integrated with Natural Excitation Technique (NExT). These stiffness values are used to identify location and severity of delamination damage in laminated composite plates from naturally excited time domain data. The application of the proposed methodology is demonstrated through numerical simulation of vibration of composite plates with delaminations of different sizes simulated at different locations. The proposed methodology is shown to be capable of assessing the size and location of delamination damage with good accuracy.

8929 | DELAMINATION IDENTIFICATION IN COMPOSITE MULTILAYERD STRUCTURES (13. Health Monitoring Techniques in Composite Structures)

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The necessity of permanent monitoring the state of the structures and prognosis of the service life brought about the development of the Structural Health Monitoring methods and systems. During the past two decades, extensive studies were conducted in the area of vibrational based damage detection methods. In this paper the guided wave propagation method has been considered in composite multilayered cylindrical panels with delaminations. The pitch-catch and pulse-echo inspection techniques have been applied in wave propagation measurement. The effect of wave disturbance by the structural defect have been used to detect and localize the delamination. The new model of structural defect has been considered in numerical and experimental analysis. The results of wave propagation in intact and defected structures has been compared numerically and experimentally.

5483 | Response of a cracked orthotropic half-plane subjected to transient anti-plane loading (14. Impact on Composites)

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Multiple cracks in an orthotropic half-plane under transient loading are investigated. Anti-plane loading condition is considered. The dislocation solution is utilized to derive integral equations for multiple interacting cracks with any location and orientation in an orthotropic half-plane. These equations are solved numerically thereby obtaining the dislocation density function on the crack faces and stress intensity factors of cracks. Numerical results are obtained to illustrate the variation of the dynamic stress intensity factors as a function of the crack orientation for different values of orthotropic constant.

5497 | 137Cs PENETRATION THROUGH CONCRETE IN RADIOACTIVE WASTE MANAGEMENT (14. Impact on Composites)

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To assess the safety for disposal of radioactive waste-concrete composition, the leaching of 137Cs from a waste composite into a surrounding fluid has been studied. Leaching tests were carried out in accordance with a method recommended by IAEA. Determination of retardation factors, KF and coefficients of distribution, kd, using a simplified mathematical model for analyzing the migration of radionuclides, has been developed. In our experiment we have achieved the lowest leaching values after 60 days in samples. Results presented in this paper are examples of results obtained in a 20 year mortar and concrete testing project, which will influence the design of the engineered trenches system for a future central Serbian radioactive waste storage center.
In order to prevent widespread dispersion of radionuclides into the human environment, radioactive waste produced in nuclear facilities has been incorporated in several kinds of matrices . The objectives of immobilization of radioactive waste is to convert the waste into forms which are:
- Leach resistant so that the release of radionuclides will be slow even though they may come into contact with flowing water;
- Mechanically, physically and chemically stable for handling transport and disposal .

6355 | Impact induced damage of laminates containing ultra-thin plies (14. Impact on Composites)

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Ultra thin-ply based laminates (laminates with ply thickness of less than 50 micrometer) are promising development in composite materials and are expected in the near future to outperform conventional laminates in mechanical performance. The idea behind reducing thickness is to increase the in-situ tensile, compression and shear strength of the individual ply. However, such increase in the laminate strength can dramatically change the failure to be more brittle in nature.
In the current communication, a test matrix is being define using optimization techniques of carbon/epoxy system. The laminates contain both ultra-thin (0.04 mm thickness) and normal plies (0.16 mm thickness) are compared to that contain only ultra thin plies. The test matrix was manufactured by TeXtreme for Tow fabric. The tests are currently ongoing and the results will be available within the next few weeks.

6499 | Performance of Glass Fiber Reinforced Structural Insulated Panels (GSIPs) Under High Velocity Impact Loading (14. Impact on Composites)

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This paper investigates the response of glass fiber reinforced structural insulated panels (GSIP) for the high velocity impact (HVI), using experimental and finite element (FE) analysis for potential use in the structural applications. The experimental HVI test was carried on the GSIP and the parameters such as damage area, sabot penetration depth, crack width were obtained and compared with FE results. The damage area obtained by HVI FE analysis on GSIP is 3.28% higher than experimental HVI. The pentration depth using FE analysis was 17% higher than experimental HVI. Furthermore, the parametric studies were conducted for variable impact velocity and variable EPS core thicknesses. From the parametric studies, it was observed that, with the increase in impact velocity the damage area, energy absorbed, and depth of penetration increased gradually. Conversely, with the increase in EPS core thickness, the gradual decrease in damage area and energy absorbed by GSIP was observed. From this study, the parameters were obtained for effectiveness of GSIPs in the high impact responses in order to implement GSIPs in structural applications.

6763 | Impact Damage and Failure Response of Aircraft Composite Structures under High Velocity Loading (14. Impact on Composites)

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Composite materials are increasingly being used for aeronautic primary structures such as wing components or fuselage panels. However, their major drawback is their vulnerability against transversal impact loads, which may lead to fiber/matrix failure. Such loads may arise from numerous impact scenarios, with bird strikes being one of the most relevant load cases. The focus of the current study is on the numerical modeling and simulation of high velocity impact loads from soft body projectiles on composite structures. The explicit finite element software LS-Dyna and Autodyn were selected to perform the simulations using Lagrangian and Smooth particle hydrodynamics techniques and comparison was performed to define the difference between two approaches. This paper demonstrates the accuracy of the methods for bird impact on a rigid target and subsequently it produces the state of the art of the bird strike simulation. The impact on a flat composite rigid plate is studied in simulation, which allows for the validation of the modeling methods. The reliability of the bird model is validated by comparing the numerical result with experimental results of a real bird of similar mass and an impact velocity impacting normally on to a flat rigid panel results are compared in terms of pressure profiles Hugoniot (Shock) and stagnation pressure. The numerical results obtained with refined bird models are presented and discussed. A range of modeling parameters is finally suggested to perform reliable numerical analyses on aircraft structures and a criterion is proposed to select the models for a reasonably conservative approach to the design of a bird proof structure.

Keywords: Damage, Impact, Failure, Bird strike, Aircraft composites, SPH, Lagrangian, High Velocity

7104 | Experimental and numerical study of oblique impact on helicopter blades (14. Impact on Composites)

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This work focuses on the study of medium velocity (>120 m/s) oblique impacts on the lower surface of a helicopter blade. This kind of impact is characterized by the angle of incidence of the impactor (between 10° and 20°). The skin is generally made of two or three plies of glass-epoxy and (or) carbon-epoxy woven fabrics stabilized with a polyurethane foam core.
Given the geometry of the impacted area, the blade is assimilated to a composite sandwich structure. In a previous work, a specific shell element was developed for modelling impacts on woven fabric composite skins made of plies with the same material and orientation. In this work, the specific shell elements are connected using 3D interface elements. As "classic" 3D interface elements cannot be used to connect shell elements, two specific interface element are developed one is based on a 3D volume element, the other on a classical cohesive approach. Each damageable interface element is compatible with the rotational degrees of freedom of shell elements and takes into account the thickness of the woven elements.
A comparison between the two approaches is presented. The numerical results are compared to those obtained experimentally on an instrumented specimen (FBG sensors) and loaded by an impact

7641 | Resistance of Mortar Containing Aggregate Composites to Chloride Penetration (14. Impact on Composites)

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Abstract

This work presents the valorization of waste plastic bottles from polyethylene terephthalate PET to design a composite material “PET-siliceous sand” which will give a lightweight aggregate; hoping to provide solutions to meet both specific and massive applications in the field of construction. Reinforcement corrosion by the chloride attacks is one of the main causes of deterioration of reinforced concrete structures around the world. So, to determine the effect of PET-siliceous sand composite (PSS) on the chloride ion permeability under immersion in 5% sodium chloride solution and sorptivity coefficients of mortar, PSS was added as replacement for conventional limestone aggregate by decreasing the aggregate weights in the ratios of 25, 50, 75 and 100% by weight. Their chloride ion penetration behaviour is discussed by applying Fick’s second law. FT-IR analysis and scanning electron microscope (SEM) were used to better understand the PSS composite microstructure of the mortar. Additionally, the chloride ion penetration depth, sorptivity and apparent chloride ion diffusion coefficients (Da) of mortar tended to decrease greatly as the mixture proportion of PSS increased. Therefore, the use of PSS in mortar composites can be recommended for preventing the chloride-induced corrosion of the steel in various reinforced concrete structures.

Key-words: Composite Materials, Diffusion, PSS, Chloride Ion Penetration, Characterization.

New sessions: Impact and effect of composite materials

7708 | Low Velocity Impact Response of Sandwiches with Micro Lattice Cores Manufactured via Selective Laser Sintering (14. Impact on Composites)

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The lightweight sandwiches obtained with the use of various core materials such as foams, honeycomb, lattice structures etc., which have high energy absorbing capacity and high strength to weight ratio, are suitable for several applications in transport industry (automotive, aerospace, shipbuilding industry) where saving of fuel consumption, load carrying capacity increase, safety of vehicles and decrease of emission of harmful gases are very important aspects. While the sandwich structures with foams and honeycombs have been applied for many years, there is a growing interest on a new generation sandwiches with micro lattice cores. In order to produce these core structures, various production methods were created with the development of the technology. One of these production technologies is an additive manufacturing technique called selective laser sintering/melting (SLS/SLM) which is very popular nowadays because of saving of production time and achieving the production of complex topologies.
The static bending and the dynamic low velocity impact tests of the sandwiches with carbon fiber/epoxy skins and the micro lattice cores produced via SLS/SLM were already reported in just a few studies.
The goal of this investigation was the analysis of the low-velocity impact response of the sandwiches consisting glass fiber reinforced plastic (GFRP) skins and the micro lattice cores manufactured via SLS in order to compare the results in terms of peak loads and absorbed energy respect to the effect of core cell size and cell wall thickness.

The micro lattice cores were manufactured using SLS technology that creates the product drawn by a 3D Computer Aided Design (CAD) software. The lattice cores which were designed as body centered cubic (BCC) model having three different cell sizes (L= 1.25, 2.5 and 5 mm) and two different cell wall thicknesses (t = 0.2 and 0.5 mm) were produced using titanium alloy (Ti6Al4V) powder. During the production of all the core materials, the same production parameters such as laser power, laser beam diameter, building direction etc. were kept constant.
Vacuum Assisted Resin Transfer Molding (VARTM) method was used to produce skin materials, made of glass fibers with [0º/45º/-45º/90º] quadraxial stitched and [Mat] fabrics and of epoxy matrix. The GFRP skins were bonded to the surfaces of lattice cores using a bi-component toughened epoxy based adhesive.
Low velocity impact tests were carried out by a drop test machine with different values of impact velocity in order to analyze its influence. The failure mode and the internal damage of the impacted sandwiches have been investigated using two experimental techniques: 3D Computed Tomography (CT), that allows a three-dimensional reconstruction of the analyzed object, and Infrared thermography (IRT), already used for analyzing the impact responses of aluminium and PVC foam sandwiches. A theoretical approach, based on the energy balance model, has been applied to investigate their impact behaviour. The model parameters were obtained from the measurements carried out on the CT images of the impacted panels and not from the results of static tests, as it is usually done in literature.
The main results of the impact tests are: force-displacement curves, peak force values, absorbed energy and influence of impact velocity. The results were compared according to the effect of cell sizes and cell wall thicknesses.
The obtained results have particular importance for applications that require lightweight structures with a high capacity of energy dissipation, such as the transport industry, where problems of collision and crash have increased in the last years. The use of these sandwich structures can lead to a weight reduction of the vehicles, providing an adequate structural strength under operating conditions.

7777 | Finite element analysis of the effect of shape impactors on the impact behavior of circular notched composite material at low velocity impact (14. Impact on Composites)

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The main goal of the present investigation was the numerical modeling of the effect of different shape impactors animated with two speeds (vertical linear speed about and vertical rotational velocity of 10 rd/s) and circular notch drilled in the laminate plate to induce damage in composite material subjected to low velocity impact by mean of commercial transient finite element package LS- dyna. The composite material was made of carbon/epoxy with a stacking sequence of [(0/90)]6s .The stainless steel material was used for all impactors. The composite material was subjected to four different shape impactors (Ball, cylinder, truncated cone and cylinder with hemispherical head). A circular notch of diameter 5 mm was drilled in the specimen laminates. All the impactors dropped the composite laminate at the center. Three different velocities were chosen 10 m/s, 15 m/s and 20 m/s. The analysis was carried out using the model MAT-59 for laminate and model Mat-20 for the impactors. The laminate and the impactor were meshed using solid element.
The contact impact load, the impact energy, displacements and the maximal Von Mises stresses were reported as function of the impact time.

7848 | Modification of selected mechanical properties of ablative composites by a selection of components (14. Impact on Composites)

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The aim of the study is to present a program and the results of experimental research of selected strength and resistance properties of thermo-protective (ablative) composite materials, examined according to the procedures specified for construction elements of the aircraft. We prepared composite specimens on a base of Epidian 52 epoxy resin, cured in room temperature with the following curing agents: polyaminoamide PAC, amine Z-1 and TFF. The ablative properties of resins were modified by means of a non modified layered aluminosilicate, Bentonite Special Extra, which contained 75% calcium montmorillonite (MMT). The composites had hybrid reinforcement of aramid (kevlar) fibre of 230 g/m2 basis weight and carbon fibre of 160 g/m2 basis weight for Group One composites, as well as aramid (kevlar) fibre of 470 g/m2 basis weight and glass fibre of 300 g/m2 basis weight for Group Two composites, layered in a composite in an alternate and even way. Phase compositions of specimens and the number of conducted experiments were determined on the basis of an adopted plan of experimental research, i.e. 2-level full factorial orthogonal design matrix for replicated experiments. The elements of the response function were mechanical properties of composites: tensile strength; interlaminar shear strength and impact loading.

7857 | Impact Mechanical Behaviour of Graphite Fiber Reinforced Peek (14. Impact on Composites)

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Peek composites are one of new generation of engineering polymers having high temperature properties, superior specific strength and stiffness. These are excellent materials for structural applications as in aerospace, automotive and chemical industries. One of the critical aspects to consider when using thermoplastics is their vulnerability to out-of-plane impulsive loading, as a result of the reduced thickness of the structural configurations. The impact behaviour of PEEK has not been deeply studied under extreme conditions in terms of high impact velocity and perforation tests are not available in scientific literature. In this work, perforations tests have been conducted on Peek and short fiber reinforced PEEK composites. The study focuses on the effects of reinforcement on energy absorption of this type of lightweight structures.

7858 | Behind-armour blunt trauma: matching measurement to injury using finite element modeling (14. Impact on Composites)

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One of the risks associated with the use of novel light-weight body armour systems is the possibility on injury due to non-perforating impacts. Even if a striking projectile is unable to completely perforate the body armour, the dynamic deflection of the inner side of the armour system might be sufficient to cause serious and even lethal injury. In order to be able to assess this risk on behind armour blunt trauma, different experimental methodologies have been developed, of which the most common is the use of the indentation of a non-perforating impact in a witness backing material (typically clay) in contact with (for bullet-resistant vests) or at a specified standoff from (for ballistic helmets) the armour system under evaluation. For obvious reasons, it is however not an easy task to link these measurements in a backing material to the real risk on trauma. Nevertheless, due to the recent development of reliable finite element models of both the armour systems (generally textile or composite based) and the human body, finite element modeling can be used to try to establish the link between the experimental results from evaluation trials using a witness material, and the actual risk on injury. This work will describe such an approach for both an amour package representative of a bullet-resistant vest and the human thorax, and for an advanced ballistic helmet design and the human head. Starting from different experimental measurement methods for these two systems, both using the traditional witness backing material method and more advanced methods using anthropomorphic test devices (ATD) or so-called 'crash test dummies', reliable finite element models are created for the textile material of the bullet-resistant vest solution and the composite helmet shell. This is followed by virtual experiments where the interaction between the numerical armour solutions and the respective numerical counterparts of the human body (the thorax and the head) is studied in detail. Finally, the results from these virtual experiments will be linked to real-life injuries using the Abbreviated Injury Scale (AIS).

7868 | Low Velocity Impact Response of Carbon/Glass - Epoxy Hybrid Composites (14. Impact on Composites)

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Composite materials are being used in many industrial applications because of their mechanical properties such as high strength with low weights. Especially in marine and aerospace industry, composite materials are crucial parts of the construction. Because of their usage in wide range of applications, the mechanical testing of the composite materials becomes an important issue.
In this study, low velocity impact response of laminated composites is investigated. The laminated composites are manufactured via vacuum infusion (VI). VI is a composite materials manufacturing technique that uses vacuum to apply a compaction pressure on the mold and drive resin into that previously compacted reinforcement material. Three different materials such as carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and carbon/glass fiber reinforced hybrid composites are used in this study. The test specimens are cut with the dimensions of 100x100 mm.
Low velocity impact tests are carried out by a drop test machine with different values of impact velocity in order to analyze its influence. The failure mode and the internal damage of the impacted composites are also investigated. Performing those experiments on CFRP, GFRP and hybrid composites provides information about the effect of hybridization on the impact behavior of laminated composites.
The main results of the impact tests are: force-displacement curves, peak force values, absorbed energy and influence of impact velocity. This study presents a comparison between the impact energy absorption of laminated composites having different reinforcement types such as carbon, glass or carbon/glass hybrid fabrics.

7913 | Numerical modelling of small calibre impact on Dyneema HB80 composite material (14. Impact on Composites)

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The ballistic helmet shells used today are made of a single layer (typically composite material) offering good protection against fragments but only limited protection against small calibre projectiles. However, nowadays, due to changes in the type of warfare and the desired higher standard of protection, an improvement of the ballistic protection offered by helmets is required.
The main idea behind the research here presented is to create a new concept of helmet able to defeat high velocity riffle bullets. The current design considered for this research is based on four layers, where the first layer is responsible for the deformation of the projectile, the second layer for dissipating the energy; the third layer for absorbing the shock wave and the fourth and last layer for stopping the combined movement of the outer layers and the projectile. The main focus of this work is on the behaviour of the second layer, made of a high performance polymer fibre material.
A large number of high performance polymer fibres have been developed since a long time. Recently developed polyethylene fibres like Dyneema are capable of stopping a projectile at relatively low areal densities.
Numerical finite element models using LS-Dyna, were developed and validated. A detailed numerical study on the behaviour of the Dyneema HB80 composite material was made for different thicknesses of the material and also for different projectiles.
The numerical predictions were afterwards compared to the available experimental data.

7931 | Simulation of delaminations induced by low velocity impacts in composites: a sensitivity study to guide an effective use of cohesive elements (14. Impact on Composites)

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Low-velocity impacts (LVIs) can seriously harm composite laminates by causing both intralaminar (fiber failure and matrix cracking) and interlaminar damage (delaminations). Extensive delaminations, although hardly detectable by visual inspections, may reduce the strength of the structure and can lead to its premature failure under compressive loads. In aeronautics, extensive experimental campaigns are used to investigate the effects of low-velocity impacts on composite structures; such experimental effort might be significantly reduced if numerical simulations were used smartly.
Even though numerical simulations of LVI events require both intralaminar and interlaminar damage models, most of the impact energy is spent to produce delaminations, hence particular care must be exerted to define and tune the interlaminar damage model. The cohesive zone model (CZM) is the most used approach to simulate both onset and propagation of delaminations. Nonetheless, recent studies simulating standard interlaminar fracture toughness tests showed that the simulation results are affected by both the constitutive parameters and the size of the cohesive elements.
The authors propose to investigate the influence of the constitutive law parameters and of the dimensions of cohesive elements on LVI simulations results; the study focuses on the variation of delamination shape, depth and extension and compares the related computational costs. A first reference analysis is performed in order to verify the implemented intralaminar and interlaminar damage models. Experimental results of impactor force and displacement time histories, extension and depth of delaminations (obtained by means of ultrasonic inspections) are used as a term of reference for the sensitivity study.
In order to perform LVI simulations in ABAQUS two distinct user-defined material routines (UMAT) are developed; UMATs model the intralaminar behavior in solid elements (C3D8) and the constitutive behavior of the cohesive elements (COH3D8). The intralaminar routine implements a continuum-damage-mechanics-based model with a smeared crack formulation for both fiber failure and matrix cracking; given the aim of the present study, the intralaminar constitutive parameters are kept constant throughout the sensitivity analyses. The interlaminar damage model uses a traction-separation bi-linear constitutive law to describe the initial elastic behavior and the subsequent progressive softening.
The proposed sensitivity analysis wants to point out the relative importance of the intralaminar phenomena compared to the interlaminar ones in low-velocity impact simulations on a carbon/epoxy material system. At the same time the authors aim at defining guidelines for the effective use of cohesive elements for such analyses through a systematic comparison between the numerical results and experimental ones. The study also evaluates the effects of different cohesive parameters on the computational costs of the simulations.

7944 | Low-Velocity Impact of Through-Thickness Polymer Pin-Foam Core Sandwich Panel (14. Impact on Composites)

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This paper presents an analysis on low-velocity impact of through-thickness polymer pin-foam core sandwich panel. The sandwich panel was fabricated by using vacuum infusion process, and it consists of chopped strand mat glass fiber/epoxy skins. The core of the sandwich panel was reinforced with cylindrical polymer pins which rigidly connect the skins. Pins of diameters 1 mm, 2 mm and 3 mm were used and the pins were aligned exactly through the thickness of the panel. Low-velocity impact tests were conducted on the Instron impact testing machine using a rigid hemispherical indentor . When the panels have been impacted the surfaces of the panels were examined to identify the damage and failure mechanisms at different structural configurations of the sandwich panel. It was found that by reinforcing the foam core with cylindrical polymer pins, the stiffness, strength and energy absorption properties of sandwich panels were increased significantly. It was also found that the diameter of polymer pins influences the impact behavior of through-thickness polymer pin-foam core sandwich panels.

7971 | Numerical and experimental studies of IED protective panel subjected to IED blast (14. Impact on Composites)

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Numerical and experimental studies of IED protective panel subjected to IED blast
Composite materials are one of promising structural solutions for aviation, automotive and military applications. They may also be used as protective structures for light armored vehicles. During military operations, both protective elements and structure can be subjected to dynamic loadings such as ballistic impact or blast wave. The reliability of such structures is crucial for military vehicle's occupants safety.
In this paper three potential protective panel configurations against Improvised Explosive Devices are examined and discussed. Specimens were tested in accordance with NATO STANAG 4569 standardization and NATO AEP 55 procedures for level 1 threat surrogate. Each panel is tested against 300 g TNT charge with approximately 750 sphere projectiles sealed in aluminum alloy container. The protective panel had the dimensions of 500x500 mm and was placed at the specified distance from the symmetry axis of the charge. After the experiment, specimens were examined and their back face deformation was measured.
Panels were made of S2 glass/epoxy composite, Twaron aramid fabric/epoxy composite, Dyneema HB50 (UHMWP) and in all cases HTK900H steel. For composite materials 5 tests were conducted: tensile test in direction 1, in plane shear test, interlaminate shear test, compression test in direction 1 and compression in a direction perpendicular to the surface of the layer. For steel a tensile and SHPB tests were conducted.
FEM analysis was conducted using LS-DYNA commercial software. The aim of the analysis was to simulate failure mechanism of different layers and to assess the energy absorbed by each configuration. Steel was modeled using Johnson Cook material model. For composite, the model used was MAT169, that allows progressive failure analysis for composite materials consisting of unidirectional and woven fabric layers. It has four different failure models such as fiber failure, matrix failure and delamination. Constitutive models were evaluated with using triple point bending test trials and showed good agreement with experimental data. Further numerical tests consisted of analysis for different thicknesses for each layer and determining amount of absorbed energy.

Keywords: FEM analysis, IED, STANAG 4569, Light Armored Vehicle, S2 glass, Aramid, Dyneema, UHMWPE

7983 | Impact Behavior Simulation of Polyphenylene Sulfide Composites Reinforced with Carbon Fibers Woven Fabric (14. Impact on Composites)

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Fiber Reinforced Polymer Composites have evolved both in reinforcement and matrix. The epoxy resin was the most common matrix for FRPC but the trend is to replace it with PPS because the mechanical properties of epoxy resin are influenced by the moisture content. The new matrix based on polyphenylene sulphide is less influenced by moisture absorption and the quantity of noxious gases at high temperature is reduced. The specific degradation of FPRC consists of: delamination due to impacts, even at low energies, or overloading of the structure; excessive porosity; water absorption. Evaluation of impact damage mechanism of epoxy composite structures is approached in numerous studies. Because of their increasing utilization in structural applications, the nondestructive evaluation (NDE) of FRPC continues to receive attention for research and development. Due to the heterogeneous nature of composites, the shape of defects is very often different from those typically of metallic material and the fracture mechanisms are more complex. This paper presents the impact behavior simulation of carbon fiber reinforced – polyphenylene sulphide composites at impacts with low energies occurring at different temperatures by using numerical methods based on explicit solvers that involve the time analyses. The principal mechanical parameters of the studied samples were determined using a Dynamic Mechanical Analyzer. Dynamic behavior of CFRP was analyzed in terms of displacement, stresses, strain and impact area. This simulation is validated by using the experimental results obtained in case of the real mechanical tests.

7984 | Analysis of obliquity in the high velocity impact of carbon/epoxy fragments (14. Impact on Composites)

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The aeronautic industry permanently seeks to optimize structural components due to the high requirements demanded to the aircrafts for both safety and reliability. Furthermore, high fuel prices constantly motivate structural solutions in order to reduce the weight of the aircraft, which matches with the social challenge of achieving a more sustainable transport.

Among all the loads to which an aeronautic structure is subjected, impact is one of the most concern, especially since the widespread use of composite materials; these materials have exceptional specific mechanical properties, but low impact strength . Currently the use of composites reaches about 50% (by weight) and one of the reasons which have limited their use beyond this percentage is its low impact resistance.

Impacts on the structure can be caused by quasi-non-deformable bodies (metal fragments), or highly deformable (hail, bird). Apart from these, which have been studied in some depth, there is another kind of impact, virtually unexplored but which pose a current problem, which are impacts of fragments of carbon/epoxy laminates (CFRPs). Turbines and turbo-prop engines made of CFRPs have numerous rotating components that may come off and impact against the fuselage of the aircraft. In addition, new developments in civil aircraft propose the use of open rotor engines (due to its higher efficiency) which have CFRP blades that could break and hit the fuselage, also made of CFRP.

In this work a numerical analysis of the impact of fragments made from carbon/epoxy laminates is carried out. Fragments of different geometries are virtually launched against a rigid plate in order to measure the induced force history, at different impact velocities and with different trajectories. This last parameter is of great importance since a small change in the fragment trajectory (far from the perpendicularity) could promote a very different induced force.

In order to model the behaviour of the composite laminate under impact, a validated model will be used, which includes both intra-laminar and inter-laminar damage mechanism. The first one will be implemented in a user subroutine, whereas the second one will be implemented by means of cohesive interaction.

This work will contribute significantly in the description of how composite laminates behave when they are the impactor instead of the target; it will help to explain which failure mechanisms appear, the influence of the impact velocity, the fragment geometry … etc. The results obtained from this work could be of great importance since aircraft designers should consider the impact of composite fragments. Knowing the force history may help the designers to model the force induced is this kind of impacts.

7989 | Analysis of the effect of high velocity impact of ice spheres upon the static and dynamic response of carbon/epoxy laminates (14. Impact on Composites)

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The study of composites materials subjected to extreme loading conditions such as crash, impact, or explosion, has become relevant in aerospace and aeronautic industries, due to its usage is spread in these industries and the possibility of occurrence of these conditions. During flight, landing and take off

aeronautics structures can be subjected to several types of loads, in particular impacts. It may cause different kinds of damage in composites, depending mainly on the projectile material and form, the velocity and the angle of impact. Steel debris strikes were widely studied, but bird strikes and hailstones are less studied, even thought are considered of high probability and risk.

Due to the problems arising from impact damage in composite laminates, there is a need to develop fast, accurate, cost-effective and non-destructive testing methods to identify this type of damage at an early stage and thus enhance the service life of composite structures. Over the past three decades, numerous researchers have devoted their efforts to developing so-called vibration-based NDT methods. The principle underlying these methods is that a vibration response depends on the physical properties of a structure; therefore, changes that occur in physical properties due to damage can result in detectable variations in the vibration response, which can serve as an indicator of structural integrity.

This work analyses the high velocity impact of ice spheres on carbon/epoxy laminates and examine the effect upon the vibration response and on the residual load-bearing capacity of carbon fibre-reinforced composite laminated coupons.

A pneumatic launcher was used to impel the projectile with its sabot, at velocities ranging from 45 to 200 m/s; a high-speed video camera was used to record the impact phenomenon. In order to study the effect of the ice size and laminate thickness, two different diameters were considered for the ice sphere, 30 and 40 mm, and 2 different thickness (21 and 32 plies) of CFRP were used.

The composite laminate was manufactured from tape prepregs made by Hexcel composites using AS4 fiber and 8552 matrix; laminates size was 300 x 300 mm, and it is clamped in its four sides during the impact. After impact the composite panels were inspected using the B and C-Scan ultrasonic testing allowing the quantification of the damaged area. In order to obtain the modal parameters to examine the effect of the induced damage upon the vibration response, modal testing of the pristine and damaged composite laminates was performed. Tests were carried out under free boundary conditions. The real-time sampled signals (excitation and response) were measured and recorded in form of time series and processed into inertance frequency response function (FRF) data. Comparison method was based in frequency domain and modal domain. In addition to the transverse modes of vibration, in-plane modes were also estimated by exciting the specimen at evenly distributed locations on each lateral side.

The effect of high velocity impact of ice on the vibrational response of laminated composites is also examined by using a numerical approach. The results allowed for conclusions to be drawn regarding the influence of the induced damage upon the vibration response. Pertinent correlations with residual bearing capacity are also presented and discussed.

8046 | Numerical study of carbon/epoxy woven laminates submitted to equienergetic impacts. (14. Impact on Composites)

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Aeronautic and aerospace industries are continuously increasing the use of composite materials, which nowadays represent more than 50 % of aircraft structures weight. High strength-to-weight and stiffness-to-weight ratio of these materials allow to reduce significantly the weight, and fulfil the strict requirements of the mentioned industries. Carbon fiber/epoxy laminates are the most used composite material in aircraft structural applications because their proper combination between mechanical properties, high resistance to corrosion and fatigue, and low density.

Due to the use of these materials in primary structures they usually are exposed to the elements and to occasional impacts, therefore it is necessary to understand how composites behave during their service life when they are subjected to different types of loads. Impact vulnerability studies of CFRP aeronautic structures are specially important in the design of any aircraft due to the low out of plane properties of these materials. It has been observed that
the response of woven CFRP panels is quite different depending on the impact velocity, thus this type of events can be classify in high and low velocity impacts.

In order to reduce the design costs, it is necessary to obtain numerical tools capable of predict the vulnerability damage with low computational effort; 3-D finite element model, based on continuous damage model, are able to predict damage on composite laminate under impacts loads at the expense of a high computational effort. Some authors have explored the capacity of neural networks to obtain the response of the materials under the impacts, but the data provided by these models are limited and sometimes not enough to achieve a proper design of the structural elements.

This work proposes a numerical approach, based on finite elements methods, to predict the response of carbon/epoxy woven laminates under low velocity impacts and study if the mass of the impactor plays any role on the laminate damage for different cases in which the impact energy is the same. The material model for the laminates takes into account different intralaminar failure mechanisms and the use of cohesive interactions to reproduce the inter-lamina failure. The numerical simulations are compared with available experimental results of drop-weight tower test, where impacts on different thickness laminates, at constant energy, were performed varying the impact velocity and the impactor mass.

8048 | Optimization of the composition of ceramics Al2O3 and aramid fabric Twaron T750 in terms of stab resistance. (14. Impact on Composites)

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In this article there is shown the problem of stab resistance of the soft body armor. Most of the bullet proof armour, which are used by uniformed forces can effectively save officers from small pistol bullets. Simultaneously that kind of armor is not effective while situation, in which attack is coming from melee weapon such as knife or spike. This differences are caused by the fact that physical phenomena during hitting a knife and bullet are unlike. Here, the most important aspect is density of the energy on the tip of object, as well as its hardness. Bullets consist of brass jacket and lead core (unless it is the armor-piercing projectile). Knife, used for experiment has parameters according to the NIJ Standard 0115.00. It is made of tool steal which yield strength is equal approximately 2000 MPa and its hardness ranges between 55 HRC to 66HRC.
As a base point there has been used experimental test. Provided solution made it possible to type composition, which was able to hold the knife in its area. This means, that the knife neither penetrate the fabric nor bounced elastically. Provided experiment was the starting point for iterations and other

considerations, because all of the elements were damaged or destroyed, so all phenomena accompanying to the knife hitting, occurred. Worth mentioning is also fact, that the knife did not abandon the composition, so the measurement of parameters such as depth of penetration and amount of cut layers is facilitated.
The experiment was provided with usage of pneumatic cannon, with which the knife was launched to the sabot made from low density foam. During hitting the composition, knife had kinetic energy equal 65 J and velocity 100 m/s. There were two ways of measuring the velocity: laser gate placed in muzzle of the barrel and high speed camera Phantom V12. Second method was also used to record the hit, with speed 20000 frames per second.
Composition consists of 4 millimeter hexagonal layer of ceramic Al203, with side 11.5 mm, and from six layers of aramid fabric Twaron T750. All lawyers were placed on the backing material.
There has been conducted numerical model, which reflected the experiment. Model is based on manufactures' cards. To perform model of ceramic there has been used the Johnson Holmquist material. Ceramic was modeled with fully integrated finite elements. To capture all existing physical phenomena, architecture of aramid fabric was conducted with usage of sub bundles, which here represent roving bundles. Every roving bundle was modeled with 9 beam elements. This solution facilitated capturing phenomena such as: sliding, tiring, cutting and flattening of the bundles as well as fitting them to object geometry.
The process of optimization was conducted In two separate ways. In first, this process concerned the space dimensions of ceramic hexagonal plate, due to eliminate bending in the plate. In the second solution, composition was optimized by layers of dry aramid fabric, due to ensure appropriate level of penetration, which cannot exceed acceptable threshold, from NIJ Standard 0115.00.
Last point of concerns was optimization of the whole composition by mass, remembering about above mention data (which result from optimization structure by dimensions and amount of layers)

8058 | Numerical simulation of rigid body impact on airboat's composite bottom coating (14. Impact on Composites)

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Special boats type airboat are widely used to quickly move around water or swamp of unknown nature and bottom and to reach areas in tough terrain. To provide adequate protection of airboat's aluminum hull, outer coating layers are used. One of possible solutions is layer made of composite material. Due to operating conditions, the possible solution can be glass fabric reinforced vinyl ester resin.
This paper presents numerical simulation of damage initiation, progression and material failure during 3-dimensional elasto-plastic deformation of a fiber glass reinforced vinyl ester composite impacted by a low speed rigid body. The material is orthogonal laminate with ply configuration (0/90)n. The matrix is made of vinyl ester resin Firestop 440. The matrix is reinforced with multiaxial layer fabric GBX 600 stitched with polyester (manufacturer DIPEX), weight 600 g/m2, warp/weft 300/300 tex. Numerical problem is solved using Finite Element Method (FEM). The model is prepared using HyperMesh basing on geometry provided by airboat's manufacturer. Numerical simulation of impact is performed using the LS-Dyna software. The composite is modeled using MAT169 material implemented in LS DYNA. The material has four different failure models such as fiber failure, matrix failure and delamination. Model formulation is based on theory proposed by Hashin. Constants required by the constitutive model of material were determined during experimental tests held in Department of Mechanics and Applied Computer Science. For the purpose of the analysis a total number of 5 tests were performed: tensile test in direction 1, in plane shear test, interlaminate shear test, compression test in direction 1 and compression in a direction perpendicular to the surface of the layer. The material model was validated using experimental data from triple point bending trial.
The numerical analysis was performed to simulate rigid body impact on the composite structure. The goal was to define the minimum thickness of outer protective layer made of composite, which have a sufficient strength for impact load. As a result, a computed time histories of the loads acting on the specimen were obtained. Failure due to impact was observed. Stress maps for each composite layers were plotted. The analysis allowed in-depth understanding of rigid body impact on the composite. Various damage and failure modes in the simulation agree qualitatively with those observed during airboat's operation.
Keywords: airboat, FE analysis, glass reinforced vinyl ester composite, LS-DYNA, impact on composite

8067 | The oblique impact response of composite sandwich plates (14. Impact on Composites)

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Sandwich structures are of particular interest and widely used, because they result in lightweight structures with high flexural properties. In high-performance engineering applications such as aerospace and aircraft applications, sandwich structures with laminated face-sheets bonded to honeycomb or foam core, are extensively used.

During their operating life, composite sandwich structures can be subjected to complex loads. Specifically, low-velocity impacts can lead to a reduction in their structural stiffness and strength, with barely visible damage on the composite face-sheets; however, because of their unpredictable nature, not all impacts are perpendicular to the composite face-sheets, and thus oblique impact can occur.

The aim of this work is focused on the experimental and numerical study of oblique impacts on composite sandwich structural components. As a first approach, an oblique impact on a composite sandwich plate will be modelled using Abaqus/Explicit code. In order to validate this model, experimental oblique impact tests will be carried out using a drop-weight tower. Once validated, the model will be used to study the effect of oblique impacts on the structural response of composite sandwich plates.

8160 | Experimental and computational investigation of low velocity impact damage of flat and curved CFRP composite laminates (14. Impact on Composites)

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Through-the-thickness direction behavior of composites has always remained a major weakness despite the advancements in composite technologies, mainly caused by weak transverse properties and unique damage characteristics of composites. Internal delamination followed by matrix cracking is the distinctive damage mode for low-velocity impacts. Past studies focused on developing improved damage resistance properties, dynamic response and damage prediction methods. Ultimately, a good correspondence has been achieved for post-impact damage footprints of advanced simulations and tests. This paper focuses on process of delamination during a low-velocity impact computationally and experimentally. Finite element simulations are conducted using cohesive elements between layers to model delamination and a user written subroutine to model ply failure in ABAQUS/Explicit. Experiments are conducted with a 1 million fps ultra-high speed camera and DIC technique to record dynamic stress fields and damage progression during impact. The results of the simulations are compared with the experiments. Furthermore, the effect of curvature on the composite failure process and delamination footprint is assessed.

8212 l IMPACT AND POST-IMPACT BENDING BEHAVIOR OF SANDWICH STRUCTURES (14. Impact on Composites)

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The goal of this paper is the comparison of two different sandwich structures subjected to impact, and post-impact forces using a slightly modified version of the ASTM D7136 Standard test method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop Weight Impact Event Test method and the ASTM C393 Bending test method with the test parameters and specimens also complying with the ASTM D790 Bending test Method.
The Sandwich structures were composed of a two layer biaxial fiberglass facing with one structure with a Divinycell® core and the other one with a CoreCork® core, in order to compare the behavior of both core types to impact events.
Results indicate a similarity in results between the two cores, since while the Divinycell® core sandwich structure presented a better behavior than the CoreCork® core sandwich structures, the differences were statistically insignificant.
This work was part of a bigger study on composites to determine the suitability of cork composites as a core component of sandwich structures.

8227 l Analytical impact response and damage of composite laminates under in-plane loads with various boundary conditions (14. Impact on Composites)

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Recently, the author have published a paper titled as ‘analytical and experimental studies on the low-velocity impact response and damage of composite laminates under in-plane loads with structural damping effects’. In the paper, low-velocity impact response and damage of composite laminates under in-plane loads were analytically and experimentally investigated. In the analysis, the author proposed a modified laminate theory including in-plane pre-strain effects and developed a finite element program to analyze the structural behavior of the composite laminates subjected to the low-velocity impact including the geometrical nonlinear effect and structural damping effect. The analytical and experimental impact behaviors were compared at various impact energy levels for the cases with an initial in-plane tensile load and a compressive load, as well as the cases without the initial in-plane load. The study showed a good correspondence between the analytical and experimental impact force histories.
In this study, the author will introduce the finite element formulation process again and use the finite element program to analyze impact response of composite laminates under various boundary conditions including simply supported and clamped with/without sliding movement at the boundary edges. Analyzed impact force and central deflection histories and maximum strain distributions will be compared each other to investigate the effects of geometrical large deflection and in-plane preload according to the various boundary conditions. The comparison between geometrical size/boundary condition of laminate and analytically estimated damaged area will be performed.

8230 l An Advanced Multi-scale Model for Composite Impact (14. Impact on Composites)

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Key words: impact crashworthiness FEM multiscale composite

Laminated Fibre Reinforced Polymers (FRPs) are gaining popularity in industries thanks to their outstanding weight specific mechanical performance. The state-of-the-art Boeing 787 Dreamliner aircraft, released in 2011, utilises advanced composites for about 50% of deadweight; the first mass-produced carbon composite car - i3 has a monocoque that weights 150KG, saving 250KG in comparison to its metallic counterpart. However, owing to the lack of knowledge on the mechanical behaviour of these materials, especially the high speed responses, the conventional way to solve the problem relies on extensive and costly experimental campaigns.

Therefore, in this study, a reliable virtual design/testing strategy for the impact/crashworthiness of composite structures accounting for the material behaviour at micro-, meso- and macro-levels is developed and implemented into a software package that is widely used by the industry (Pam-Crash). The simulation is validated by coupon characterization tests and impact test on the level of coupon and sub-component. The proposed approach takes the advantages of the hierarchical fashion of the composite structures, granting a sound physical meaning to the whole modelling work from the lowest material scale (fiber, matrix and interface) where properties are characterized by conducting delicate experiments (e.g. matrix nano-indentation and fiber push-in tests). It gives the possibility to i) less conservative designs that will represent decreases in vehicle weight, associated use of resources and gas emissions; ii) a reduction in physical tests and associated costs; and iii) faster (right-first-time) development times and shorter times-to-market of composite products. The overall modelling strategy is:

Micro-level The fiber bundle mechanical response will be obtained by FE analysis of a Representative Volume Element (RVE) of the ply microstructure . Fiber-matrix decohesion is simulated using cohesive elements, while the appropriate constitutive models are adopted to reproduce the plastic deformation

as well as the fiber fracture and matrix crack. This modelling generates the failure locus of the impregnated roving and this information is passed to the mesoscale analysis.

Meso-level The geometry of the woven fabrics is detailed represented using the modeler WiseTex. The cohesive elements are used to represent the interply interface. The normal strength, shear strength as well as mode I and mode II fracture toughness of the interface are obtained from tests. Continuum Damage Mechanics (CDM) is used to describe the homogenized microcracks and to capture the degraded average properties.

Component level The laminate is simplified using shell element that has as many integration points in thickness as the number of the plies in laminate. There are no interplay surfaces. So the virtual delamination on macro-level is described as a stack of shells in the possible delamination zone, bound with bar elements. The damage onset and propagation are captured and simulated using failure locus delivered from meso-level and CDM, respectively.

The aforementioned approach will be finally applied to crashworthiness of an aeronautic component, defined by one of the greatest plane maker. The orientated materials are unidirectional laminates and plain weave laminates.

8244 | Experimental Study on CFRP Strengthened Concrete-Filled Steel Tubes under Transverse Impact (14. Impact on Composites)

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Carbon fibre reinforced polymer (CFRP) strengthened concrete-filled steel tubular (CFST) columns are advanced composite members which can be used in bridge piers, high rise buildings or car parking. However, attention is needed to strengthen/retrofit these members where transverse impact force is expecting to occur due to accidental actions. In this paper, circular section CFST columns are strengthened with externally bonded normal modulus CFRP and tested under drop weight impact apparatus. The results have shown that both concrete filling and CFRP wrapping helped in strength enhancement of impacted columns. The findings have confirmed that CFRP composites can be applied successfully to strengthen CFST columns subjected to transverse impact from vehicular/ship accidents.

8246 | Impact Energy absorption of CFRP-Steel composite tubes (14. Impact on Composites)

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The frontal crash safety and energy absorption of thin walled tubes have been studied in the last decade. With the development of CFRP materials there is a new approach to design light weight vehicular structures to maximise the efficiency. The crashworthiness properties and the energy absorption characteristics of CFRP-steel composite tubes are not fully investigated and there is a need of studying the impact behaviour of CFRP-steel composite. This paper investigates the crashworthiness properties of CFRP-steel composites tubes under axial impact loading. A comprehensive parametric study was carried out to evaluate the influence of steel thickness, CFRP thickness and steel grade on the crashworthiness properties. Understanding of the crashworthiness properties of CFRP-steel composite materials will be helpful to designers to develop efficient light weight automobile structures while maintaining the passenger safeguard.

8302 | Mechanical response of composite laminates at high strain rates: Effect of hostile solutions (14. Impact on Composites)

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The interest in composite materials for hostile environments, as an alternative to stainless or coated steel ones, is becoming common. This phenomenon is consequence of their high specific strength and stiffness, competitive cost, good static and dynamic properties, good resistance to corrosion and simplified fabrication. For example, composite pipes are largely used in the chemical industry, building and infrastructures.
However, the studies presented on the open literature are not sufficient to establish a full knowledge about the effect of hostile solutions on the PMC mechanical properties. For example, it is well known that the composites are very strong in the plane, but with very low impact performance through the thickness. Various types of damages can occur, which are very dangerous because they are not easily detected visually and they can affect significantly the residual properties and structural integrity of those materials. In terms of low velocity impact associated with highly corrosive environments, the open literature shows that the resistance of composite laminates is very dependent of the corrosive environment, exposure time and solutions' concentration. The alkaline solution shows to be more aggressive than the acid solution, promoting the lowest impact strength. On the other hand, a significant effect of the temperature can be found, independently of the aggressive solution.
However, the mechanical response of all materials is sensitive to the rate at which they are loaded. The most widely used technique for obtaining direct determination of material properties at strain rates between 200 and 104 sec-1 is the split Hopkinson bar. In this technique a short material specimen is deformed at a high rate while it is essentially under a homogeneous state of stress. Unlike metals, which have been studied extensively, only a limited amount of information is available on the open literature about the effect of strain rate on the response of composite materials. This information decreases significantly when the composites materials are exposed to the hostile solutions.
Therefore, the main goal of the present study is to evaluate the effect of the hostile solutions on the mechanical response at high strain rates. Unidirectional composite laminates of carbon/epoxy were submerged into hydrochloric acid (HCl) and sodium hydroxide (NaOH), at room temperature, during different exposure time. It was concluded that the corrosive environments affect significantly the mechanical response at high strain rates, but their effects are strongly dependent of the exposure time. The alkaline solution shows to be more aggressive than the acid solution.

8303 | Effect of electrical discharges on the structural integrity of composite laminates (14. Impact on Composites)

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In recent years, there has been a rapid growth in the use of fiber reinforced composite materials in engineering applications and there is a clear indication that this will be continuing. Carbon fiber reinforced composite materials, for example, have been widely used in automobiles, ships, aircraft, satellites, sporting goods and others as consequence of their stability, light weight and high stiffness. Particularly, in the automotive and aerospace industries, the use of composites is justified by reducing the structural weight with consequent fuel saving and improving the performance.
However, the poor tolerance to accidental low velocity impacts of composite laminates is yet a limitation to their use in many industrial applications. Various types of damages can occur, which are very dangerous because they are not easily detected visually and they can affect significantly the residual properties and structural integrity of those materials. These damages, and consequently the residual properties, can be affected significantly by the environments that surround the composite materials. Lightning, for example, can induce damage on an aircraft structure by melting or burning at lightning attachment points, resistive heating, magnetic force effects, acoustic shock, arcing and sparking at joints, and ignition of vapors in fuel tanks. The main focus of direct lightning strike threat studies to date has been on its potential to arc and generate a spark (ignition studies). However, little research in the public domain has been done in order to assess the potential losses in structural integrity of the CFRP structure due to the lightning strike damage. Therefore, the main goal of the present study is to evaluate the effect of the electrical discharges on the impact strength. For this purpose, unidirectional and multidirectional carbon/epoxy laminates were exposed to an electrical current, at room temperature, during different exposure time. It was concluded that the electrical current affects the impact response, but its effect is dependent of the exposure time.

8391 | A dual-scale modelling approach for multi-layered, multi-directionally reinforced laminated structures subjected to impact loading (14. Impact on Composites)

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Fibre reinforced polymers (FRP) exhibit exceptional mechanical properties given their comparatively low mass density, which makes these materials very attractive for utilisation in high-performance aerospace applications. The numerical simulation of the mechanical behaviour of large FRP systems and structures comprised of numerous laminae cannot include the kinematic modelling of individual plies using one or more solid finite elements through-thickness of each ply. As a result, a dual-scale modelling approach has been developed to simulate the homogenised macroscopic response of several plies within one solid finite element. This approach allows for the evaluation of delamination at macro scale by taking into account the out-of-plane stresses in the laminate coordinate system. The in-plane failure modes fibre rupture, fibre kinking and inter-fibre failure are addressed at meso scale by evaluating the material exposures of the corresponding failure modes with respect to each ply's material coordinate system. The damage evolution process corresponding to each failure mode is hereby not enforced by a prescribed function, but uses the respective failure envelope as an energy dissipation potential. Hence, damage propagation is driven entirely by the rate at which the failure envelopes are exceeded.

8499 | MAGNETOHYDRODYNAMICS AND COUPLED ELECTRICAL/THERMAL/MECHANICAL FINTE ELEMENT SIMULATION OF LIGHTENING STRIKE EFFECT ON COMPOSITE PANELS (14. Impact on Composites)

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A lightning strike is a plasma, made up of high temperature and fast moving electrons (30,000°C, 5,000 m/sec), conducting significant energy within micro-seconds (40k-200k Joule/Ohm). Lightning strikes have a significant impact on any structure they strike; resistive heating, magnetic forces, and overpressure. The recent simulation of lighting strike effect ignores the thermal plasma part, applying the electric current directly on the composite panel. A novel numerical technique is developed to simulate thermal plasma on composite structures (waveform-B) based on Magnetohydrodynamic theory. This technique is sequentially integrated with fully coupled mechanical-thermal-electrical finite element analysis to investigate the design variables space that can affect lightning strike damage on epoxy/graphite composite panels. The mechanical finite element module uses the cohesive elements/surface approach to model delamination of composite panel. This paper is the first full virtual simulation of the lighting strike effect on composite panel.

8610 | THE STRAIN RATE EFFECTS ON THE COMPRESSIVE BEHAVIOR OF WOVEN CARBON/EPOXY LAMINATES (14. Impact on Composites)

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This paper presents an experimental investigation of the strain rate effects on the dynamic behavior of woven carbon/epoxy composite laminates. Specimens were manufactured using the Resin Infusion under Flexible Tool (RIFT) process. The specimens were tested under compression loads at different strain rate levels using an in-house Split Hopkinson Pressure Bar (SHPB) testing apparatus. The lamination angle was varied from 0 to 90 degrees in order to investigate its influence on the dynamic behavior of composite specimens. The preliminary results indicate that the dynamic behavior of these composites is dependent on both lamination angle and strain rate effects. The proposed testing programme provides an experimental database for the development of failure criteria for spacecraft composite structures subjected to extreme loading conditions.

8656 | Effect of binder viscosity on granulation mechanism in a high intensive mixer and physical properties of

geopolymer/granule composites **(14. Impact on Composites)**

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High intensive mixer is granulation processing equipment through the elastic behavior of the experimental variables on changes in the physical properties of the granules. Many studies have been conducted. In this study, Fluidized-bed coal fly ash generated by combustion in a circulating layer granulation mechanism. Three kinds of alkali activator are different from each other, each having a viscosity of granulated showed different behavior, thereby analyzing the granule size distribution of growth stage and were divided into three stage. In addition three type of granule using fly ash were assessed. The properties of geopolymer/granule composites were analyzed as function of size of the granules and molar concentration, as well as the molding pressure. The physical properties analyzed compressive strength and density of the geopolymer composites containing the various granules.

8682 | A STUDY OF SCALING EFFECTS IN FILAMENT WOUND GRE TUBES SUBJECTED TO LOW VELOCITY IMPACT (14. Impact on Composites)

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1 General Introduction

Scaling effects in thin walled glass reinforced epoxy filament wound cylindrical tubes with [±55º] layup subjected to low velocity impact are presented in this work. Recently scaling effects are studied for such specimens under indentation load . It has been observed that behavior of GRE tubes scales well to certain extent [1, 2]. It has been already established that behavior of laminated tubes under impact can be approximated with their indentation behavior [3]. Since indentation results are already published, experiments under impact loading are carried out in this work as a logical next step to understand adherence of their behavior to scaling law, if exists. Scaling studies on behavior of thick walled GRE tubes under indention and impact type load has shown substantial compliance to the scaling laws [4, 5] where authors used only two scales in their experiments on thick walled tubes though.
Purpose of this experimental work is to scale impact force and energy behavior of thin walled GRE tubes to show these response parameters can be estimated for large structures by using results from a model test.

2 Formulation

Bucking pi theorem is used to establish non-dimensional relation between input and output for GRE tubes subjected to indentation load [1, 2]. This formulation is adapted here to develop non-dimensional relation when these tubes are subjected to impact load.

3 Experimental Set up

[±55º] cylindrical GRE Specimen for four different scales (n=1/4, ½, ¾, and 1) are used in the experiments. The geometric dimensions are scaled. Impact tests are carried out on Instron drop weight impact tester. Required parameters including force, displacement, time and energy are recorded with the help of integrated Instron data acquisition system and software. Damage initiation and growth due to impact is monitored with the help of an upward facing mirror placed inside the tube during the experiment and aligned with the indenter location. Videos for all scales are captured for post experiment analysis and for the measurement of the damage growth reflected by the mirror.

4 Expected results

This work will present experimental results including slope of force displacement relation, Energy absorbed by the specimen and permanent deformation experienced by each specimen. Damage initiation and growth with respect to displacement, force, energy and time will be plotted and scaled to understand if there exists a scaling law for these parameters for thin walled GRE tubes.

5 References
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8698 | Tribological properties of polymer-ceramic composites under dry sliding and artificial saliva lubrication (14. Impact on Composites)

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Presently, the implantology is the most dynamically developing domain of dentistry which presents one of the most important part of the esthetical dental. The treatment by dental implants subjects constant improvements in range of surgical technique, prosthetic technique and materials, which implants are executed by. The purpose of the hereby work is to present results of reasearch on generally applicable materials in dentistry. The research carries for the composite which consists of methyl dimethacrylate (about 18%), copolymer and SiO2 (about 82%). Samples from oxide of zirconium was covered by this composite. The particle size of unorganic composite's filler took away 10-100 nm. The topography and surface analysis was evaluated by scanning electron microscope and profilometer. The tribological research was carried on ball-on-disc and pin-on-plate apparatuses. The tests was conducted for dry and lubricated friction conditions with artificial saliva. Balls and pins from oxide of zirconium and oxide of zirconium layered by ceramic was used as counterspecimens. Research has shown that counterspecimen's material and kind of friction pairs effected on wear mechanism.

8887 I Impact damage observations of CFRP composite laminates by using X-ray Computed Tomography (14. Impact on Composites)

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In this study, carbon fiber reinforced plastic (CFRP) composite laminates were fabricated for drop-weight impact tests with the impact energy varied at 4.26, 8.53 and 12.79J. X-ray CT images of the present CFRP laminates and damping CFRP laminates with impact-induced damages were obtained. From the CT images of the present specimens, so-called damage volumes were defined and quantitatively acquired by using the image analyzing software (simpleware ver.6). Some positive co-relations between the energy absorptions and the damage volumes were observed. In addition, by using the present CT images, damaged CFRP laminate analytical models, which had stiffness reduction regions as one of damage modeling schemes, were also proposed and their usability was partly shown from some numerical results by using finite element analysis (FEA) along with impulse hammering modal test results, although further better analytical modeling schemes for damaged CFRP laminates might be found out.

8943 I Impact properties of thermoplastic high performance woven composites with Poly(ethylene 2,6-naphthalate) (PEN) matrix. (14. Impact on Composites)

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Reinforced thermoplastic composites offer the aerospace industry opportunities to couple structural performances to weight and cost savings and to a more environmental oriented technology with respect to thermosets. Thermoplastic polymers have increased impact resistance, higher damage tolerance and interlaminar toughness due to the presence of the amorphous phase that can retard the crack propagation and allow larger deformations. Among them, Poly(ethylene 2,6-naphthalate) or "PEN" is an affordable high performance polymer (when compared to PEEK and PEI). It has a glass transition temperature higher than 120°C and its melting temperature is around 265°C, which reduces the power requirements for its processing. But despite that, only limited literature is available on the use of such polymer in composite applications.
In this work, we study the impact properties of composites laminates, employing PEN polymer as a matrix. Three typology of fibers are considered: carbon fibers, polymeric (aramid) and mineral (basalt) fibers. For each type of fiber, the composite plates were manufactured by using the film stacking technique where 8 layers of balanced plain weave fabrics (0°/90°) were intercalated with films of amorphous PEN polymer. Those laminates presented very low void content and good fabric impregnation, as confirmed by the morphological analysis performed with SEM. The impact properties were studied by means of drop-weight impact tests. Several energy levels were tested and also different fiber volume content was analyzed for each type of reinforcement. Results of impact damage and impact parameters are discussed for all configurations.
This study has been carried out with financial support from MIUR Ministry (Italy) within the TECOP project (PON02_00029_3206010).

9067 I Theoretical foundations of splats formation at impact of decamicron-sized porous composite particles "liquid binder – solid ultra-fine inclusions" onto substrate (14. Impact on Composites)

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The use of composite powders (WC-Co, TiC-NiCr, Cr3C2-NiCr, etc.) in thermal spraying presents a promising strategy in formation of wear- and corrosion resistant coatings. The high volume content of ultra-fine carbide inclusions in the cermet particles (50-80%) leads to a high viscosity of the binder melt with high-melting solid inclusions suspended in it. That is why takes place a low value of deformation of the quasi-liquid particles impinging onto the substrate or onto previously deposited coating layer. All these explain why plasma-sprayed cermet coatings have a comparatively high porosity at the interfaces between individual splats and at the coating-substrate interface. In addition to aforesaid, at fixed volume concentration of carbide inclusions in cermet particle, their porosity and size of inclusions play a key role under splats formation.
The 'quasi-liquid cermet particle — base' interaction process, in the stage of viscous inertial spreading, generally follows one of the four basic scenarios: 1 — flattening the cermet particle on the solid surface with simultaneous solidification of the binder melt followed by subsequent cooling of the formed splat; 2 — flattening the cermet particle on the surface with simultaneous solidification of the binder melt and partial submelting of the substrate in the contact spot of the particle with the substrate, followed by subsequent solidification of the melted substrate layer and cooling of the splat-base system; 3 — complete flattening the particle on the solid base/substrate followed by subsequent cooling and solidification of the spread layer; 4 — complete flattening the particle with simultaneous partial submelting of the base/substrate, followed by subsequent cooling and solidification of the spread particle and the near-surface melted layer in the base.
Theoretical analysis of splat formation at quasi-liquid porous cermet particle "melted binder — ultra-fine solid inclusions" impingement onto substrate was carried out for the 1st and 2nd scenarios taking into consideration the key physical parameters (KPPs) of particle–substrate interaction: temperature, velocity and size of cermet particle, substrate temperature, volume concentration of ultra-fine solid refractory inclusions finely dispersed in a liquid metal binder as well as the inner porosity of the cermet powder particles.
Using the obtained solutions, as an example of cermet powders WC-Co and TiC-NiCr, we performed the calculations which have demonstrated the possibility of formulating adequate requirements on the KPPs of the spray process in designing a technology for spraying cermet coatings with predictable

splat thickness and degree of particle flattening on the substrate, and also with desired contact temperature at the coating-substrate interface during the formation of the first coating monolayer.
The theoretical foundations developed, in our opinion, will further stimulate a more in-depth experimental study of the formation process of cermet splats under full control of KPPs. The latter will in turn allow scientific substantiation of the technological niches of the various methods of thermal spraying of wear- and corrosion resistant cermet coatings. Besides, the obtained results may prove useful for specialists in the field of thermal and, in particular, suspension plasma spraying of nano- and submicrometer structured composite coatings intended for various applications.

9089 | Effect of gas pressure infiltration on microstructure and mechanical properties of porous mullite reinforced aluminium matrix composites (14. Impact on Composites)

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The purpose of this work was to elaborate the method of manufacturing of composite materials based on porous mullite preforms infiltrated by AlSi12 aluminium alloy. The process of manufacturing the metal matrix composites by pressure infiltration is the subject of many scientific studies because it is characterized by high efficiency and allows for accurate mapping of elements of shape and surface of elements, while the structure and properties of the composites determine ceramic skeletons. The eutectic aluminium alloy AlSi12 was used as a matrix while as a reinforcement were used ceramic preforms fabricated by sintering of halloysite nanotubes (HNT) powder with addition of pore forming agents as carbon fibres. Aluminium alloy matrix composites were fabricated by gas pressure infiltration of porous mullite reinforcement preforms, using halloysite as a startup material. The quality of the obtained composite material depends on the preform fabrication method. For sintered porous ceramic preforms, the influence of the carbon fibres as a pore forming agent on the porosity has been observed. Simultaneously, a slight effect of the compacting pressure on the porosity of prepared preforms has been also noticed. Geometrical dimensions and masses of the obtained ceramic materials measurements allow to conclude that there is a possibility to manufacture preforms, based on the presented method, with 70% porosity. The investigations of the fracture topography show the proportionate arrangement of canals arisen after the degradation of carbon fibres and the presence of micro-pores around the ceramic particles. Metallographic investigations has shown that infiltrated composites are characterized by the percolation type of the microstructure, a very homogeneous distribution of the mullite phase and the absence of unfilled pores. It has been proven that the developed technology for obtaining porous ceramic preforms with the use of sintering of halloysite powder with the addition of carbon fibres, as the pores forming agent, provides the required structure and properties and for this reason it can find practical application. Furthermore the obtained materials can be a cheaper alternative for widely used preforms based on ceramic fibres.

9100 | Enzymatic grafting: A Novel Approach to Develop Multifunctional Materials of Interest (14. Impact on Composites)

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Today more than 99% of plastics are petroleum-based because of the availability and cost of the raw material. The durability of disposed plastics contributes to the environmental problems as waste and their persistence in the environment causes deleterious effects on the ecosystem. Environmental pollution awareness and the demand for green technology have drawn considerable attention of both academia and industry into biodegradable polymers. In this regard green chemistry technology has the potential to provide solution to this issue. Enzymatic grafting has recently been the focus of green chemistry technologies due to the growing environmental concerns, legal restrictions, and increasing availability of scientific knowledge.
Over the last several years, research covering various applications of robust enzymes like laccases and lipases has been increased rapidly, particularly in the field of polymer science, to graft multi-functional materials of interest. In principle, enzyme-assisted grafting may modify/impart a variety of functionalities to the grafted composites which individual materials fail to demonstrate on their own. The modified polymers through grafting have a bright future and their development is practically boundless.
In the present study series of graft composites with poly(3-hydroxybutyrate) (P(3HB) as side chain and cellulose as a backbone polymer were successfully synthesised by introducing enzymatic grafting technique where laccase and lipase were used as model catalysts [1-3]. Subsequently, the resulting composites were removed from the casting surface under ambient environment and characterised by Fourier-transform infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), and X-ray diffraction (XRD) in detail. Moreover, the thermo-mechanical behaviours of the grafted composites were investigated by differential scanning calorimetry (DSC) and dynamic mechanical analyser (DMA) measurements, respectively. In addition, hydrophobic and hydrophilic characteristics of the grafted polymers were studied through drop contour analysis using water contact angle (WCA).
In comparison to the individual counterparts improvement was observed in the thermo- mechanical properties of the composites to varied extent. The tensile strength, elongation at break, and Young's modulus values of the composites reached their highest levels in comparison to the films prepared with pure P(3HB) only which was too fragile to measure any of the above said characteristics. Interestingly, untreated P(3HB) was hydrophobic in nature and after lipase treatment P(3HB) and P(3HB)-EC-based graft composite attained higher level of hydrophilicity. This is a desired characteristic that enhances the biocompatibility of the materials for proper cell adhesion and proliferation therefore suggesting potential candidates for tissue engineering/bio-medical type applications [3]. The present research will be a first step in the biopolymer modification. To date no report has been found in literature explaining the laccase/lipase assisted grafting of P(3HB) [1-3]. The newly grafted composites exhibit unique functionalities with wider range of potential applications in bio-plastics, pharmaceutical, and cosmetics industries, tissue engineering, and biosensors.

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Presentation Method: Oral (Preferred) / Poster

9109 | Influence of SMA reinforcement on the impact resistance of GFRP composite laminates under higher

temperatures (14. Impact on Composites)

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Plain Glass Fiber Reinforced Polymeric (GFRP) laminates and Shape Memory Alloy (SMA) short strips reinforced as randomly oriented GFRP laminates were prepared by hand lay-up method. The composite specimen reinforced with SMA short strips as random orientation placed at 0.75 thickness of the laminate (t) with various SMA fiber wt. % of 2% 4% and 6% were fabricated and drop weight impact tests were conducted at a constant low velocity of 2.80m/s at three different temperatures: 303K, 333K and 363Kfor the plain GFRP laminates (laminates without SMA short strips) and SMA/GFRP laminates (laminates embedded with SMA short strips). The impact damage area was evaluated by using lighting technique and fracture behaviors were analyzed using Scanning Electron Microscopic (SEM) images. Impact energy absorption and damage area due to low velocity impact on the plain GFRP composites and SMA/GFRP composites under higher temperatures were calculated and efficiency of absorption was compared with respect to temperature and SMA wt. percentage.As a result, it was observed that the damage resistance of glass/epoxy laminates is influenced by embedded SMA wires and embedding SMA wires into laminates does not compromise the structure any differently to laminates without wires. In fact, it has been shown that under higher temperature, the SMA/GFRP laminates have a little superior damage resistance the plain GFRP laminates.

9115 | The impact performances of GLARE laminates (14. Impact on Composites)

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An experimental investigation was carried out on the damage resistance to a concentrated quasi-static indentation force and low-velocity impact of four kinds glass-reinforced aluminum laminates (GLARE for short). Compared with the experimental results of the CFRP (Carbon Fiber Reinforced Plastics) laminates, the performance of GLARE was determined. By means of concentrated quasi-static indentation force test, typical force-displacement response, the maximum contact force and dent depth were received. Through drop-weight low-velocity impact tests, impact force histories, indentation depths (through a new method) and dissipated energy were obtained. The test results show that the force-displacement response of GLARE 4 laminates under the concentrated quasi-static indentation force has an obvious flat roof, and the failure is instantaneous, which are different from CFRP laminates. The indention will be visible once the impact happens. C-scan results find that there is no delamination besides the impact area after both the concentrated quasi-static indentation and low-velocity impact. The dissipated energy approximately equals the impact energy.

9137 | Synthesis and properties improve of superhard lightweight composites (14. Impact on Composites)

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The superhard lightweight composite was synthesized by attrition milling, self-propagating high-temperature synthesis (SHS), and heat treatment under nitrogen gas flow/pressure, respectively. Such processing features were conducted for production of the superhard B13C2, c-BN and c-BC2N chemical compounds in composite. These compounds were formed in B4C (70 wt.%)-Al/WC-Co/Cu base composite via SHS and nitrogen gas presence. The powder for composites production as well composite properties were studied by X-ray diffraction (Bruker AXS, D5005), light optical (Nikon CX) and scanning electron (Zeiss EVO MA-15 and ULTRA-55) microscopes equipped with energy dispersive spectrometer (EDS) system. The micromechanical properties of composite phases were characterized by nanoindentation device NanoTest NTX testing center (Micro Materials Ltd.). The qualitative and quantitative X-ray analyzer identified the disappearance of Al and some Al-containing compounds. The Al content was decreased from 26.9 wt.% to 4 wt.% in composite. During SHS the B4C was transformed into B13C2 in quantity of 61,7 wt.% in composite. At follows, during chemical eaching in concentrated hydrochloric and nitric acid of desintegrated and attrition milled powder the B13C2 was increased to 83.8 wt.% and the c-BN content was increase to 2.3 wt.% in powdered compound. The c-BC2N content in composite was 12.3 wt.% after heat teratment under nitrogen gas flow at temperature of 850 °C for 2 h. Such concentration of superhard phases in ceramic-ceramic composite increase the hardness of superhard composit over HV = 40 GPa and indentation modulus over Er = 430 GPa. The composite has high wear resistance and chemical inertness also.

9168 | Dynamic response of Kevlar: Numerical analysis (14. Impact on Composites)

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Composites have become increasingly important in defence and security industries in the last years. The use of these materials in combat helmets, body protections and combat vehicles requires an exhaustive analysis of their behaviour in order to satisfy the safety requirements. One of the main challenges of modern personal protection is the optimization for energy absorption. In this sense, personal protections are usually based on fibre reinforced polymer composites, especially Kevlar fibres due to its high stiffness, light weight and high energy absorption capacity. In order to improve the damage resistant characteristics of composites, it is important to understand their damage behavior under impact loadings. Various researchers [1-5] have developed different techniques to model the impact behavior of composites. These models include various effects and phenomena associated with the impact of composites.
The objective of this work is developing a numerical analysis of f Kevlar under dyanmic loads. Numerical modelling was carried out using the finite element code ABAQUS/Explicit. A user subroutine reproducing the behaviour of Kevlar® has been implemented in the code ABAQUS/explicit. The model was validated with experimental work in the literature showing good accuracy.

Ackowledgements
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9219 | Composite Structural Characteristics Based Progressive Damage Response in Hypervelocity (14. Impact on Composites)

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The catastrophic effects of hypervelocity impacts from orbital debris threatens the success of space missions due to their incredible impact velocity (≥ 5 km/s). This debris is frequently too small to be detected, yet are still capable of resulting in catastrophic failure and posing a serious risk to the operational efficiency of satellites, shuttle modules, and/or crew. In this research, it has been attempted to characterize these type of impacts by their fluidic deformations, intense heating, and damaging shockwave propagation. This approach will include composites that offer a unique alternative to existing homogenous shields due to their high strength to weight ratios, low coefficients of thermal expansion, and potentially shockwave propagation arresting properties.

Experimental testing of hypervelocity impacts is often prohibitively expensive due to its need for multiple stage cannons and specially designed test chambers. Also, traditional implicit codes are unable to simulate such impact scenarios due to their characteristically large deformations and high strain rates in a time marching domain. Therefore, coupled meshless Lagrangian particle and Lagrangian-Eulerian methods have been adopted in order to accurately predict damage propagation throughout the impacted structure. Using this strategy, initial hypervelocity damage investigations have shown that primary shock pressure is transferred through the fibers, whereas the matrix serves to dissipate the shock and resulting stress field. Additionally, as the shockwave passes through multiple composite layers, its transition from fiber to matrix results in reflections and rarefactions that further dissipate the stress. Other unknown individual effects such as weaving density, fiber volume ratio, angle-ply on the shock dissipation, and shock heating affects play a major role in determining the progressive, as well as final damage, product and are currently under investigation by the authors.

As will be documented in the forthcoming paper, the aim of this study is to uniquely make use of the aforementioned coupled computational method to investigate the dependence of shockwave propagation arrest to the particular composite structural properties such as weaving density. In addition, further inquiries into the micro-scale mechanics of anisotropic composites under impact will be made in order to further current understanding of the mechanics governing hypervelocity impacts in composite structures.

9231 | Impact response analysis of fiber-reinforced composite laminates (14. Impact on Composites)

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With different unit, material model and constitutive, impact response of composite laminates subjected to high and low velocity impact is researched correspondingly.The results show that,energy absorption of composites laminates increases with higher velocity of impact; specific energy absorption changes with target’s surface density, which is affected by ply thickness; the target’s energy absorption is decreasing with the increase of layer angle. Under the low speed impact, the maximum contact force, the damage area of adhesive layer, and the displacement of the center of laminated plateincreases with the increasing impact energy, it shows that the impact energy is not directly relative to impact duration and energy absorption of composites laminates. Meanwhile, the results of different geometry shapes of impactor such as hemispherical flat and conical show that, the damage area of adhesive layer and the displacement of the center of laminated plates is biggest under conical impactor, that is smallest under flat impactor.

9288 | Numerical modeling of nonlinear transversal behavior of an aramid yarn (14. Impact on Composites)

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This paper presents a numerical microscopic investigation on transversal behavior of an aramid yarn. Interactions with frictions between single fibers in a yarn have been taken into account. In order to validate numerical calculation, a bloc of about 36500 single fibers was studied in the case of a transversal compression using assumption of plane strain. Results showed that the transversal behavior of yarn is highly non-linear. Transversal modulus of yarn depends on loading. A nonlinear behavior model was proposed for an equivalent homogeneous material. Dependence of the two parameters of this latter on microstructure of yarn is discussed.

9303 | SOFT IMPACT RESPONSE OF LAMINATED GLASS PLATES USING FINITE ELEMENT ANALYSIS (14. Impact on Composites)

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Laminated glass windows consist of one or more bonded polymer interlayers, which minimises the hazards of flying glass fragments and retains an intact glass structure under a blast load [1] and some high rate impacts, such as a birdstrike. This sandwich-based glass structure provides more protection for the civil building façade or aircraft windshields against birdstrike even though the laminated glass withstands lower impact resistance than a monolithic glass plate for the same thickness.

In this paper, birdstrike impact was performed using Lagrangian and Coupled Eulerian-Lagrangian finite element methods on laminated aircraft windshield containing a polyvinyl butyral (PVB) interlayer or a thermoplastic polyurethane (TPU) or both. The finite element modes were developed in Abaqus and key material parameters were calibrated using the laboratory-based tests. Both rubber and gelatine projectiles (14 mm diameter and 30 mm length) were adopted to be the substitute bird using hyper-elastic and Equation of State material models available in Abaqus and impacted onto the laminated glass target (180 mm x 180 mm) with a maximum speed of 230 ms-1.

Simulation outcomes were then optimised and compared to the experimental results obtained using a light-scaled gas gun, which fired the rubber and gelatine projectiles against a laminated glass structure, from which high speed camera and 3D digital image correlation techniques were adopted. The simulation work will eventually benefit the structural design of the laminated aircraft window.

Keywords: Laminated glass window, birdstrike, FE simulation, Coupled Eulerian-Lagrangian

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9334 | Assessment of Damage Tolerance in Composite Sandwich Structures with Cork Film Interleaves (14. Impact on Composites)

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During the last 30 years, composite materials have been used, more and more, as structural and multifunctional components. They are a combination of two or more materials, of different nature, scales and shapes, resulting in a multiphase system where the best characteristics of each one are associated in a synergetic way.
Among different possibilities, cork may be used to create a specific composite system. Coming from the nature, cork is a rather versatile material with specific properties. In fact, it integrates low specific weight with high compressibility, elasticity and flexibility, thermal and acoustical insulation and impermeability. Moreover, cork is an excellent natural energy absorber.
Composite systems are frequently subjected to low energy impact situations (e. g., tool falling on a panel, bird collision with an aircraft…) that create non visible damage. Hence, there is a need to develop damage tolerant structures. Interleaving is one of the techniques used to enhance damage tolerance. Bearing in mind the need for light and damage tolerant structures, there is an eventual potential for the use of cork as a damage tolerant layer, either in monolithic or sandwich composite systems.
The purpose of the work is to study the potential impact, particularly at National level, of solutions using different cork solutions and compare with alternative materials. Hence, the following research questions were raised:
• Customer users’ requirements
• Concept definition
• Evaluation and selection of materials and technologies for a given application
• Structural design
• Testing procedures
The work aims to study the influence of introducing a cork layer in a sandwich structure, particularly w. r. t. bending strength, impact and damage tolerance.
The reference sandwich structure which included two skins of a glass fibre (+/- 45º fabric) reinforced epoxy resin, produced by RTM – Resin Transfer Moulding, and a polymethacrylimide (PMI). In the cork modified sandwich structure two cork agglomerate film layers were added between the facesheets and PMI core.

In this work, four-point bending, compression and low velocity impact tests were performed on specimens from sandwich constructions based on the above sandwich structures.

9523 | DYNAMIC BEHAVIOR OF COMPOSITE DEEP CURVED TIMOSHENKO BEAMS UNDER BLAST LOAD WITH NUMERICAL METHODS (14. Impact on Composites)

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This study focuses on linear dynamic behaviour of composite deep curved Timoshenko beams under the blast loading. Deep curved beams exposed to high stresses and impact loads are studied in depth. Equations of motion of the Timoshenko deep curved beam is obtained by using the virtual work principle and by taking into account the effects of rotational inertia and the transverse shear. Dynamic equations are solved by using the finite difference and the finite element method. Deep curved beam results are presented and compared with the finite element counterparts. Effects of the different boundary conditions, radius of curvature and laminate lay-up order on dynamic responses are analysed. In addition, analyses are repeated for various beam structures for the same material for different radius of curvatures. Finally, dynamic responses of these structures in similar loading circumstances are compared.

5401 | Effects of friction stir welding on microstructure and crystallographic texture of ultrafine grained Al-TiC composite produced by accumulative roll-bonding (15. Joints in Composite Structures)

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In this research, ultrafine grained sheets of aluminum matrix composite (Al-TiC) were produced by accumulative roll-bonding (ARB) technique. As-received, ultrafine-grained aluminium composite sheets were successfully joined by friction stir welding. The Microstructure, crystallographic texture and Vickers hardness in the weld zones were investigated. Electron backscattered diffraction (EBSD) results showed occurrence of dynamic recrystallization and also revealed existence of different orientations within the weld nugget. As a result, Al composite plates dominated by the Rotated cube component. Moreover, in the nugget, a well-recrystallized grain structure having characteristic strong copper and brass texture finally developed. Friction stir welding refined the grain size to 0.7μm from the starting grain size of 3μm. The hardness also improved with the peak hardness being observed towards the advancing side.

6305 | INVESTIGATION NUMERICAL BEHAVIOR OF MECHANICAL PROPERTY OF STEEL BRACE THAT Modified BY CFRP SHEET (15. Joints in Composite Structures)

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Steel Bracing is one of the main elements against vertical loads in building that many researches try to improve its behavior by increasing of ductility, energy absorption and etc. Due to heavy weight materials and more stiffness such as "UNP" and "IPE" steel profile in making them, this paper presents a novel method to introduce a more lightweight section bracing elements with more ductility and energy absorption as steel plate that combined with Carbon Fiber Reinforced Polymer (CFRP). This new model can be effective on steel bracing buckling, in addition it has been improved some of the functional of the brace components. This new brace consists of two separated steel plates which are connected by CFRP sheet to each other. The CFRP is an extremely strong and light fiber-reinforced polymer which contains carbon fibers. By presenting the numerical method is based on computer simulations using finite element software, the brace under cycle loading force was simulated and the numerical results compared with usual steel braces which conclusions will be presented. By this new model, the compressive forces will be omitted which is the sub reason of buckling on braces. On the other hand, it could be lighter than usual braces by improving ductility and energy absorption.
Keywords: Steel Bracing, Carbon Fiber Reinforced Polymer (GFRP), Ductility, Energy absorption.

6838 | Evolution of surface and bulk structures in La-Zr-O/La-Al-O composite (15. Joints in Composite Structures)

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For La2Zr2O7 (P1)/LaAlO3 (P2) composite prepared by aging (100oC/10 h) of the mixture of precipitated La-Zr-O and La-Al-O hydroxides, the thermal evolution of surface and bulk structures in the range of 300-1300oC were investigated by complex of methods. Structural features and disordering of coordination polyhedra in oxides were elucidated by XRD, HRTEM, FTIR, Raman and UV-Vis spectroscopies. The states of Al and La cations were probed by 27Al and 139La MAS NMR. Surface and bulk composition of powders were characterized by XPS and SIMS. For composite, unlike the separated structures (P1, P2), the presence of both phases and their interfaces hampers sintering and favors ordering for the P1 structure and disordering for P2 structure due to specific effect of domain boundaries on defects in oxygen sublattices of these oxides characterized by different coordination of oxygen anions by cations and packing type. Removal of residual surface hydroxyls and carbonates stabilized on La cations could favor coalescence of nanodomains with P1 and P2 structures at high temperature treatment but it seems to be hampered by pronounced difference of La-O coordination numbers -12 for the P2 structure and 8 for the P1 structure. Such a difference can hinder the growth of each phase particles in large aggregates, thus stabilizing porosity and sustainability of the coating layers. This molecular –scale feature of domain boundaries in nanostructured La-Zr-O/La-Al-O composite as well as applied inexpensive method of its fabrication provides required bases for a broad practical application of this material for TBCs.
Acknowledgment. This work was in part supported by the Seventh Framework Programme TEBACRODE Project (grant no. 310750).

7139 | Damage behavior of pin loaded CFRP at elevated temperatures (15. Joints in Composite Structures)

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The stress and damage distribution in a pin loaded hole in CFRP specimens was investigated under thermal load in order to understand the damage behavior of riveted joints in CFRP. Thermal loads play an important role in the design of mechanically fastened joints in automotive body shop applications as the car body has to pass the cathodic dip paint with temperatures up to 180°C in the drying oven. Thus thermal behavior of the joined structures, especially for pierced CFRP parts, has to be investigated as stresses on the joints appear as a consequence of different thermal elongation of the joined materials.
This research presents analytical and experimental investigations to describe damage behavior of CFRP specimen under combined thermal and tensile load. Therefore an analytical tool was developed which considers the calculation of thermal induced internal stresses as well as stresses through uniaxial pin load at varying temperatures. In corresponding experiments a C-fiber epoxy laminate was examined in a double lap shear test at 23°C, 60°C, 100°C, 140°C and 180°C focusing on the damaged area in relation to the pin load. Non-destructive ultrasonic C-scans of the damaged area and microsections were used to detect damage propagation.
It was found out that damage morphology in the CFRP for a certain thermal and mechanic load is unique. Depending on the shown consecutive damage propagation for rising loads it is possible to assign the detected damaged area to a foregone load.

7497 | FAILURE MODE AND ANALYSIS OF BONDED/BOLTED JOINTS BETWEEN HFRP AND ALUMINIUM (15. Joints in Composite Structures)

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Composites are being used extensively in several engineering applications. However, the efficiency of the joints used in joining composites and metals can be improved. To move towards a sustainable and environment friendly future, natural fibre composite material was used. Towards the above objective, research work was carried out for the assembly between a composite and aluminium. Three different joints namely adhesive bonding, mechanical fastening and hybrid joining were considered for the assembly of variable substrates. Two different types of adhesives namely high modulus acrylic adhesive and low modulus rubber adhesive were chosen for the study. Tensile tests were performed to evaluate the joint strength and failure modes for different joining techniques. It has been found that for acrylic type adhesive, adhesive bonding proves to be suitable. The effect of bolting had no significant effect on the joint strength in hybrid joints for the acrylic type adhesive. For the rubber type adhesive, hybrid joint shows better performance than other types of joints. The effect of bolting for rubber type adhesive in hybrid joint significantly improved the load carrying ability of the joint.

7531 | DAMAGE ANALYSIS OF COMPOSITE-ALUMINIUM ADHESIVELY-BONDED SINGLE-LAP JOINTS (15. Joints in Composite Structures)

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Adhesive bonding is a permanent process that uses an adhesive to bond the components of a structure. This bonding process is used to fabricate structures of complex shape that could not be manufactured in one piece, to provide a structural bond that theoretically should be at least as resistant as the base materials. Composite materials reinforced with fibers are becoming increasingly popular in many applications as a result of a number of competitive advantages. In the manufacture of composite structures, although the fabrication techniques reduce to the maximum the connections by means of advanced manufacturing techniques, the use of connections due to the typical size limitations and design, technological and logistical aspects, is still required. Moreover, it is known that in many high performance structures, unions between composite materials with other light metals such as aluminum, for purposes of structural optimization, are required.

This work addresses numerically and experimentally adhesive joints between aluminum and carbon-epoxy composite components, considering different adhesives and geometric conditions. The strength and failure modes are studied, optimizing the geometry and material parameters of the joints. Numerically, the Finite Element Method is used to perform a detailed stress analysis allowing to explain the joints' behavior. The use of cohesive damage models enables predicting the joint strength and creating a simple and rapid design methodology.

7593 | Analysis of Bolt-to-Laminate Interference Friction in Bolted Composite Joint with Interference-fit (15. Joints in Composite Structures)

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Friction is a key element that alters the load transferring in bolted composite joint, especially for interference-fit. This paper presents an analytical model to predict the friction force in CFRP composite joint, which is caused by surface contact between bolt shank and fastener hole with interference-fit. Based on the plane stress analysis in composite laminate, the approximate value of through-the-thickness friction is calculating according to the Coulomb friction criteria. This model takes into account composite material property, joint geometry dimension, interference-fit percentage and friction coefficient. It is found that friction is sensitive to the interference-fit variation in this model, namely the minimal change of interference-fit will lead to extensive variation of friction value. An interference-fit bolt inserting process simulation using three-dimensional finite element analysis (FEA) is conducted to verify the analytical model. During the simulation, the friction value is obtained after the bolt exited the hole in the bottom of the specimen, which the bolt shank contacts with hole from top to bottom. The results of two methods are shown well agreement, but the analytical model is higher than which of FEA with different interference-fit percentages and hole diameters, because of some assumptions in modeling.

7680 | Stress and damage initialization analysis of interference-fit pin installation process in composite laminates (15. Joints in Composite Structures)

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A three-dimensional finite-element model (3-D FEM) is developed to predict the response of interference-fit composite plates during the process of installing the pin into the hole. The model takes into account contact at the interface, the nonlinear shear stress-strain relationship and the progressive damage of the property. To predict progressive failure, the three-dimensional mixed failure criteria combining Hashin and the maximum stress failure criteria are adopted, and the corresponding property degradation rules are conducted. The failure criteria consider a three-dimensional stress field and include out-of-plane failure modes. The progressive damage model is implemented in Abaqus by using a separate subroutine called user-define-field (USDFLD). In the analysis, the material properties depend on several field variables (FV), which separately represent the matrix tensile and compression failure indexes in the transverse direction, the matrix tensile and compression failure indexes in the out-of-plane direction, the fiber tensile and compression failure indexes and the fiber-matrix shear failure index. Three group interference-fit of 0.4%, 0.8% and 1.2% are studied. The damage initialization and delamination onset around the hole are discussed. Numerical and experimental results both show that different interference-fit results in different damage scale. The 1.2% interference-fit causes the maximum damage. And the damage mainly occurs around the hole at the in-plane side. The insertion force and stress distribution around the hole are also predicted and compared with experimental results. Better agreement between experimental results and numerical predictions is observed.

7757 | Experimental Research about the Interface Bonding Performance between CFRP and Steel (15. Joints in Composite Structures)

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Using FRP (fiber-reinforced polymer) to strengthen steel structures has become an attractive method due to their unique advantages including their high strength-to-weight ratio and excellent corrosion resistance. The interface performance between FRP and Steel play an important role in such strengthened systems. In this paper, the parameters such as bond length, bond width, curing temperature and curing time which impact the interface performance have been examined through a series of double shear tests under static tensile loading. Based on the test results, the strain distribution and the bond-slip relationship relating the interfacial shear stress to the interfacial slip is then investigated.

7793 | The effect of titanium bush repairs on the static strength of CFRP coupons and joints (15. Joints in Composite Structures)

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The fuselage of A350 and B787 aircrafts is an assembly of composite stiffened skin panels, which are mostly mechanically connected together. The production process of the CFRP panels sometimes leads to manufacturing defects, due to deviations in the assembly and machining processes. Hence, it is required to have a number of applicable solutions, in order to repair defects/damages (like miss/wrong drilling, etc.). Moreover, the stress redistribution, acting on the holes, and the hole protection from damage, due to the fasteners repeated installation (in service and in production), need to be ensured. In such cases, the common procedure involves re-drilling the damaged plate and installing fasteners with oversized or next diameter codes. Another method consists in re-drilling and inserting a metallic bush in the hole too. This repair approach avoids the use of bigger fasteners and guarantees a higher joint residual strength, by increasing its efficiency.
This paper discusses an experimental investigation on mechanically fastened coupons. Common static tests are analyzed: Filled Hole, Pull Through (head-side) and Single Lap Shear (not supported). Coupons with nominal fasteners are tested in order to collect reference data. Selected holes are repaired using titanium bushes and adopting different installation principles. The aim is to analyze the impact on the static strength of the CFRP riveted samples.
The results show that the laminate lay-up and material properties, of the CFRP plates, have significant influence on the static strength of the coupons. However, the load distribution between the joint parts and the occurred failure modes are strongly affected by the manufacturing tolerances (bush/plate and bush/bolt) and by additional factors as environmental conditions (HW), use of proper adhesive, etc... Therefore, in order to prevent the bush rotation during the hole drilling, to reduce the clearance fit and the hole in-service elongation, the use of an appropriate adhesive is required.
In the case of Filled-Hole coupons, the use of increased bush sizes leads to a reduced ultimate net strength, due to the reduction of the net-section area. However, comparing the coupons with dry installed bushes to those with bonded bushes, these latters show a higher limit load for both the bush disbonding and the final laminate failure. On the other hand, the same coupons with bonded bushes, but subjected to ageing, achieve a lower ultimate net strength, due to the matrix relaxation.
For the Pull Through (PT) coupons, the increased bush size provokes a change in the failure modes: from the fastener in the reference coupons, to the ductile and, then, to the brittle failure of the bush. Furthermore, the adhesive does not seem to add benefit in terms of load transfer. However, in the case of HW coupons, the matrix relaxation seems to increase the PT strength, in contrast with common expectations.
Also in the case of single lap shear (LSJ) coupons, the increased bush size leads to a reduced ultimate net strength, with respect to the reference coupons, due to the reduction of the net-section area. The failure modes are mainly driven by the fasteners. However, for selected series of coupons, the bushing principle provokes an unexpected joint behavior (as plates sliding, tilting, etc.). Increasing the size of the bush a larger surface is in contact with the plate. Hence, the higher load required to reach the ultimate failure results in a higher compressive stress around the hole surface (results proved by strain gauge measurements). In the case of bonding, despite the stronger adhesion and the reduced clearance fit, a lower ultimate strength than the one of the dry assembly coupons is achieved, unless the matrix relaxation was induced by the ageing process.
Hence, this paper analyzes this large experimental database through the comparison with the reference coupons and tries to give some design guidelines for for the repair approaches.

7827 | Comparison of Static and Fatigue Characteristics of Hybrid and Standard Joints for Thick Composite Structures (15. Joints in Composite Structures)

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Materials such as carbon fibre and aramid reinforced polymer composites are now commonly used to fabricate aircraft components such as fuselage skins and formers. Their use has resulted in stiffer, light weight structures with good fatigue durability and corrosion resistance. Metallic structures are suitable for bolted repairs due to their ability to share load among the bolts. Composite materials on the other hand are known to be brittle and thus have less structural efficiency when bolted together. So when it comes to the repair of these composite structures, more work is required to understanding the joint behaviour and failure mechanisms in order to make an optimal and efficient repair. Bonded repairs are far more efficient and they may also avoid additional holes being made to the parent structure. However, the quality of adhesively bonded repairs critically relies on the process control during the repair application. Improper processes may result in a weak bond that is generally not detectable by conventional non-destructive inspection (NDI).
This has led to the investigation of using both bonding and mechanical fasteners to form 'Hybrid Joints' in which fatigue strength is provided by the adhesive, and fasteners withstand the peel stress, as well as provide a failsafe mechanism. Work conducted by the authors in the past has consisted of static and fatigue testing of relatively thin double lap joints in three configurations, firstly only rivets, secondly only bonding, and lastly, both rivets and bonding. Several parameters were considered such as bond strength, initial bondline cracks, the configuration of the fastener array, and so on. Overall, the results have shown that under static test conditions, there was no significant difference between a perfectly-bonded joint and a hybrid joint. However, under fatigue testing it was found that the addition of fasteners in the hybrid configuration delayed the progression of bondline cracking and provided significant fatigue resistance for a bondline containing impurities or voids. This investigation has now resulted in the need to explore the effects of fasteners, bonding and the combination of the two for thicker aircraft structures.
Compared with a single or double lap joint, scarf and step-lap joints are known to be more efficient methods of joining thicker composite adherends together. They are able to restore original stiffness and design strength by evenly distributing the stress along the bond line. Alongside this, they are considered to be flush repairs, maintaining outer surface smoothness for the aerodynamics requirement.
The aim of this study is to provide an adequate comparison between the three configurations to determine whether the relationships seen in thin double lap joints for static and fatigue performance agree with thicker step lap joint configurations. A parametric investigation conducted with the nonlinear 3D finite element analysis code ABAQUS is discussed, taking into account parameters such as the number of plies per step, the step length and the step lap joint configuration. Information on the effects of shear stress distribution across the overlaps is discussed. Results from static and fatigue tests on step lap joints made from carbon fibre/epoxy adherends are presented. Thermal imaging is used to monitor crack initiation in the bondline and delamination in the adherends. It is hoped that this study will aid in the certification for repair of thicker composite structures currently in service with the Australian Defence Force.

7884 | Meshless Analysis of Stresses in a Single Lap Bonded-Bolted Composite Joint (15. Joints in Composite Structures)

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Recent experimental research has demonstrated that, subject to judicious design, a joint that is both bonded and bolted can achieve greater strength than the underlying bonded and bolted joints separately. To date, however, there has been only limited theoretical consideration of this type of joint. Although a few researchers have investigated the adhesive stresses in bonded-bolted joints, the adherend (substrate) stresses have not as yet been studied in detail. This is nevertheless crucial in determining the strength of the joint, particularly in the case of brittle composite adherends. To address this deficiency, we propose a single lap bonded-bolted joint model based on plate theory for the adherends, beam theory for the bolts and a shear lag theory for the adhesive. Nonlinear adhesive behavior and contact are taken into account. The model is solved using the element-free Galerkin method (in particular, the recent moving Kriging approach is used). This provides the advantages of continuous displacement and stress fields as well as facilitating p-refinement. Furthermore, the use of shear lag theory for the adhesive leads to finite stresses at the adhesive overlap edges, minimizing the discretization dependence of the solution. A comparative study is subsequently performed between a bolted joint and a bonded-bolted joint to investigate the effect of the addition of a flexible adhesive layer on the adherend stresses.

7894 | Parametric analysis for stress singularity of interface edge on adhesively bonded joints of GFRP bridge deck (15. Joints in Composite Structures)

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Abstract:

Due to its outstanding advantages of high strength and good corrosion resistance, adhesively bonded GFRP (Glass Fiber Reinforced Plastic) joints have been widely used in application of GFRP bridge deck structures. However, the presence of free-edge stress singularity leads to that the failure often initiates in interface edge of adhesively bonded joint. Therefore, in order to predict accurately this type of failure, a better understanding the characteristic of stress singularity of adhesively bonded joint on GFRP bridge deck is of considerable interest.
Follow the construction feature of the adhesively bonded joint of GFRP bridge deck and the recommendation of published literature, the equivalent mechanics model of adhesively bonded joint is constructed. Firstly, the effect of the material parameters (i.e. the fiber laying angle and the poisson ratio of GFRP substrates, the elastic modulus and the poisson ratio of the adhesive layer) on the stress singularity of interface edge of adhesively bonded joint are investigated using finite element method. The empirical formula for stress intensity coefficient of adhesively bonded joint consisted of a thin layer between two substrates concerning Dundurs parameters (i.e. α, β) is put forward based on the results of parameter analysis. And the results of numerical calculation indicate that the empirical formula can calculate the stress intensity coefficient of interface edge on the adhesively bonded joint of GFRP bridge deck with high accuracy. Then, the effect of geometric parameters (i.e. the chamfers of the substrates near the interface edge, the chamfers of the thin adhesive layer) on the stress singularity of interface edge of adhesively bonded joint are investigated using finite element method. Some suggestions are put forward to minimize the stress intensity coefficient of interface edge of adhesively bonded joint based on the results of geometric parameters analysis. The research results of this paper can provide a reference and guidance for the designation of adhesively bonded joint on GFRP bridge deck.

Keywords: stress singularity; interface edge; adhesively bond joint; GFRP bridge deck; finite element method.

7899 | Tensile Behavior of Double-Lap Joints of FRP Laminates Bonded/Bolted to FRP/Steel Splice Plates (15. Joints in Composite Structures)

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This paper presents experimental and numerical results of double-lap joints of hybrid CFRP/GFRP (HFRP) laminates bonded/bolted to FRP/steel splice plates. Sixteen coupon specimens were prepared and tested under tensile loading. Test variables included two types of double-lap joints (bolted-only and hybrid bonded-and-bolted), three types of splice plates (HFRP, GFRP, and steel), and four types of bolts (stainless steel, high corrosion resistant steel (HCRS), stainless steel wrapped with FRP, and GFRP). The experimental results indicated that the failure of specimens with GFRP-bolt connections was brittle. These specimens failed due to debonding of epoxy layers followed by shearing of the GFRP bolts. Unlike the GFRP-bolt connections, failure of specimens with steel-bolt connections was ductile as the steel bolts exhibited a yield point with a yield plateau. Typical failure modes of these specimens were delamination and tensile failure of the HFRP laminates and shearing of the steel bolts. Specimens with steel-bolt and HFRP-splice-plate connections showed more ductile behavior than the others. The study revealed that ductile behavior of the hybrid bonded-and-bolted joints can be achieved if the strength of bolts is higher than that of epoxy connection. The combined use of HCRS bolts, HFRP splice plates, and epoxy adhesive for joining HFRP laminates may significantly enhance the durability and ductility of FRP structural members. Finite element (FE) analysis of multi-bolt double-lap bonded/bolted joints was performed using ABAQUS. Distribution of bolt-load in the bolted-only and the hybrid bonded-and-bolted joints were discussed. Load-slip curves obtained from the FE analysis were compared against those obtained experimentally and a fairly good agreement was observed.

7932 | The Behavior of Reinforced Concrete Slab-Column Connection Reinforced with Headed Shear Studs Arranged in Orthogonal and Radial Layouts. (15. Joints in Composite Structures)

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Shear capacity of the reinforced concrete slab-column connections can be increased by headed shear studs. These studs are placed vertically in the portion of the slab around the column in two layouts, orthogonal and radial. While the latter is suggested in Europe, the former layout is preferred by construction practice in the North America because of its less complicated installation. Some research indicated that the two layouts are equally effective for providing shear strength to the connections. Other experimental research, however, raised a red flag over the orthogonal layout. For the orthogonal layout, large spacing between adjacent stud rails at the corner of the column may cause the premature shear failure in the connections. This problem may not be noticeable in the experiments that tested slabs with either short-spans or with a high flexural reinforcement ratio. For the sake of public safety, the shear behavior of slab-column connections reinforced with shear studs in these two layouts has to be studied more thoroughly. This paper presents an experimental and analytical study to evaluate the effectiveness of both stud layouts. The experiment consists of three full scale slab-column connections that represent a flat slab structure of 25 ft. (7.62 m) long span. All three specimens are identical in a flexural design, in which the reinforcement ratio is 0.8%. One specimen is built without shear reinforcement, and the remaining two specimens are reinforced with shear studs in the two layouts. A three-dimensional finite element model has been developed in ABAQUS to simulate slab-column connections. While concrete is modeled by 8 node continuum solid elements, rebars and shear studs are modeled by the 2 node truss elements. The parameters of the finite element model are calibrated with the experimental results. The calibrated model is then used to study the effect of other variables on the shear strength and behavior of reinforced concrete slab-column connections reinforced with shear studs.

7960 | Influence of substrates' fibers orientations on the behavior of composite substrates double lap bonded assemblies under impact shear loads (15. Joints in Composite Structures)

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The main concern of this work is the mechanical characterization of the double-lap composite bonded assemblies under impact shear loads. The assemblies were made of unidirectional PEEK/Carbon composites and a brittle epoxy adhesive. The impact shear strength and failure strain were measured experimentally by the Split Hopkinson Pressure Bar apparatus, taking into consideration the set-up accuracy correction by finite element methods. Four configurations of the assembly were considered by maneuvering of fibers orientations of the substrates. Highest shear strength appeared for the joints with longitudinally tougher substrates. The outer and inner substrates appeared to have the same influence. Highest failure strain appeared for longitudinally softer substrates. Adhesive failure occurred for all specimens.

7980 | Analysis of Bolted and Bonded Composite Joint using Experimentally Determined Flexible Adhesive Properties (15. Joints in Composite Structures)

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This study investigates the joining of composite materials using a simultaneously bolted and bonded joint, otherwise known as a hybrid joint. There is a clear benefit for combining the bolt and bond: mechanical efficiency of the bond and the fatigue resistance of the bolt. However, due the considerable stiffness of common industrial adhesives, the bond tends to carry most of the load. In order to achieve desired load sharing between the bolt and bond, it is advantageous to implement a more flexible adhesive to hybrid joint. Preliminary finite element analysis also shows that the flexible adhesive alleviates the stress concentration inside the bond.
Introduction of a flexible adhesive adds considerable complexity to the problem. The stress/strain response of the flexible adhesive is highly nonlinear and can be subjected to large deformation. Initially, tensile tests are performed to obtain the stress/strain response as well as the failure strain. The tensile test also measures the evolution of Poisson's ratio throughout the significantly large strain region. Biaxial testing follows to capture the yielding so that an appropriate yield surface model is defined for the bilinear stress/strain relation. Experimentally characterized adhesive properties are then used to analyze the composite hybrid joint with flexible adhesive. Its performance is quantified and compared to a bolted joint, a bonded joint, and a hybrid joint with stiff

adhesive.

7981 | Numerical analysis of modified CFRP laminate in bearing conditions (15. Joints in Composite Structures)

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Nowadays, there is a tendency to use various materials in the aircraft structures. It is caused by weight and strength optimisation as well as manufacturing and service (including repairs) cost optimisation. Different materials in aircraft structures provide a necessity of joining dissimilar materials such as composite and metallic components. Various techniques are used to connect the skin with the stiffening elements, however, mechanical joints used for decades are proved to be reliable. Strength of composite laminates is dependent on the joint geometry and it is strongly influenced by the laminate lay-up. There are five global failure modes for mechanically fastened composite laminates: net-tension, bearing, shear-out, cleavage and pull-through. The bearing failure is a safe progressive mechanism not leading to catastrophic failure and therefore it is acceptable. Different attempts to improve bearing performance in composite parts are considered by many authors. One of the most interesting solution is bonding thin titanium sheets between composite layers in some distance from the edge of the composite panel in the way that causes gradual load transfer into the composite structure. The main goal of the work is to design a metal-composite mechanical connection with improved bearing performance of a composite panel. The particular tasks of the paper are to study the local phenomena in composite material subjected to bearing load as well as to investigate possible benefits of local laminate modification in the hole vicinity in mechanical joints of composite panels. Different inserts (foils) content is taken into account. Joining panels are made of CFRP laminate and titanium alloy. The finite element analysis is used to solve the problem since some statements are possible to be made without many expensive experimental tests. A deep study of load transfer by means of shear stress and numerical analysis of various locally modified laminate configurations are the principal investigation method. Identification of material properties as well as validation and verification tests using DIC and strain gauges are also performed.

7985 | Damage sizing of thermoplastic bolted joints on composite materials (15. Joints in Composite Structures)

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Composite materials appear to be a promising alternative to metallic materials by lightening structures in many industrial sectors. Moreover, composite thermoplastic matrices have a more adapted cost to the manufacture of parts with large throughput. It also meets the proficiency requirements of end of life products, due to their recyclability. At first, it could lead to hybrid solutions combining composite materials and metal components. The assembly areas can be characterized by mechanical junctions based on rivets, screws or bolts. In these assemblies, the composite material can suffer from specific damages as pull-through failure and delamination which will subsequently decrease the static resistance and fatigue strength of the bolted connections. Most of the studies in this area focused on the holding whereas the number of work on pull-through behavior of bolted composite materials is very limited and more particularly with thermoplastic composites materials. Therefore, there is currently no existing design rule which would enable to predict a bolted fracture based on thermoplastic composite substrates bonds. In this study, we are investigating the pull-through failure of bolted joints in thermoplastic composites. An experimental study of the bolted joint using the 3D image correlation process will be presented. Conical damaged areas under the head of the bolt, as well as the opening angles of the cones, have also been observed. Meanwhile, numerical simulations based on a 3D finite elements analysis have been realized to predict the break out of the assembly plane and have then been compared with experimental results. Finally, a semi-empirical equation predicting the pull-through failure of thermoplastic bolted joints on composite materials has been developed.

8029 | Bearing Failure Prediction for Hybrid Bolted-Bonded Composite Joints using Onset Theory (15. Joints in Composite Structures)

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Composite laminates are highly susceptible to the localised failure induced by geometric discontinuities and concentrated loads, even more so than metallic structures. Consequently, bolted joints in composite structures are significant drivers for overall structural sizing and performance. Bonded joints are much more efficient but much less robust and fault tolerant, leading to the common addition of “chicken rivets” to prevent catastrophic joint failure modes.

Hybrid bolted-bonded joints are a compromise between the two joint technologies that, when well-designed, can retain the main advantages of both methods. Unfortunately, predicting the failure of these joints is an extremely difficult task due to the complex load sharing between the bond and the bolt. The minimum sufficient modelling strategy includes material nonlinearity, contact, thermal residual analysis, bolt prestresses and progressive material degradation. This imposes great challenges on traditional failure theories used to predict the onset and progression of damage through the joint.

Onset theory, based on scalar strain invariants evaluated at the constituent level, explicitly accounts for 3D deformation states, nonlinearity and thermal residual strains. This paper presents a failure analysis based on Onset Theory which has been implemented in the MSC.Marc finite element program. It has been applied to predict both the bearing failure of the composite adherands as well as failure of the bondline. A novel progressive material degradation model, based on the same scalar strain invariants, has been applied to track the progression of damage.

8037 | Design and implementation of an ARCAN-style test rig for off-axis testing of bolted joints in composite laminates (15. Joints in Composite Structures)

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Bolted joints play a critical role in the design and sizing of composite structures. Consequently a significant amount of effort has been expended to

investigate the failure of bolted joints in composite structures both experimentally and numerically. Most experimental single-fastener joint studies consider only bearing failure (ASTM D5961) and occasionally pull-through failure (ASTM D7332).

There is growing evidence from quasi-static and dynamic structural testing that the failure mechanisms present in bearing and pull-through are not independent; rather there is a strong coupling between the failure modes which is both state dependent and history dependent. In addition, the loads applied to most fastened composite structures induce a combination of both shear loading (bearing) and tension loading (pull-through) across the joints. Despite this, there are currently no systematic methods to investigate the "mixed-mode" failure of composite bolted joints experimentally.

This paper presents a modified ARCAN test fixture which has been designed to accommodate a single bolted joint in a composite laminate. The rig allows a suite of mixed-mode experiments to be conducted between pure shear and pure tension loading with identical fixity applied to the bolt and laminate. Preliminary results will be presented which show the strongly coupled failure processes involved when combined loads are applied to bolted joints.

8053 | Numerical investigation on the effect of bolt-hole position alignment errors on strength of bearing-type multi-row bolted connections for FRP composite structures (15. Joints in Composite Structures)

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A statistical analysis is performed to examine the effect of bolt-hole position alignment errors on the strength of bearing-type multi-row bolted connections with a double lap configuration for fiber reinforced polymer (FRP) composite structures. To generate the bolt-hole position variability in the loading direction of connections, Latin hypercube sampling technique is adopted for simplicity and accuracy. Progressive damage analyses are performed of the connections numerically. These data are examined in detail to understand the effects of bolt-hole position alignment errors on strength of the connections. The statistical tests on goodness of fit shows that the strength of the connections with bolt-hole position alignment errors can be modeled by using either a normal or a log-normal distributions for a significance level of 0.05. The results show that the strength of bolted connections is significantly affected by the bolt-hole position alignment, and that the strength can either increase or decrease with a higher probability to decrease. Connections with steel cover plates are more sensitive than those with FRP cover plates. About 40% decrease and 20% increase are found in the strength of connections with steel cover plates when compared to those with a perfect bolt-hole alignment.

8102 | Numerical design of a dismountable spar for a light airplane in carbon fiber reinforced plastic. (15. Joints in Composite Structures)

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The weight saving is a requirement for airplanes in order to reduce the energy consumption. The challenge is the weight saving of a composite wing for light aircraft which can be dismantled. The wing spar is assembled with a fuselage spar. The main difficulty is the conception of the joining able to support critical loads of +12g and -6g in aerobatic flies. The assembly volume around the spars is reduced to its minimum to secure enough space for battery storage. These wings are mounted on the Airbus Innovation Group electric aircraft E-Fan.

In order to achieve this objective, some predictive numerical simulations are elaborated by taking account of the requirements of French civilian aviation administration “DGAC” and manufacturing processes of the project partner “C3Technologies”. The whole spar sizing of this complex wing is validated by static rupture tests of the complete structure. This step requires the construction of a special testing tool which is able to generate a load compared to real flight. The results of the test are the qualification of the wing for flight by DGAC. The spars are equipped with strain gauges, force and displacement sensors and acoustic emission. The recorded data enable to quantify the level of model precision. In order to confirm it, a representative model of the certification test is built and compared with the data for validating it.

The work based on the numeric design avoids the manufacturing of unnecessary prototype. A single spar is produced for the certification and another is mounted on the E-Fan prototype aircraft which has been flying for a year.

8139 | On the numerical modelling of reinforced timber structures and joints (15. Joints in Composite Structures)

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Timber brittle failure mode, by splitting, is often occurred by tension perpendicular to the grain. For a proper design of timber structures, in particular doweled connections, brittle failure modes must be avoided. In addition to the use of minimum timber dimensions and minimum spacing distances of fasteners, splitting of timber is generally avoided by means of several reinforcement techniques. However, the determination of load carrying-capacity of reinforced timber is not described by any standard design procedure and must be determined by numerical simulation. In this paper we present an efficient finite element model for the simulation of the behaviour of reinforced timber structures. The present study is devoted to the reinforcements by screws. The Abaqus finite element software is chosen to simulate the behaviour of reinforced timber. The splitting of timber has been described by a cohesive zone model (CZM) in which the progressive failure is expressed by a bi-linear traction-separation law. The reinforcements by screws are modelled using the beam-to-solid approach (BTSA) recently developed by the authors in the context of screwed connections. The capability of the proposed numerical approach is verified by comparison of the numerical results against experimental ones.

8248 | EFFECT OF THICKNESS AND LAYUP ON THE MECHANICAL PROPERTIES OF COMPOSITE-METAL JOINTS STRENGTHENED BY SURFI-SCULPT (15. Joints in Composite Structures)

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The effect of composite thickness and layup design on the mechanical properties of composite-metal joints strengthened by surfi-sculpt is experimentally studied. In the thickness influence study, the quasi-isotropic layup is adopted and only the thickness of the composite adherend changes; In the layup design influence study, the thickness of the composite adherend is kept constant and the content of ±45° ply is increased from 10% to 90%. Joints without any strengthening are manufactured as control specimens. 3D Digital Image Correlation is used to investigate the strain field changes in the composite and metal adherends. Compared with the control composite-metal joints, the ultimate load, failure strain, and absorbed energy capacity of the joint strengthened by surfi-sculpt increase significantly. The improvement to these properties is due to the metal pins on the bonding surface of metal adherend which are manufactured by electron beam surfi-sculpt (EBS). The pins resist unstable (rapid) delamination growth along the bond line of composite-metal joint. Although adherend layup and thickness have no effect on control specimens where failure is always along the bond line between composite and metal, these two parameters influence the mechanical properties of composite-metal joint. The ultimate load decreases with increasing thickness and the failure mode changes from composite intra-laminar failure with pins bending to interlaminar delamination with pins intact. The ultimate load increases as the content of ±45° plies increase and failure mode changes from composite adherend breakage to interface delamination in the composite. This research is supported by the AVIC Centre of Structural Design and Manufacture at Imperial College London.

8558 | Experimental Investigation of Low Velocity Impact Behavior of Simple and Hybrid Joints (15. Joints in Composite Structures)

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Behavior of low velocity impact of simple and hybrid joints is investigated in this study. Three different joint types are generated. The first one is a simple joint having only the adhesive bonding. The other two joint types are hybrid joints having both adhesive material and rivets for bonding. One of them has 3 rivets located with the angle of 120 degrees between them and the other one has 4 rivets having 90 degrees between them along with the adhesive material. The test specimens consist of two types of plates. One of them is aluminum plates having the dimensions of 100x22.5 mm and other one is E-glass/epoxy composite plates. The plates are bonded with the adhesive thickness of 0.1 mm. The test specimens are subjected to impact experiments with three different impact energies.

This study presents low velocity impact behavior of simple and hybrid joints subjected to different impact energies. The paper will contribute to the knowledge for the comparison of the behavior of different structures and geometries under different impact energies.

Keywords: Simple joints, Hybrid joints, Low velocity impact

8570 | Analysis of Cf/SiC composite/304 stainless steel joints brazed with Ti-Zr-Be (15. Joints in Composite Structures)

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In this paper, Cf/SiC composite was successfully brazed to 304 stainless steel with Ti-Zr-Be filler foil at 950-1050°C for 15-90 min. Microstructure of the brazed joints was examined by SEM, EDS, AES and XRD. And the mechanical properties of the brazed joints were measured by mechanical testing machine. The results show: the reaction layers of ZrC/TiC+TiSi+Ti_5Si_3 are formed adjacent to Cf/SiC composite while the diffusion layers of Ti-Zr+TiFe+$FeZr_2$/TiFe/α-Fe are formed near to 304 stainless steel. The joint strength is seriously affected by the degree of the interfacial reactions between Cf/SiC composite and Ti-Zr-Be filler. The maximum shear strength of 109.13 MPa is obtained at 950°C for 60min.

8592 | Study on flexural mechanical property of penetrated mortise-tenon joints (15. Joints in Composite Structures)

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Relationship of moment-rotation, length of the tenon pulled out-rotation and failure modes are got through monotonic loading test on four penetrated mortise-tenon joints. The stress distribution and failure modes are simulated with solid element by finite element software. On the premise of some simplifying assumptions, the mechanical model is built based on experiments and numerical simulation. Research results show the positive and reverse damage types of joints are tearing along the grain-breaking failure in the variable cross section and bending damage near the roof of tenons respectively. The flexural capacity and extremely rotation of the positive are both about half of the reverse. Resisting torque is mainly synthesized by local pressure stress and friction of the “Xiao-chu” part. The upper gaps of tenons have a certain degree of effect on flexural behavior. The positive and reverse relationships of moment-rotation can be simplified as double broken line model.

8611 | Rapid resistance welding of Fe78Si9B13 bulk metallic glasses (15. Joints in Composite Structures)

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Bulk metallic glasses (BMGs) are a promising class of engineering material, but the size limits the use for some engineering and structural applications. Aiming the Fe-based BMG which has the very wide application field, the rapid resistance welding of Fe78 Si9 B13 BMG has been tried, utilizing the superlastic-like deformation behavior in the supercooled liquid region. The research provides the combination of welding time, welding voltage and welding force required to avoid crystallization and visible defect in the interface. Meanwhile, the temperature field of Fe78 Si9 B13 BMG joints was investigated by Finite Element Methods shows that the average cooling rate is far greater than the critical cooling rate of Fe78 Si9 B13 BMG, which can avoid crystallization and solidification to obtain the amorphous joints.

8628 | Design the adhesive joints between PEI and CFRP for the composite ultracentrifuge rotor (15. Joints in Composite Structures)

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The ultracentrifuge is widely used to separate biomolecules such as proteins, polysaccharides, nuclei acid. The ultracentrifuge should create sufficient gravitational forces more than 600,000×g. Recently, the hybrid composite rotor for the ultracentrifuge equipment was successfully designed using the PEI (Polyetherimide) which is the thermoplastic material and CFRP (Carbon Fiber Reinforced Plastic) which is the thermosetting (Epoxy)-based composite with filament winding and adhesive bonding methods. When ultracentrifuge rotates with high rotational speed to make sufficient gravitational forces, large shear and peel stresses are generated in the adhesive bonding area due to modulus and inertia differences between the CFRP and PEI.
In this work, FE analysis was performed to calculate the critical shear and peel stress on the adhesive bonding area with the harshest condition for the ultracentrifuge rotor. The thickness effect of the PEI and CFRP was verified to reduce the stress on the adhesive bonding layer. Finally, the flame treatment method was used to increase the adhesion strength of the adhesive bonding area and the optimal process of the flame treatment method was determined by the double lap shear tests.

8753 | Finite element analysis of the timber-to-concrete connection under dynamic loading using BTSA approach (15. Joints in Composite Structures)

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Timber is a very old structural material and has been widely used down through the ages in the construction of houses. On the other hand, the timber-to-concrete system is an effective means for combining the structural and non-structural benefits and eliminating some weaknesses of each material. Today, it is still used extensively to build low rise buildings, mainly one and two storey houses, and it is especially suitable on account of its resilience under load for structures situated in earthquake prone areas of the world. Traditionally, the timber joint has been the weakest link in a timber structure necessitating research into the various types of mechanical fasteners and connectors and hence the performance of the joint. Timber joint details are wide-ranging, varying from a simple nailed joint to the use of shear connectors and nail-plates. The performance of joints is determined by the material properties of the timber, concrete and connector, the joint configuration and the loading condition. While the load-slip characteristics of nailed joints have been studied by several researchers, little is known about their cyclic performance.

This paper is an extension of previous work developed by the authors on a new simplified numerical approach (BTSA), to assess the non-linear load-slip behaviour of screwed timber-to-concrete joints under static loading. The main purpose of the beam to solid approach (BTSA) is the ability to avoid the detailed 3D finite element modeling of screws using solid elements. Therefore, the screws were modeled using one-dimensional beam element, while the timber and concrete members were modeled, in detail, using 3D solid elements. The main novelty of the present paper is the introduction of the non-linear behaviour to the model previously presented and its application on timber-toconcrete joints connected with screws under reversible cyclic loading. The dynamic effect is a parameter involved in the behavior of the system screw connection, it is very interesting to know its influence on the behavior of the screw, as well as some non-linear phenomena such as elastic and plastic sliding interfaces timber to concrete assemblies. The finite element results show that the developed approach can adequately capture the global behaviour of timber to concrete joints under cyclic loading.

8783 | effect of the influence of the fiber orientation and the use of a hybrid composite on the reduction of the integral J for a damaged structure repaired by patch (15. Joints in Composite Structures)

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The objective of our work is to analyze by the finite element method, the effect of repair of a damaged composite patch to reduce the integral J in the bottom of the crack structure.
In this work, the composite repair is considered As a multilayer material contrary to most studies where they consider the patch as being one orthotropic

layer. several parameters were considered; the effect of the fiber orientation, the effect of the thickness of a layer and the use of a hybrid composite

8785 | Investigation of creep phenomenon on composite material for bolt connections (15. Joints in Composite Structures)

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Nowadays one of the target in the automotive design is the weight reduction of the structures. The weight containment is one of the key factor for the reduction of pollutant emissions. Indeed the pollutant emission are directly connected to the fuel consumption of the car. Consequently, the consumption are directly influenced by the weight of the car. Thus reducing the weight leads to the reduction of the gas emissions. Moreover, in the last years the tendency is to equip vehicle with even more devices and gadgets, therefore the weight of the cars is increased along the years.
For these reasons, the designers tend to use innovative material for the automotive field such as plastics and composites for example. Moreover, in order to use the right material for the right application, even more often multi material solutions are adopted. Using non traditional materials or multi material solutions, the traditional joining technologies adopted in the car manufacturers, such as the spot welding, cannot be used. It is necessary to adopt solutions like adhesive, bolt and nuts, riveting. Consequently, to ensure a correct working of the connection, it is also necessary to know the behaviour of the materials to be joined, under different loading conditions.
In this frame, bolt connections have been selected. It is well known that bolt connection are based on appropriate tithing of the bolt so give enough compression force between the joined members. This work is dedicated to investigate the behaviour of a carbon fibre reinforced material under compression load taking into account creep.
A specific experimental equipment has been developed and described in the work. With this testing machine it is possible to do experimental creep compression test. It allows to do the tests not only at room temperature but also at controlled temperature. A series of experimental tests have been done on a carbon fibre reinforced material. Different set-up in terms of temperature and surface roughness have been investigated. In particular, the compression behaviour in the direction perpendicular to the fibre have been studied. The results obtained from the experimental tests will be processed and discussed in the paper. With these results it will be possible to define a reliable instrument for the design of bolt connection where one or more of the joined parts are made with the evaluated materials. A practical example will be discussed in the work.

8871 | Effect of shimming on bearing response of composite-aluminium joints with countersunk bolt (15. Joints in Composite Structures)

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Abstract:
An experimental investigation of the effect of shimming on bearing response of composite-aluminium joints with countersunk bolt is presented. Both solid and liquid shims with varying layer thicknesses were used respectively. The laminates were manufactured from carbon fiber/epoxy prepreg unitapes. To obtain the complete surface strain field and to analyze the out-of-plane deformation of the joints, 3D DIC measurement technique was used. The experimental results showed that the strength and stiffness of the joints decreased with increased layer thickness, and the bearing behavior of joints with solid shim was better than that of joints with liquid shim.

Keywords: Composite-aluminium joints; Countersunk bolt; Shimming; Bearing response; Experimental study.

8912 | PREPERATION AND MECHANICAL PROPERTIES OF WOVEN FABRIC REINFORCED ALL POLYPROPYLENE COMPOSITES (15. Joints in Composite Structures)

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In the present work, all polypropylene composites were prepared by film stacking technique using terpolymer and copolymer matrixes and woven fabric reinforcement. Composite sheets were prepared by use of hot press at different processing temperatures of 5,10 and 15 °C over the melting temperature (Tm) of the matrixes in constant pressure of 8 MPa. Consolidation quality of composites was studied by scanning electron microscopy (SEM) and density measurements. Mechanical properties of composite sheets were subjected to tensile, flexural, and impact tests. The results showed that strength, stiffness and consolidation quality of composites increased by increasing the processing temperature while impact properties decreased. It was established that composite with terpolymer matrix demonstrated good strength, stiffness as well as consolidation properties in lower preparing temperature that indicate terpolymer matrix can expand the processing window in manufacturing of all polypropylene composites.

Key Words: Woven fabric, All polypropylene composite, Mechanical properties, Consolidation, Film stacking technique.

8925 | Numerical simulation of the mechanical performance of composite bonded joints containing X-bolt crack stoppers (15. Joints in Composite Structures)

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Adhesive bonding of thin-walled composite structures is a very promising method to reduce aircraft cost and weight, while it brings several technical

advantages compared to traditional mechanical fastening. For secondary structures adhesive bonding is a common practice but until today the certification rules that are applicable for primary bonded structures prevent the use of bolt-free bonded joints for primary structures, as a result of earlier experiences, where the interpretation of the rules led to in-service premature failure incidents on adhesively bonded joints [1]. The first among the three Means of Comply, defined by the international airworthiness authorities to demonstrate that a bonded joint exhibits the required load bearing capacity, states that "The maximum disbond of each bonded joint consistent with the capability to withstand the required loads must be determined by analysis, tests or both. Disbonds of each bonded joint greater than this must be prevented by design features". In this item it is stated that "Design features can be proposed to prevent cracks or disbonds larger than the larger size for ensuring the load bearing capacity in a damage tolerance manner". According to [1] crack stoppers may be of the following types: Through thickness reinforcements, Surface and geometry modification, Surface interfacing features, Adhesive bonding architecturing and Supporting adhesive modification.
In the presence work, the mechanical performance of composite bonded joints containing X-bolt crack stoppers (through thickness reinforcements) has been simulated using the LS-DYNA explicit FE code. The joint configuration investigated refers to two CFRP UD plates of unequal length adhesively bonded and additionally connected using X-shaped steel pins. The assembly was loaded to axial tension which caused a mixed-mode I+II load to the bondline. The fracture behavior of the adhesive was simulated using the Cohesive Zone Modeling method (bilinear traction-separation law). Damage in the composite substrates was modelled using the progressive damage modeling method. Between the bolts and the plates contact was modelled and the feature of contact break (pin detachment) was enabled. The numerical results show the following failure sequence: early contact break between the pins and the plates; debonding initiation at the edge of the adhesive; debonding growth up to the pin-area; delamination of the first layer of the plates in the pin-area; total delamination in the pin-area; local fiber failure in the pin-area and finally, total debonding between the two plates. The numerical results agree well with respective mechanical tests. Comparing the performance of the X-bolted bonded configuration with that of the bonded configuration without the X-bolts it is concluded that if properly designed the X-bolt crack stopper maybe proved effective.

Acknowledgement
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8948 | Investigation of the transition zone for locally metal reinforced joining areas (15. Joints in Composite Structures)

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One of the major challenges for efficient lightweight structures made of CFRP is the design of load introductions. The use of fasteners as bolts or rivets is common. In contradiction to metals, a low bearing strength, especially parallel to the fiber orientation is present. One of the solutions for highly concentrated loads is a ramp up of the layup to a thickness which is able to sustain the load. The major weaknesses of this solution are occurring eccentricities, secondary bending effects and an increase of part complexity, which lead to a relatively high load increase.
One approach to overcome these effects is the intrinsic increase of the bearing strength using thin metal foils. The foils have the same thickness as the CFRP material and are used to substitute layers locally in the load introduction region. Therefore, the metal's plasticity can be exploited in this region, whereas, in in the rest of the structure the high stiffness and strength to weight ratios of the CFRP material are retained.
This technology involves the presence of a transition zone between the monolithic CFRP part and the full metal substituted part. This transition zone can be conducted in different staggered patterns. Hereby, the loads are transferred mainly through shear and as a consequence, debonding is the dominating failure type.
The work contains static experiments including different patterns of the transition zone under tension and bending in comparison to monolithic and full metal laminate references. Following, finite element simulations of the tests are used to evaluate the numeric methods. As debonding plays a significant role, beside a plasticity material model and a progressive failure model, the use of cohesive elements to simulate separation processes is important. Therefore, required material input parameters are obtained from fracture mechanical tests known from pure CFRP material, which are adapted to the metallic-CFRP interface.

8967 | Study of damage risk of bolted joints with hybrid laminates (stainless steel - GFRP) at low temperature (15. Joints in Composite Structures)

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Mechanical and thermal properties of composite materials, with polymeric matrix and fiber reinforcements, do of them prime candidates for the design of structures working under cryogenic conditions. However regulations limit the application of these materials by requiring, in some cases, the use of metallic materials. Therefore, employment in the same structure of two different materials requires to working on the multi-material assembly area.
This study focused on an analysis of specific joints between two stainless steel parts and a glass fiber reinforced polymer (GFRP). The polymer used here was an epoxy resin. Two main objectives were identified, first corresponding to the definition of a best bolted assembly geometry and second one to the investigation of failure modes of bolted joints at low temperature.

First, we worked on the definition of assembly geometries between composite and metal. Geometries had to respect two requirements:
- be based on the principle of double-lap bolted joint which means that the composite part is caught in a vice between the two metal parts and the whole is traversed by a bolt,
- allow to transfer loads from one part to other.
Ten various solutions were tested. For each designed geometry, a 3D finite element model was built using MSC MARC software. Two elementary loads were next considered, first one in traction and the second one in compression. To select a best design, three criteria were considered based on:
- $K_t = (\sigma_{Imax})/\sigma_n$ - the stress concentration coefficient defined as a ratio between the maximal value of the maximal principal stress σ_I revealed on the model and the nominal stress σ_n applied to the structure,
- $K_c = (\sigma_{IIImin})/\sigma_n$ - the stress concentration coefficient in compression using the minimal principal compressive stress σ_{III} obtained by the model

normalized, as before, by the nominal applied stress,
- $K\Delta\sigma = (\sigma Imax-\sigma IIImin)/\sigma n$ - a coefficient indicating the maximal dimensionless stress range defined as the difference between the tension and compression stresses obtained at the same point of the structure.
Numerical results have thus shown that the geometry that presents the most interests is a bolted joint with a local reinforcement of the composite plies replaced by metallic sheets.

In a second time, the experimental tests were performed on the selected joint. The composite material with a balanced glass fabric reinforcement of 600g/m² weight was experienced. Balanced term means that the mass in the warp direction (0°) is equal to the mass in the weft direction (90°). For the cryogenic aspect, a specific experimental setup was developed in order to carry out the tests in a liquid nitrogen bath.
To begin the classical properties of composite were determined. The tests were performed at room and cryogenic temperatures. The fabric of the reinforcement being balanced, tensile tests were conducted on specimens cut at 0°, 15°, 30° and 45° relatively to the axis of the warp direction. The specimens were 250 mm long, 25 mm wide and 5 mm thick.
Next, bolted joints were tested. The tests were performed at room and cryogenic temperatures. Following the results of the numerical study, we used a configuration based on scheme of double-lap bolted joint. The composite parts of the samples were 150 mm long for tensile tests, 110 mm long for compression tests, 50 mm wide and 5 mm thick. The specimens have 10 plies on the total thickness and the stacking sequence is a symmetric alternating between composite plies and metal plies (6 composite plies and 4 metallic plies). The stacking sequence has been defined in function of the results obtained by the numerical study.

The work presented in this study allowed us:
- to define, using the numerical approach, the most interesting assembly geometry in the case of a double-lap bolted joint,
- to identify, through an experimental approach, the damage risk of a bolted joint with hybrid laminates (stainless steel - GFRP) at cryogenic temperature.

8974 | Seismic performance of RC engineered cementitious composite (ECC) exterior beam-column joints under reversed cyclic loading. (15. Joints in Composite Structures)

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This study investigates the effects of engineered cementitious composite (ECC) on the seismic behavior of RC exterior beam-column joint. Flexural load-deflection, ductility, the principal stresses and failure mode are the main parameters considered in this study. The experimental work consists of casting and preparing two full-scale RC exterior beam-column joint specimens without transverse reinforcement. The first specimen was thoroughly cast with normal concrete. In the second specimen, the concrete in the joint region was replaced by ECC using polyvinyl alcohol fibers (PVA). For each specimen, rosette strain gauges were installed on the joint region to analyze the principal stresses occurred in the joint. At the primary stages of loading, results showed that the ECC mitigates the tensile stresses occurred in the joint compared to the joint with the normal concrete due to the reduced E modulus of ECC. At post cracking stages, the joint with normal concrete sustained low tensile stresses and failed at drift of 4.5%. The failure was fully brittle and a part of joint was damaged into several pieces. On the contrary, the joint with ECC sustained higher tensile stresses at post-cracking stage and failed at drift of 6%. Numerous of tiny reduced width and space between cracks propagated within the joint region. The joint was almost intact due to the superior properties in sustaining higher tensile and shear stresses as well as the higher ductility of ECC. The loading capacity in ECC joint was 20% more than the normal concrete joint. The ECC joint sustains 20% higher than the ultimate loading capacity of normal concrete joint.

9093 | Cyclic behaviour of an all pultruded FRP beam-column joint (15. Joints in Composite Structures)

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In absence of ductile behaviour of pultruded FRPs (Fibers Reinforced Polymers) materials the seismic performance of FRP structures depends both by the global geometric configuration of strut and tie structure and by the response of beam-to-column joints. The composite joints in seismic regions must provide adequate performance under load reversal, with energy dissipation. So, considering the limit of elastic-brittle behaviour of pultruded FRP material the improvement of sesimic response can be entrusted to the joints.
This work analyses the behaviour of innovative FRP joints under cyclic loading to quantify the dissipative capacity offered by the effects of degradation of strength and stiffness in successive loading cycles. These joints are characterized by FRP gusset plates where are bolted the built-up members made of FRPs (Fiber Reinforced Polymers) pultruded channel sections. This solution has been adopted in a temporary complex structure (rectilinear frame structure of up to 30 m in height, and covering 1050 m2) builds to protect the partially collapsed Santa Maria Paganica Church in L'Aquila (Italy), following the devastating earthquake of 2009.
The experimental and numerical analysis have been carried out on different beam-to-column joints considering the gusset plates made of pultrusion or bag molding processes in order to quantify the effects of in plane' actions on different gusset plates in term of failure mechanisms, ultimate strength, stiffness and dissipative capacity. The results are compared with the state-of-the-art of FRP joints characterized by traditional angle connections in order to classify and demonstrate the advantage of the innovative proposed joints.

9118 | Analyzing the modal behavior of adhesive bonded thermoplastic honeycomb sandwich panels to estimate the elastic properties of the joint (15. Joints in Composite Structures)

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Abstract
In recent years adhesive bonds are more and more used in structural joints where mechanical performance is crucial. Currently, many different material types are combined in a sole product. Especially in applications where lightweight materials are used, adhesive bonded joints can offer distinct advantages over traditional joining techniques like welding, bolting and riveting. The possibility to join different material types and the ability to smoothen structural stress concentrations are very attractive from a mechanical-elastic point of view.

A lot of research work has already been carried out in the field of adhesives. However, much of the documented work mainly focuses on the more fundamental physical-chemical properties of the different adhesive types, the substrate adhesion and theoretical models that describe the viscoelastic behaviour of adhesives. There are not many publications that discuss application driven research on elastic properties of adhesive joints, certainly not in the area of structural dynamics.
There is a high number of environmental parameters that influence the elastic behaviour of an adhesive joint. Therefore, also the vibration behaviour of adhesively bonded structures is a process that is subjected to many uncertainties.
This paper focusses on the joining of glass fibre reinforced polypropylene honeycomb sandwich panels by means of a hotmelt adhesive bond. The simple case of lap-joining two rectangular panels is considered.
A first part discusses the adhesive type and bonding application. It thereby focusses on the estimation of elastic properties of the bonded zone.
The second part estimates the impact of the uncertainty on bonding parameters on the resonant behaviour of the two joined honeycomb panels. As reference data, experimentally determined resonance frequencies and mode shapes under free boundary conditions are used. This part fully discusses how finite element modelling is used to estimate the bonding layer's shear modulus.
The third part discusses the influence of vibration frequency, temperature and amplitude on the bonding layer's complex shear modulus. Various validation experiments are considered.
Finally, the paper summarizes the research work and prospects to further application driven research.

9152 | Compressive and tensile behavior of aluminum foam joint fabricated by fluxless soldering with surface self-abrasion (15. Joints in Composite Structures)

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Fluxless soldering with surface self-abrasion has been developed for joining aluminum foams with metallic bonding. The effect of the self-abrasion on the wettability of molten solder alloy and mechanical properties is determined by microstructural observation, tension and compression tests. No apparent macroscopic deformation and collapse of foam structure are observed adjacent to the joint interface. The average tensile strength of the joints is about 14% higher than that of aluminum foam, and the compressive strength can reach 200% of that of aluminum foam. The deformation mechanisms and energy absorbing characteristics of aluminum foam and the joint are investigated. The aluminum foam joint fails primarily by bending, crushing, and compaction of cell walls and cracking of the solder seam. The interdiffusion process is explained based on thermodynamic equations.

9204 | Failure prediction and high-strain-rate behaviour of composite and hybrid fastened joints through physical and virtual testing methods with an aim to develop an idealised shear-tension macro model for large-scale structural simulations (15. Joints in Composite Structures)

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Mechanically fastened joints play a crucial role in the joining of composite and hybrid aircraft parts due to the ease of installation, inspection and maintenance as well as resistance to creep and environmental degradation effects. Due to the operating environment of the aircraft, the structure may be subjected to high loading rates in the event of a high velocity impact like a bird strike or a hard debris impact, involving high kinetic energy. Properties of composite materials change with loading rate, and so does the failure behaviour of the joint significantly. This research develops an understanding into the failure behaviour and damage prediction including energy dissipation of a bolted joint under an increasing rate of loading, through a combination of experimental or physical testing and numerical or virtual testing methods. Experimental investigation is conducted in a servo-hydraulic machine and drop tower, using high speed camera and digital image correlation. Advanced finite element explicit algorithms are used to develop an understanding of the tests, as well as to develop Detailed 3D-FEM Meso-Models, capable of predicting inter- and intralaminar delamination in the composite including bearing and pull-through behavior in the fastener. Substitute 2D-FEM Macro-Models are then developed that would encompass complex behavior of the joint failure mechanism, ranging from its elastic response, quasi-plastic response to progressive damage response, in shear and tension, for implementation in large-scale structural models. This is achieved through joint representation by an idealised fastener model and defining of its properties through generation of fastener properties dataset in elasticity, quasi-plasticity and damage through mathematical approximation techniqes using optimisation algorithms.
The investigation is focussed both on the in-plane and out-of-plane failure modes, in both shear and pull-through loading response of bolted joints. An experimental campaign is conducted to cover the influence of laminate thickness, layup and stacking sequence, bolt head type and diameter and strain rate effects on the failure behavior of the bolted joint. It has been found that pull-through failure is substantially characterised by matrix cracking and delamination in the laminate, extending through-the-thickness from the hole area towards the edges. Complex damage behavior in the joint is investigated through phyical and virtual testing methods as detailed 3D-FEM Mesomodels and captured in a substitute 2D-FEM Macromodel for implementation in large-scale structural aplications for crash and vulnerabilty.

9211 | Experimental investigation of the mechanical behavior of spot welding-adhesives joints (15. Joints in Composite Structures)

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Hybrid joints can be obtained by the use of two or more techniques to attach two materials. This technique was well discussed, in the last two decades, for the use of different welding process, e.g. Hybrid laser-arc welding and hybrid laser plasma welding. The development of new structural adhesives

improved the use of adhesive bonding in the manufacturing sector to join assemblies, specialty aerospace and automotive industries. Compared to the common welding methods, adhesive bonding has many advantages such as simplified process, favorable fatigue properties, and the ability to join dissimilar metals. Also, with the modern adhesives is possible to obtain high bonding properties for metal joints. However, some adhesive joints presented adverse behavior in different temperatures, become brittle at low temperatures and have a low strength at high temperatures, thus limiting the use of adhesive bonding in many applications. To increase the application of adhesive bonding, many researchers have developed special hybrid welding technologies to improve bonding properties. Weld bonding as a hybrid welding method combines welding and adhesive bonding to join many metals. This work presents experimental procedures and a numerical model based on the finite element method to compare the mechanical response of weld bonding joints to the effectiveness of classical weld joints and bonded joints. The experimental procedureis composed by tests with: spot welding joints without adhesive, single lap joints and hybrid joints combining both joining techniques - spot welding and adhesive bonding. A numerical model based on the finite element method is used to study the stress distribution of the weld bonding joint. The proposed model considers a cohesive zone model to represent the adhesive bonding behavior. Several loading conditions were analyzed with the proposed model to assess the capability of the supporting loading capability of thejoint for the different configurations. The necessary data for the elaboration of the numerical model were estimated using appropriate testing samples. Also, investigations with different heat inputs were performed. Two different damage modes were expected: the degradation of the adhesive by the heat input of the spot welding and the degradation of the spot-welding nuggets and the heat affected zone (HAZ) by the decomposition of the adhesive. Finally, the load capacity and the energy absorption of the hybrid joints were observed and compared to the classical joints.

9218 | ANALYSIS OF STATIC AND FATIGUE PERFORMANCE OF HYBRID BOLTED/BONDED SINGLE-LAP ALUMINIUM-CFRP JOINTS (15. Joints in Composite Structures)

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Hybrid joints, are usually obtained by the superposition of a mechanical joint with a bonded joint, and nowadays are used in many fields of the mechanical design, because of their excellent performances and low weight.
Mechanical fasteners (using bolts, rivets, etc..) are the most important methods of assembling structural elements; they are characterized by easy manufacturing that does not require careful preparation of the adherents surface, easy positioning and disassembled, easy repairing, and good tolerance to environmental effects.
Adhesively bonded joining techniques, originally considered to improve the damage tolerance, in the last years are in used because they allow to obtain joints characterized by good stiffness, lightweight, good static and fatigue strength properties.
The combination of mechanical fastening and adhesive bonding, initially employed only as a safeguard against the presence of defects within the adhesive layer and, more recently are used to improve the performance of the adhesively bonded joints by decreasing the maximum stresses at the adhesive layer close to the free edges, with particular reference to the induced peeling stress.
In order to give a contribution to the knowledge of the mechanical behavior of the hybrid joints, obtained by the superposition of adhesively bonded and bolted joints, in the present work a systematic numerical-experimental study of bonded/bolted single-lap joints between aluminum and carbon fiber reinforced polymer (CFRP) laminates, has been carried out.
The simple adhesively bonded joint and the hybrid simple-lap joint between CFRP and aluminum plate have been bonded together by means of ISOBOND SR 1170 high performance epoxy resin produced by Sicomin Epoxy Systems.
In order to analyze the influence of the laminate lay-up on the static and fatigue performances of hybrid joints, three different layout configuration of the CFRP laminates are examined: [02]s, [(0/±22.5)2]s, [(0/±45)4]s.
These type of laminate lay-ups, have been appropriately selected; in fact, the external layers aligned with the applied load allows to obtain the maximum performance of the adhesively bonded joint, whereas, according to the classical laminate theory (CLT), the internal layers oriented at ± 22.5 or ± 45° allows to obtain a good stiffness and shear strength of the laminates, that is necessary condition to avoid a premature shear failure of the mechanical joint.
Several experimental static and fatigue tests are carried out on a servo hydraulic MTS 810 testing machine.
Moreover, based on the experimental tests, the effects of clamping force and stacking sequence on joint strengths are systematically investigated by means of several numerical analyses carried out in ANSYS APDL environment and explicit solver.
The numerical analyses have been carried out by using three-dimensional models of the single-double-lap joint discretized by means of 8-node SOLID 164 elements. Boundary and load conditions reproduce the experimental conditions.
Special attention has been taken in the simulation of the interface between the composite laminae and between the composite adherents and the aluminum plate. In fact, the composite layer is modeled and discretized by using tiebreak surface-to-surface contacts (TSTS) elements located at the interface between the laminae. The use of this type of contact element allows to define the extension of the interlaminar damage during manufacturing and loading phase.
The study has permitted to highlight the influence of the main joint parameters on both the static and the fatigue performance of such joints, as well as to know the particular damage mechanisms and the possible premature localized delamination related to the stacking sequence of the CFRP composite.

6878 | Free Vibration of Orthotropic Plate on Foundation with Four Edges Free by Finite Integral Transform Method (16. Numerical Methods)

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Abstract:
The double finite cosine integral transform method is exploited to obtain analytical solutions for the natural frequencies and mode shapes of the orthotropic rectangular plate on foundation with four edges free. In the analysis procedure, the classical Kirchhoff orthotropic rectangular plate is considered and the Winkler elastic foundation is utilized to represent the elastic foundation. Because only are the basic dynamic elasticity equations of the orthotropic thin plate on elastic foundation adopted, it is not need prior to select the deformation function arbitrarily. Therefore, the solution developed by present paper is reasonable and theoretical. In order to illuminate the correction of formulations, the numerical results are also presented to comparing with that of the other references.

7553 | Volume integral equation method for scattering of SH waves by multilayered anisotropic inclusions (16. Numerical Methods)

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The Parallel Volume Integral Equation Method (PVIEM) is applied for the analysis of elastic wave scattering problems in an unbounded solid containing multiple multilayered anisotropic circular inclusions. It should be noted that this relatively new numerical method does not require the use of the Green's function for the inclusion - only the Green's function for the unbounded isotropic matrix is needed. This method can also be applied to solve general elastodynamic problems involving arbitrary shape and number of inhomogeneous and/or anisotropic inclusions. A detailed analysis of the SH wave scattering problem is presented for multiple multilayered orthotropic circular inclusions. Numerical results are presented for the displacement fields at the interfaces for square and hexagonal packing arrays of multilayered circular inclusions in a broad frequency range of practical interest. When a large number of inclusions are used in the VIEM formulation, computation time increases. Therefore, it is natural to use parallel programming standard, such as MPI, to speed up computation. It is demonstrated that the MPI-based PVIEM is very accurate and effective for solving this class of elastodynamic problems.

7606 | Convergence theorems for Haar wavelet based discretization method. New concept for expansion (16. Numerical Methods)

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During last years the use of Haar wavelet based discretization methods show increasing tendency (Elsevier scientific publication statistics). Also, the Haar wavelet method is referred in a number of papers as a „simple and effective" method. However, no convergence rate proof found in literature for this method. It is shown in several papers that in the case of function approximation with direct expansion into Haar wavelets, the convergence rate is one. Latter result does not hold good for wavelet based discretization methods where instead of the solution its higher order derivative is expanded into wavelets. Thus, obviously here is need for proof of the convergence rate of Haar wavelet based discretization method. Furthermore, it can be shown that the Haar wavelet expansion
principles proposed by Hsiao et. al. in [1-2] and used up to now can be improved.

In the current study an analytical proof of the convergence rate of Haar wavelet based discretization method is given for general n-th order ODE (convergence theorem for general case). The exceptional/particular cases of the Haar wavelet based discretization method are identified. Analytical proof of the convergence rate for these particular cases has been performed (convergence theorem for particular cases). The obtained convergence rates are validated numerically on model problems. New concept for Haar wavelet expansion, providing higher order convergence rate, has been developed. It has been shown that the Haar wavelet expansion principles suggested by Hsiao et. al. in 1997, and used practically in all studies exploiting Haar wavelet discretization up to now, can be completed in order to achieve higher convergence rate for certain class of problems.

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7608 | USE OF ARTIFICIAL NEURAL NETWORKS AND MONTE CARLO SIMULATIONS AS A PREDICTIVE METHOD TO DETERMINE STRENGHT OF HIGH PERFORMANCE CONCRETE (ASTM C39/C39 M) (16. Numerical Methods)

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High Performance Concrete has become one of the most important structural materials in civil engineering practice. The increase in its use has led to more stringingly quality controls of its mechanical properties. However, in most cases these quality controls require large and expensive testing equipment to allow tests up to 30KN. Since it is often difficult to have these machines in place for in situ tests, construction companies usually involve external laboratories to conduct such tests. In addition, concrete reach its ultimate strength after different curing periods, therefore is difficult to have immediate final test results in the field. Therefore, it is important to provide industry with a tool that allows forecasting in a reliable manner, final mechanical properties of concrete on the basis of manufacturing data. Using an artificial neural network approach and data from nearly 1000 laboratory tests, a new tool to predict compressive strength of high performance concrete (ASTM C39/C39 M) based on manufacturing parameters and curing time has been successfully developed. This tool, when used in combination with Monte Carlo simulation techniques and known empirical relationships between the different mechanical properties of concrete (i.e. compressive strength, bending strength, tensile strength and shear strength), will allow to obtain not only concrete mechanical properties but also the accuracy of those results.

7637 | Simulation and optimization methodology for the development of structures manufactured by a combined sheet moulding compound and prepreg compression moulding process (16. Numerical Methods)

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The demand for fuel efficient aircraft and vehicles led to the development of innovative lightweight constructions and the use of lightweight materials, such as carbon fibre reinforced plastics (CFRP). In the same manner competences in new production technologies have been built up in the aerospace industry. However, current processes for developing and producing composites with an excellent mechanical performance cause high costs and long

process cycles in comparison to approved metal processes. Furthermore, the used raw materials, such as carbon fibres and resin, are very expensive. In contrast to these technologies sheet moulding compound is characterised by a very high productivity, excellent part reproducibility, cost efficiency and the possibility to realise complex components with integrated functions. The biggest disadvantage of Sheet moulding compound parts is a low level of stiffness and strength because of a low fibre-volume fraction and a short fibre length. In this context the combination of sheet moulding compound and prepreg compression moulding in an one-shot compression moulding and curing process merges the advantages of both materials to create load-bearing and autoclave-quality parts without an autoclave.
The intention of the present work is the development of a finite element based simulation and optimization method for a new hybrid composite technology for aerospace applications which includes innovative material combinations and an efficient production process in equal measure.
The whole development process for the technology is guided efficiently by implementing different numerical optimization methods. Modern simulation methods are applied for validating robust material models, design, dimensioning and calculation of composite or hybrid aircraft components which should be produced with this new technology. This includes a complete structural FEM-analysis, regarding to stresses, strains and rupture of the composite material component. Topology optimization tools will be implemented in order to design load orientated structures with a minimum of material usage.

7726 | Modified Fourier method for free vibration of laminated composite cylindrical and conical shell with a viscoelastic core under general boundary restraints (16. Numerical Methods)

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An accurate solution method based on the first-order shear deformation theory (FSDT) is developed for the free vibration analysis of cross-ply laminated composite and sandwich cylindrical and conical shell with a viscoelastic core under arbitrary boundary conditions and various lamination schemes. The formulation describing laminated composite layers and viscoelastic material layer employs laminated and sandwich theories respectively. The present theory is based on a displacement field in which the displacements of the middle surface can be expanded as a combination of a standard Fourier series and auxiliary functions. Due to the introduced displacements of this form, rapid convergence and high accuracy can be easily obtained. The current method can be universally applicable to a variety of boundary conditions including all the classical cases, elastic restraints and their combinations. Natural frequencies and loss factors under various boundary conditions and lamination schemes are calculated, which may be served as benchmark in future. The effects of fiber orientation angle and the thickness of the layers on natural frequency and loss factor are illustrated. The various boundary conditions and the number of layers are also investigated in affecting the damped vibration of the laminated composite sandwich cylindrical and conical shell.

7735 | STRONG FORMULATION FINITE ELEMENT METHOD FOR ARBITRARY SHAPED COMPOSITE STRUCTURES (16. Numerical Methods)

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When it comes to numerical methods a huge amount of methodologies and techniques comes out. Since several researchers throughout all the past decades tried a better way to solve different problems in engineering. It can be pointed out that most of the numerical approaches hitherto proposed can be simply classified as based on two different formulations. Engineers in several branches know that physical problems can be mathematically solved, generally, using a system of partial differential equations. Since analytical solutions for these problems are usually limited to very simple cases numerical techniques must be employed in order to find an approximate solution for these problems. Historically speaking two approaches have been followed. On one hand the system is directly discretized using the so-called collocation methods based on the distribution of points upon the physical domain. On the other hand variational or weak formulations find an approximate solution evaluating the equations in their weakened form. As it is generally known collocation methods are global and use polynomials of high degree for approximating the unknown field, whereas domain decomposition techniques, such as the Finite Element Method (FEM), decompose the domain in several subdomains evaluating several local solutions which are related by the assembly. The aim of this work is to present several methods under the heading of SFEM (Strong Formulation Finite Element Method). Since a strong formulation, analogous to the collocation approach, is coupled with a domain decomposition technique, proper of the FEM. In this way the standard FEM could be termed WFEM. Due to the fact that it is based on the weak formulation and in opposition to SFEM, which is based on the strong formulation. Summarizing the main contributions are the general view in which strong formulation methods could be presented and the introduction of the mapping technique (generally connected to the FEM) for the solution of arbitrary shaped elements without introduction a variational form of the differential system, but solving it directly. Convergence, stability, accuracy and reliability of the SFEM are illustrated varying the principal parameters of this approach and comparing them to WFEM. Thus varying the number of points, the point location, the basis functions and the number of elements it is possible to observe the numerical behaviour of the SFEM.

7803 | On the use of an efficient wave based method for analysis of functional graded plates vibration (16. Numerical Methods)

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Forced vibration analysis of functionally graded elastic plates is presented based on a wave based method. Although functionally graded materials (FGMs) are highly heterogeneous in nature, they are generally idealized as continua with mechanical properties changing smoothly with respect to the spatial coordinates. The material properties of functionally graded plates are supposed here to be varying through the thickness of the plate in a continuous manner. The Young's modulus and densities vary continuously in the thickness direction according to the volume fraction of constituents which is mathematically modeled as a power law function, with the Poisson ratios of the FG plates being constant. This paper gives an overview of the principles of the WBM for the steady-state dynamic analysis of plates. First the flat plate bending behavior are described. Throughout the paper the performance of the WBM is compared with that of the FEM, which demonstrates the enhanced computational efficiency of the WBM.

7819 | Modeling of CFRP/Ti interface when drilling hybrid composite (16. Numerical Methods)

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This study proposes an original FE model to address the key physical mechanisms controlling the material removal process within the CFRP/Ti composite interface when mechanical drilling. The 2D orthogonal cutting configuration (OCC) considered to modeling the cutting operation was adopted with respect of phenomenological assumptions. The FE model was developed into ABAQUS/Explicit commercial code. The CFRP phase was assumed equivalent homogeneous material with elastic behavior. However, the Ti phase was considered isotropic with elastoplastic behavior. Hashin damage criteria and Johnson-cook ductile damage were used to model the local failure in the composite and metallic phase, respectively. The CFRP/Ti interface physically described as intermediate constituent was modelled using the concept of cohesive zone (CZ). The material separation within the CZ was controlled by traction-separation criteria. The cutting responses were investigated with respect of the cutting sequences strategy referring to the multistage machined phase (Ti-to-CFRP and CFRP-to-Ti), feed rate, and the cutting speed. A special focus was made on the cutting-induced damages. The numerical results highlighted the significant effects of cutting sequences strategy on machining responses and the pivotal role of interface properties in governing delamination and, hence, the material removal process, when cutting CFRP/Ti stack.

7826 | ISOGEOMETRIC COHESIVE ZONE MODELING FOR MIXED-MODE DEBONDING PROCESSES (16. Numerical Methods)

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In a context where adhesive-bonded joints are increasingly used in aerospace and automotive industries, prediction of interfacial and cohesive failure mechanisms is an important issue to be treated both analytically and numerically. To this end, a successfull numerical tool towards failure prediction of adhesive joints has been achieved in the literature using standard low order finite elements (FE) relying on Lagrange polynomial bases. The two most popular numerical methods for the analysis are the Virtual Crack Closure Technique (VCCT) and interface elements with cohesive zone (CZ) laws. The numerical application of CZ models for debonding problems within finite element frameworks, however, usually suffer from unphysical stress oscillations at large stress gradients unless fine meshes discretize the fracture process zone (FPZ) ahead of the crack tip. An innovative framework where better geometrical accuracy is combined with higher and tailorable inter-element continuity is provided by isogeometric analysis (IGA), as here adopted to describe the interface damage mechanisms for adhesively-bonded interfaces in mixed-mode conditions. The debonding process along the adhesive interfaces are herein treated with CZ modeling by adopting “analysis-suitable” T-splines discretizations of the meshes. The interface is discretized with zero-thickness contact elements which encompass both contact and mixed-mode debonding within a unified framework, using a Gauss-point-to-surface formulation. A coupled exponential cohesive interface constitutive law is then employed to treat the debonding phase, where all the components (I and II) of the traction vector depend on all the components of the interface separation. The methodology is explored for bi-dimensional composite-to-composite single lap joint specimens, composed of four composite substrate segments bonded by thin layers of adhesive. The numerical results show that mixed-mode CZ models combined with T-spline-based discretizations allow for a more accurate and robust treatment of debonding phenomena with respect to standard linear and higher-order Lagrange interpolations.

7915 | Numerical and experimental analysis of commingled yarns thermoplastic composites consolidation process (16. Numerical Methods)

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Thermoplastic composites are becoming more and more popular in industry such as automotive, aerospace, microelectronic, etc. Thermoplastic composite processes such as thermoforming or hot stamping attract great attention from many researchers. One of the difficulties in those processes is to reach complete resin impregnation into fiber bundles due to the high viscosity of thermoplastic resin at molten state. Therefore, commingled yarns are widely used by dint of their short flow distance for resin to facilitate impregnation. A typical processing cycle of thermoplastic composites consolidation consists of three major stages : preheating the commingle yarns above the melting temperature, applying a pre-assigned pressure for a chosen time to consolidate the commingled yarns and cooling the material to room temperature under pressure. The molten polymer matrix is therefore forced to impregnate the dry fiber bundles under pressure during this process. Temperature, pressure and holding time are the major parameters which affect the impregnation quality.
Experiments on commingled yarn consolidation were conducted to study the influences of process parameters such as pressure and temperature on the impregnation quality. Braided fabrics of glass fiber/polypropylene commingled yarns were tested. The consolidation experiments were conducted at two different temperature and pressure conditions. To investigate the void content in a quantitative way, micrographs were taken for transverse sections of consolidated plates, and converted into white and black pictures where black pixels stand for pores.
In this study, temperature condition was chosen at 170°C and 210°C respectively and pressure conditions set to 1.5MPa and 2MPa. Two different types of voids, intra-bundle voids and inter-bundle voids, were found in the micrograph, and porosity was calculated for each type of void as well as total porosity. It is found that as temperature and pressure increase, intra-bundle porosity decreases from 1.02% to 0.41%. In contrast, inter-bundle porosity increases from 0.17% to 1.77% as the processing temperature increases from 170°C to 210°C, which leads to a higher total porosity for higher temperature. This is in contradiction with the results found in the literature, and one possible reason is the shrinkage of polypropylene matrix during cooling process.
Numerical simulations were as well conducted to model the consolidation process based on the most widely used Darcy’s law. The molten matrix was assumed to be Newtonian fluid, and its viscosity only depended on temperature and can be described by an Arrhenius equation. The permeability was assumed to be constant and was calculated by Gebart’s equation for hexagonal arrangement which is a function of volume fraction of glass fiber only.
A radial flow case was calculated by 1D analytical model to give the intra-bundle porosity revolution with time under different processing conditions, and the results were compared with intra-bundle porosity data obtained experimentally.
FE method was used for both 2D and 3D simulations. A representative volume element was chosen and different permeabilities were assigned to different types of yarn. Only impregnation process was simulated for now as it is the major physics during consolidation. Air flow and entrapped air were considered in 2D and 3D simulations which played an important role on void formation and final impregnation quality. The porosities obtained were also compared with experiment results to validate the FE model.

8016 | Modeling and experimental verification of Dielectric Constants of Different Weave Structure Textile Reinforcements (16. Numerical Methods)

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Dielectric constants of the textile reinforcements are of great importance when the final composites are used in the wave transmitting or absorbing fields. In these cases, the textile structures were usually tailored to obtain the required dielectric constants. However, to the authors' knowledge, few papers have been found in discussing the relation between the textile weave structures and the dielectric constants. In this paper, the relation between different weave structures and dielectric constants was modeled and subsequently verified with weave glass fabrics. The results showed that a good agreement could be obtained from the above.
Keywords: Dielectric constant, Weave structures, Modeling, Glass fabrics.

8100 | MODAL PARAMETERS FITTING OF COMPOSITE FLAT PLATES AND PIEZOCERAMICS INTERACTION (16. Numerical Methods)

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In this work a parameters fitting methodology is applied to determine an equivalent numerical model of composite flat plates and piezoceramic interaction for aeroelastic simulations. Aeroelastic phenomena are related to the inertial, elastic and aerodynamic forces interaction. The aeroelastic system dynamic characteristics, such as modal parameters, change due to aerodynamic conditions like free flow velocity and angle of attack. Numerical methodologies are employed to predict when and where catastrophic instabilities may occur, indicating the normal modes and frequencies that are envolved in the event. Piezoceramic pads attached to the plates can be used either to measure the aeroelastic response by observing eigenfrequencies evolution or to activelly avoid the instability. Recently, laminated composite flat plates with different fiber orientation and with attached piezoceramics were experimentally investigated in order to identify modal parameters. One important experiment consists in wind-tunnel tests where the dynamic evolution due to aerodynamic forces are measured. The data obtained from these tests are used to define a simplified equivalent structural numerical model for use in aeroelastic solvers that predict instabilities and response of the system. An automated parameters fitting methodology is used for fitting a few chosen elastic properties of the simplified numerical model. The method consists in an optimization process aiming the minimization of a cost function based on the residue between numerical and experimental data. The fitted parameters are updated using sensitivities of the numerical frequencies and modal shapes.
Results of aeroelastic simulations using the simplified models agree with experimental data, validating the use of such methodology.

8120 | COMPARATIVE STUDY OF NUMERICAL METHODS FOR DESIGNING SFRC SECTIONS SUBJECTED TO AXIAL FORCE AND BENDING MOMENT (16. Numerical Methods)

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A critical point for the development of steel fibre reinforced concrete (SFRC) as a structural material is the quantification of the residual stresses developed under tension. In present practices, the residual stress is quantified by means of bending tests. After that, an inverse analysis is used to determine the stress–crack opening or the stress–strain relationships, as depicted in the Model Code 2010 (FIB, 2010). In this analysis, which requires computing the section iteratively, the computational cost of the integration method becomes important. Several integration methods for reinforced concrete sections were compared recently (Bonet, 2006). The comparison included the layered section method, which is being used by different authors as an integration method of stresses to determine the moment–curvature diagrams of sections built with different materials, and a numerical method based on the Gauss-Legendre quadrature. The objective of this paper is to compare the aforementioned integration methods when they are applied to SFRC sections, aiming to contribute to a decrease of the computational cost of the integration. The constitutive equation for the compressive response of concrete and the tensile response of the SFRC were taken from the Model Code. Rectangular sections of SFRC subjected to axial loads and bending moments were calculated. The results of the Gaussian integration were compared to those of the layered integration regarding accuracy and computational time of each method.

Keywords: fibre concrete, composite section, stress integration, cross-section analysis

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8140 | Adaptive Concurrent Recursive Multi-Scale Method for Simulation of the Response of Laminated Composites to Underwater Blast Loading (16. Numerical Methods)

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Dynamic excitations, such as those caused by underwater explosions, may generate undesirable effects, both near as well as further away from the

primary loading location, in large composite structures typically employed in naval applications (surface ships and submarines). In view of available computational power, the transient and non-linear nature of the underlying physical phenomena requires concurrent attention at multiple length scales during the design of such large laminated composite structures to withstand blast loading.
In this paper, the results of the study directed towards an automated, adaptive concurrent recursive multi-scale numerical simulation are presented. A blast on a laminated structure is simulated in a concurrent and recursive manner, using a coarse and corresponding more detailed constitutive models activated only when certain criteria are met at each consecutive length scale. The developed analysis framework allows for the communication between the scales by keeping the computational cost to a minimum, while providing a high resolution insight in the process zone. The results show that the mapping between distinct length scales is energy conserving.

8156 | FE analysis of carbon foam under multiple compressive loading (16. Numerical Methods)

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In this paper, finite element (FE) analysis of multiple compressive loading of carbon foams prepared from a tannin-based resin and exfoliated graphite used as filler is studied in detail. Numerical results are compared to compression test results for multiple loadings.
The compressive force–displacement response of carbon foam elements is numerically evaluated for different cells and strain rates. The results of the numerical analysis are compared with experimental data. Good agreement is found. Quasi-static loading is investigated by making use of numerical analysis and verified by comparison with experimental results.

8254 | Predictions of the strength of bonded connections in space opto-mechanical domain (16. Numerical Methods)

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In the spatial and opto-mechanical domains, bonding is already very often preferred to other solutions of connections. Its applications in these domains have really a promising future on account of the numerous advantages of the bonding (large field of products, great adaptability, relative easiness of the realisation, reduced fixation sizes, high strength performances, very limited mass,…) and, last but not least, two majors advantages,
. soft interface created between metallic parts and brittle optical ones,
. rather easy management of induced stresses and deflections

In the case of cryogenic optics, the bonded connections are subjected to quite stringent conditions:
. temperature excursions from roughly +60°C down to –170 °C for the structural fixations and down to # –290° C for bonding of thermal control components,…..for the time being!
. at least some tens of thermal cycles on ground, then several years of storage in ambient humidity and finally launch and several years in cryogenic conditions,
. several tens of vibrations runs at maximal load level, i.e. under some tens of g.

Materials used for the various spatial optics include from metallic ones (not often) to the complete field of ceramics, without forgetting composite materials (CFRP and carbon/carbon); the most usual materials are ceramic ones (SiC, CeSiC, Si3N4 and all the grades of glasses).

The strength of bonded connections is a phenomenon rather complex involving numerous parameters relative to the adhesive, to the adhesion surfaces and to the assembled materials. It remains difficult to predict their performances with accuracy, leading often to rather long and iterative studies and tests.

With composite materials and above all with ceramics, the weak component is often no more the adhesive, but the adherent material itself. Ceramics and mainly Glasses, brittle and sensitive to static fatigue phenomenon, make mandatory a very good knowledge of the behaviour and of the particular rules of design and of sizing of such materials too.

The adhesive keeps nevertheless an essential role with these brittle materials as deeply involved:
. in the very local mechanical and thermal-elastic over-stresses which lead first to the partial degradations then to complete failure,
. in the thermal-elastic deflections induced in the optic during the cool-down, with allowable deformations limited to some nano-or even pico-meters ! A very good knowledge of the behaviour of the adhesive remains thus quite important in the whole temperature range.

Often faced to needs for advanced bonded connections, THALES ALENIA SPACE has developed a methodology to characterise adhesives and adherents and efficient tools to predict with a good accuracy the strength of bondings:
discrepancy ≤ 15 % on 55 different bondings with

. 3 different adhesives and 4 main types of connections
. 7 couples of metallic, ceramics and CFRP / GFRP materials,
. a very large set of bonding lengths (1 to 40) and adherents thicknesses (1 to 32),
. a very large range of rupture loads (1 to # 100)
. at room and at very cold temperatures including complex loading cases

That allows :
. an optimization from the beginning of the design : the optimized definition is achieved directly by analysis and not by successive tests
. and thus significant savings in cost, schedule, performances and reliability.

A survey of the application scope is given through the validation panel and in particular by three examples of bonded assemblies subjected to large temperature excursions.

8255 | A Simple and Reliable method for the Strength prediction of the CFRP UD Pieces (16. Numerical Methods)

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The reliable prediction of the failure of the CFRP pieces is a domain which still calls for academic and industrial improvements, even for the pieces made with unidirectionnal plies. The usual industrial methods are simple, conservative but very often with scatters between Predictions vs Tests rather important. This limits drastically the confidence in the predictions and leads to numerous elementary or sub-assembly tests. That is why national and international great studies, syntheses or research ones, with numerous teams, appeared in the last years whereas some large studies are still in progress.

Among the numerous proposed methods, the most efficient seem to be the ones based on the progressive damage of the plies. Some very detailed works gave very good results. These methods have nevertheless some drawbacks: they are not easily handled (for analytical brain storming phases or by non acute experts) and they are not always implemented in usual FEM codes. But the main drawback is really that they require the characterisation and the watch of numerous additional material data, values derived from extensive additional material testing. That asks for particular and very brittle samples inducing a poor reliability and increasing significantly the cost of the characterisation and above all of the following-up of the materials scattering along the years.

Taking benefit of a large data base and of a survey of some detailed works, it was attempted to derive a simplified method with the following guidelines:
. for pieces subjected to plane stresses (e.g. sandwiches extensively used in space projects)
. compatible with fast sensitivity comparisons for the optimisation of the stackings as well as for the final detailed strength evaluation
. to demand for meshing refinement compatible with industrial time and cost constraints
. to limit clearly the additional characterisation tests and the supplementary material intrinsic values to evaluate (mean value and scatter) and to follow along the batch deliveries
. to improve significantly the reliability vs. usual industrial methods.

The preliminary conclusions of the presented work are :
. a quite good correlation between the predictions and the test results, close to the best but more intricate, expensive and more difficult to manage methods :

an average correlation Prediction vs Tests equal to 0.97

on 60 different stackings of 5 various materials in Tension, Compression, bi-axial loadings, at room and extreme Temperatures between [- 110° and + 150° C],
. an important mass saving in the most of the cases with a minimum of 15%, whatever the plies stacking and the materials,
. but the strength benefit is particular interesting when predicting the strength in case of stress concentrations, i.e. the most critical case of the most of the pieces : increase of the predicted rupture of at least 60 % vs usual methods,
. the cost of the elementary and sub-assembly tests can be drastically reduced thanks to the achieved reliability.

8731 | The inelastic analysis of plates considering a meshless method (16. Numerical Methods)

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In this work, plates submitted to transversal loads are studied considering a non-linear three dimensional analysis and assuming a hyperlastic material. The numerical method used to obtain the field variables is the Natural Neighbour Radial Point Interpolation Meshless Method (NNRPIM) [1,2].

The NNRPIM is a flexible and accurate meshless method, which uses the Natural Neighbour concept to enforce the nodal connectivity. This geometric concept permits to construct the Voronoï diagram of the unstructured set of nodes discretizing the problem domain. Such geometric discretization permits to obtain directly the “influence-cells”, which are in fact influence-domains entirely nodal dependent. The background integration mesh, required to numerically integrate the integro-differential equations governing the studied phenomenon, is obtained from the Delaunay triangles (the dual of the Voronoï cells). The NNRPIM shape functions are constructed using the Radial Point Interpolators (RPI). The obtained interpolation functions posses the delta Kronecker property, which simplify the imposition of the natural and essential boundary conditions.

In this work the plate is studied considering the complete three-dimensional domain. Thus, assuming the three-dimensional deformation theory the plate displacement field is obtained from the weak-form of Galerkin. Since the scope of this work is to extend and validate the NNRPIM in the large-deformation hyper-elastic plate analysis, non-linear solution algorithms are considered. In order to demonstrate the effectiveness of the method, several non-linear problems are studied. The numerical results indicate that NNRPIM handles large material distortion effectively and provides an accurate solution under large deformation and material inelasticity.

Keywords: Radial Point Interpolation Method (RPIM), Natural Neighbours, Meshfree Method, Large Deformations, Hyper-elasticity

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8843 | Determination of ultimate strength and fatigue limit of particulate reinforced metal matrix composites (PRMMC) by using upper-and-lower bound approaches (16. Numerical Methods)

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For PRMMC materials submitted to a variable loading, the unbounded development of the plastic deformation constitutes a major cause of the material failure. To determine the load bearing capacities of these materials against the long-term fatigue typed loadings, shakedown analysis in a Melan-Koiter sense provides an elegant solution by avoiding the cumbersome step-by-step simulation. In this study, based on both static (lower bound) and kinematic (upper bound) theorems, we developed numerical tool for modeling and solving shakedown problems. By applying this tool to PRMMC representative volume element (RVE) models built from the real material images, the endurance limits of the models are predicted. To take into account the intrinsic randomness of PRMMCs' microstructural morphology, the study is performed on a great number of samples. By collecting the data from samples and interpreting them by statistical methods, the relationship between the structure and the composite strengths are identied and examined in detail.

8907 l Fabric Reinforced Cementitious Matrix (FRCM) strengthened masonry wallettes: FE modelling of diagonal compression tests (16. Numerical Methods)

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In recent years the interest for innovative masonry seismic upgrading with FRP materials has increased. One of the most attractive techniques is the so--called Fabric Reinforced Cementitiuos Matrix (FRCM) reinforcement. FRCM represents a particular type of composite material for which a dry-fiber fabric is applied to a structure by means of a cementitious mortar with short fibers. When compared with other traditional reinforcing techniques, FRCM exhibits several advantages, as a greater resistance to high temperatures and ultraviolet radiations, as well as a better compatibility with the substrates. For these reasons FRCMs are often used to repair and strengthen existing structures.
In the present paper, the behavior of FRCM strengthened masonry wallettes under diagonal compression tests iswas investigated by means of a series of numerical simulations using a commercial code and a heterogeneous approach.
In particular, mortar joints, bricks and the fabric reinforced cementitious matrix are meshed separately. For mortar and bricks, standard isotropic elasto-plastic materials with damage and softening are utilized, after proper calibration of the elastic and inelastic parameters.
The FRCM strengthening system, composed of a fiber grid, is modeled with trusses exhibiting a non linear behavior, whereas the cementitious matrix is discretized with elasto-plastic 3D elements. The simulations performed are conducted to evaluate the effectiveness of such typology of retrofitting, used to prevent brittle behavior or sudden failure of the masonry supports and to improve their deformation capacity. Finally, a series of simulations on masonry panels retrofitted with FRCM materials applied on cracked substrates is conducted. In order to analyze the influence of the cracked supports on the overall behavior of the system, two configurations of cracks are considered. To properly reproduce the behavior of the retrofitting during the two series of simulations the possible delamination of the grid from the matrix are suitably taken into account. The results of the numerical simulations show the advantages of these materials when used for the reinforcement of existing masonry structure and highlight the crucial role played by the fiber grid to improve the global behavior and the ductility of the system.

8945 l Static and instability analysis of thin and moderately thick viscoelastic plates using a fully discretized nonlinear finite strip formulation (16. Numerical Methods)

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In this paper, a semi-analytical finite strip method was developed for the analysis of thin and moderately thick viscoelastic plates by using continuous harmonic function series that satisfies the boundary conditions in the longitudinal direction and piecewise interpolation polynomials in the transverse direction. The mechanical properties of the material are considered to be linear viscoelastic by expressing the relaxation modules in terms of Prony series. A recurrence formulation was used to evaluate the entire deformation history that requires only the storage of the displacements from the previous time step only. The standard finite strip procedure based on virtual work method was used to derive stiffness and geometric matrices. Using this solution technique, a simple expression was developed to predict the critical buckling load of the plates with different end conditions.
A comprehensive parametric study was conducted where the maximum deflection of the viscoelastic plates with different boundary conditions subjected to time-dependent loads was calculated. The results showed that the error in the solution propagates when time increases. The effect of the time interval, plate length, plate thickness and biaxial loading on critical buckling load of the viscoelastic plates was also evaluated. The results indicated that the critical buckling load of the plate decreases with time when the relaxation modulus decreases. Moreover, the results showed that the buckling capacity of the rectangular viscoelastic plates decreases when the aspect ratio of the plate or the value of the transverse loading increase or when the plate thickness decreases. It was also demonstrated that the developed finite strip method is able to capture creep properties at the unloading phase.

8981 l Numerical comparison of geodesic, non-geodesic and generalized spline paths in order to wind complex, axisymmetric geometries (16. Numerical Methods)

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As part of an integral approach in the development process of filament wound structures, three types of fiber trajectories are studied and compared on this research: geodesics, non-geodesics and generalized splines. Considering certain filament winding technical requirements such as non-slippage, full coverage, bridging-free, turn-around and uniform distribution these trajectories are compared between themselves so as to establish their feasibility and the convenience of their usage. A numerical simulation is developed in Matlab software and its validation is achieved with Cadwind software. The geometries under study are considered simple such as cylinders, and complex e.g. convex and concave geometries, and their combination. A previous fabrication procedure demonstrates the feasibility of the fiber paths under study to wind the desired geometries using geodesics and non-geodesics.

8987 | Element Free Galerkin Model for Orthogonal Cutting of Unidirectional Fibre-Reinforced Plastics (FRP) (16. Numerical Methods)

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Demand for accurate predictive models of FRPs machining is on the rise due to the increased market share of these materials across several industries. Finite element method has been the conventional choice in numerical modelling. Modelling of machining processes using FEM is challenging for several reasons such as severe element distortion, the need for remeshing and the definition of separation criteria in Lagrangian formulations. Many of these problems are attributed to the mesh-based discretisation of the domain. Meshfree methods rely on non-connecting nodes in domain representation and as such, has the potential to alleviate some of those challenges.
This paper therefore aims at developing a meshfree model for orthogonal cutting of uni-directional FRP using 'Element-Free Galerkin Method' (EFGM), which is one of the most widely used meshfree methods. The developed model investigates the effect of fibre orientation angle, fibre-volume fraction and cutting tool geometry on cutting forces. The workpiece material is assumed to be orthotropic and in plane stress condition. Moving least squares approximation is used in constructing the meshfree shape functions. Central difference method is used in time integration of the semi-discrete equations. The effects of weight function choice and nodal density are investigated. The advantages and disadvantages of the EFGM applied to orthogonal cutting are discussed and results are compared with existing literature.

9088 | An incremental multilevel computational homogenization method for elastoplastic composites (16. Numerical Methods)

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In the present work, a multilevel computational homogenization method is proposed for solving structure problems made of elastoplastic phases. To reduce computations costs of classical multi-level finite element methods [2], we use an incremental framework, initiated in Hill citehill1965 and developed for semi-analytical method e.g. in [1]. In semi-analytical approaches, the approximation of the Mori-Tanaka scheme induces limitations in accuracy for some configurations like strongly anisotropic microstructures and does not allow capturing effective smooth hardening induced by the different elastoplastic phases. In the proposed method, we use the incremental approach by computing directly the effective macroscopic tensor related to the linearized problem numerically by Finite Elements on an RVE. The method is validated through an example of homogenization of a composite microstructure with elastic rigid fibers, embedded in an elastoplastic matrix. The results showed that the method is more accurate than semi-anlytical methods and is less computationally demanding than FE2.
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9128 | A finite element method for plate bending problem of Reissner-Mindlin model (16. Numerical Methods)

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A finite element method is proposed and analyzed for the Reissner-Mindlin plate problem subject to various boundary conditions. Rotation and transverse displacement variables are approximated by continuous linear elements (enriched with local bubbles) and an L2 projector is applied to the shear
energy term onto the Raviart-Thomas H(div;Ω) finite element. Stability and optimal error bounds hold uniformly in the plate thickness. Numerical experiments are presented to illustrate the performance of the proposed method.

9154 | OPTIMIZATION AND EXPERIMENT OF COMPOSITE SQUARE BEAM (16. Numerical Methods)

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The aim of this article is to design a composite box beam in three-point bending with a high ratio of load-bearing/weight. First of all, a three-point bending experiments was conducted to the manufactured composite box beam and it was found the top of the box broken for exceeding the compressive stress limitation. Then, a finite element model the same as the experimental (original) parameter was established; comparing the analysis results with experimental data, they were in good agreement. Then, a basic shape of the square beam was got by using topological optimization of ANSYS. ANSYS APDL was used to model a parametric composite square beam, which can perform the geometric optimization of the square beam. The result shows that increase the height of the square beam's arch and the thickness of the top of the square beam within a certain range helps to reduce the maximum stress

and increase the load
apply on the square beam. Finally, the second composite square beam, which is almost the same as optimized result, was manufactured. An experiment was conducted to the second beam. The experiment results show: the square beam with optimized parameter has a better mechanical performance than the square beam with initial parameter.

9163 | Numerical Modelling of Progressive Failure in Filament Wound Cylindrical Pressure Vessels (16. Numerical Methods)

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Laminated fibre reinforced composites are widely used in various engineering sectors due to their versatility both in geometry and mechanical properties. These relatively new materials are tailor designed to meet specific structural stiffness with high strength to weight ratios. However, the complex interaction between the different constituent phases and lamina creates significant challenges in material and mechanical modelling. This complexity is even more augmented when modelling the structural behaviour following the onset of first-ply failure. The uncertainty in modelling techniques and failure criteria reflects itself in high safety factors quoted in relevant standards. In particular, a safety factor of the order of four or above is assigned to calculated design loads, based on first ply failure, in composite pressure vessels. This is significantly conservative, considering that at this stage the vessel can still offer some degree of structural stiffness, often withstanding higher ultimate pressure failure loads. Nonetheless an accurate and robust predictive technique is required to base design codes on the ultimate failure load
This study present the results of a progressive failure algorithm based on a sudden mode-dependant degradation methodology and applied to filament wound cylindrical pressure vessels subject to an internal pressure. Progressive failure was modelled through a material orthotropic degradation damage model where the material stiffness is degraded according to the failure mode and mechanism detected from the homogenised stresses at macro level. The numerically predicted results were corroborated with realistic experimental test results. Both experimental and numerical results show that the investigated laminated pressure vessels are able to sustain considerable higher pressures beyond the predicted first-ply failure. The good agreement with experimental results provides significant confidence in the usage of numerical models and stretching the boundaries of filament wound pressure vessels.

9207 | A new device and inverse method to characterize thermal properties of composite phase change materials: thermal conductivity, sensible and latent heat. (16. Numerical Methods)

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A new experimental device and inverse method has been developed in order to characterize the thermal properties of phase change material in the solid phase, during the solid-liquid transition and in the liquid phase. It allows to measure cylindrical samples of maximum 60 mm radius and 10 mm thick. A typical measurement consists in imposing a vertical temperature gradient through the PCM sample driven by a heat source, monitoring during the experiment time all the boundary conditions (temperatures and heat fluxes) and measuring temperature evolution in three locations within the PCM sample. These experiment data are used to inverse the heat transfer model (heat conduction in the solid phase, heat transfer with phase change during the solid-liquid transition and heat convection in the liquid phase) by applying the conjugate gradient method and finally, to determine the PCM thermal properties. Two types of composite PCM have been thermally characterized: paraffin mixed with synthetic graphite (Timrex SFG75) and paraffin mixed with graphite waste.

9279 | Comparative Study of Flexural Versus Tensile Behaviour of fibre reinforced and sandwich composite Materials Using Finite Element Analysis (ANSYS code) (16. Numerical Methods)

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The main reason for using composite materials instead of their counterparts in the automotive industry, marine structures and infrastructural applications is their high specific strength and modulus (strength, modulus to density ratio), consequently they are ideal candidates for deploying in the wide range of applications, but considerable experimental data is needed to aid in material selection and qualification. A critical problem when working with composite materials including fibre reinforced polymers and sandwich composite structures is their anisotropic behaviour that makes their simulation difficult and modelling results inaccurate. In addition, variability in materials processing and microstructures created leads to a scatter in measured properties of composite structures, required for a correct and reliable design.

In this study we have combined experimental analysis and finite element analysis incorporating failure modes to determine the extent of failure in composite materials with an aim to assess if materials properties and uncertainty can be correctly captured in the FE failure analysis. The quasi static tensile and flexural characteristics of two different categories of composite materials, fibre reinforced composites and sandwich composite structures, were examined by mechanical testing according to BS EN ISO 525 and BS EN ISO 14125 respectively. For fibre reinforced composite materials different fibre/matrix arrangements were assessed; Glass fibre reinforced epoxy resin with woven glass fibres (GFRP 0/90 orientation of glass fibres), Carbon fibre reinforced epoxy resin (CFRP 0/90 orientation of Carbon fibres) and Kevlar fibre reinforced epoxy resin (KFRP 0/±45/90 orientation of Kevlar fibres) were selected. For comparison, sandwich composite structures with three different configurations of face sheets and core mat thicknesses were tested. It was observed that although the both tensile and flexural strength of glass fibre reinforced epoxy is lower than the carbon and Kevlar fibre reinforced composites, the tensile and flexural stiffness of this composite is higher. Three point bending tests and tensile tests on sandwich composite structures showed that decreasing the thickness of the core and number of layers will result in better mechanical properties.

SEM and light microscopy in conjunction with Nano-indentation were used in order to analyse the failure mechanisms as a result of both static flexural and tensile testing and it was found that interfacial debonding between fibres and matrix, resin cracking, and fibre breakage are the main failure mechanisms as expected.

Three-dimensional finite element analyses were then carried out to determine the stress, strain distributions and deflection contours of a test sample both in bending and tension. This was used to predict failure of the composites, to interpret the experimental results and to examine the failure modes of the specimens. Comparison between experimental and analytical results showed that there is a good compatibility between FEA and experimental results at lower loads in the load displacement curve of three point bending and tensile test. Deviations at high loads highlight the effects of defects created during the test. Using ANSYS mechanical APDL, Tsai-Wu and maximum stress failure criteria were employed for failure prediction and failure mode identification respectively and it was found that the major failure modes in the three point bending and tensile test of composite materials are related to fibre tension and compression (fibre breakage as result of tensile stresses and buckling due to compressive stresses in the concave and convex side of the test specimen).
A parametric survey was performed using ANSYS Composite Pre-Post software to assess the effect of fibre orientation uncertainty and manufacturing defects. Similar scatter as observed in experimental results was predicted by FE analysis.

7047 | Analysis of micro-shear test of titanium nitride coatings deposited on left ventricular assist device (17. Micromechanics)

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The ventricular assist device Religa_EXT will be made of thermoplastic polycarbonate-urethane Bionate II, nanocoatings: titanium nitride and gold. The two-scale model of Religa_EXT developed in the authors' finite element code is composed of a macro model of blood chamber and a micro model of wall. The numerical analysis of stress and strain states in the model confirmed the possibility of fracture. The introduction of gold interlayer between titanium nitride and polymer improves the toughness of the connection, and increases the compressive residual stress in the coating what results in reduction of stress and strain close to the boundary between substrate and coating. The proper design of wall of the Religa_EXT requires the introduction of the real stress and strain states in the deposited coatings. The mechanical properties of titanium nitride (residual stress, material model and fracture model) were determined in nanoindentation tests, profilometry studies and in situ scanning electron microsopy's micro-tension tests. The goal of present work is development of the experimental micro-shear test, the numerical model of the test, and its calibration. The critical strains taken from experiment and considered as the effective strains in the model of test are the values which are the function of triaxiality factors for the tested samples. The finite element model of Religa_Ext enriched with critical strain enables prediction of probability of fracture.

7600 | A study of macro-microstress concentration in composite plate with circular hole (17. Micromechanics)

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The present study aimed to compute macro-microstress concentration in reinforced composite plate with circular hole to the volume ratio of the component materials in composite. The contour of the circular hole and its dependency on the structure of plates were calculated to study the behaviors of macro and microstress. In this paper, the stress around a circular hole was calculated by orthotropic fiber-reinforced plates dependent upon the volume ratio of the component materials in the composite. Stress distribution using a theoretical method and finite elements method (FEM) was calculated. The boundary conditions at a large distance from the hole are pressure, uniformly distributed on the plate. In this present study, the use of a new numerical method by FEM for solving the microstress for the composite plates with a circular hole. The finite element model incorporating the necessary boundary conditions was developed using package ANSYS to predict the elastic property of the composite, a representative plate model was used in this study for this purpose.
The results demonstrated the macro- microstress and behavior of the orthotropic plate calculated for square and hexagonal structures.

7635 | Application of couple-stress theory for description of large strain bending of fibre composites (17. Micromechanics)

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Keywords: hyperelasticity; anisotropy; fibre composite; couple stress; finite element method.

Unidirectional fibre-reinforced elastomers are investigated. Conventional theory of fibre-reinforced solids employs an anisotropic homogeneous model with a unit vector field characterizing fibre direction based on assumption of infinitesimally thin densely and uniformly distributed fibres. Size effects arise when the characteristic length scale of inhomogeneity is comparable with dimensions of the specimen. A respective finite strain model was formulated within the couple-stress theory and implemented for three-dimensional finite element analysis. The homogeneous anisotropic model is based on kinematics and constitutive equations proposed by Spencer and Soldatos (2007) and takes the contribution of fibre bending stiffness to behaviour of the composite into account. A specific form of strain energy density was proposed with an additional term taking the bending stiffness of fibres into consideration. The higher order continuity required on element boundaries is solved by means of C1 elements, and parameters of the model are determined on the basis of fictitious experiments. It is shown that the discrepancy between the conventional unit vector based model and the topology based heterogeneous model can be overcome by the presented approach.

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7753 | Predicting the mechanical behaviour of a visco-plastic particulate composite at high volume fractions (17. Micromechanics)

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The mechanical behaviour of composites can be predicted accurately up to a certain volume fraction using a number of different analytical models. However, the effect of inter-particle interactions which are not accounted for, increases with volume fraction. As a result, the analytical solutions tend to diverge from the experimentally measured behaviour as volume fraction increases. An alternative method is the use of micromechanical finite element models. The advantage of such method is that it allows micromechanical behaviour such as fracture to also be predicted. However, due to meshing difficulties for a highly packed volume, the maximum volume fraction which can be modelled using the finite element method is limited.

A combined method, which utilises both the analytical and finite element method, is proposed here for modelling a visco-plastic particulate composite filled to 96.5 % volume fraction. For bulk material behaviour prediction, the method is based on the assumption that a highly filled composite is only achievable with a large particle size distribution. The larger particles are explicitly modelled geometrically in FE. The stiffening effect of the remaining smaller particles are included by replacing the pure polymer material properties with modified properties determined using the analytical models. For prediction of fracture behaviour, the combined method is only valid for particulate composites where debonding is the dominant fracture failure mechanism and that the assumption of debonding occurs first around large particles holds.

The material used for this work is a Talc filled visco-plastic polymer and the mechanical behaviour has been investigated at room temperatures for strain rates of 0.02, 0.1 and 1/min. Compressive and tensile modulus, yield stress and yield strain of the composite and the pure constituents have been measured experimentally. Fracture properties for the composite have also been obtained. The accuracy of the mechanical behaviour predicted using the combined method is investigated by comparison with the analytical and FE method and to experimental data at various volume fractions.

7796 | A micromechanics study to derive the effective property of a piezo- elastic multilayered plate (17. Micromechanics)

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The prediction of the mechanical and electrical properties of piezoelectric fiber composites became an active research area in recent years. Micro mechanical methods provide an overall behavior of piezoelectric fiber composites from known properties of their constituents (fiber and matrix) through an analysis of a periodic representative volume element (RVE) or a unit cell model. The advantage of the micro mechanical approach is that not only the global properties of the composites can be calculated, but also various mechanisms such as damage initiation and propagation, crack growth, etc. can be studied through the analysis.
In this study we present the quadratic discretization to calculate the effective property of a piezo-elastic multilayered plate. We find that this micromechanics approach is rather efficient in the sense that:we can change size of the inclusion, put an elastic inclusion in a piezoelectric matrix and vice versa, see the influence of vacuum on the material behavior. The multilayered plate consists of linearly elastic (with piezoelectric inclusion) or piezoelectric (with elastic inclusion) laminate of arbitrary thickness.
Using the Stroh formalism associated with the propagation matrix, this will provide solutions for multifunctional multilayered plate, to predict exactly the mechanical and electrical behaviors near or across the interface of material layers.

7925 | SENSITIVITY OF MATRIX-DOMINATED FAILURE MODES TO CARBON/EPOXY CONSTITUENT PROPERTIES VIA COMPUTATIONAL MICROMECHANICS (17. Micromechanics)

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A micromechanical approach can promote understanding of composite material failure mechanisms and increase our knowledge of the key parameters that control intralaminar damage. Such knowledge is vital in order to develop mesoscale (ply level) damage models of composite materials.
Classical micromechanics can predict the elastic properties of a lamina, but capturing intralaminar failure modes needs finite-element based approaches that incorporate the modeling of damage for each of the constituents.
The response of micromechanical models of unidirectional composite plies is affected by many factors; among them there are: the randomness of fibers distribution, the constitutive and failure models of each constituent and the mechanical characteristics of the matrix-fiber interface layer (interphase).
Sensitivity studies to volume fraction, to fiber distribution and to the explicit simulation of the interphase do exist in recent literature. Yet, the influence on failure stresses and modes of constituent properties and damage parameters is still an open issue.
The authors present a sensitivity study of micromechanically computed strengths to the most relevant constituent parameters which affect matrix dominated failure modes (transverse traction, transverse compression and shear).
For this purpose finite-element (FE) Representative Volume Elements (RVEs) are generated in SIMULIA-ABAQUS by means of a dedicated Python script. The script applies multiple sets of boundary conditions in order to guarantee the periodicity of the microstructure and to reproduce the different load cases. Global RVE mechanical responses, i.e. averaged stresses vs. strains, are obtained by homogenization. The size of the RVEs is selected so that the homogenized stress fluctuations are vanishingly small for any random distribution of fibers generated using the probability density function that, according to recent studies, produces the smallest FE model for RVEs.
The typical non-linear behavior of epoxies is reproduced by means of a pressure-dependent elasto-plastic constitutive relation, characterized by an exponential hardening followed by a linear softening law. The interphase is modeled using ABAQUS cohesive elements modified through an ad-hoc traction-separation constitutive model. Both matrix and interphase constitutive laws are implemented via user-defined material routines (UMAT).
The systematic comparison of the mechanical responses, in terms of homogenized stress vs. strain curves, is used in order to discover correlations between the constituents properties and lamina failure stresses for modes of interest. The insight gained with the proposed approach will also constitute the basis for the development of specific tests aimed at determining the most relevant micromechanical parameters whose measure is a major challenge for current experimental procedures.

8198 | FINITE ELEMENT ANALYSIS OF MECHANICAL PROPERTIES OF WOVEN COMPOSITES THROUGH A MICROMECHANICS MODEL (17. Micromechanics)

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In a woven fabric composite, arrangement and behavior of the fibers contained in the yarn and yarns themselves, leads to an intricate deformation mechanism. The current research, therefore, intents to purpose a simplified mathematical micro mechanics model for calculating mechanical properties of the plain weave composite using finite element analysis (FEA).A repetitive volume element (RVE) cell approach has been adopted for properties evaluation of plain weave composites. The FEA allows the modeling and portrayal of fabrics by taking into account various geometric parameters such as the yarn undulation, the probability of existence of consonances in a unit cell and interaction between warp and fill tows. These factors help in generating a mesh close to the actual. Additionally, a technique to represent internal layout of composite structure employing actual dimensions of yarn geometry using conventional measurement devices, rather than the demanding method of obtaining measurements from photo micrographs of sectioned laminates, is also proposed. The geometric symmetries as reported in the available literature were also incorporated during the of the model formulation. Theory of comparative displacements was then used to construe these symmetries into appropriate mechanical terms. This consequently leads to the formulation of boundary conditions for the repetitive volume element. The finite element micromechanics model proposed is different from the existing models in a way that it defines the yarn cross-sectional path based upon computational fluid dynamics (CFD) technique rather than conventionally obtained photo-micrographic results or the proposed sinusoidal paths by various researchers. Experiments were then performed on the laminates used for obtaining the geometric parameters with the aim of supporting the validity of the suggested model. The outcomes of the experimental investigation were found to be in close approximation of the computational analysis.

8292 | Fabrication, analysis of mechanical properties, and finite element model of shape memory alloy(SMA) fiber-reinforced polymer composites (17. Micromechanics)

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With advancements in science and technology, and a deeper understanding of the effects of microstructure and processing techniques on the material behavior, the field of material science has radically improved through the past decades.Along the way, Shape Memory Alloys (SMAs) have been on the forefront of research for thelast several decades. They have been used for a wide variety of applications in various fields.Due to their shape memory effect, pseudo-elasticity, highdamping capability and other remarkable characteristics, combining the unique properties of SMAs with other materials can createintelligent or smart composites.Amongthem,shape memory alloy (SMA) fiber reinforced compositeshave been developed as one of the new type of smartcomposite. And in the high-tech fields,especially in the aerospace industry, SMA fiber reinforced composites demonstrates the wild application prospect.
In the present study, comparing to other articles,wefocuses on the completeprocess about fabrication, analysis of mechanicalproperties, tensile test, proposing the analytical procedure and finite element model for SMA fiber-reinforced composites. Production of SMA composites in this research has been based mostly on conventional polymer composite fabricationmethods. In this paper, SMA composites are to be fabricated by embedding SMA wires into a polymer matrix. Then, a tensile test is conducted to study the mechanicalproperties of the SMA compositesand is performed to discussthe effect of SMA recovery stress on the mechanical propertiesof SMA fiber composites.Following,an analytical procedure, which could be achieved using the micromechanical method,is to be proposed for the determination of the effective mechanical properties of the composite from those of the fiber and matrixmaterials. In order to validate the analytical procedure, the properties of the shape memory alloy and the composite material used for the matrix are to be determined experimentally. The analytical method will then be used to estimate the effective properties of the composite and the results will be compared to the experimental values for validation. As a final step, modeling of the functionalbehavior of SMA composites has becomean indispensable part of the SMA composite. Here, a model for SMA fiber-reinforced composites is to be developed and used for finite element simulation of engineering structures made from such composites.

8545 | Micromechanics study of Hydrogen Embrittlement in Pulse Plated Polycrystalline Nickel using experimental and multiscale modelling (17. Micromechanics)

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Microstructures play a prominent role in aerospace components which are typically made of high toughness, corrosion resistant and high strength structural polycrystalline metallic materials such as nickel and nickel based superalloys. Nickel and nickel based superalloys are made up of complex microstructures which are susceptible to delayed failure caused by absorption of hydrogen produced either during fabrication in manufacturing process (i.e electrodeposition, welding etc…) or during operational use under environmental conditions. Premature failure due to hydrogen embrittlement (HE) have been observed in the electrodeposited pulse plated polycrystalline nickel (PPP-Ni) and the hydrogen pickup during plating process, welding process etc.. are the major source of hydrogen for hydrogen induced crack formation. In order to understand the effect of hydrogen on the deformation and fracture in pulse plated polycrystalline nickel were studied by means of in-situ electrochemical tensile test by charging the nickel samples with hydrogen and tensile tests in air. The hydrogen charged pulse plated polycrystalline nickel specimen shows decrease in ultimate tensile strength and tensile elongation by resulting with fracture, when compared with the specimen tested in air. The micromechanics investigation of HE in PPP-Ni have been studied using scanning electron microscope (SEM), electron backscattering diffraction analyses (EBSD) and multiscale modelling. Then the results shows the role of micromechanics on the fracture are discussed.

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8593 | Three dimensional mesoscopic dynamics analysis of cement-based composites (17. Micromechanics)

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In the study of mecromechanics problem in cementitious composites, currently most are 2D static and dynamic tests. But with the development of mecromechanics, the numerical simulation of 3D dynamic meso-scale mechanical properties of cementitious composites could be achieved. This study based on composite interface damage model, which showed discontinuity, heterogeneity, anisotropy. Extended it to 3D, studied the process and destruction of dynamic impact of cementitious composites, and do the similar experiment.
With experiments and numerical simulations, the impact assessment of the overall strain rate effect on the mechanical properties of the cementitious composites is analyzed. Using the composite interface damage model, 3D analysis of cementitious composites dynamic compression failure process is showed and analyzed. In this paper, the Matlab and Ansys / Ls-dyna are combinated to establish composite interface damage model. And use explicit algorithms and unit optimization to make the computation efficiencient. The failure process under macro-dynamic compression is in studied meso-scale, and given the simulation of crack propagation, intensity values, and issues such as dynamic growth factor DIF.

8650 | Failure Envelopes for Unidirectional Composites Generated by the HFGMC Micromechanical Method (17. Micromechanics)

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The use of laminated composite materials have exponentially increased over the last four decades spanning both civil and military industries. Failure theories for an orthotropic layer under multi-axial and combined stress states have been extensively investigated and many macro-failure theories have been proposed. These failure criteria share the use of stress or strain invariants for the homogenized medium in order to generate failure envelopes in the stress or strain space, e.g Hashin[5,6], Tsai and Wu[10], Puck[9], Christensen [3], among several others. In fact, it has been previously argued, e.g. Hashin[5,6], that the complexity of damage at the microstructural scale offers little or no hope for using micro-mechanical methods for failure prediction of composite materials. However, the recent advances in computational and nonlinear micromechanical methods allow the use of failure predictions based on the invariants of the average stress and strain in the matrix and fiber phases, e.g the SIFT[4] criteria.

This study deals with using the high fidelity generalized method of cells (HFGMC) micromechanical method, Aboudi[1,2], and its nonlinear and parametric extensions, Haj-Ali and Aboudi [7,8], in order to predict ultimate failures of fiber composite media. To that end, Continuum damage constitutive models are implemented for the fiber and matrix subcells in order to generate the effective softening behavior. The formulation and the computational implementations will be discussed. The generated HFGMC failure envelops will be compared to some well-known failure criteria.

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8749 | On the use of the Anisotropic Yield Criterion of von Mises (1928) as a yield condition for Particle Reinforced Composites. A calibration procedure based on numerical analysis of multi-particle cells. (17. Micromechanics)

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In particle reinforced composite materials (PRC) in which the reinforcing particles are embedded in a matrix in a more or less ordered or aligned way, not only the elastic stiffness tensor can be expected to have an anisotropic tensor form, also the yield condition should be formulated with an anisotropic criterion.

Various yield criteria for anisotropic materials are available in the literature, which can be used to assess the limit of elastic response for various kinds of composites. Among many others, the orthotropic criterion by Hill (1948a, 1950) with its many subsequent extensions or the fully anisotropic criterion by Tsai-Wu (1971) can be cited. However, an earlier anisotropic criterion by von Mises (1928) is, comparatively, seldom mentioned (probably, as a consequence of being overshadowed by the classical isotropic von Mises (1913) yield criterion). As compared to the orthotropic criterion of Hill, the anisotropic Mises criterion may describe, if needed, an influence of the hydrostatic stress in the yield condition. As compared to the Tsai-Wu criterion, the anisotropic Mises criterion lacks the ability to describe different elastic limits in tension and compression. This criterion is defined by a fourth order tensor

containing the necessary yield parameters; it can be applied to a fully anisotropic situation or to some specific cases, such as orthotropic or transversely isotropic behaviours.

In the present work, the suitability of the anisotropic Mises criterion to characterize initial yielding of PRCs is studied with a computational micromechanics approach. First, a calibration procedure is described which allows for experimental quantification of the parameters of the anisotropic yield criterion. Then, an actual calibration is performed by means of numerical experimentation which uses FEM analysis of multi-particle cells representing the microstructure of a model anisotropic PRC material.

The multi-particle cell used in the numerical experiments consists of a representative volume element (RVE) of the material, including a number of reinforcing particles, randomly distributed inside the RVE. Particles' aspect ratio and orientation are controlled in such a way that the microstructure of the model material shows an explicit geometric anisotropy. Results show that the fully anisotropic von Mises yield criterion (1928) is a good candidate to characterize initial yield of PRC materials.

8940 | Size-dependent thin sandwich microbeams based on modified couple stress theory (17. Micromechanics)

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Based on modified couple stress theory, a novel size-dependent thin sandwich microbeam model is developed. Euler-Bernoulli beam theory is employed to develop the size-dependent governing equations of modified couple stress sandwich microbeams. The effect of size-dependency on static bending behavior of a sandwich microbeam under three point bending is investigated analytically.

8964 | Free vibration of micro-tube conveying ferrofluid via Reddy beam model and Strain gradient theory (17. Micromechanics)

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This present study investigates vibration and instability of the Boron Nitride micro-tube conveying ferrofluid under the combined magnetic and electric fields. Based on Reddy beam (RB) theory, piezoelasticity strain gradient theory and Hamilton's principle, the motion equations are obtained in which containing displacement and electric potential. The differential quadrature method (DQM) is employed to discretize the coupled motion equations. Natural frequency and critical velocity of the RB micro-tube are computed by strain gradient, modified couple stress and classical beam theories and obtained results are compared with Timoshenko beam (TB) and Euler-Bernoulli beam (EBB). Natural frequencies of RB and TB have dramatic difference with EBB in low aspect ratio since rotary inertia and transverse shear deformation are included in their theories. Moreover, influences of elastic medium's modulus, aspect radio, temperature changes and magnetic field on vibrational characteristic are studied. As main result, it is indicated that effect of magnetic field appears in higher speed of ferrofluid and makes to increase the critical velocity or enlarges the region of stability.

8995 | Numerical analysis of composites with inclusions periodically arranged in non-orthogonal coordinate system (17. Micromechanics)

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In this contribution, different techniques are used in order to evaluate strain and stress fields in composites with inclusions or defects periodically arranged in non-orthogonal coordinate system. These composites have been studied by several authors [1,2] and also include the unidirectional composites with hexagonal symmetry and transverse isotropy, which have been analysed in many works on homogenization, see e.g. [3]. In this work, the composite material is represented by a homogeneous solid subject to a suitable eigenstrain, according to the Eshelby method, and the variables appearing in the governing equations of the problem are represented by Fourier series [4]. The eigenstrain may be considered constant in the inclusion [2]. However, not only the strain and stress fields but also the evaluation of the overall properties of composites may result inaccurate when the eigenstrain is approximated as constant in the inclusion. Here, better estimates are obtained by assuming that the eigenstrain can vary in the inclusions. Finally, the proposed results are compared with the strain and stress fields provided by the finite element method.

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9186 | 3D NUMERICAL COMPUTATION OF ELASTIC PROPERTIES OF A UNIDIRECTIONALLY REINFORCED LAMINA CONSIDERING A RANDOM ARRAY OF FIBRES (17. Micromechanics)

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In this work, an estimation of the elastic constants (elastic moduli, shear moduli and Poisson's ratios) of a unidirectionally reinforced lamina is provided. To this aim, 3D micromechanical finite element models that include a random distribution of fibres in the transverse plane normal to the fibre direction have been generated. A sufficiently large domain is analyzed and periodic boundary conditions have been applied. Thus, the model can be considered quasi-random as far as the distribution of fibres is concerned.

Several random models have been developed for different fraction volumes. This way, the reinforcement factor xi typical of the Halpin-Tsai equations can be estimated inversely for each relevant elastic constant: transverse stiffness E2, shear modulus in the lamina plane G12 and in the transverse plane G23, Poisson's ratio in the lamina plane nu12 and in the transverse plane nu23, etc. The reinforcement factor for these properties is only given in the literature for E2 and G12 and is limited to a square array distribution of fibres, which is not as realistic as the random distribution proposed here. Therefore, the present work provides a full 3D micromechanical description of the elastic constants in terms of the reinforcement factor of the Halpin-Tsai equations as a function of the volume fraction for a realistic random distribution of fibres.

9194 | The influence of metallic and non-metallic fillers on the polymer laminate structures (17. Micromechanics)

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Paper presents research results of morphology, quantity and purity of metallic and non-metallic fillers influence on the structural properties of polymer laminates. Tests based on the microstructural characteristics of the laminate, oriented to quality of connection of laminates components. The base ingredient of the laminate were two kinds of polymer resin, reinforced with glass fiber fabric. The fillers of Al metal powders and SiC non-metallic particles have been used.

9201 | MULTISCALE MEAN-FIELD MODELING OF DUCTILE DAMAGE IN COMPOSITES (17. Micromechanics)

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In various engineering-related disciplines, the simulation of composites behaviour under severe loading, leading to damage initiation and failure is still subject to serious challenges. For ductile materials, the damage's onset begins at microscale by the nucleation, growth and coalescence of micro-cavities as for instance in metal matrix composites (MMCs). These occurred phenomena within the microstructure require careful modeling strategies to account for their effects at the macroscopic level. The micro-macro transition is often set up through homogenization tools among which are the mean-field approaches (MFH). For multiscale analysis, MFH approaches constitute a good compromise between the prediction's accuracy and the computational cost through either analytically and/or numerically derivations from the constituents' properties.

In this work, an attempt is made to compute the ductile damage behavior within composite materials by the means of the Incremental Micromechanics Scheme (IMS) as Mean-Fields Homogenization (MFH). The nonlinear behavior of the composite is addressed in a general framework based on the Lematre-Chaboche's ductile damage model. Numerical results are obtained for Metal Matrix Composites (MMCs) and Carbon fibers reinforced Composites. The model predictions are compared to experimental data from the literature.

9342 | Analysis of composite sleepers-ballast interaction using experimental and discrete element methods (17. Micromechanics)

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Composite sleeper is an effective method to reduce dynamic force of track, but result in reduction of ballast resistance, which is an important value for keeping track from buckling. The Experimental and numerical discrete element analysis have been performed to investigate the composite sleeper and normal sleeper interaction of railway ballast, the ballast resistance value as well as ballast-sleeper micro-interface characteristics were determined. Results indicated that ballast resistance value of composite sleeper was less than normal sleeper, modifications or attention should be taken where bigger ballast resistance should be guaranteed.

9351 | VISCOELASTIC ANALYSIS OF UNIDIRECTIONAL COMPOSITE MATERIAL IN PRESENCE OF ELLIPTICAL HOLE (17. Micromechanics)

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The objective of this study is to investigate the time dependent analysis of load transfer during interaction between a polymeric matrix and elastic fibers in the axial direction, as a function of the matrix time-dependent properties. The laminate is subjected to an elliptical damaged zone of radii "d" and "D". The stress state in the composite is solved at incremental time intervals to obtain the stabilized solution, and the time required to reach a stable state. To study the effect of viscoelasticity on unidirectional composite material used the general Maxwell model. A hexagonal arrangement of fibers is postulated to satisfy the equilibrium equations. It is assumed that all unidirectional long fibers lie in a finite width laminate. Upon proper use of boundary and boundness

conditions, stress and displacement fields are derived within the laminate and as well as elliptic hole surrounding. The solution is obtained analytically as well as numerically, using finite element technique. Comparison of the predicted shear stresses and average normal stresses based on analytical results to finite element analysis demonstrates that analytical model can be used to rapidly estimate the average normal stress distribution in the various constituents.

9365 | Microstructure and Anti-penetration Resistance of Composite Ceramics containning Preexisting Defects (17. Micromechanics)

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Composite ceramics mainly consisted of rod-shaped crystals turn into the optimization materials of shellproof plate, for their high hardness, high strength, high fracture toughness and high temperature chemical stability. During the sintering process, composite ceramic experience complex physical and chemical reactions and temperature variation process, micro-pores and micro-cracks are inevitable. The effect of preexisting defects (i.e. micro-pores and micro-cracks) on anti-penetration resistance is extremely notable. The relation between anti-penetration resistance and microstructure is established by micromechanical strength of composite ceramic. Composite ceramic is mainly composed of rod-shaped crystals containing nano-micron fibers, and a small amount of particles and preexisting defects are distributed in the rod-shaped crystals around. The composite ceramic is simplified to a mesomechanical model in which the random mesomechanical cell is embedded in an infinite effective medium, and the mechanical property of the effective medium is the same as composite ceramic. In the mesomechanical cell, effective matrix around a preexisting defect consists of the uniform distributed rod-shaped crystals which is transversely isotropic, and the preexisting defect is assumed as a ellipsoid.
1. The mesomechanical damage stress field
The incremental compliance of effective medium obtained by the IDD method. The corresponding Eshelby tensor is computed by Gaussian quadrature method. Assuming that all defects for the same shape with stiffness of zero, the macroscopic equivalent stiffness is denoted by considering the spatial randomness of cell distribution. According to the Chaboche's damage theories, define the fourth-order damage variable. Then, damage stress field on mesomechanical cell is computered.
2 Mesomechanical strength
In line with boundary conditions on the surface of preexisting defect, stress disturbance is simulated by the eigenstress derived from an equivalent ellipsoidal inclusion with eigenstrain. Suppose the defects propagate self-similarly, the mesomechanical strength is obtained by Griffith fracture criterion.
3 Anti-penetration Resistance
After the penetration of projectile body, there was a cylindrical cavity in the composite ceramic plate. Around the cavity, there were broken region, crack region, elastic region and undisturbed region. In the elastic region, the relation between stress and dispiacement can be expressed by elastic modulus and poisson ratio that can be deternined by microstructure of the composite ceramic. When the circumferential stress exceeds the mesomechanical strength, radial cracks will appear, i.e. circumferential stress vanish in crack region. The failure condition of composite ceramic in broken region is obtained by using unified strength theory. In line with the rotational symmetry equilibrium equation and the continuous condition among different region, anti-penetration resistance of composite ceramic plate is given.
The anti-penetration resistance of composite ceramic is determined by mesomechanical strength and elastic constants. The mesomechanical strength and elastic constants is closely related to the microstructure of the composite ceramic. So the anti-penetration resistance is ascertained by the microstructure of composite ceramic.
The influence of microstructure paremeters on anti-penetration resistance is quantitatively analysed. Results show that: Anti-penetration resistance decreases as the increase of the volume fraction of preexisting defects and the relationship is approximately linear. (2) Defect size to significantly reduce the anti-penetration resistance, and when the size is smaller, anti-penetration resistance changes sharply as defect radius increases. (3) Anti-penetration resistance would decrease approximate linearly as the increase of volume fraction and diameter of nano-micron fibers in rod-shaped crystals

6854 | Multiscale Modeling of Fiber-reinforced Composites (18. Multiscale Analysis)

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Physical testing of composites to determine their elastic and strength properties is difficult owing to their inherent heterogeneous character. Multiscale analysis presents a sequential approach to the prediction of these properties at micro, meso and macro levels for 2D laminates and 3D composites. The homogenized properties at any length scale are always derived from the well-defined properties of the constituent phases of the composite. The micromechanical analysis of the repetitive unit cells (RUCs), along with the periodic boundary conditions, initiates the computation of homogenized properties of the composites. In this paper, different types of RUCs have been identified and appropriate periodic boundary conditions are formulated to determine the homogenized properties of the composites which can be further used for meso and macro-mechanical analyses. An algorithm based on the available literature is used to generate the random distribution of unidirectional fibers and check for their compatibility. In the random fiber generation, two types of models have been analyzed, the first is the random fiber unit cell with periodicity, and the second is without considering any periodicity at the edges of the RUC. This also leads to the evolution of a representative volume element (RVE). This paper also attempts to inspect the progressive degradation in properties of a debonded unidirectional composite by using contact criteria at the fiber-matrix interface.

6928 | Multi-scale analysis of moisture diffusion coupled with stress distribution in CFRP composites (18. Multiscale Analysis)

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Composites served in marine environment are subjected to changing moisture content. Due to the slow procedure of moisture diffusion, the distribution of

moisture concentration is not uniform and then laminates can develop hygrothermal stresses. The present paper investigates the time-dependent moisture diffusion and its couple with stress distribution in Carbon Fibre Reinforced Polymeric (CFRP) composites by means of multi-scale experimental approach and Finite Element Analysis (FEA) approach. Pre-preg CFRP composites were autoclave manufactured and immersed in fresh water and sea water (normal pressure and with 70 bar hydrostatic pressure) which were kept in oven with constant 50°C for the accelerated moisture diffusion testing. Laminates with [0]16, [90]16, [±45]4s, [0/90]4s lay-up sequences were investigated. Raman spectroscope was employed to evaluate the distribution of hygrothermal stress on the surface of composite laminates. A macro 3D FEA model was developed to investigate the stress distribution in composite laminates, while a micro 3D FEA model was developed to evaluate the mechanism of stress transfer between polymer matrix and carbon fibre. The multi-scale analysis revealed that both the stress distribution and stress level were time-dependent. Significant edge effects of the interlaminar shear stress and transverse stress induced by hygrothermal expansion were observed, and the stress level was equivalent to 20% of the laminate strength.

7535 | Meso and Macro Scale Numerical Modelling of 3D Woven Composites (18. Multiscale Analysis)

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In this paper, two finite element approaches are presented to numerically model the elastic properties and damage progression of two 3D weaves under tensile loading. The first method, a full-finite element unit cell model, was used to model the behaviour under tension load in the warp direction, which was validated against experimental data. This full FE model predicted the elastic and strength properties with less than 15% difference from the experimental results, and showed the meso scale damage initiation and propagation of different failure modes. The full finite element method is not applicable for modelling a large-scale 3D woven composite structure, in which the damage can propagate from one unit cell to another, rather than being confined within one cell in the meso-scale model. To this end, a macro-scale mosaic finite element model was used to model the open-hole tensile behaviour of two 3D woven composite specimens. The macro-scale model was built by assembling mosaic blocks with distinctive material properties to simulate the discrete tow/resin woven architecture. Overall, the mosaic model was able to predict the elastic and strength properties of the 3D woven composites with acceptable accuracy. The strain distribution predicted by the mosaic model also showed similarity to the experimental results obtained using Digital Image Correlation (DIC) measurements of the region around the hole in the specimen.

7605 | Multi-scale Evaluation of the Linear Elastic and Failure Parameters of the Unidirectional Laminated Textiles (18. Multiscale Analysis)

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Unidirectional laminated textiles (UDLT) are flexible non-crimped fabric structures, the UD layers of which are bonded together by small amounts of thermoplastic resin and covered by polyethylene films over their external surfaces. Applications of them in ballistic protection clothes ensure lesser costs and ability to resist the penetration of humidity, which may substantially decrease the overall ballistic strength of the structure. This research focuses on the hierarchical multi-scale approach formulated for large displacement, material non-linearity and failure. Two finite element models were developed. The micro-scale model of UDLT represents the matrix and fibres by means of 3D solid elements. A representative small volume (micro-cube) of the UDLT composite is subjected to a series of large deformation tests up to the failure, which enable to approximately evaluate the linear elastic and failure parameters of the mezzo-scale model. Obtained longitudinal, transversal and shear strength parameters in association with the corresponding strains are the parameters used at the mezzo-scale in order to calculate the Hashin criteria for the shell element failure at the macro-scale. Minimum size of the mezzo-scale model suitable for the parameter evaluation is considered for each component of deformation individually. The results of the research are employed in order to achieve reasonable computational costs during the simulation of ballistic penetration through multi-layer UD composite textile structures.

7734 | Micromechanical modelling of high velocity impact damage on laminated composite structures (18. Multiscale Analysis)

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In-plane failure modes of laminated composite structures are an immediate result of processes within the heterogeneous material. Therefore, accuracy of numerical failure prediction methods can be increased by modelling damage and failure processes at the microstructural scale. This approach has been applied as to enhance the bird-strike damage prediction procedure developed by the authors in their previous work. The further development of the methodology is based on the application of the semi-analytical High Fidelity Generalized Method of Cells (HFGMC) micromechanical model,which has been employed as to model damage processes at the micro-structural level.The HFGMC model has been selected for implementation in the high velocity impact damage prediction methodology, as it represents a good compromise between accuracy and the required computational effort, which is an important factor for the application within the explicit finite element analyses environment.
Micromechanical methods can be applied in engineering problems using multiscale methods. The multiscale approach separates the analysed problem on two length scales - the macro-scale, which solves the problem at the engineering level, and the micro-scale, at which the stress and strain fields within the microstructure are determined.The methodology has been developed with the aim of modelling high velocity impact damage on aeronautical structures using Abaqus/Explicit to perform computations at the structural level. The link between the finite element macro-level analysis and the micromechanical model has been achieved with the user material subroutine VUMAT, which for each material point performs micromechanical calculations based on the applied macroscopic strain given by the FE analysis. Consequently, nonlinear processes in complex composite structures, such as damage and failure, have been modelled using micromechanical principles. Several constituent based failure initiation criteria have been validated for the application in the developed multiscale methodology. Additionally, two progressive damage approaches applied within the HFGMC model have been implemented and applied in the explicit damage analyses. The first damage model is the complex multiaxial damage model based on damage strains where the damage effects in the matrix have been modelled using six separated damage variables.
The second damage model is based on the maximal principal stress criterion. Two matrix failure modes have been considered within this failure model, which are initiated depending on the tensile/compressive type of the principal stress with the maximal absolute value. Degradation of the subcell elasticity properties in the first failure mode, which is initiated for positive maximal absolute principal stress, is modelled in the principal stress coordinate system. Progressive damage principles applied in the second failure mode degrade matrix properties in the coordinate system aligned to the maximal shear stress coordinate system. The Smeared Crack band approach has been employed as to alleviate size dependency of progressive damage modelling within the

HFGMC model.
The two-scale damage prediction methodology has been applied on numerical impact simulations on laminated composite structures. The micromechanical model and the progressive damage models applied on the matrix subcells have been verified by comparison with WWFE experimental results, while the multiscale methodology has been verified in comparison with experimental soft body impact gas gun experiments available in the literature. It has been demonstrated that the applied micromechanical models and the investigated failure criteria are able to accurately predict in-plane failure modes of laminated composite structures under high velocity impact loads.

7901 | Prediction of web-core sandwich plate nonlinear stiffness from a representative volume element (18. Multiscale Analysis)

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The demand for cost-efficient structures has extended the design frontiers towards lightweight solutions. As large structures become lighter, nonlinear effects become more relevant and omitting these, even in the whole structure scale, might lead to safety issues. Nonlinear response assessment of plated structures often relies on the Finite Element Method through 3D shell topologies. However, this often becomes unfeasible when large structures are concerned due to the inherent computational cost and modelling efforts needed. Multiscale modelling can reduce the 3D to a 2D shell problem with equivalent stiffness. This may be done by coupling the micro-structure-based composite stiffness to an equivalent single layer 2D FEM code. This paper proposes a methodology for extracting the nonlinear constitutive relations of periodic sandwich plates. The idea is to determine a representative volume element (RVE) to predict the nonlinear ABD stiffness coefficients consistent with the First-Order Laminated Plate Theory. This is achieved by performing geometrically nonlinear finite element analyses of the volume element. A framework for choosing the RVE critical length according to the eigenvalue buckling load is established. Initial local imperfections due to manufacturing are also considered in the analyses. A homogenization scheme, with averaging of stress resultants and strains across the volume is defined with mathematical justifications. Appropriate loading and periodic boundary conditions are chosen to determine each stiffness coefficient separately. The stress-strain curves that characterize the stiffness evolution are given for axial, bending, axial-bending coupling and transverse shear components. The curves are compared in the linear range with their closed-form solutions showing excellent agreement. The stiffness coefficients are then introduced to a global ESL plate model. The stress-strain relations are compared to the 3D shell solution as means of validation, showing good agreement. Overall, the paper introduces a method to extract the constitutive relations of all-steel composites. By coupling this to a consistent multiscale approach, a method relevant for the design of large, complex structures can be achieved. This may lead to time and cost savings without largely compromising the solution accuracy.

8066 | A multiscale approach to the effects of void geometry on the elastic properties of unidirectional fiber reinforced composites at different temperature (18. Multiscale Analysis)

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Voids are one of the most common types of manufacturing induced defects that has significant influence on material properties of the composite materials. In this paper, the effective elastic constants of unidirectional fiber reinforced composites are obtained by a multiscale method. Representative volume cells(RVC) on different scales: the fiber-matrix scale and the void scale, are established based on fibers distribution and void geometry. Finite element method is employed to predict the elastic properties of unidirectional fiber reinforced composites. The results of the fiber-matrix RVC are compared with the Halpin-Tsai equation and the results of the void RVC are compared with available experimental data. Good agreement are found in both results. A parametric study indicates that the void content has different impact on different moduli. The in-plane properties are less affected than the out-of-plane modulus. Results also show that the reduction of the elastic properties due to void content is influenced by temperature.

8162 | Numerical prediction of the uncertainties in the structural response of sandwich structures consisting of solid foams (18. Multiscale Analysis)

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In modern sandwich construction, solid foams are important core materials. Their main advantage is their rather low specific weight in combination with a reasonable stiffness and strength. Further benefits derive from their inherent good thermal and acoustic damping characteristics as well as from their advantageous energy absorption properties. Compared to other materials such as honeycomb structures, solid foams have the advantage that they can easily be processed to any desired shape. Their main disadvantage is their disordered random microstructure leading to distinct uncertainties in their macroscopic material response.

The present study deals with a numerical scheme for prediction of the uncertainties in the effective material response, based on the known geometric and topological uncertainty of the microstructure. For this purpose, a probabilistic homogenization scheme is proposed. In contrast to deterministic approaches, where the average stress-strain behavior of statistically representative volume elements is analyzed, small scale, “testing volume elements” are considered, since – especially for foams with large cell sizes – a statistically representative volume element might have edge lengths in the same order of magnitude as the smallest characteristic length of the sandwich structure, i.e. the core thickness. As the smallest feasible testing volume elements, the individual cells of a large-scale foam model are considered. The foam models are generated randomly by means of a Voronoï process in Laguerre geometry, based on the statistical descriptors of the microstructure. The results of the testing volume element analyses are evaluated by stochastic methods, considering the probability distributions of the effective properties as well as the correlation between the properties at neighboring points of the effective material.

For transition to the structural level in the sense of an integrated computational materials engineering (ICME) type approach, a macroscopic structure is considered. The material properties of its ranges consisting of solid foams are modelled in terms of a random field approach. The random field is determined such that its statistical properties coincide with the results of the previous probabilistic homogenization analysis. Using a Monte-Carlo type simulation with repeated generation of the random fields, the effect of the microstructural uncertainty of the foam material on the uncertainty of the

structural response can be analyzed.

In an illustrative case study, a single edge clamped sandwich beam with a metal foam core is considered. The structure is loaded by a point force applied to the free end. The core material is modeled as a random field with properties determined in the aforementioned probabilistic homogenization analysis of the effective properties of aluminium foams. Whereas the material uncertainty is found to cause only minor scatter in the deformation of the beam, significant uncertainties are observed in the strength of the considered structure, illustrating the necessity and the capability of the probabilistic multiscale analysis procedure.

8598 | Non-linear multiscale strategy to analyze composite materials efficiently (18. Multiscale Analysis)

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The use of multiscale procedures is encouraged by the continuous increase of computational capacity, and also because the composite materials become more complex, such as carbon nanotubes reinforced matrix, or the use of crimped woven micro-structures. Multi-scale methods based on homogenization principles are gaining strength; as these allow obtaining the material performance taking into account its micro-structural configuration.
However, it is still a challenger performing a non-linear multiscale analysis of a real composite structure if it is not used a super-computer, which is not available in most cases.
This work proposes a strategy to conduct non-linear multiscale analysis in an efficient way, which has as objective a large reduction of the computational cost of the analysis, facilitating its use by researchers and engineers without large computational means.
The proposed method takes into account that, in general, in a large structure, material non-linear processes only take place in a localized region (or in a reduced number of elements, if the analysis is performed with the FEM), and therefore, multiscale analysis is only required in the elements found in the non-linear region.
The strategy determines the elements that require a non-linear analysis by calculating the available limit elastic energy of the element for a given strain estate, and comparing it with the elastic energy required for the actual load applied to the structure. The calculation of the limit elastic energy takes into consideration the more critical point in the micro structure. The multiscale analysis is activated only in the specific elements where these two energies are similar. The non-linear micro-structure parameters are stored also only for these elements.
The procedure is capable of taking into account changes in the strain state of the structure due to the non-linear process, which will require recalculating the new limit elastic energy available.
The validity of the strategy is shown with the analysis of several composite structures. The results obtained, and the computational times required to conduct the simulation, prove the efficiency of the method.

8626 | Effective Elastic Moduli of Fiber-reinforced Semi-crystalline Polymer Matrix Composites Filled with Nano-particles (18. Multiscale Analysis)

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Improving the mechanical properties of polymer matrix composites by filling with nano-particles has been a major interest in recent years. The fiber-reinforced semi-crystalline polymer matrix composites filled with nano-particles are composed of nanoparticles, polymer non-crystalline phase, polymer crystalline phase, and fiber and therefore, have some hierarchical structural characteristics across several levels of matter inside. The size of the nanoparticle ranges from a few nanometers to several decades nanometers, and the size of the polymer crystalline ranges from a few micrometers to several decades micrometers while the size of the fiber is in the millimeter level. The size difference among the three groups is 2 to 4 orders of magnitude. As for the crystalline polymer, its composition consists of a crystalline phase and non-crystalline phase. In nanoscale, nanoparticles are homogeneously dispersed in the non-crystalline phase and crystalline phase of the composite; in mesoscale, the crystalline phase is dispersed uniformly throughout the non-crystalline phase. Thus, the scale system contains two nanoscale subsystems, namely an equivalent particle composed of the nanoparticle and crystalline phase and an equivalent matrix composed of the nanoparticle and non-crystalline. In macroscale, the composites are composed of the fiber and mesoscale equivalent matrix, which is composed of the above two nanoscale subsystems. In this paper, fiber-reinforced semi-crystalline polymer matrix composites filled with nano-particlesis considered as a periodical multi-scale structure, and then its periodic mesostructure on various scales is analyzed. Based on the Mori-Tanaka methods and the multi-scale homogeneous theory a multi-scale model of the fiber-reinforced semi-crystalline polymer matrix composites filled with nano-particles was established, and a method for predicting effective moduli of the composite filled with nano-particles was presented. Numerical calculations were performed. Finally, the elastic modulus of a nano-silica/glass fiber/nylon 6 composite was obtained, and the effects of the size of nanoparticle and the volume fraction on the elastic modulus of the composite were discussed. The results show that the addition of a few nanoparticles can apparently increase the elastic modulus of fiber-reinforced composites. The predict method is suitable for the calculation of the elastic modulus of the composite.

Key words: nano-particles, semi-crystalline polymer matrix composites, modulus tensor, multi-scale method

8645 | Effect of cooling rate on the nano-scaled oxide precipitation distribution of Mg-Ti complex deoxidation steel (18. Multiscale Analysis)

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In this paper, the effect of cooling rate on the nano-scaled oxide precipitation distribution was investigated using Mg-Ti complex deoxidation steel. In the

laboratory experiments, the liquid steel (1600°C) cooled at three cooling rate such as 20°C/s, 50°C/s and 200°C/s, while the composition, number and size of nano-scaled oxide precipitation of as-cast steel have been observed. The volume fraction of the nano-scaled precipitation have been examined. It is shown that cooling rate has a great effect on the size and distribution of precipitates. With the increase of cooling rate, the number of precipitates increases and the size decreases. On the other hand, the precipitates distribution was more homogeneous when the cooling rate was increased. Moreover, TiOx, MgO and TiN are the major nano-scaled oxide precipitation in the steel, which was effected by the cooling rate. When cooling rate increase, the MgO particles were abundantly observed at the 700nm-1um size range, and the Ti-rich particles (TiOx or TiN) were more abundantly at the <500nm size range. It has been proved that nano-scaled oxide can be precipitated during solidification by solute enrichment.

Keywords: nano-scaled oxide precipitation, complex deoxidation, cooling rate

8930 | HIERARCHICAL FINITE ELEMENT BASED MULTISCALE COMPUTATIONAL HOMOGENISATION OF COUPLED HYGRO-MECHANICAL ANALYSIS FOR FIBRE-REINOFRCED POLYMERS (18. Multiscale Analysis)

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Key words: Multiscale computational homogenisation, Hygro-mechanical analysis, Fibre reinforced polymer, Textile composites, Transverse isotropy.

Abstract

This paper presents a multiscale computational homogenisation of the coupled hygro-mechanical analysis of the fibre-reinforced polymers (FRPs). This is ongoing research work for the development of a computational framework to predict the long-term durability of these materials for use in the construction industry. Textile or woven composites, in which interlaced fibres are used as reinforcement, is a class of FRPs which provides full flexibility of design and functionality due to the mature textile manufacturing industry and is commonly used in many engineering applications, including ships, aircrafts, automobiles, civil structures and prosthetics [1]. During their service life textile composites are exposed to different hygrothermal environmental conditions in addition to mechanical loading, which leads to matrix plasticisation and degradation of fibres/matrix interfaces [2]. Therefore, understanding of moisture transport mechanisms and their effect on the mechanical performance of these materials are vital for predicting their long-term durability.

The heterogeneous microstructure of textile composites requires a detailed multiscale computational homogenisation. The use of multiscale computational homogenisation results in the macroscopic constitutive behaviour of the structures based on its microscopically heterogeneous representative volume element (RVE). A plain weave textile composite RVE is considered in this case, consisting of matrix and yarns embedded in the matrix. These yarns are modeled with elliptical cross section and cubic spline paths. An automated parameterised RVE geometry along with material properties, boundary conditions and meshes are generated in CUBIT with Python scrip, which allows rapid generation of different types of composites.

The multiscale computational homogenisation framework is implemented in our group's FE software, MoFEM (Mesh Oriented Finite Element Method). A unified approach is used to impose the RVE boundary conditions, which allows convenient switching between displacement, traction and periodic boundary conditions [3]. The effect of moisture concentration on Young's modulus and moisture induced swelling are considered in the model. The final resultant nonlinear discretised system of equations is solved using the Newton–Raphson method. Matrix and yarns are considered as isotropic and transversely isotropic materials respectively. The required principal directions of the yarns for the transversely isotropic material model are calculated from a computationally inexpensive potential flow analysis along these yarns. Furthermore, the computational framework utilises the flexibility of hierarchic basis functions, which permits the use of arbitrary orders of approximation leading to very accurate results for relatively coarse meshes. Convergence studies based on hierarchical finite element analysis is also performed to show the effectiveness of the developed approach. The developed code is based on distributed memory parallel programming and is tested on high performance computer facilities. The implementation and performance of the developed computational tool are demonstrated with numerical examples.

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9066 | Efficient multiple length/time-scale simulation of large composite structures (18. Multiscale Analysis)

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Numerical simulation of the mechanical response of large composite components usually requires that different parts of the structure are modelled at different length- and time-scales. However, the coupling of subdomains discretized with finite elements of different physical dimension/formulation can introduce artificial stresses at the shared boundaries; as a result, in problems involving failure, the damage pattern might not be correctly replicated. Moreover, due to the heterogeneous microstructure of composite materials, the feasibility of standard FE analyses based on 3D models is limited to small components; 2D FE models with equivalent properties are preferable for larger components.

This paper addresses the issues of (i) coupling areas of large composite structures discretized using different finite element types and (ii) using accurate unit cell models to efficiently predict the performance of large aeronautical components.

Firstly, a novel Mesh Superposition Technique (MST) for the progressive transition between differently-discretized subdomains is proposed and implemented in an FE code. The interfaces between these subdomains are replaced by transition regions where the corresponding meshes are superposed. The MST is applied to the multiple length/time-scale analysis of a low-velocity impact of a projectile on a composite plate. Unlike when using a sudden discretization-transition approach, the use of the MST eliminates the undesirable stress disturbances at the interface between differently-discretized subdomains and, as a result, it correctly captures the impact-induced damage pattern at a lower computational cost. Finally, the MST is coupled with an implicit/explicit co-simulation technique for a multiple time/length-scale analysis. The results indicate that, if the length-scale transition is performed using the proposed MST instead of a sudden discretization-transition, the CPU time can be nearly halved.

Secondly, a solid-to-shell numerical homogenization of periodic structures based on a novel set of Multiscale Periodic Boundary Conditions (MPBCs) is presented. The MPBCs are prescribed at the boundaries of a 3D Unit Cell (UC) in which the structure is explicitly resolved at the lowest length-scale. Hence, the 2D constitutive response can be directly evaluated, including shear-extension, bending-extension and bending-twisting coupling effects, thus enabling the construction of an equivalent shell model. An equivalence framework for the analysis of periodic structures is proposed and the formulation of the MPBCs is derived; furthermore, details on their FE implementation are provided, including details on their use within the context of a solid-to-shell homogenization. The key-aspects of the proposed MPBCs are: (i) symmetries in the Unit Cell are exploited in the definition of reduced Unit Cells (rUCs), (ii) no limitations on the deformed and undeformed shape of the UCs/rUCs are assumed, (iii) no a priori restrictions to the nonlinear behaviour at the lowest length-scale are made (as long as there is no localization), (iv) the formulation is valid for large deformations and (v) any loading combination can be prescribed to the UC/rUC, including bending and twisting. When applied to a generic asymmetric laminate, all terms of the fully-populated ABD matrix are computed with negligible error, of the order of machine precision. The application of MPBCs and their potential are illustrated through practical examples, e.g. determination of the 2D homogenised stiffness matrix of a periodic pin-reinforced sandwich structure using both a UC and a rUC and, homogenisation and simulation of a large aeronautical component, otherwise infeasible with 3D FE models.

The results of these analyses demonstrate the relevance of the proposed approaches for an efficient multiple length/time-scale simulation of large composite components.

9090 | Effective size of RVE for finite element analysis of structures made of nonlinear random composites (18. Multiscale Analysis)

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In the present work, we propose to determine the size of a representative volume element (RVE) in the case of nonlinear random composites with either elastoplastic or elasto viscoplastic phases. In such a case, the general form of the effective constitutive behavior is not known in advance and the response must be evaluated either by direct numerical computations on the RVE, either by an appropriate approximation scheme. Previous methodologies [1,2] for determining the size of RVE usually rely on analyzing the convergence of the RVE response computed numerically with respect to its size. In the present work, we analyze the convergence of parameters related to an incremental homogenization scheme, with respect to (i) the size of the RVE and (ii) to statistical convergence related to microstructure realizations. For that purpose, we combine an incremental homogenization method [3] with a statistical convergence analysis of parameters related to the matrix phase only. The advantage is that the range of parameters to be identified is much narrower than for a general empirical constitutive law. Once identified and the convergence analysis performed with respect to both size of RVE and statistical realizations, the macroscopic constitutive law can be readily used for structure calculations. We illustrate the methodology by analyzing two-dimensional microstructures with randomly distributed cylindrical elastic rigid fibers, embedded in a elastoplastic or elasto-viscoplastic matrix. For these materials, the existence of an RVE is demonstrated for sizes of RVE corresponding to 17 – 18 and 14 – 15 times the diameter of the inclusions, respectively.
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9153 | COMPUTATIONAL MODELLING OF THE PROGRESSIVE FAILURE IN HETEROGENEOUS ADHESIVES (18. Multiscale Analysis)

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In the last years the adhesives employed especially in the aeronautical field are characterised by a matrix (usually an epoxy resin) reinforced by particles of glass, aluminium or more recently by carbon nano-tubs. The addition of stiffer particles to the matrix, with an easy fabrication process, can improve the mechanical properties of the matrix with a slight increase of weight. This work represents a progression of a previous work of the authors [1] on the elastic homogenisation of particulate-polymer composite adhesives.
The aim of this work consists in finding the non-linear strength properties characterising this class of adhesives through a multi-scale numerical procedure: the effective strength properties at the macro-scale are calculated through a finite element-based homogenisation procedure on a representative volume element of the heterogeneous microstructure of the material. The non-linear strength behaviour of the material is then expressed as function of all of the possible design variables characterising the micro-scale: the particles volume fraction, the porosities volume fraction, the particles size, the porosities size as well as the particles distribution.
Unlike periodic structures, such as cellular solids, particle-filled adhesives do not have a real repetitive unit that neatly reproduces the microstructure of the composite. In these materials the particles, in fact, are more or less randomly distributed and the resulting microstructure is a matrix containing a certain volume fraction of inclusions inordinately distributed. Another feature of the actual microstructure of the adhesive concerns the presence of a third phase: the air. In fact, the porosities represent a certain percentage of the volume of the composite which primarily varies as a function of the manufacturing process of the adhesive itself. Therefore, we will analyse the progressive failure at the micro-scale (the scale of the particles) on a representative finite element model able to reproduce with a good level of accuracy the real microstructure of the adhesive by considering a random distribution of both particles and porosities (that are generated by the fabrication process). The non-linear material behaviour of the matrix is modelled

using a damage model which is activated once the failure criterion of Christensen, able to take into account the different traction and compression strength behaviour of isotropic materials, is satisfied. On the other hand the stiffer inclusions are made of an isotropic linear-elastic material. Finally, the inclusion/matrix interface failure is obtained using a cohesive zone model describing the non-linear behaviour of the interface. The effect of volume fraction and size of both particles and porosities upon the stability of crack propagation, on the fracture energy and on the adhesive strength has been studied. The effectiveness of the proposed model is proved by comparing the results with those provided by analytical [2] and numerical [3] models present in literature.

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9184 | Computational analysis of damage in hybrid composite structure (18. Multiscale Analysis)

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A novel type of hybrid cell composite structure has been developed and used for many practical applications. Typical macroscopic sub-cells in the cross section structure are formed by the stamping process of partially cured and axially-oriented high modulus carbon fibre bundles (about 4-6 mm in the diameter). Each bundle is wrapped around by a thin layer of high strength fibres (oriented in ±45 or 89 degrees). This new material structure has its own specific stiffness properties and specific damage behavior and failure modes respectively. Complex modeling of damage progression even in a few cells would demands of tremendous computational performance. Therefore hierarchical modeling strategy is used to solve it. Modified Non-uniform Transformation Field Analysis (NTFA) was proposed for this purpose. Original method was developed for materials exhibiting elasto-plastic behavior. The method is based on assumption that field of plastic strain in each phase can be decomposed on finite set of fields, called plastic modes. Analyzed cell composite structure is built from parts with mostly brittle micro-behavior. Modification is based on introducing damage modes instead of plastic modes. Damage modes have chosen in specific material directions of unidirectional composites. Macroscopic state can be decomposed into sum of certain contribution of building parts with their damage modes. Evolution of damage in every damage modes is based on experimental observation. In generally, numerical models of damage modes consist of combination of plastic behavior with subsequent degradation mechanism. They have different behavior in tensile and compressive loading. Each material damage mode can fail ultimately but even failed mode can contribute to macroscopic state in certain directions. Moreover failed damage mode in compressive loading has still certain residual stiffness. Modified NTFA method was incorporated into FEM code and verified in several four-point bending tests.

9330 | A Multi-Level Seismic Damage Model for Reinforced Concrete Structures. (18. Multiscale Analysis)

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A Multi-Level Seismic Damage Model for Reinforced Concrete Structures.

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Keywords: multi-level seisimic damage model, multi-level performance limits, equivalent deformation principle, performance-based design; RC structures

ABSTRACT:
A multi-level seismic damage model for RC structures is proposed based on the equivalent deformation principle and the generalized force-deformation relationship. According to the damage states of each level, a multi-level seismic damage performance is presented and its critical performance limit indicators are specified. In order to build the correlations between the generalized damage model and the multi-level seismic damage performance, a normalized corresponding parameter for each level is introduced into the damage model to specify the same damage limit values for each level. Those corresponding parameters are obtained by statistical analysis of data from simulation of small scale test results of a 12-storey RC framed structure subjected to 54 shake-table loading cases and also tests of 400 columns, and compared with some other damage models. The proposed multi-level damage model was validated by test results of a full scale three-story RC structure subjected to lateral load in situ. The model provided a good evaluation of the observed inherent damage mechanism.

5504 | Influence of the nano- and biostructures on the optical features of the materials (19. Nano-Composites)

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Influence of the nano- and biostructures on the optical features of the materials

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Structural, spectral, and nonlinear optical features of the organic materials are studied under the nano- and biostructurization condition. The main accent is given to show the perspective of the different types of the nano- and boiobjects to modify the structural and photorefractive properties. Special role of the dipole moment as a macroscopic parameter of a medium accounts for a relationship between the photorefraction and the photoconductivity characteristics and it can be considered as an indicator of following dynamic parameters changing. Moreover, some mechanical achievement of the nanoobjects-containing network is observed and polarization plane rotation ability of the bioobjects-containing systems is shown. New results are compared with that obtained before [1-3]. The presented results are correlated with the work partially supported by RFBR grant No.13-03-00044 (2013-2015) as well as by FP7 Marie Curie Action, project “BIOMOLEC” (2011-2015).

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5507 | Conductivity and Optical Percolation in Polymer-Carbon Nanotube Composites (19. Nano-Composites)

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Abstract; Effect of Multiwalled Carbon Nanotube (MWCNT) addition on the electrical conductivities, optical transparencies and fluorescence emissions of Poly(vinyl acetate-co-butyl acrylate) P(VAc-co-BuA)–MWCNT composite films were studied. 15 different composite films were prepared by mixing various mass fractions of MWCNT in P(VAc-co-BuA)-water dispersions. Optical transmission, fluorescence emission and two point probe resistivity techniques were used to determine the variations of the optical, fluorescence and electrical properties of composites, respectively. Transmitted photon intensity, Itr, fluorescence emission intensity, Ifl and surface resistivity, Rs of the composite films were measured as a function of MWCNT mass fraction (M) at room temperature. All the measured properties of the composites were decreased by increasing the content of MWCNT in the composite. Conductivity results were attributed to the classical percolation theory, optical and fluorescence results were attributed to the site percolation theory. The conductivity, optical and fluorescence percolation thresholds and critical exponents were determined as M□ = 0.01, Mop = 0-0.005, Mfl = 0.016 and, β□ =2.15, βop =0.404, βfl =2.04, respectively.

5837 | Photocatalytic Activities and Structural Formation of Au-Pd Nano Alloys Embedded into Amphiphilic Graft Copolymer (19. Nano-Composites)

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Au-Pd nanaoalloys were embedded into a series of polypropylene (PP)-g-polyethylene glycol (PEG) amfifilic graft copolymers with very good film properties. Metal salts were coreduced to metal nanoparticles less than 10 nm into tetrahydrofurane solution of the graft copolymer. Chain length of hydrophilic segments (PEG) were affected the size and organization of the nanoalloys obtained. the nanocrystal structure with the paralel lines as shown in the picture with white arrows and the nanoparticles were observed as smaller than 10 nm. the surface of bimetallic nanoparticles held more Pd atoms and surface plasmon bands disappeared. However, the fluorescence emission spectra of Au-Pd@PPEG are detected at 445, 450 nm. Photocatalytic activities of the nanocomposite film were observed in the oxidation reaction of Rhodamine B. When a piece of nanocomposite film inserted into the toluene solutions of Rhodamine B was UV-irradiated, oxidation reaction of Rhodamine B was much faster than that of pure Rhodamine B solutions.

6282 | analysis of FGM vibrating rectangular nanoplates in thermal environment (19. Nano-Composites)

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In the present study the free vibration analysis of functionally graded rectangular nanoplates in thermal environment is investigated. The modified coupled stress theory based on the first order shear deformation theory has been used to obtain the natural frequencies of the nanoplate. Modified coupled stress theory is a non-classical theory. In this theory material length scale parameter is applied to capture the size effect of the microstructures which the earlier classical plate theories were not able to explain these effects. The functionally graded material properties are varied continuously and smoothly along the thickness. The Poisson’s ratio of the FGM plate is assumed to be constant in the whole plate. In order to validate the present method, the natural frequencies of the both functionally graded rectangular plate and rectangular nanoplates are compared with those are reported in the literature, separately. Finally, the effect of various parameters such as; the power law index, the thickness to length scale parameter ratio, aspect ratio, thickness ratio on the natural frequencies of plates in thermal environments with different temperatures are presented and discussed in detail.

6426 | Experimental investigation on solid particle erosion characteristics of epoxy/MWCNTs nanocomposites (19. Nano-Composites)

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The solid particle erosion behavior of Multiwall Carbon Nanotubes (MWCNTs) reinforced with pure epoxy was investigated experimentally. The erosion tests were conducted using irregular silica sand particles (100±20μm) as an erodent with the impact velocity of 70m/s. The epoxy with 0.1, 0.5, 1.25, 2.5 and 5wt.% of MWCNTs were used in this study. The erosion rate of pure epoxy and epoxy/MWCNTs nanocomposites have been evaluated at various impingement angles of 30º, 60º and 90º with the changes in erodent exposure time of 5min. The weight loss was considerably increased for all the samples at 60º impingement angle and increasing exposure time. However, the 0.1, 0.5 & 1.25wt.% of MWCNTs nanocomposites possess good erosion resistance and exhibit 25%, 30% and 73% better than pure epoxy respectively and also the weight fraction of 1.25wt.% MWCNTs nanocomposites shows superior erosion resistance than pure epoxy. Moreover, the erosion loss rate of all nanocomposites considerably increases with the increasing of nanotubes content until the content reaches 1.25wt.%. The morphology of eroded surface was examined by using field emission scanning electron microscope (FESEM) and possible erosion mechanisms were discussed.

6888 | Nanoparticles impact on mechanical and physical behaviour of aluminium based nanocomposites. (19. Nano-

Composites)

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Ultrafine grained nanocomposites (aluminium reinforced with boron nitride nanoparticles) were prepared by ball milling and hot extrusion. Resulting grain size was 600. nm. The same procedure was used for the preparation of pure aluminium without nanoparticles. Mechanical properties were estimated in tension at temperatures between room temperature and 300 °C at a constant initial strain rate. The yield stress and the maximum stress decrease with increasing testing temperature. The influence of reinforcement on both characteristic stresses falls down with increasing temperature. The linear thermal expansion was measured over a wide temperature range from room temperature up to 400 °C in as cast state and after small predeformation. Amplitude dependence of internal friction was measured at room temperature after thermal cycling between ambient temperatures and increasing upper temperature of the thermal cycle. Possible influence of BN nanoparticles on anelastic, plastic and thermal properties of ultrafine grained aluminium is discussed.

6894 | Manufacturability and Properties of Nanopaper Enhanced Fiber Reinforced Polymeric Composites (19. Nano-Composites)

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Carbon nanofibers (CNF) nanopapers have shown great potential to improve the surface of fiber reinforced polymeric composites, including providing EMI shielding and erosion resistance, at the sacrifice of processability or easiness of impregnation. During typical Resin Transfer Molding process (RTM), the CNF nanopaper is incorporated into the fiber preform as a surface layer. In order to learn how resin flows through the fiber preform and nanopaper layer, permeabilities of the fiber preform and nanopaper need to be measured. As is well known, measuring the permeability of fiber preforms is experimentally challenging. Results usually exhibit large experimental variability. Measuring permeability of nanopapers is even more complicated. To improve the accuracy of results, permeability of carbon nanofibers based nanopapers was measured using different experimental setups. In-plane permeability of nanopaper was measured by both uni-directional micro-slit flow and radial flow approaches. Trans-plane permeability was measured as well, using a trans-plane flow cell and a flow visualization mold. In this paper, we present results on the improvement of surface erosion as well as EMI shielding efficiency, as well as the effect of the nanopaper on the flow in the composite. The methods to measure permeability are discussed and experimental results provided.

6974 | Mechanical Behavior of Three-dimensional Graphene Foam and its Polymer-filled Composites (19. Nano-Composites)

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We have developed a simple method for fabricating three-dimensional (3D) graphene structures with better mechanical stability, electrical conductivity, and controllability on shape and size. The method involves dip-coating of poly-urethane (PU) sponge with graphene oxide (GO) and selectively removing the PU core by heating at 900°C in nitrogen atmosphere. Scanning electron microscopy (SEM), and in situ SEM were carried out to study the morphology/failure modes of the GF structure under load-free condition and under compressive loads. The GF samples have good mechanical stability where a compressive strength of 20 kPa was obtained for samples of density 8 mg.cm-3. The stress-strain curves for the GF samples were obtained during compressive tests using a micro-force tester. These curves are similar to that of metal foams with an elastic region, plateau region, and a densification region. The GF samples have shown an electrical conductivity of 100 S/m. In addition, we have fabricated GF composites by infiltrating the GF with a range of polymers. The mechanical behavior of the composites will be presented.

6978 | Stochastic analysis of interfacial effects in polymeric nanocomposites (19. Nano-Composites)

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Interfaces and interphases play an important role on the global properties of nanocomposites. The first few molecular layers close to solid surface which are responsible for the adhesion between two materials are called interface. Far from solid surface, the properties of polymer is same as the bulk polymer but the properties of the polymer near to the interface differ from the bulk polymer due to influence of the adhesion in interface. This intermediate area is called interphase. Based on the property under consideration and the combination of polymer and solid surface, the thickness of interphase can vary from a few nanometers to several micrometers.
There are some analytical micromechanical approaches to deal with the interface effects in the nanocomposites especially for the overall elastic properties of the nanocomposites. But lack of exact deterministic values for the interfacial behaviours of polymeric nanocomposites limits the use of the deterministic models.
In this study, we use a combination of stochastic analysis and hierarchical multiscale method to investigate the effect of interfacial behaviours in the polymeric nanocomposites. We use an equivalent model to model both interface and interphase regions in a finite element model. The numerical results show that the interfacial area is significant when the thickness of equivalent model is thick enough which is in a very good agreement with analytical predictions.

7022 | Structure and functional properties of zein based films added with nanoclays and nanocarbonate (19. Nano-

Composites)

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This study evaluated the structure and some functional properties of zein edible films added with modified clays and nanocarbonate. Modified clays Cloisite® 15A and Cloisite® 30B were added in the filmogenic solution in the proportions of 1, 2 and 4% and nanocarbonate as 1, 2 and 3% (w/w) based on the weight of zein. The films were formed by casting method. Oleic acid and glycerol were used as plasticizer agents. Structural characteristics were analyzed by Scanning Electron Microscopy (SEM) and Optical Microscopy (MO). Functional properties evaluated included Water vapor permeability (WVP), Water Solubility, color, opacity and mechanical properties . SEM images showed an heterogeneous microstructure with the additions of clays and nanocarbonate. MO showed an even distribution of lipids globules in the protein matrix, for all films samples. Water vapor permeability of the films added with both, clays and nanocarnonate, were not different from control samples. There were no statistical differences on water solubility of films added with clays but it was increased as nanocarbonate concentrations increased. Color were affected by compounds addition increasing L* parameter. The clays did not altered opacity, however it decreased with nanocarbonate addition. Nanocarbonate decreased tensile strength and increased elongation at a break. A formation of a microcomposite was possible adding either clays or nanocarbonate.

7520 | Preparation and characterization of DNA/allophane composite hydrogels **(19. Nano-Composites)**

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Clay mineral surfaces have been important for the prebiotic organization and protection of nucleic acids The preparation and characterization of the composite hydrogels based on double-stranded deoxyribonucleic acid (DNA) and natural allophane (AK70) were reported. To understand the propensity of the natural allophane to adsorb the DNA molecules, the adsorption characteristics were assessed by using zeta potential measurement, Fourier Transform Infrared Spectroscopy (FTIR) and electrophoresis analyses. The freeze-dried DNA/AK70 hydrogels were demonstrated that the DNA bundle structure with a width of ~ 2 µm and a length of ~ 15-20 µm was wrapped around the clustered allophane particles as revealed by FE-SEM/EDX analysis. The incorporation of AK70 in hydrogels induced the increase in the enthalpy of the helix-coil transition of DNA duplex due to the restricted molecular motions of the DNA duplex facilitated by the interaction between the phosphate groups of DNA and the protonated Al-OH groups on the wall perforations of the allophane.

7555 | Radar absorbing structures composed of the nano-composites dispersed with the carbon black and the carbon nanotube **(19. Nano-Composites)**

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The nano-composites composed of the E-glass/epoxy composites dispersed with carbonaceous conductive particles such as the carbon black and the carbon nanotube (CNT) are usually adopted to the radar absorbing structures (RAS). It is because that the electromagnetic (EM) wave absorbing performance of the nano-composite RAS is much dependent on the particle concentration of the nano-composites.
In this study, the nano-composite RAS were designed by the optimum design method and the nano-composites in the optimum design window were selected. The EM wave absorbing characteristics of the RAS were obtained by the numerical simulation with respect to type and concentration of nano-composites and verified by the experimental measurements. Also, the effects of the nano-materials on the mechanical properties of the nano-composites were measured. Finally, the optimum nano-composite RAS was suggested considering both the electromagnetic and mechanical performances.

7586 | Development and characterization of biocompatible magnetic nanoparticles based on magnetite (Fe_3O_4) and ferrite (Fe_2O_4) and its application in the treatment by hyperthermia. **(19. Nano-Composites)**

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Composites of magnetic nanoparticles in a polymeric matrix are of great interest for both fundamental research and emerging applications, due to their capacity to respond to external magnetic or electromagnetic field. In the biomedical field, magnetite (Fe_3O_4) and ferrite (Fe_2O_4) have shown promise as tumors therapeutic agent using hyperthermia treatments. However, preparing suitable solubilized magnetic nanoparticles is challenging, primarily due to aggregation and poor biocompatibility. Thus for use with biological purposes, methods for coating Fe_3O_4 nanoparticles with biocompatible stabilizers are required. Algal polysaccharides such as agar are used extensively as gel-forming agents, thickeners, and stabilizers due to their low cost and high degree of biocompatibility and biodegradability. Therefore, in this study, Gelidium robustum agar has been chosen as a natural biocompatible polymer to build the matrix of cobalt ferrite ($CoFe_2O_4$) and magnetite (Fe_3O_4) nanoparticles, which were synthesized by the co-precipitation method in agar gel. After that, agar gels were then dried and ground into powder, yielding agar-conjugated Fe_3O_4 and $CoFe_2O_4$ nanoparticles. The samples were characterized by X-ray diffraction, and scanning electron microscopy (SEM). The nanoparticles were identified as cobalt ferrite ($CoFe_2O_4$) and magnetite (Fe_3O_4) and had a well-defined crystalline structure with sizes in the range of 5-7 nm. The potential of these nanoparticles as hyperthermia agents in different phantoms is also explored.

7596 | EXPERIMENTAL VALIDATION OF AN INNOVATIVE COMPOSITE CERAMIC MEMBRANE OF HIGH SELECTIVITY CO_2 SEPARATION FOR CLIMATE CHANGE MITIGATION **(19. Nano-Composites)**

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EXPERIMENTAL VALIDATION OF AN INNOVATIVE COMPOSITE CERAMIC MEMBRANE OF HIGH SELECTIVITY CO2 SEPARATION FOR CLIMATE CHANGE MITIGATION

Carbon dioxide a major greenhouse gas responsible for global warming which is considered as the greatest environmental challenge the world is facing account for about 80% of all greenhouse gases (GHG). The scuffles to control the GHG emissions include the recovery of CO2 from flue gas. This concern has been improved due to recent advances in materials process engineering resulting in the innovation of novel materials possessing the thermal and mechanical stability required for most gas separations. This paper looks at an experimental validation gas separation in a single gas permeation experiment by means of a high selective membrane for CO2 recovery applications for climate change mitigation. Analysis of results obtained are in total agreement with literature data. Further results show that CO2 permselectivity to that of N2 supported the theoretical Knudsen with a high selectivity factor confirming a reasonable capture of CO2 to that of N2 as a major component of a flue gas stream.

7604 | Thermomechanical behavior of polymer nanocomposites considering reinforcement damage (19. Nano-Composites)

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In this paper, a thermo-elasto-plastic incremental constitutive equation of the reinforced nanocomposite considering the debonding of the reinforcement and as well as the elastoplasticity using micromechanics principles is presented. The proposed model investigates the influence of the reinforcement damage mode (the debonding of the inclusions from the matrix), aspect ratio, and volume fraction on the effective thermomechanical properties of polymer nanocomposites. It is observed that the coefficient of thermal expansion depends on the volume fraction and the aspect ratio of the reinforcement, and the considered damage mode. This coefficient is inversely proportional to the aspect ratio and volume fraction of the reinforcement and it increases when the inclusions gradually turn into voids due to the reduction of reinforcement volume fraction. Based on the present model, analysis of stress-strain response for nanoclay/polymer composites under uniaxial tension is carried out while considering interfacial debonding of inclusions and elasto-plastic behavior of matrix.

7621 | A modified parallel electrodes method for fabricating highly aligned composite nanofibrous membranes (19. Nano-Composites)

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During the electrospinning process, the collected nanofibers are typically randomly oriented in the form of nonwoven mats. The randomly oriented nanofibers lead to low molecular orientation and as a result materials with low mechanical properties are obtained. It is desirable to generate aligned nanofibers to broaden the applications of electrospinning, such as tissue engineering, drug delivery, electrochemical sensors, reinforcements, optoelectronic devices, and so on.
A modified parallel electrodes method (MPEM) was presented to improve the diameter distribution and the degree of alignment of electrospun composite nanofibers. Compared with the parallel electrodes method (PEM), a positively charged ring was placed between the needle and the parallel electrodes collector in the electrospinning process. The effectiveness of the MPEM was demonstrated by measuring the diameter distribution and the degree of alignment of electrospun composite nanofibers and comparison of them with those obtained from the PEM. The results showed that the MPEM could decrease the diameter of composite nanofibers and enhance the uniformity of electrospun composite nanofiber diameter distribution, and it could improve the degree of alignment of electrospun composite nanofibers two times more than the PEM.

7720 | Interfacial Phenomena in Structural Polymeric Nano-clay Synthetic fibre-reinforced Cementitious Composites (19. Nano-Composites)

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Fibre-reinforced materials have been used to improve brittleness due to the low tensile strength of cementitious composites. Such fibres require high tensile strength and modulus of elasticity to improve the tensile properties of cementitious composites. For this reason, steel fibre has been primarily used. However, steel fibre is also susceptible to corrosion. Recently, studies have focused on a substitute for steel fibre using a non-corrosive material with low specific gravity for the structural synthetic fibre component. Structural synthetic fibre has disadvantages, including rapid stress reduction and displacement after the peak load.
Fibre-reinforced materials exhibit bridging effects at the initial cracking of the cementitious matrix after the peak load. This mechanism is caused by the pull-out resistance of the fibre. However, structural synthetic fibres that elongated or fractured without pull-out in a cementitious matrix could not function properly due to their low tensile strength and modulus of elasticity. In this study, structural synthetic fibre, which elongates without pull-out, was enhanced with cementitious materials to improve tensile properties. Additionally, the toughness of the cementitious composite was maintained under elongation. Addition of a nanoscale material improved the bond properties of the structural synthetic fibre, thereby enhancing the material properties of the polymer through changes in the surface morphology and three-dimensional (3D) fibre structure. The bond properties of the structural nano-synthetic fibre were investigated by analysing the surface morphology, 3D structure, and number of fibres according to JCI SF-8.

7784 | Process Intensification (PI) of Microbial Gas Absorption by Biocomposite Materials (19. Nano-Composites)

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Bioprocesses that use living cells to absorb gases and convert them into useful products require significant energy input to disperse poorly soluble gases in large volumes of water in bioreactors. However, engineering nano-structured composite structures, may enable more energy and resource efficient approaches to bioconversion of gases. Single carbon gases (CO, CO_2, CH_4) can be assimilated by highly concentrated microorganisms embedded in nano porous composite polymer materials known as biocomposites for recycling carbon emissions or gasification products into fuels or chemicals. These composite nano porous structures are formed during drying which can also stabilize and preserve the embedded cells in a desiccated state. These cells can be heterotrophic or photoreactive bacteria, cyanobacteria or algae engineered for assimilation of gaseous carbon compounds with synthesis of lipids, oils, alcohols or alkanes. Critical to engineering biocomposite microstructures is control of cell deposition, nano porosity surrounding the cells, the rate of water removal, and the final water activity of the stored cells. Biocomposite porosity is monitored using SEM, confocal microscopy or directly measured by tracer diffusivity or gas flux. Our investigation is a new composite nano-structured materials approach to increasing the rate of large scale microbial gas absorbers using novel structures formed on or within papers or nonwoven fabrics. We are investigating biocomposite falling film gas-absorber designs using as a model system carbon monoxide (CO) absorption by the anaerobic microorganism Clostridium ljungdahlii OTA1 that assimilates CO and H_2 and produces ethanol and acetate. Biocomposites are fabricated by mixing concentrated cell paste with excipients to aid in drying, porosity, adhesion and applied to papers or nonwoven materials by aerosol deposition followed by drying under controlled conditions in an anaerobic atmosphere. When rehydrated and placed in the gas-phase, the paper wicks the liquid phase into the pore space behind the cell coating allowing the biocomposite to be dispersed in a tangential gas stream without the cells becoming dehydrated. Absorbed CO can be assimilated by C. ljungdahlii without outgrowth from the composite structure and the products, ethanol and acetate, secreted into the pore liquid accumulate in the low volume bulk liquid phase. CO uptake by the biocomposite remains high as liquid volume is reduced and power input to move the liquid phase is also significantly reduced. Composite material's gas transport and reactor modeling approaches are also being investigated for extension to other microorganisms. Modeling of this system could enable design of highly reactive gas-absorbing biocomposite materials with low power input and low water usage for recycling of gas-phase pollutants (e.g. CO_2, CH_4) or conversion of methane into fuels and chemicals.

7889 | Microfibrillar composites of PCL matrix and layered silicates (19. Nano-Composites)

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Microfibrillar composites (MFCs) are advanced materials with in-situ formed reinforcement. They can be easily prepared by cold- or melt-drawing of immiscible polymer blends and subsequent conventional processing. Reinforcement is caused by fibrils of dispersed rigid semicrystalline polymer, such as PA6 and PET, of melting point sufficiently exceeding processing temperature of the matrix. Advantage of MFC is good dispersion and adhesion of fibrils, which is usually a problem in composites containing polymeric and organic fibers. Relatively low parameters of polymeric fibres can be improved by simultaneous application of nanofillers as we have demonstrated with high density polyethylene/polyamide 6 MFC.
Promising materials include not yet studied biodegradable MFC based on suitable combination of linear polyesters with significant difference in melting points and, thus, processing temperatures.
Polycaprolactone (PCL) selected as the matrix is an attractive biodegradable material, however, with applications limited by low glass transition temperature and less stable crystalline structure. In this work, a combination of PCL, polylactic acid (PLA) reinforcing fibrils, and organophilized montmorillonite (oMMT) is studied. Although PLA with different rheological parameters was applied, melt drawing of PCL/PLA 80/20 blends was not possible. On the other hand, application of oMMT with various addition protocols led to successful drawing thanks to achievement of favourable viscosity ratio of modified components. The fibril formation was confirmed by SEM observations and especially by markedly improved mechanical parameters, namely yield strength and modulus. The modulus enhancement corresponds to contribution of both polymer fibrils and oMMT reinforcement. Moreover, oMMT addition brings certain synergy which consists in enabling the fibril formation, their reinforcement, and influencing crystallinity and interface parameters. Due to relatively favourable and similar values of wetting coefficients of both polymeric components, we consider oMMT to be predominantly present inside both phases and just scarcely at the interface, as is has been confirmed by TEM observations. As a result, glass transition temperature of both components of MFC was affected by oMMT similarly to corresponding PCL and PLA nanocomposites. Of importance is simultaneous increase in Tg of PLA phase (i.e., fibrils) and thus dimensional stability at elevated temperatures. Moreover, significantly higher crystallinity of PCL phase in the MFC system was also found. Due to the fact that modulus of undrawn sample is higher in comparison with predicted values using spherical particles model, formation of elongated PLA particles with low aspect ratio (AR) <5 is also anticipated in the course of mixing in a twin screw extruder. The significantly improved mechanical parameters of the related MFCs due to the subsequent melt drawing correspond to formation of fibrils with AR exceeding 15; another further important factor is drawing-induced reinforcement of oMMT containing fibrils. Experimental values of stiffness correspond to the Halpin-Tsai model showing significant dependence of modulus on AR in the range 0-25. The results indicate that the nanofiller-modified PCL/PLA microfibrillar composites represent a biodegradable material with significantly broader range of applications.
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7895 | An effect of epoxy laminate composites modified using metallic powders (19. Nano-Composites)

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This paper presents the results of epoxy laminate composites examinations. Laminates were reinforced with glass, carbon, basalt and aramid fiber mat, and also was modified using metallic powders with different granulations and content. The investigations contents static tension, dynamic tension and fatigue tests. Flammability test, Charpy and impact resistance tests was also performed. The results were compared to numerical simulation results, and were used to verification of mathematical models.

7902 | Novel Colloidal Processing Routes to Layered Hydroxide Filler-Based Nano-Composites (19. Nano-Composites)

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Organic coatings for large scale industrial applications like coil or automotive coatings are facing increasing economic constraints. Thus modern automotive OEM coatings often comprise less individually applied coating layers in order to shorten the process and to save energy used for thermal crosslinking [1]. On the other hand, in the context of electro-mobility and aviation, lightweight construction is expected to be increasingly based on numerous different materials comprising aluminium and magnesium based alloys besides carbon-fibre-reinforced plastics [2]. Protection of the metallic substrates against mechanical impact and corrosion therefore will become a major technical concern in the development of coating materials.
Layered particle based nano-composites recently have been shown to impart stone impact resistance to automotive coatings by making use of polymer intercalated layered double hydroxide (LDH) platelets in a variety of different film morphologies [3]. However the LDH particles used were obtained via coprecipitation of the metal salts in the presence of small organic anions in order to render the LDH particles organophilic and to facilitate the intercalation of carboxylate group bearing matrix polymers. Thus anion exchange in the course of colloidal processing and during film formation leads to the release of ionic species which deteriorate the coatings barrier function.
In order to circumvent objectionable counter ions involved in the synthesis and/or the coatings formulation novel preparation routes for layered hydroxide based hybrid phases are proposed comprising the polyol route [4], the in-situ synthesis in the presence of polymers as well as bola-amphiphiles [5] and/or the use of volatile anions. The impact of both the process conditions as well as the chosen system with regard to the metal hydroxide framework and the organic counter ions on the obtained hybrid phases as well as the morphology and properties of corresponding organic coatings are presented and discussed.

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7945 | Development and research of nanostructured multilayer composite coatings for tungsten-free carbide with extended area of technological applications (19. Nano-Composites)

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The paper discusses the aspects of the development of nanostructured multilayer composite coatings (NMCC) formed using processes the filtered cathodic vacuum arc deposition (FCVAD). These coating are applied to tungsten-free carbides (cermets) of types TiC- (Ni,Mo) and TiCN- (Ni,Mo) in order to expand their technological applications. The multi-layered coatings are applied to improve the physical and mechanical properties of the working surfaces of the tool. This allows to functionally control contact processes when cutting and it is shown that, despite, the high hardness, thermal stability and resistance to scaling, low tendency to diffuse from the material being processed, the tool has a relatively low fracture toughness and bending strength, and low thermal conductivity. Therefore, cutting tools made of tungsten-free carbide have a limited range of technological applications for interrupted cutting, machining of hard-to-cut steels and alloys. Considering the possibility of a functional control of contact processes when cutting using multilayered coatings on tools, one can achieve a good balanced between hardness and toughness. Three-component architecture of nano-structured multilayer composite coatings was developed using methods of selecting functions and parameters of tungsten-free carbide tools made. The developed compositions of NMCC have improved cutting tool properties of tungsten-free carbide and significantly expand the area of their technological application in milling of hardened steels and hart-to-cut alloys.

7951 | Electronic-energy spectrum and atomic structure of aluminum-silicon nanocomposite films (19. Nano-Composites)

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Nanostructured silicon revealing substantial luminescence can be obtained using nanocomposites fabricated by composite aluminum-silicon target magnetron sputtering. Lithium-ion batteries with nanostructured silicon anode, obtained by etching aluminum from Al-Si nanocomposites, are stable after a large number of charging cycles and of higher capacity then the common graphite anode batteries.
This work reveals the study of nanocomposite 0.5 micron-thick Al+Si films, obtained by magnetron sputtering of composite target on the silicon monocrystalline substrates (111). The first target consists 45 at. percent of Si and 55 at. percent of Al, and the second one is composed of 30 at. percent of Si and 70 at. percent of Al. Selective removal of aluminum was carried out in phosphoric acid at 50 C.
X-ray diffractometric studies of initial Al-Si composite film allowed to discover a broadening of aluminum and silicon reflections. The pure aluminium reflection disappears after etching the aluminium. The average size of silicon nanocrystals, calculated by the broadening of silicon reflection (220), is about 25 and 20 nm for the samples of series 1 and 2 respectively and does not change after removal of Al.
According to scanning electronic microscopy, the 30-40 nm granules are visible on the surface of the initial 1st series sample. The silicon sponge-like structure with the mean size of elements about 25-30 nm is observed after removing aluminium from the nanocomposite.
The study of silicon valence band electronic states was performed by analyzing the Al-Si nanocomposites X-ray emission Si L2,3 spectra. The depth of analysis was about 60 nm, i.e. the layer of about 2-3 granules was studied.
It was found that the shape of emission spectrum, and hence the density of silicon valence electronic states, almost coincides with the reference c-Si spectrum. This fact confirms the results of diffractometric studies.
However, in case of initial composite (silicon nanocrystals are situated in aluminum matrix), there is a noticeable difference between the composite Si L2,3 spectrum and the single crystalline silicon L2,3 spectra in the energy region corresponding to transitions from the lower part of valence band to the core

L2,3 level (82-92 eV). In particular, the Auger processes-caused spectrum broadening disappears, and the width of the valence band is reduced. Intensity becomes linearly dependent on energy near the bottom of the valence band.
Such dependence can be caused by rearrangement of the valence electrons wave functions in silicon nanocrystals located in aluminum matrix and not interacting with each other. That's why the quantum effects-caused narrowing of the valence band and the electronic states localization near the bottom of the valence band occurs. This effect causes the spectrum linearity in this area.
The silicon nanocrystals start interacting with each other after removing the aluminium and the form of Si L2,3 spectrum becomes similar to the crystalline silicon spectrum.
The synchrotron studies of the conduction band electronic states density were carried out by the means of X-ray Absorption Near-Edge Structure (XANES) spectroscopy to analyze the surface layers of Al-Si nanocomposites and resulting nanocrystalline silicon. The depth of analysis was about 5 nm. XANES Si L2,3 spectra of the initial sample could not be registered due to unsufficient concentration of silicon on the films' surface. Analysis of the XANES Si L2,3 spectra for the removed aluminium samples shows that the surface of silicon nanoparticles is covered with a layer of amorphous silicon. Besides, the density of states tails are found in spectra, occuring in the band gap close to the bottom of the conduction band. These tails are more substantial then ones showed in the case of amorphous silicon.

7987 | Thermal, mechanical and morphological properties of nanosized silica/polyethylene and POSS/polyethylene nanocomposites (19. Nano-Composites)

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Key words: Nanocomposite; Polymer; Polyhedral Oligomeric Silsesquioxane (POSS); Silica; Sol-gel method

In recent years, the organic–inorganic hybrid nanocomposites have attracted much attention from researchers in the polymer science, because of their interesting and unique properties. Especially the application of silicon compounds as a fillers in polymer composites provides opportunity to develop new classes of advanced materials.
One of the most important fillers in polymer composites is nanosized silica. The widely used route for synthesizing silica nanoparticles is sol-gel method, that allows to obtained monodispersed with narrow-size distribution nanoparticles at mild conditions. Furthermore, their surface properties can be varied by controlling of substrates used and reaction conditions [1,2].
On the other hand, polymer nanocomposites with polyhedral oligomeric silsesquioxanes (POSS) have also evoked much interest recently. POSS molecules consist of an inorganic cage of silicon and oxygen surrounded by organic groups covalently bonded to the silicon atoms. The structure of POSS compounds provides enormous opportunities of the unlimited surface modification and the relatively excellent compatibility with organic/polymeric materials. Moreover polymer nanocomposites with POSS as a fillers have shown enhanced properties such as increased thermal stability, and improved mechanical stiffness in comparison with the corresponding neat polymers [3,4].
This work focuses on the comparative study of the thermal, morphological and mechanical properties of polymeric composites manufactures with polyethylene and the nanosized silica produced by sol-gel method and the different POSS compounds as filler. The preparation of composite samples was performed by melt-blending with using a two screw laboratory mini-extruder. The properties of nanonomposites obtained were investigated by DSC, TGA, PALS, SEM and EDS techniques. The influence of the kind of silicon-nanofiller on the mechanical properties, such as elongation at break, impact strength and hardness of nanocomposites was also determined.

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7988 | POSS/ethylene copolymer materials – study on structural, morphological and thermal properties (19. Nano-Composites)

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Key words: Hybrid materials, Polyhedral oligomeric silsesquioxane (POSS), Ethylene copolymers, Structural properties, Thermal characteristic, Morphology

Organic–inorganic hybrid nanocomposite materials – a new generation of high performance materials, have attracted a great deal of attention recently. They combine the advantages of the inorganic materials (rigidity, high stability) and the organic polymers (flexibility, dielectric properties, and processability) [1]. In particular, the use of polyhedral oligomeric silsesquioxane (POSS) nanoparticles as modifiers of organic polymers provide new opportunities. Because of the tailorability of structure of POSS molecules, through the proper selection of organofunctional substituents in inorganic silicon-oxygen cage, they can be tailored to suit specific needs [1,2]. The incorporation of POSS into polymer chains has provided improvements in polymer properties, such as increased glass transition temperature, thermal stability, oxidation resistance, reductions in flammability, and mechanical strength [3].
This work focuses on properties of POSS/polyethylene hybrid materials obtained by low-pressure copolymerization of ethylene with alkenylsilsesquioxanes, that differ in kind of non-reactive groups and structure of vinyl-terminated substituent. Polymer structure characteristics of the copolymers were studied using FTIR and NMR techniques. The morphology of materials obtained was determined by SEM techniques and the thermal

properties were evaluated with DSC and TGA analysis. The effect of the ethylene/POSS copolymers structure on the properties of these organic-inorganic materials were investigated.

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8025 l SUPERHYDROPHOBIC COATINGS BASED ON NANOSECOND LASER TEXTURING (19. Nano-Composites)

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Direct irradiation of materials by ultrafast laser pulses often results in the material surface modifications. Such modification is associated with the formation of structures, which are characterized by different length scales, that is forming multimodal surface roughness. Subsequent chemical functionalization of fabricated textures may be employed for tailoring the surface properties with unique functional properties.
Microstructuring by ultrafast laser pulses such as femtosecond and nanosecond is specifically attractive for the wide range for industrial applications since it is simple, well reproducible, easily adaptable and scalable through parallel. At the same time the surface textures obtained by femtosecond laser treatment differ significantly from those produced by using nanosecond laser pulses. As a result the surface composition of multicomponent materials and their mechanical and chemical stability may be significantly different for femto- and nano- laser treatment.
In this presentation we will discuss the peculiarities of surface texture, composition and durability of superhydrophobic coatings fabricated on the surface of different materials by nanosecond laser irradiation.
Superhydrophobic surfaces have attracted significant attention of the scientific community as well as the industrial world owing to very wide area of their applications. Nowadays due to unique functional properties these coating are actively used to protect engineering materials against corrosion, icing, biofouling, pollutions etc. However, poor mechanical stability of superhydrophobic coatings hinders their application in hazardous conditions of exploitation. Thus, great efforts have been made in designing durable superhydrophobic surfaces which demonstrate long-term chemical and mechanical stability.
In this presentation it will be shown that appropriate choice of laser treatment regime and chemical pretreatment and functionalization allows one to prepare superhydrophobic surfaces with very high contact angles and low hysteresis. Besides we will demonstrate the impact of different mechanical loads and long-term contact with aqueous media on the evolution of superhydrophobic properties of fabricated coatings. It will be shown that the appropriate choice of laser treatment regime allows fabricating the coatings robust to abrasive wear and cavitation.

8042 l Multi-walled carbon nanotubes based composite membranes for electrical applications (19. Nano-Composites)

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Multiwalled Carbon nanotubes (MWCNTs) have been observed in 1952. The interest in their use has been focused in the last two decades due to their relevant properties that make them suitable in a wide number of technological fields. In fact, the application as fibres or fillers in polymeric matrices for the preparation of nanocomposite materials could open new research paths. In particular, the high performances as conducible materials could be used to create new electrical sensors. The possibility to choose a polymer as binder could avoid deformation phenomena and increase the mechanical strength of these composites. The aim of this study is to characterise the obtained MWCNTs based nanocomposites materials using PMMA (polymethyl methacrylate) as binder. The synthesis of nanotubes has been carried out by Catalytic Chemical Vapour Deposition (CCVD) at 700°C, with a reaction time of 20 min. The catalyst used is a cobalt iron based supported material, the purity of obtained product is ca. 94 wt %. The thermal analysis points out a high graphitisation of MWCNTs with no carbon amorphous presence. The conductibility tests have been performed after preparation of nanotubes pellets with ca. 2 cm of diameter. The PMMA is introduced in low percentages as fixative. Two percentage values of PMMA are used to characterise the obtained material. Surface and volume measurements have been carried out to define the better pellet preparation and they have highlighted the high performances of theses samples. As a conclusion, the nanocomposites could be used as safety sensors in domestic and industrial contests.

8079 l CNT/Al nanocomposites produced by hot extrusion and powder metallurgical route using dispersion/mixture technique (19. Nano-Composites)

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Nanocomposites reinforced with carbon nanotubes (CNTs) have attracted growing attention from the research community.. The biggest challenge for the production of these composites is the development of processes that promote a dense and uniform dispersion of CNTs, undamaged and well bonded to the matrices, to accomplish its full reinforcement potential and achieve an effective load transfer. The production process of the nanocomposites has a great influence on the dispersion of the reinforcement in the matrix.
This research is focused on evaluation of two different processes for production of aluminum matrix composites reinforced with CNT; hot extrusion vs. hot-pressing. CNTs used in this work (from composites Fibermax) are mostly multi-walled CNT. Powders of aluminum (from Goodfellow) were mixed with the

CNT using an ultrasonicator for 15 minutes in isopropanol. Hot extrusion of the mixture was performed at 450 ° C with a load rate of 2 kN/s while the hot pressing was conducted by pressing at 300 MPa and sintering at 640° C for 90 min. Microstructural characterization of CNT/Al nanocomposites was performed by scanning and transmission electron microscopy (SEM and TEM), electron backscattered diffraction (EBSD) and high resolution transmission electron microscopy (HRTEM). Mechanical properties of the nanocomposites were evaluated by microhardness and tensile tests. The hardness was evaluated by Vickers microhardness using a 98 mN load; ten tests were performed on each sample. The tensile tests were performed at a rate of 0.2 mm/s; three specimens were tested for each condition.
Microstructural characterization by SEM images of the nanocomposites reveals that the CNTs are mainly observed in clusters at grain boundary junctions. However, the composites produced by hot extrusion show less porosity and smaller CNT clusters in comparison to the hot-pressed ones. TEM observations revealed that, in addition to these clusters, is also possible to identify individual CNT well dispersed inside the Al grains, for both nanocomposites. Nevertheless, it is possible to identify more individual CNT in hot extruded samples meaning that the dispersion was improved by this process. The formation of Al4C3 phase due to the reaction between the CNT and Al was also detected by HRTEM observations. The texture of the nanocomposites was evaluated by EBSD. While the nanocomposites produced by hot pressing did not present any preferential crystallographic orientation, the ones produced by hot extrusion exhibited a strong <111> texture. Mechanical characterization reveal that the nanocomposites produced by hot extrusion and hot pressing have an increase of 20 and 50% in hardness and 50 and 200% in tensile strength, respectively. These results were not expected since the SEM and TEM microstructural characterization indicated a dispersion more efficient and a denser sample for the hot extruded nanocomposites. HRTEM images of the nanocomposites produced by hot extrusion show CNT shorter and with a different shape, suggesting that this process can induce damage that hinders its strengthening effect. The increase in the number of defects in the CNT appears to be responsible for the reduced mechanical properties of these nanocomposites, when compared with those produced by hot-pressing. Although the extrusion process promote a better dispersion of the CNT through the Al matrix, this process needs to be improved to reduce the damage of the CNT structure and achieve the expected strengthening effect.

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8087 I Composites based on calcium-deficient hydroxyapatite for bone remodeling (19. Nano-Composites)

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Composites based on hydroxyapatite are an attractive materials for practical application in biomodelling surgery as scaffold for implants and cements in dentistry. There are several investigations in which such composites are produced by different methods. Some of them represent hydroxyapatite as solid solutions of substitutions, where the positions of calcium atoms are occupied by other metal atoms. Such composites have an elemental composition that resembles bone's tissue and thus have a similar properties with it.
It is known that metal ions (Na, Mg, Zn, Cu, Fe, Sr), incorporated in the hydroxyapatite (HAP) tier of bone tissue plays an important role in osteogenesis and also affect the mechanical and optical properties of biogenic HAP. Deliberate injection of metal ions in synthetic hydroxyapatite lattice can lead, besides better biocompatibility, to the changes in structural properties of these materials. Among other impurities zinc, copper and magnesium are actively also involved in process of ontogenesis. However, the problems concerned with the study of the structure and physicochemical properties of modified hydroxyapatite depending on the concentration of dopants and their influence on the phase composition of HAP have been studied rather incompletely. The aim of this work is to determine the influence of metal ions Zn, Cu and Mg on the phase composition and structure of calcium-deficient hydroxyapatite.
Calcium-deficient hydroxyapatite (CDHAP) was prepared by chemical precipitation route. The solution of 0.3 M ammonium diphosphate was added to the solution of calcium nitrate dropwise and pH was adjusted to 9.5 by adding of 25 % ammonia solution. Copper-, zinc- and magnesium substituted HAP (Me-HAP) were prepared in the same process with addition of 3 M metal salts solutions: copper, zinc and magnesium nitrates with three different concentrations of metal in final sample 1,3,5 at.pct. In all cases pH = 10.5 was attained by adding of 25 % solution ammonia solution. The samples synthesis was monitored by measuring of pH values during the reaction using pH-meter/ionometer IPL-111—1 by «Multitest» as well as acid addition rate to the solution and also by the stirring rate. After 24 hours the samples were filtered, washed with distilled water, and annealed. The annealing temperature is conforming to the maximum vacancies content in the cation sublattice of CDHAP.
According to the results of X-ray analysis, it was found that all Zn-HAP, Mg-HAP and Cu- HAP samples (for the 1 %and 3 % of substitution) comprise a single phase — calcium hydroxyapatite. Meanwhile, in the sample obtained with a higher content of copper Cu- HAP (5 %) have an additional lines of the second phase Ca19Cu2H2 (PO4)14 that are detected along with the main phase HAP. The behavior of Zn, Cu and Mg under replacing of calcium atoms in the HAP lattice can be explained by a significant difference in their electronic structure. Atomic structure of copper Cu 3d 10 4s 1 allows one to have as the divalent state in Cu-HAP phase as monovalent state in Ca19Cu2H2(PO4)14 phase.
It was discovered with the usage of photoluminescence and microhardness measurements that incorporation of metal atoms in calcium-deficient hydroxyapatite changes the intensity of PL and hardness of the samples in different ways. The common is that all composites have a wide PL band with maximum in the area 2,6 eV with different fine structure depending on metal (Zn, Cu, Mg).

8092 I Structure and elastic properties of modified polycarbonate (PC) / acrylonitrile-butadiene-styrene (ABS) copolymer blend composites with organically modified nanoclay (19. Nano-Composites)

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Over the last few years, due to their considerably enhanced properties, polymer nanocomposites have gain increasing popularity in many application areas, even in spite of their considerably higher price. One of the most important challenges at the development of commercially viable effective polymer nanocomposites is ensuring of nanosize dispersion of the used filler throughout the bulk polymer matrix at sufficiently high level of interfacial adhesion

between the system's ingredients. Purposeful modification of nanofiller and functionalization of polymer matrix both have been successfully used for increasing effectiveness of polymer nanocomposites. In the same time the research of interfacial modification of polymer nanocomposites is restricted to limited amount of polymer-nanofiller combinations. Besides it comparatively few researches consider modification of polymer blends with purposefully selected nanofillers in spite of the fact that polymer blends are increasingly used to replace individual polymers in many of everyday applications.
On this score the current research is devoted to investigation of structure and elastic properties of polycarbonate-acrylonitrile-butadiene-styrene blends (PC/ABS) nanocomposites with organically modified layered silicates (OMLS). OMLS has been selected as perspective modifiers of PC/ABS blends by considering plate-like shape of the nanofillers, allowing considerably improve elastic as well as thermal and barrier characteristics of the materials primarily depending on the level of orientation within the polymer matrix. The nanocomposites have been developed on the bases of PC blend with 10 wt. % of ABS. Concentration of OMLS has been changed in between 0 and 2 wt. %. Twin-screw extrusion has been used for manufacturing of the respective nanocomposites. For the sake of better compatibility between the organic polymer blend matrix and the inorganic nanofiller certain amount of specific hydrocarbon compatibilization agent (CA) has been added. The effects of OMLS and CA on the structural, calorimetric, as well as elastic properties of the aforementioned nanocomposite compositions have been investigated.
As a result of tensile stress-strain as well as dynamic mechanical investigations, it has been revealed that addition of nanoclay to PC+10wt.%ABS matrix allows increase quasistatic tensile modulus, dynamic storage modulus and yield strength of the nanocomposites. Besides it greater properties increment in respect to the neat polymer blend matrix is observed at 1.5 wt.%. of OMLS. It is worth mentioning that by modifying manufacturing technology as well as by treating the PC/ABS based systems with CA it is possibly further increase mechanical characteristics of the investigated composites. Growth in mechanical properties of the investigated nanocomposites is justified by intercalation of polymer macromolecules within the interlaminar space of the OMLS galleries as it can be revealed from the corresponding x-ray diffraction patterns. Another reason for improved elastic characteristics of the investigated nanocomposites is effect of OMLS on the amorphous regions of the polymeric phases, predominantly ABS phase, as testified by corresponding relaxation processes measurements by means of dynamic mechanical thermal analysis. It is interesting to note that addition of OMLS to the polymer blend matrix to a certain extent can be viewed as a mean of increasing compatibility between both polymeric phases by considering approaching glass transition temperatures of PC and ABS phases.

8144 | Formation of porous silicon nanocomposites with deposited Sn and In by sol-gel method and their optical properties . (19. Nano-Composites)

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Design of multifunctional composite materials with a high sensitivity and selectivity in combination with the routine silicon technology is of a great interest both for researchers and practical applications. The main problem concerned with a wide application of the structures based on porous silicon is their degradation with time.
Formation of the nanostructured Sn and In obtained by sol-gel technique on por-Si substrates and their optical characteristics were studied after a long-term exposure in the atmosphere. Por-Si was obtained in the usual manner by electrochemical etching in HF alcoholic solution. Metal deposition was performed as sol deposition of metal chloride and TEOS in such a way that metal-oxide layer on porous silicon was composed of ~ 90 mol. % of metal oxide and 10 mol. % of SiO2. SEM images of the surface and elemental analysis were made by Auger-spectroscopy. Chemical composition and optical properties were investigated by IR spectroscopy and photoluminescence (PL). PL spectra were obtained under laser excitation with l = 337 nm. All of the samples were stored in atmosphere for 6 months.
IR spectral bands at 804 and 906 cm-1 characteristic of Si-H bonds were observed as rather intensive that means hydrogen preserved in the pores covered with metal-oxide films. In addition, deposition of metals by this method leads to a change in the band shape of the IR spectrum at 1030-1260 cm-1, corresponding to silicon-oxygen bonds.
As shown in [1], sample composites exhibit an increased selectivity for various gases as compared with the original porous silicon and tin dioxide obtained by the same method on a silicon substrate.
The main PL peak both for original por-Si and that one with the deposited metals was arranged at 560 nm. It is important that PL intensity in por-Si with metals was equal to the value for originally annealed por-Si. This provides new possibilities for creating multifunctional electronics devices.
This work was partially supported by a grant of the President of the Russian Federation (MK-4535.2014.2), Russian Federation Government Assignment and by Russian Federation Government Assignment for Higher Education Institutions (Projects №740, Task № 3.130.2014/K).

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8182 | Cellulose nanocrystals and cellulose nanofibers: extraction and application in corn starch plasticized films (19. Nano-Composites)

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Cellulose at the nanoparticle scale has been studied as a reinforcement for biodegradable matrices to improve film properties. The goal has been to investigate the properties of corn starch films reinforced with highly crystalline rod-like nanostructures obtained from cellulose, called cellulose nanowhiskers (CNWs) or cellulose nanocrystals (CNCs) and long flexible micro and nanofibres consisting of alternating crystalline and amorphous cellulose chains called cellulose nanofibers (CNNs) both obtained from eucalyptus. Eucalyptus kraft wood pulp with high a-cellulose content (96–98%) was gently supplied by Bahia Pulp Company (Brazil) and cellulose micro/nanofibres were obtained from mechanical procedures and 'whiskers" from chemical procedures. Bionanocomposites based on corn starch and cellulose nanofibers (CNNs) and cellulose nanocrystals (CNCs) were prepared by dispersing the CNNs and CNWs in poly(ethylene glycol) (PEG) plasticizer subsequently incorporating the CNNs/PEG and CNCs/PEG suspensions in the matrix. The thin films composed of corn starch/ cellulose nanocrystals and corn starch/cellulose nanofibers were characterized using color spectroscopy,

scanning electron microscopy (SEM) and mechanical properties. The present work contributes to the widespread use of different methods for the production of cellulose reinforcements from Eucalyptus, which after apply in corn starch matrix originate corn starch films with distinct morphological and structural characteristics that can be used to engineer polymeric composites for different applications.

8199 | Si(100) Based Nanocomposite Ultra-Thin Al2O3/por-Si Films Obtained Using the Methods of Ion Plasma Diffusion (19. Nano-Composites)

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Presenly, silicon is a major material in micro- and nanotechonologies. Basically, size scaling of functional silicium-based elements is only hampered by the development of the design of a qualitative insulator layer. Aluminium oxide, which has a high thermal stability, a dielectric constant of ~ 11 and the widest optical transparent area in the range of 200-5000 nm, has recently been used in the same way. However, it is impossible to design effective optical silicon-based electrical devices, since it is a nondirect gap semiconductor with a very poor radiative capacity and electrical energy cannot be transformed into a visible light in silicon-based devices. Electrical properties can be modified resulting in nanostructures which are divided in space, minimum-size silicon areas of a few nanometers. Besides, the fact that the properties of porous materials are easy to modify and combine with the technological properties of silicon microelectronics raises hopes for developing more electrical and por-Si based optical devices with a low, medium and high porosity as well as macroporous regular structures. Therefore the objective of the paper is to obtain silicon-based nanocomposite ultra-thin Al2O3/por-Si films as well as to study their morphology, structural and optical properties.
A porous silicon layer is obtained by means of electrochemical etching of p-type monocrystal silicon plates (111) with a specified resistance of the plate of 10 Ohm*cm in an alcoholic solution of hydrofluoric acid using the standard methods. The thickness of a porous layer was about 200 nm. Ultra-thin nanocomposite Al2O3/por-Si/Si films were then obtained by means of ion plasma diffusion. For that, a 99% aluminium target was bombarded by oxygen ions in a pure oxygen plasma without adding argon. X-ray diffraction, infrared, ultraviolet and photoluminescence spectroscopy as well as atom force microscopy were used to prove that the obtained nanocomposite films are good at transmitting optical radiation in an infrared, visible and ultraviolet range. The calculated dispersion of the refraction coefficient of Al2O3/por-Si composite film grown using silicon showed that the structures obtained in such a manner have a forbidden band of ~5.5 eV in width and can potentially contribute to the design of promising MIS structures followed by the integration with AIIIBV semiconductors.

The work has been carried out with the support of the Ministry of Science of Russia as part of 2014-2015 state scientific tasks for higher education institutions. (Project №740, Task №3.130.2014/K) as well as the grants of the Russian Fund of Fundamental Research: 14-32-50159 mol_nr, 14-32-50289 mol_nr and the Russian Federation Presidential Grant MK-4535.2014.

8249 | Formation of self-assembled macroporous titania templated by micrometric latex spheres in glass substrates by evaporation induced self-assembly method (19. Nano-Composites)

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The aplication of macroporous titania covers different technological fields like: catalysis, batteries, solar cells and biomaterials. In this work, titania was incorporated in latex spheres template whose diameter is approximately 2.9 micrometers. This template has been prepared by evaporation induced self-assembly method (EISA). It has been used commercial latex spheres dispersion whose concentration was varied from 1% to 3% (V/Vo) to modify the number of latex spheres layers coated on glass substrate. The temperature of dispersion was also changed from 50 oC to 80 oC in order to analyze which temperature would be more suitable to obtain well defined self assemblies. The samples were infiltrated by a mesoporous titania solution constituted by a ternary system: 1-Butanol, triblock copolymer (P-123) and chloridic acid (HCl) using titanium ethoxide as inorganic precursor. This solution was spread in latex spheres template forming a thin coating. This composite was heat treated at different temperatures (300 oC - 600 oC). The samples has been characterized by scanning electron microscopy (SEM) in terms of surface morphology and topography showing that there is the presence of huge pores (> 1micrometer) associated to the presence of latex spheres template. Other characterization techniques like X-ray diffraction (XRD), atomic force microscopy (AFM) and optical absorption show that this new pore architecture changes the physical-chemical properties of bulk titania which could be very worthy for devices involving high surface area like catalizers, sensors and solar cells. The main contribution of this work is to show the availability to fabricate macroporous titania with micrometric latex spheres in a controlled route to be applied in industrial scale.

8258 | Particularity concerning the use of magnetorheological fluids / nanofluids, to obtain polymeric nanocomposites materials (19. Nano-Composites)

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Keywords: magnetorheological fluids, magnetic nanofluids; nanocomposites; resins; magnetic field.

This research started from the intention to exploit the possibility to achieve some new materials in the context of Nanotechnology Constructions. (1, 2)
Currently, there is a very strong interest in using nano-sized metals (i.e., metal clusters ontaining from 100 to 100,000 atoms) as advanced additives in

plastics functionalization, and considerable research activities are being done in this novel field of composite science. The embedding of nanoscopic metal structures into polymeric matrices represents the most simple way to take advantage of some of these novel physical characteristics. .[3, 4].
Experimental work has shown that virtually all types and classes of nanocomposite materials lead to new and improved properties, when compared to their macrocomposite counterparts: they tend to drastically improve the electrical conductivity, specifically the ionic conductivity, and thermal conductivity of the original material as well as the mechanical properties, e. g., strength, modulus, and dimensional stability.
Therefore, nanocomposites promise new applications in many fields such as echanically reinforced lightweight components, nonlinear optics, battery cathodes and solid state ionics, nanowires, sensors, and many others. Much effort is going on to develop more efficient combinations of materials and to impart multifunctionalities to the nanocomposites.
We study the influence of the addition of small amounts of magnetorheological fluids / nanofluids in resins, some specific properties of these fluids and the possibility to produce a new category of magnetisable nanocomposite materials.
Magnetic suspensions are complex fluids with remarcable property of changing their rheological properties, under the influence of an external magnetic field \. There are two classes of magnetic suspensions: magnetic nanofluids and magnetorheological fluids. (5, 1)
It is important to understand how the magnetorheological fluids / nanofluids interacts with the host material, both at the level of induced changes in processing variables and final property changes in the resulting composites.
The target of these investigations is to obtain new materials having magnetic and mechanical controllable properties.
The research was focused on the compatibility between the various types magnetorheological fluids / nanofluids and resins. (6, 7)
The polymerisation process of nanocomposites was investigated under the influence of applied magnetic field.
Results of investigations presented in this paper refer to the microstructure of the samples (optical and/or electronic microscopy), and to the mechanical properties corresponding to different preparation methods.

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8267 | Carbon Nano Composites: in-situ Polymerization Technique for preparing CNT/Graphene Nanocomposites at low Cost and by scalable Procedures (19. Nano-Composites)

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The graphene gold rush started about a decade ago and resulted in many publications and a high expectation of favorable use in everyday life applications.[1] Carbon nano based composites comprising those of carbon nano tubes (CNT) and graphene precursors have reported desirable extensions of mechanical, electrical and or thermal properties of the matrix polymer.[2–5] The larger part of the studies and hence of the composites may be of academic interest only as preparation is not possible at an acceptable cost level. Here, we want to report on carbon nano composites that may be commercially attractive on account of their ease of synthesis and use of low cost components. The in-situ polymerization procedure yields carbon composites with various types of CNTs and modified graphite/graphene e.g. expanded or exfoliated material as fillers.
Various carbon fillers were used to prepare composites, which were fully-characterized in terms of mechanical, electrical and thermal properties as well as to their rheological behavior. Superior properties can be reached, showing that the simple procedure using simple equipment is a viable route.

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8307 | Natural Hydroxyapatite-Hardystonite; a novel bio-nanocomposite ceramic with excellent properties (19. Nano-Composites)

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Abstract:

In this study, hardystonite powder ($Ca_2ZnSi_2O_7$) was synthesized by mechanical activation method as a solid state process. Hardystonite was composed of nano-crystalline structure with approximately diameter 40 nm. Specimens were composed of a blend of pure Calcite ($CaCO_3$) (98% purity, Merck), silica amorphous (SiO_2) (98% purity, Merck) powder and pure zinc oxide (ZnO) with 50 % wt., 30 %wt and 20 %wt., respectively. These powders were milled by high energy ball mill using ball-to- powder ratio 10:1 and rotation speed of 600 rpm for 5 and 10 h. Then, the mixture mechanical activated has

been pressed under 20 MPa. The samples pressed have been heated at 1100 ºC for 3 h in muffle furnace at air atmosphere. X-ray diffraction (XRD), scanning electron microscopy (SEM) and BET performed on the samples to characterize. According to XRD results, the sample milled for 10 h just indicated the hardystonite phase, while the sample milled for 5 h illustrate hardystonite phase along with several phases. In fact, our study indicated that hardystonite powder was composed of nano-crystalline structure, about 40 nm, can be prepared by mechanical activation to use as a new biomaterials for orthopaedic purposes.
Keyword: Hardystonite, Nano crystalline, Ball milling, Mechanical Activation, Synthesis

8542 l Investigation of electrical transport properties of poly(methyl methacrylate) infiltrated in long aligned carbon nanotubes mat (19. Nano-Composites)

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Electrical transport properties of poly(methyl methacrylate) [PMMA] infiltrated in long aligned carbon nanotubes(CNTs) has been investigated. Investigation shows that the conduction mechanism in the parallel and perpendicular direction of PMMA in filtrated aligned CNTs mats are different. Magneto resistance (MR) study also suggests the anisotropy behavior of the PMMA infiltrated aligned CNTs mat. Though MR is negative, upturn in MR has been observed when magnetic field is decreased further. This is due to the interplay between weaklocalization and electron-electron interaction.

8544 l Sulfur Doped Graphene/Polystyrene Nanocomposites for Electromagnetic Interference Shielding (19. Nano-Composites)

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Here, we present a simple and straightforward method to improve not only electrical conductivity and permittivity but also electromagnetic interference (EMI) shielding effectiveness of reduced graphene oxide (rGO)/polystyrene (PS) nanocomposites through sulfur doping. Sulfur-doped reduced graphene oxide (SrGO) with thiophene-like structure, synthesized through a simple heating process of a mixture of graphene oxide and sulfur powder, had almost three times larger electrical conductivity (1095 S m^{-1}) than undoped rGO (395 S m^{-1}). The SrGO/PS nanocomposite showed not only 150% larger electrical conductivity and 60% larger dielectric properties, but also 22% larger EMI shielding effectiveness (24.5 dB) at 18 GHz than rGO/PS nanocomposite at the same loading level of 7.5 vol%. Considering the simplicity and effectiveness, sulfur doping of graphene is expected to be used as a versatile method to improve EMI shielding efficiency of graphene/polymer nanocomposites.

8554 l Influence of micro- and nano-particles on the mechanical and physical properties of pure copper (19. Nano-Composites)

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Pure copper was reinforced with alumina micro- and nano-particles by powder metallurgy method. The vol.% used for fabricating microcomposites was 5, 10 and 20 % of alumina microparticles, and for nanocomposites it was 1, 3, 5 vol.% of alumina. The powders were blended using turbula mixer and were compacted under a pressure of 500MPa, followed by firing in the furnace at 900°C in an argon atmosphere. Specimens were deformed in tension and in compression at temperatures between room temperature and 300 °C at a constant crosshead speed giving an initial strain rate in the order of $10^{-3}.s^{-1}$. The true stress-true strain curves were determined. The characteristic stresses are significantly influenced by the test temperature. Internal friction of the micro- and nano-composites was measured in free-free flexural mode at room temperature and also after thermal cycling between room temperature and increasing upper temperature. The thermal expansion of these micro- and nano-composites was measured from ambient temperature to 700°C. The acoustic measurements show that the specimens possess appreciable elastic modulus as well as damping. The thermal cycling response is characterised by thermal stresses that can be relaxed by anelastic as well as microplastic strain. Micro- and nano-particles influence the mechanical and physical properties in a different way. Possible mechanisms are discussed.
Keywords: Microcomposite; Nanocomposite; Internal Friction; Thermal expansion

8569 l Facile fabrication of graphene nanoribbon/silicone rubber nanocomposite as a conductive elastomer (19. Nano-Composites)

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The graphene and its derivatives have received intense interest in the last few decades due to its unique structure and excellent properties. As a newly-emerged candidate of the graphene family, the graphene nanoribbon (GNR) showed great promise in composite applications. In this work, we have prepared the GNR through unzipping the carbon nanotubes and incorporated it in fabricating the silicone rubber (SR) nanocomposite. The electrical properties of the fabricated SR/GNR nanocomposite were studied afterwards. The results showed that with the help of an ionic liquid, 1-butyl-3-methylimidazolium chloride, the GNR dispersed very well in the SR. The prepared SR/GNR nanocomposite with the GNR loading of 12 wt% had very excellent mechanical strength compared to the pure SR. The resistance of the prepared SR/GNR 12 wt% nanocomposite had a nearly linear dependence to the applied strain when the strain was below 50%. The SR/GNR nanocomposite has potential to be used as the conductive elastomer or the strain sensor in the smart textile industry.

8595 l A nonlocal finite element approach for capturing size effects in nanocomposites (19. Nano-Composites)

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Keywords: Nonlocal integral elasticity, long-range interactions, size effects, finite element implementation, nanocomposites.

Classical continuum mechanics theory yields a local (length-scale invariant) continuum description of the problem fields assuming the length-scales to be much larger than the inter-atomic distances. If we look at the stress field for example, the stress at a point is considered to depend uniquely upon the strain at that point. Consequently, the classical (local) theory fails to capture phenomena where nano-scale interactions influence the problem outcome, for example at crack-tips, or in presence of defects, or for describing size effects, wave dispersion and so forth. In contrast, atomistic models are inherently nonlocal, i.e. they are able to take into account the interactions between neighboring atoms within a certain influence distance. Nevertheless, the latter models are often unfeasible to cope with real engineering problems because of computational burdens.
To fill the gap between atomistic models and classical continuum mechanics theory, a variety of approaches have been long studied as extensions of the classical continuum field theories for applications in microscopic space and time scale, such as microcontinuum field theories, Mindlin microstructure theory, micropolar elasticity, Cosserat continuum theory, peridynamic theory, nonlocal theories following either an integral formulation or a higher-order gradient one. Such theories incorporate nonlocal effects into an enriched continuum field theory so as to describe microscale effects at a macroscale.
The present study adopts an elasticity model of integral type, known as strain-difference-based model [1], and promotes a nonlocal finite element method to deal with mechanical problems of engineering interest. The method named NL-FEM, where NL stands for nonlocal, was conceived in [2] implemented with reference to the strain-different model in [3] and, very recently, deeply rephrased by the authors. In its present formulation the NL-FEM seems indeed very effective from both a theoretical and computational point of view.
The main aim of the present contribution is to investigate the applicability of the NL-FEM on nanocomposite structures where long-range interactions, length-scale issues and size effects play a major role. A few case-studies are analyzed and the obtained numerical results are critically commented.

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8622 | Experimental analysis of PLA and PLA/CNT-COOH biodegradable polymer-matrix nanocomposites thin films during hydrolytic degradation (19. Nano-Composites)

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Biodegradable polymers such as polylactic acid (PLA) have been studied for being used on a temporary approach of the natural ligament replacement, combined with Tissue Engineering techniques, instead of the permanent approach. These approach aims to recover damaged natural ligament remaining from a rupture, by using a biodegradable scaffold that allows the growing of the new tissue, promoting the regeneration. Biodegradable scaffold should degrade during the recovery period of the ligament maintaining essential mechanical properties and loosing molecular weight until scaffold is no longer required.
PLA degrades chemically mainly by hydrolytic degradation into lactic acid which is broken down into water and carbon dioxide via the citric acid cycle, been eliminated from the body in carbon dioxide and water form. Water diffusion from degradation media promotes ester bond chain-scission and crosslinking, leaving chains shorten and the polymer brittleness. This mechanism can be affected by factors like the polymer molecular structure, ester group density, degradation media, temperature and mechanical loads. Hydrolysis can be modeled by the Michaelis–Menten scheme, concerning the formation of carboxyl end groups, ester concentration and water concentration.
Attending to some previous results for ligaments replacement, there is the need to mechanically reinforce some of these biodegradable polymers scaffolds, avoiding plastic deformation which is one of the main causes for device failure. Aiming improvement of PLA mechanical properties, the inclusion of carbon nanofillers into PLA matrix, in particular, functionalized carbon nanotubes (CNT-COOH) have been developed, due to their strong sp2 carbon-carbon bondings and their geometric arrangement that enhance mechanical properties of the polymer matrix.
Hydrolytic degradation was studied for PLA and PLA/CNT-COOH nanocomposites, namely molecular weight and tensile strength evolutions through degradation time which are relevant concerning the ligament replacement application described.
PLA (4% D-lactide, L-lactide 96%, Mw ~ 170,000 gmol-1, Natureworks™ LLC, USA) and the nanocomposites were produced by melt blending followed by compression molding in a hot press. Small weight percentages of CNT-COOH (Nanocyl™, Belgium) were added to PLA, namely 0.2, 0.3, 0.5, 0.7 and 1% for PLA/CNT.COOH nanocomposites. The specimens were placed in cell culture flasks (BD Sciences™, USA) with 500mL of PBS (phosphate buffered solution), the saline solution to degrade, into a water tank at a temperature of 37ºC for stages of 4, 8, 12 and 16 weeks. The degradation conditions were defined for mimicking human body primarily physiological conditions. For each degradation stage quasi-static mechanical tests were performed according to standard D882 along with DMA tests and fatigue tests. Also GPC analysis for molecular weight determination, pH and mass measurement of the specimens were done.
Without the degradation effect nanocomposites PLA/CNT-COOH exhibited a higher mechanical strength of PLA, up to 8 to 20%. Through mechanical analysis of the nanocomposites it is found that up to 16 weeks degradation, the tensile strength is reduced by about 21% for PLA and 21 to 37% for PLA/CNT-COOH nanocomposites. Relatively to molecular weight, this reduces to 15% for PLA and 7 to 15% for PLA/CNT-COOH. After 16 weeks, the Young's modulus of all nanocomposites is higher than that of PLA as well as toughness, being nanocomposites mechanical properties not considerably affected during degradation. DMA storage modulus results confirms tensile tests ones and for fatigue tests was verified that PLA/CNT-COOH nanocomposites in general have higher resistance to fatigue than PLA. The pH value of the PBS remained constant, registering slight reductions of only 4% only in 16 weeks stage.

8684 | Biodegradable polymer composites containing cellulose nanocrystals: preparation and property characterization. (19. Nano-Composites)

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Homogeneous dispersion of cellulose nanocrystals (CNC) in polymer matrices is difficult to achieve by means of traditional melt processing techniques owing to the high tendency of CNC to form aggregates. Proper dispersion and distribution of nanoparticles in the polymer matrix are the prerequisite for obtaining polymer nanocomposites with improved physical and mechanical properties. In order to increase the dispersion of cellulose nanoparticles in non-aqueous polymer solution or suspension, several strategies have been adopted including the use of surfactants and chemical modification of the particle surface. In this communication we report on the preparation, functionalisation and characterization of various nanocomposites with biodegradable polyester matrix – such as polylactide (PLA), polyhydroxyalcanoates (PHB, PHBV) and polybutilensuccinate (PBS)- obtained by dispersion of CNC in PVAc acqueous emulsion (or PEG solution) as well as by mixing in organic solvents, followed by melt blending with bulk polyesters. Owing to the miscibility of the components and the biodegradability of their blends, the nanocomposites are expected to display a wide application potential as ecocompatible systems with tunable properties.
Cellulose nanofibres were prepared by acid hydrolysis of commercial microcrystalline cellulose. CNC was functionalized with glycidyl methacrylate (CNC-GMA) and grafting percentage was determined by FT-IR analysis.
The morphology of nanocellulose and composites was characterized by TEM (Philips CM12) and SEM microscopy (JEOL JSM-5600LV). AFM analysis (Agilent Technologies 5500) was carried out in contact mode in air. Thermogravimetric analysis (Q500 TA Instruments) of plain components and composites was carried out from 50 to 600 °C at 5 or 10 °C min-1 under both nitrogen and air. Differential scanning calorimetry (Perkin-Elmer Pyris Diamond DSC) was employed to study the phase transition behaviour at a heating/cooling rate of 10 °C/min. Tensile mechanical tests were performed on dumb-bell shaped specimens at room temperature by an Instron machine (model 4505) operating at a cross-head speed of 10 mm/min, according to ASTM D638.
The results of morphological analyses indicated that at lower CNC content (1-3 wt%) the cellulose nanoparticles were almost homogeneously dispersed inside the polyester matrix with limited formation of agglomerates. These agglomerates increased as the CNC content increased. An improved dispersion of nanofibres into PLA matrix was obtained for nanocomposites containing either functionalized components (PLA-GMA, CNC-GMA) or nanocellulose dispersed in PVAc, as compared to unmodified PLA/CNC composites. Thermal analyses demonstrated that glass transition, melting temperature and crystallinity of PLA were affected by the PVAc amount. Nanocomposites with PVAc dispersed CNCs exhibited higher thermal resistance than other composites. The filler effectiveness (CFE) was evaluated for all samples on the basis of storage moduli: CNC-GMA and PVAc dispersed CNCs (3 wt%) resulted the most effective fillers.
The results of tensile mechanical tests showed that the addition of cellulose nanofibres into PLA (or PHB) increased the elastic modulus of nanocomposites due to the higher modulus of CNC. Samples with CNC content ≥ 3 wt% did not show further improvement of elastic modulus, probably due to agglomeration phenomena of nanocrystals. The functionalization of components contributes to a significant increase of both elastic modulus and tensile strength. For the same concentration of CNC (3 wt%) the highest values of tensile parameters were recorded for PLA/PVAc/CNC composites, likely due to a better dispersion of CNC in PVAc followed by mixing with PLA (or PHB).

8721 | Investigation of the Transfer Print Quality Analysis Program on Nano Hybrid Coated Nonwoven Surfaces (19. Nano-Composites)

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In this study, polyester and polyester/viscose nonwoven surfaces were coated by the application of nano hybrid process. The coated materials have the properties as transferring water drops outside from the inside of the fabric as well as not transferring the water drops from outside to inside of the fabric. The coated textile surfaces were colored by use of transfer printing technique of which being ecological printing technique. The transfer printing procedure was applied in different temperature and time and print quality was evaluated by use of print quality analysis program. The color intensity and color fastness to crocking properties of the samples were also studied.

Key words: Nano Hybrid Coating, Nonwoven Fabric, Print Quality Analysis Program.

8746 | Beating phenomenon and energy localization in Single-Walled Carbon Nanotubes (19. Nano-Composites)

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In this paper, the low-frequency nonlinear oscillations and energy localization of Single-Walled Carbon Nanotubes (SWNTs) are analysed. The SWNTs dynamics is studied in the framework of the Sanders-Koiter nonlinear shell theory. The circumferential flexure vibration modes (CFMs) are considered. Simply supported, clamped and free boundary conditions are analysed. Two different approaches are compared, based on numerical and analytical models. The numerical model uses a double mixed series expansion for the displacement fields based on the Chebyshev polynomials and harmonic functions. The Lagrange equations are considered to obtain a set of nonlinear ordinary differential equations of motion which are then solved using the implicit Runge-Kutta numerical method. The analytical model considers a reduced form of the shell theory assuming small circumferential and tangential shear deformations. The Galerkin procedure is used to get the nonlinear ordinary differential equations of motion, which are then solved using the multiple scales analytical method.
The natural frequencies of the SWNTs obtained by considering the analytical and numerical approaches are compared for different boundary conditions. A convergence analysis in the nonlinear field is carried out for the numerical method in order to select the correct number of the axisymmetric and asymmetric modes providing the actual localization threshold. The effect of the aspect ratio on the analytical and numerical values of the localization threshold for SWNTs with different boundary conditions is investigated in the nonlinear field.

8793 | Mechanical Behavior of Graphene encapsulated Plastics (19. Nano-Composites)

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In this paper, we discuss the mechanical behavior including impact resilience, flexural resistance and compression resistance of a novel construction of composite plate. The used materials are fabricated by a novel approach which are plastics (polypropylene, polystyrene and polycarbonate) encapsulated by few layers of graphene sheets, instead of conventional direct feeding or compounding process in the pellet preparations. These composites are with features of light, cost-effective, tough, processing friendly. eco-friendly and less toxic and recyclable. The composite plates were fabricated by both extrusion and hot-pressing processes. The results show that the graphene sheets enhance the mechanical properties of tensile strength, flexural strength, and impact strength of the plastic/graphene composite plates. The higher feeding amount of graphene sheets caused an increment in rigidity and Young modulus; however, it reduces elongation. Optimal feeding amount of graphene for Increment of flexural strength and impact strength is 0.2-0.4 wt%, however it depend on material and processing parameters (pressure, temperature and time). The extrusion process reveals more stable results in physical properties; whereas a precise manufacture control is needed for hot-pressing process. Nevertheless, a honey-comb structure can be formed by hot-pressing which can be applied in many applications. We also set up a model for describing the behavior of these plates related to their impact resilience, flexural resistance and compression resistance. However, although we had found some trends, it still a long way to go.

8852 | Laser-Induced Fabrication of Hollow Platinum Nanospheres with Enhanced Catalytic Performances (19. Nano-Composites)

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Noble metal nanostructures have attracted considerable attention from researchers scientifically as well as industrially because of their novel optical, physical, and chemical properties, which are substantially different from the respective properties of bulk-scale noble metals. Hollow noble-metal nanoparticles have shown a range of interesting properties compared to their solid counterparts. In the particular, hollow-structured platinum nanoparticles have high surface-to-volume ratios and low densities to exhibit a large enhancement in their catalytic activity. Reactions occurring in the cavities of hollow nanoparticles could be facilitated by two main factors: theincreased concentration of reaction intermediates within the cavity of the hollow nanocatalyst and the possibility of catalytically more active sites within the inner surface of the hollow nanocatalyst. Therefore, the rates of the reactions in cavities increase due to the nanocage effect, otherwise known as the confinement effect. However, it is quite difficult to produce complete metal nanoshells. Laser-induced fabrication is the simplest and cleanest technique among diverse synthetic methods.
The simple irradiation of 355 nm nanosecond laser pulses to SiO2@Pt core-shell nanospheres at fluence of 2.7 mJ cm-2during the preparation process of hollow platinum nanospheres has been found to enhance the catalytic performances of platinum nanocatalysts on a large scale. Laser irradiation has transformed platinum nanoclusters topped on silica nanospheres into well-defined platinum nanoshells having uniform and smooth surfaces; the thickness of platinum nanoshells has been tuned easily by adjusting the irradiation time only. Laser irradiation increases the catalytic performances of hollow platinum nanospheres in the degradation of rhodamine B in the presence of KBH4 by five times via lowering the energy barrier. The energetically more favorable formation of the activated complexes in the nanocavity surfaces is suggested to reduce the activation energy substantially. The restructuring of surface atoms induced by photothermal annealing during laser irradiation has rendered the metallic surfaces much easier to chemisorb reactants and to facilitate electron relays, enhancing the catalytic performances of platinum nanocatalysts extensively.

8853 | Ag/Au@silica nanocomposites with enhanced catalytic performances (19. Nano-Composites)

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Noble-metal nanostructures with different sizes and shapes have been studied extensively because they can be possibly used in diverse applications such as catalysis, devices, transistors, and optoelectronics. Among the nanostructures of noble metals, gold and silver nanoparticles have attracted widespread interest in the field of nanocatalysis as gold and silver exhibit unique catalytic activity for important chemical reactions such as selective reduction and oxidation reactions. Bimetallic hollow nanoparticles possess structurally tunable features such as shell thickness, chemical composition, and interior cavity size, leading to relative high surface-to-volume ratios and low densities compared their solid nanomaterials. SiO2, known as a porous material, has been reported to coat metallic nanoparticles, forming core-shell nanostructures. Silica coating to improve the durability of precious-metal nanocatalysts has been studied by several research groups. The waste water produced in textile and dye industry has a very bad effect on the environment, due to their large discharge volume and toxic composition. With the development of dye industry, the studies on the treatment of waste water containing dyestuffs have become increasingly important. The decomposition of these organic pollutants via catalytic oxidation or reduction using nanocatalysts is considered to be the most efficient green method for the management of organic waste. In this work, we have synthesized silver nanocubes and coated them with SiO2 via the modified stÖber method to enhance the stability of metallic nanocatalysts. Moreover, as temperature is increased and NaBH4(s) is added into a colloidal solution of SiO2-coated silver nanoparticles, the amount and the sizes of pores in the coated SiO2 increase, enabling metallic ions and organic molecules to penetrate through the SiO2 shells more efficiently. Then, SiO2-coated silver nanocubes have been transformed into SiO2-coated Ag/Au composite nanoboxes easily via galvanic replacement reaction to increase the catalytic efficiency of the core metallic nanostructures. The coating of core metallic nanomaterials with SiO2 has been also utilized usefully in the field of catalysis as the coating blocks the dissoulution and aggregation of nanopaticles to sustain the catalytic acitivity of metallic nanomaterials. Finally, produced nanosturstures having high catalytic performance can be recycled consecutively as aggregation and dissolution that tend to decrease catalytic activity hardly take place during the decomposition of an organic dye. The catalytic activity of SiO2-coated Ag/Au composite nanoboxes has been measured by monitoring the absorption spectral changes of 4-nitrophenol in the presence of NaBH4, revealing that hollow-morphological nanoparticles have highly enhanced catalytic activities and that catalytic activity of the SiO2-coated nanocatalysts can remain almost invariable in spite of consecutive reuse.

8863 | Fabrication of Au@SiO2 Core-Shell Nanowires by Laser-Induced Nanowelding of Linearly Assembled and Silica-Coated Gold Nanorods (19. Nano-Composites)

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Noble-metal nanoparticles have attracted much attention in the field of catalysis, optoelectronics, and biological and chemical sensing especially due to their tunable optical properties originating from their surface-plasmon resonance (SPR). Gold nanorods (NRs) exhibit rich SPR-derived properties, which have made them useful for many interesting applications such as optical and optoelectronic devices, sensors, and biomedical technologies. In particular, gold NRs possess two distinctive, transverse and longitudinal, SPR modes, the latter one of which exhibits a strong peak tunable from the visible to the near-infrared region with increasing aspect ratios. Laser irradiation can melt or reshape metal nanoparticles without causing any significant perturbations in the surrounding media. Because laser irradiation can heat contacting regions selectively, the laser-induced transformation of metal nanoparticles has provided a controlled mean to modify the shapes of the nanoparticles precisely.
In this work, Au@SiO2 core-shell nanowires have been fabricated at room temperature simply by irradiating infrared nanosecond pulses to linearly self-assembled and silica-coated gold nanorods just for 5 min. Gold nanorods have been self-assembled linearly by adding isopropanol in the absence of any assembling agents to form gold nanochains. Isopropanol-mediated linear assembly takes place as CTAB monolayer molecules on the end surfaces of gold nanorods tend to form a bilayer for the enhancement of colloidal stability. Then, the end-to-end assembled gold nanorods have been directly encapsulated with uniform silica shells having tunable thickness to produce silica-coated gold nanochains. It has been found that isopropanol can not only induce the linear assembly of gold NRs but also provide co-solvent environment, which is important to direct silica coating on CTAB-stabilized gold nanochains. The thickness of a silica shell has been controlled by adjusting the supplied amount of ammonia hydroxide. The irradiation of the nanostructures loaded on a TEM grid with nanosecond laser pulses of 1064 nm at fluence of 0.38 mJ/cm2 has produced Au@SiO2 core-shell nanowires. Laser pulses, selectively absorbed by the hybridized surface-plasmon resonances of linearly assembled gold nanorods in silica shells, are thermalized to heat selectively the contacting surfaces of the gold nanorods, which then fuse and weld together. This is a novel and straightforward synthetic approach for the production of silica-coated gold nanowires having strong near-infrared absorption, high stability, and easily functionalizable surface.

8894 | Experimental and theoretical investigation of anisotropy of the mechanical properties of reinforced elastomeric nanocomposites (19. Nano-Composites)

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The study of the mechanical properties of anisotropic elastomeric composites reinforced by nanoparticles of different types indicates that they differ in both the strength properties and the degree of softening. The samples were subjected to uniaxial loading acting in two orthogonally related directions. The anisotropic properties of composites appeared most vividly in the samples exhibiting a high degree of hysteresis in the first cycles of deformation. The results of numerical simulation obtained for the loaded fragment of a filled elastomer show that such difference becomes possible because of the elastoplastic behavior of an interfacial layer in which residual strains are accumulated differently under loading that acts in different directions. The study is supported by the RFBR (grants 13-01-96016-a and 14-08-96013-a) and the Ministry of Education of Perm Krai (agreement C-26/627).

8906 | Organic semiconducting/ferroelectric blend memristors fabricated by temperature controlled spin coating (19. Nano-Composites)

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Organic semiconducting/ferroelectric blend films attracted much attention due to their electrical bistability and rectification properties and thereof the potential in resistive memory devices. During film deposition from the blend solution, spinodal decomposition induced phase separation, resulting in discrete semiconducting phase whose electrical property could be modulated by the continuous ferroelectric phase. However, blend films processed by common spin coating method showed extremely rough surface, even comparable to the film thickness, which caused large electrical leakage and thus compromised the resistive switching performance. To improve film roughness and thus increase the productivity of these resistive devices, we developed temperature controlled spin coating technique to carefully adjust the phase separation process. Poly(methyl metacrylate)(PMMA) was also introduced into such blend films as additive in order to improve their electrical stability and fatigue endurance. Here we reported our experimental results from the blend films of ferroelectric poly(vinylidene fluoride-trifluoroethylene (P(VDF-TrFE)) and semiconducting poly(3-hexylthiophene) (P3HT). By temperature control during film deposition, it is convenient to efficiently fabricate ferroelectric/semiconducting blend films with good electrical bistability.

8919 | Effect of Water Absorption and Sorptivity on the Durability of CNTs modified mortars (19. Nano-Composites)

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The modification of cement-based materials with carbon nano-inclusions is expected to lead to the development of innovative products possessing multi-functionality and smartness. Target properties of a cement-based multifunctional material are: exceptional mechanical properties which would enable a highly resistant lightweight structure, electrical and thermal conductivity, and piezo-electric characteristics. Carbon Nanotubes (CNTs) are promising fillers due to their unique properties such as great mechanical, electrical and thermal properties along with extremely high aspect ratios up to 108, as well as large specific surface area [1-2]. The beneficial effects of CNTs on the hydration process of CNTs filled cement composites and the hydration products, pore structures and transport of water in the composites has been recently reviewed [2]. It was shown that the addition of CNTs was able to reduce the porosity of Portland cement paste, most notably by lowering the amount of mesopores and resulted in a denser microstructure due to the interactions between CNTs and hydration products of cement pastes [2].
The durability of cement-based materials strongly depends on their transport properties. Transport properties define the rate of ingress of deleterious species (e.g., water, chlorides, and sulfate) from the service environment into the cement-based structures and components throughout their service life [3]. An understanding of moisture transport in CNTs modified mortars is important to estimate their service life. Recent studies indicated that CNTs-reinforced cement-based composites exhibited improved transport properties relative to the conventional cement-based composites linked to the porous structure of the modified materials [3].

In this paper, the effect of CNTs addition on the sorptivity and water absorption properties of nanomodified mortars is being studied. The water sorptivity test was carried out to determine the rate of absorption of water and study the effect of CNTs on the development of the capillary pores and the capillary water suction of the nano-modified mortars. For this purpose varying amounts of CNTs (0.1-1 wt % cement), surfactants and/or plasticizers were incorporated in water using a sonicator. After the sonication, cement and sand were added using a mortar mixer. For comparison purposes, specimens without CNTs were prepared. The effect of the CNTs addition on the water penetration is critically assessed. The durability of the nanomodified mortars is evaluated on the basis of the reduction of the compressive strength.

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8932 I Sandwich-structured film: an approach to enhance breakdown strength and energy density in polymer-based nanocomposite (19. Nano-Composites)

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A novel sandwich-structured multilayers nanocomposite added with different aspect ratio BTO particles for the storage of electrostatic energy was fabricated employing layer-by-layer casting process. In the sandwich-structured composite PVDF-based film, the outer layer with BTO nanoparticles increased the electric displacement while the central layer with BTO nanofibers maintained the high breakdown strength. Comparing with the single layer films, the extractable energy density was highly enhanced in the sandwich-structured film and further improvement was obtained by preparing the film with suitable thickness in each layer. The maximal Udis reaches upto 9.72 J•cm-3 at 453 kV•mm-1 in the nanocomposite film with 2 vol% BTO-nf inner layer and 10 vol% BTO-np outer layers. The novel sandwich structure is much promising in developing nanocomposite film with high energy density.

8939 I Synthesis of MnO2/graphene Nanocomposite Electrode by Two-steps Electrodeposition for Energy Storage Application (19. Nano-Composites)

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MnO2/graphene nano-composite electrode was developed via cathodic deposition of nanostructured MnO2 film on electrophoretically reduced graphene oxide (EPD-rGO) film. The electrodeposited MnO2, EPD-rGO and MnO2/EPD-rGO electrodes were characterized and investigated for supercapacitor application using scanning electron microscopy, transmission electron microscopy, X-ray diffraction, fourier transform infrared spectroscopy, cyclic voltammetry, galvanostatic charge/discharge, and electrochemical impedance spectroscopy. The electrophoretic deposition enables the development of rGO film composed of overlapped platelets of defective graphene sheets. The MnO2/ EPD-rGO composite electrode shows better specific capacitance and rate capability than MnO2 electrode; it exhibits specific capacitance of 822 Fg-1 and better cyclic stability at a current density of 1 mA cm-2. The large surface area and defective nature of EPD-rGO film in conjunction with an efficient utilization of MnO2 nanoparticles facilitated rapid ion transport and electrochemical cyclic stability, and hence offering the potential of the unique capacitive behavior. The obtained results indicate electrophoretic deposition could set a facile base for providing graphene-based materials, at room temperature without using harsh and toxic chemicals or high synthesis temperature

8947 I Pt dispersion and structure of alumina-platinum composites obtained by thermal oxidation of Al-Pt thin layers. (19. Nano-Composites)

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The large surface coatings play an increasingly important role as a support for active materials in the production of catalytic and inhibiting systems. The work was focused on the new technology designed to oxide-metal composites obtained as a result of high- temperature oxidation of the nanofilms deposited by PVD metod on the metal support. Two magnerton sources made possible to obtain Pt/Al and Al/Pt nanolaminates as well as Pt+Al composites. The layer systems were subjected to oxidation under Ar+O2 for 48 hours at 860oC. The surface structure, microstructure and platinum distribution within the oxide films were studied by Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). The focused jon beam was used for the preparation of samples for TEM observations. The surface examination by SEM has shown that the support of the oxidised laminates was covered by the fine structure of the tiles and whiskers with anisotropic orientation of growth. On the contrary, oxidation of composite layers provided for the growth of chaoticaly oriented and mutually penetrable whiskers and small crystals. The structure of nanolayers examined by TEM has shown that growth of oxide crystals had effectively dispergated Pt films and particles. Comparizon of the oxide films produced by sputtering the foil with Pt/Al system with the oxide films obtained by sputtering the support with Pt+Al composite nanofilms revealed that the last one were better developed. The reason for this is partly occlusion of Pt particles by Al particles that results in effective fragmentation of Pt nanofilm in the process of oxidation. In conclusion our data indicated that Pt clusters located between the Al particles and after oxide whiskers are subjected to dispersion towards the surface. It results from stresses and nanocraks in whole volume of composite nanofilm and influence on increasing its activity.

8962 I Enhancement of Tribological and Mechanical Properties of Tungsten Carbide Nano Composite Using Spark Plasma Sintering Technique (19. Nano-Composites)

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Tungsten carbide is a well known hard material, but, it needs special contributions to overcome the shortage of fraction toughness and strength. This work comes to investigate the effect of spark plasma sintering technique in the modification of both mechanical and tribological properties of WC/TZ-Y3 nano composite, taking into consideration particle size reduction due to mechanical milling. . Initial powders were mechanically milled for 72 and 432 ks to obtain different sets of particle sizes prior to sintering. The milled composites were then processed via spark plasma sintering (SPS) in the temperature of 1773 K for 3600 s. The experimental results indicate that high hardness values and high elastic modulus can be obtained with both sets of particle size when sintered at 1773 K using SPS technique. However, only the finer particles can maintain these properties at 1773 K sintering temperature with the traditional pressure less sintering. Nanoindentation testing showed that hardness values up to 25.34 GPa can be obtained for finer composite when the final density is increased to 84% of the theoretical density.

8978 | EFFECT OF INTERFACE CONNECTIVITY ON THE MECHANICAL PROPERTIES OF NANOCOMPOSITES (19. Nano-Composites)

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Nanoparticle reinforced composites are becoming an important research topic. Unlike in composites with micro- or larger sized reinforcements, effects of nanoparticles are found to be more unpredictable, sometimes enhancing the properties while other times diminishing them. An overview of the experimental results on the mechanical properties of nanoscale reinforcement will be provided in this talk. For nanoparticle reinforcements, the interface provide a larger share of influence from particle-matrix interactions, compared larger particles. The effect of interface structure on the mechanical behaviour of nanoparticle reinforced composites is studied using, for alumina (Al2O3) and magnetite (Fe3O4) nanoparticles embedded in poly(methyl methacrylate) (PMMA) and polystyrene (PS) matrices. The structure and density of the interface of these systems are characterized using the results from thermal gravimetric analysis (TGA) and scanning electron microscopy (SEM). Fourier Transform Infrared Spectroscopy (FT-IR) is used to calculate the nature of bonding between polymer and nanoparticle surfaces and the density of the interface for two PMMA-based nanocomposite systems. Tensile testing, dynamic mechanical analysis (DMA), and nanoindentation tests are used to characterize mechanical properties and its dependence of the strength of interface connectivity (and the number of anchoring points) was evaluated.

8990 | Sulphone Containing Epoxy Nano-Hybrid Anti-corrosive and Anti-bacterial Coatings (19. Nano-Composites)

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The scope of the present work is to synthesize 1,4'-bis (4-amine-phenoxy) benzene epoxy resin (TGBAPSB) via 1,4'-bis (4-amine-phenoxy)sulphone benzene (BAPSB) and epichlorohydrin. The molecular structure of TGBAPSB epoxy resin was confirmed by FTIR and NMR spectroscopy and molecular weight was determined by GPC and epoxy equivalent weight (EEW) by titration method. Amine functionalized (POSS) was synthesized and structural has been confirmed by FT-IR, and 29SiNMR spectral studies. The TGBAPSB epoxy resin was further reinforced with varying weight percentages (2.5 and 5wt %) of POSS and cured with polyamidoimidazoline (Aradur 140). The surface morphological images were taken by TEM and SEM. The anti-corrosive properties of the TGBAPSB epoxy/POSS hybrid coatings investigated by electrochemical impedance (EIS) indicate that the coating film had good corrosion resistance. Furthermore, the antimicrobial test indicated that TGBAPSB/POSS coating had strong antimicrobial activity against high concentration of Escherichia coli (Gram-negative) bacteria. The results showed improved antibacterial and anticorrosive properties for TGBAPSB /POSS nano-hybrid coatings

8996 | Localized surface plasmon resonance for Quantum Dot-gold nanoparticle hybrid (19. Nano-Composites)

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Recently, the quantum dots (QDs)-metal coupling structure has become research focus because of the complex interplay of enhancing and quenching physicochemical processes due to the surface plasmons (SPs).In this paper, we have synthesizedCdSe/ZnS quantum dot(QD)-gold nanoparticle(Au NPs) hybrid in aqueous solution via bi-functionallinkermercaptoacetic acid (MPA).The localized surface plasmon resonance (LSPR) effect of QD-Au NPs has been demonstrated by increased fluorescence intensity and reduced exciton lifetime carried out by time-resolved PL measurement. The absorption peaks of CdSe/ZnS QDs and Au are both located at 520 nm. It is investigated that PL intensity of QD-Au hybrid can be affected by the amounts of Au and pH value of hybrid solution. The phenomenon of fluorescence enhancement can be maximized under the optimized pH value of 9.5. LSPR enhanced QD-Au hybrid will be beneficial for the potential applications in the area of biological imaging and detection.

8997 | Carbon nanotube coated glass fiber using ionic interaction and their thermoplastic composites (19. Nano-Composites)

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Thermoplastic matrix composites have attracted much attention due to rapid process speed for mass production. But, thermoplastic composites have

lower mechanical properties than thermosetting composites. Some researches using nano- or mirco- particles for reinforcing thermoplastic resin are published. However, the particles increase viscosity of resin and cause the lowering of processabiliy as a result. We used the particle coating method to overcome these problems.
The thermal gradient control is also important process in manufacture of thermoplastic composites. Thermal heat from exterior make thermal gradient in process. Therefore, composites integrity becomes worse due to lower resin fluidity at the inside. To solve this problem, the direct heating from interior of composites is needed.
In this study, glass fabric was coated by carbon nanotube (CNT). The CNTs were used reinforcement for mechanical properties and heating element for composite processing. CNT and surfactant solution were used to coating and the fabric was coated by hydrophobic interaction between fiber and CNT. The composites were fabricated by laminated molding of coated fabric and polypropylene film. Mechanical and electrical properties of composites were investigated.

9006 | NANOCOMPOSITE BIOMATERIALS FOR COMPAUND BIOLOGICAL TISSUE (19. Nano-Composites)

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Laser welding of biological tissues has a number of advantages as compared with conventional surgical techniques, namely, non-contact removal of biological tissues, minimal level of injuries, prevention of cicatrization after healing of scar biotissues etc. Various solders based on biomaterials including such a protein as albumin have been used to improve mechanical properties of laser welds. However, laser welds are less strong than the joints made using surgical suture materials (thread, metal staple etc.). In this respect, the study aims at the laser solder (LS) based on the nanocomposite biomaterial for compound biological tissues. LS consist the bovine serum albumin (BSA, matrix) and carbon nanotubes (CNT, filler).
In our experiments we used LS based on the aqueous dispersion: 25 wt.% BSA+0.2 wt.% single-walled CNT (SWCNT) and 25 wt.% BSA+0.2 wt.% multi-walled CNT (MWCNT). SWCNT had the external diameter ~1 nm, the length <1 μm and the high purification rate of SWCNT-99A [1], while MWCNT had the external diameter ~30-80 nm, the length >20 μm, being of Taunite-MD type and manufactured by "Taunite" company [2].
Laser welding tests were carried out on dissected pig skin and bovine cartilage. The thin layer of LS was placed on the surface of the biological tissues to be joined and then the junction was exposed to laser irradiation with the following parameters of continuous irradiation mode: power ~1 W/cm2, wavelength 970 nm. Laser welding process lasted for 5-20 s. After that we measured the tensile strength of the welded joint, □, and the tensile strength of the uncut region of the tissues, □s. As a result, welded joints obtained using LS based on the aqueous dispersion 25 wt.% BSA+0.2 wt.% SWCNT were characterized by □s □15 ± 5 MPa, □/□s □ 10 % for pig skin and □s □6±2 MPa, □/□s □ 20 % for bovine cartilage. In case of MWCNT dispersion-based LS the values of □/□s were lower by 20-30 % compared with SWCNT-based LS.
In many cases the welded joints are not strong enough at the early periods after the operation. To avoid it the surgical mesh of polypropylene of the PROLENE type manufactured by Ethicon was used in addition to LS. The surgical mesh overlaped the junction of tissues by 2-3 mm leading to the value □/□s~25-35 % for both types of alloys containing either SWCNT or MWCNT.
Thus, the laser solders based on CNT (SWCNT or MWCNT) allow to increase the level of laser weld strength (□ ~ 2–4 MPa , □/□s □ 20–35 %) by 1-2 orders of magnitude compared with LS based on pure BSA. These results demonstrate the potential of laser solders based on composite materials with carbon nanotubes for welding of biological tissues.
This work has been supported by Russian Federation Ministry of Education (No. 14.575.21.0089)

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9021 | Microscopy Aspects of Cellulose Nanocrystal Composites (19. Nano-Composites)

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Cellulose nanocrystals are new emerging biomaterials that are considered to posses extremely high mechanical properties. However, the effects of resources on the mechanical properties of cellulose nanocrystals are rarely studied. Differences in hydrogen bonding patterns result in two allomorphs in native cellulose (Iα and Iβ). In turn, Iα and Iβ have distinct crystallographic structures and are composed of one chain triclinic and two chain monoclinic unit cells, respectively. The objective of this study is to quantify the transverse mechanical properties of cellulose I nanocrystals (CNCs) prepared from tunicate (Iα-rich) and cotton (Iβ-rich) using acid hydrolysis. Atomic force microscopy (AFM) were performed under peak force mode on individual CNCs. The transverse elastic modulus (ET) was also calculated by comparing the experimental AFM indentation results with 3-dimensional FEA analysis of CNC indentations. We observed that tunicate and cotton CNCs have different nanomechanical (ET and adhesion) properties. These properties are dictated by the localization of Iα and Iβ and Iα/ Iβ ratio along their chains, and the single crystal morphology (aspect ratio and diameter).

9023 | Flexible field emission lamps made using BaO nanowires emitters (19. Nano-Composites)

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BaO nanowires were synthesized on ITO glass substrates by hydrothermal process. The morphology and composition of BaO nanowires were characterized by field emission scanning electron microscopy. The BaO nanowires show superior field emission properties, which exhibited a low turn-on field (~1.24 V/μm), a low threshold field (~3.18 V/μm), and a high field enhancement factor (β=2458). Flexible field emission lamp was made using the BaO nanowire emitters. Our flexible field emission lamp using BaO nanowire emitters generate very uniform and bright emission patterns under convex bending conditions. These results demonstrate that BaO nanowires emitters could be important candidates for flexible field emission devices in the future.

9031 | Adjusting the acid strength of sulfonated polystyrene in confined nanospace of silica hollow nanospheres (19.

Nano-Composites)

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Tightening environmental legislation is driving the chemical industries to develop efficient solid acid catalysts to replace conventional mineral acids. Polystyrene sulfonic acid resins as one of the most important solid acid catalysts have been wildly studied. However, the influence of the morphology on their acid strength closely related to catalytic activity has seldom been reported. Herein, we report for the first time the fabrication of a novel hybrid solid acid with a double-shell nanostructure (DSNs) via sulfonation of PS@SiO2 yolk-shell nanospheres. It was found that the transformation from yolk-shell to double-shell nanospheres is derived by the self-assembly of PS-SO3H in the confined nanospace of silica hollow nanospheres during the sulfonation process. The reversible morphology transformation from double-shell hollow nanospheres to hollow nanospheres could be observed, which is mainly driven by the formation and breakage of hydrogen bond interactions among adjacent sulfonic acid groups within the confined nanospace of silica hollow nanospheres. As a result, the acid strength of PS-SO3H can be reversibly enhanced and decreased by expansion and aggregation of PS-SO3H within the confined nanospace, which is confirmed by 31P MAS NMR, ammonia adsorption calorimetry and TEM characterizations. In a series of important acid-catalyzed reactions, such as esterification of fatty acid, Friedel-Crafts alkylation of toluene and cumene hydroperoxide (CHP) cleavage, the solid catalyst exhibits much higher activity than Amberlyst-15, and in some cases even higher than liquid acid, H2SO4, under similar reaction conditions. Our findings may offer a new approach to fabricate highly efficient solid acid catalysts for green chemical processes.

9032 | Nanoscale wrinkling of graphene on substrates with asperities (19. Nano-Composites)

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As a two-dimensional crystal, the freestanding graphene sheet tends to corrugate and thus can hardly display its extraordinary properties in materials or devices. So graphene sheets are often used with substrate materials as coating layers. However, the substrate is rarely perfectly-flat, but has nanoscale and even microscale asperities. Whether or not the graphene sheet can conform fully to a substrate with nanoscale and microscale asperities is essential for the performance of the graphene-based devices, because the wrinkling morphology of graphene impacts significantly on its electronic and mechanical properties.
In this paper, a theoretical model is developed to predict the morphology of a monolayer graphene sheet attaching to the substrate with nanoscale and microscale non-developable asperities by an energy-based analysis [1]. The final graphene morphology is revealed to result from the competition between two energy terms: the adhesion energy between graphene and substrate, and the strain energy stored in the graphene due to the deformations. Thus, by accounting for these two parts of energy, the critical condition to predict the morphology conversion from full conformation to wrinkling is established, which agrees well with the results of molecular dynamics simulations. The following conclusions are achieved.
(1) The full-conformation/wrinkling criterion can be expressed as a function of the graphene size and radius of substrate curvature, which are thus the two dominating parameters on the morphology of graphene.
(2) Using this criterion, for a spherical substrate asperity with a given curvature, the maximum radius of fully conformed graphene sheet can be easily attained, and the graphene sheet wrinkles if it larger than the maximum size. This is very helpful for the decision on the sheet size in electronic eye cameras [2], as well as the size of coating graphene sheets on the AFM tip [3]. One the other hand, for a graphene sheet with a given radius, the minimum radius of substrate curvature can also be easily obtained by the full-conformation/wrinkling criterion.
(3) It is amazing to find that the two dominate parameters can be reduced into one, the cone angle of the dome-shaped substrate asperity, which is determined by the curvature and area of the substrate asperities. A critical cone angle of 57.68 degrees is obtained for silicon dioxide substrate. Graphene sheet conforms to the substrate fully and smoothly when the cone angle less than the critical value, while wrinkles appear in the graphene when it larger than the critical value. Therefore, the final morphology of the adsorbed graphene sheets is dominated only by the cone angle of the asperities.
This work can be used to make active and precise prediction and control on the graphene conformation to substrates with asperities and substrates with spherical surfaces, which could provide guidance to fabricate high quality nanostructured coatings. Besides, the critical state between wrinkling and full conformation can be utilized to design new nanoelectronic devices, such as nano-sensors and nano-switches.

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9034 | The structure and surface defects of the SnO2 - SiO2 nanocomposites obtained by the sol-gel method (19. Nano-Composites)

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SnO2 - SiO2 nanocomposites (NCs) have been synthesized using the sol-gel method by means of direct mixing of the tin oxide precursor SnCl2 · 2H2O solution and tetraethyloxysilane (TEOS) in relations Sn:Si = 25:75, 50:50, 75:25 and 90:10 (at.%). Depending on the type of the SnCl2 · 2H2O solvent (isopropyl alcohol (i-PrOH) or HCl) gelation occurred, respectively, for 8 to 12 days, or just during draining in air at 23°C. In 50 SnI xerogel (dissolved in i-PrOH) after heat treatment at 80°C highly dispersed hydrated tin oxide {SnO2 • Sn (OH)4} (HTO) and amorphous silica hydrogel have been observed by XRD data and FT-IR. Solid phases of silica hydrogel and HTO were preserved up to 400°C, while they transformed to dehydrated oxides at 700°C.
The facts of phase interference have been revealed in mixed oxides. 1. The size of the HTO nanocrystallites depends on the ratio of Sn: Si (6 nm for 90SnI, 3 nm for 50SnI and <1 nm for 25SnI treated at 350°C). This means that silica gel acts dispersing on the HTO crystallites. 2. The IR spectrum (200 cm-1 - 4000 cm-1) obtained from the 50SnI and 90SnI xerogels heated at 350°C and 700°C, exhibited the vibrations of the Sn - O – Si bonds at 625 cm-1. 3. The form of the xerogel particles indicates that the larger particles (300 nm) compose of secondary particles (L ~ 30 - 50 nm) and both of them repeat the structure of primary small particles (L ~ 5 -7 nm) - these structures are characteristic of percolation systems, reproducing the geometry of the primary element in the surrounding space. The observed regularities in the formation of mixed (SnO2 • xH2O - SiO2 • yH2O) xerogel particles are similar to the hierarchy character demonstrated by silica particles at their growth [1].

These facts allowed us to conclude that the growth of the SnO_2 crystallites occurred in the matrix (a net) of hydrogel SiO_2 which played a role of template in the formation of the SnO_2 crystallites.
Nanosized products of tin chloride and TEOS hydrolysis interact in gels in forms of oligomers and polymers while in solids (xerogels) the interaction takes place at SnO_2 crystallite boundaries and overlying net of silica gel.
For the first time, absorption bands caused by vibrations of the bonds with surface oxygen vacancies (OVs) in various positions have been observed in the FT-IR spectra obtained from the NCs SnO_2 - SiO_2. The size of the nanocrystallites in the SnO_{2-x} located within the range of 3.5 - 8 nm and the density of OVs in samples with $x \geq 0{,}06$ comprise the conditions for these vibrations appearance. The modes at 580 cm-1, 300 cm-1 and 250 cm-1 correspond to the OVs "in plane" [2], OVs "bridging" [3] and OVs "subbridging" [4] positions, respectively. They are indicative of the presence and amount of surface defects (oxygen vacancies) in the NC materials based on SnO_2.
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9040 | Synthesis and characterization of chitosan coated $MnFe_2O_4$ nanocomposites (19. Nano-Composites)

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Chitosan coated $MnFe_2O_4$ nanocomposites (CCMNCs) were successfully synthesized by a simple method. The composition of CCMNCs was studied by X-ray powder diffraction (XRD), and the result indicated that indicating the crystal structure of $MnFe_2O_4$ nanoparticles wasn't influenced by coated chitosan. The magnetic properties measured by Superconducting Quantum Interference Device (SQUID) magnetometer revealed the superparamagnetism of both CCMNCs and $MnFe_2O_4$ nanoparticles. Transmission electron microscope (TEM) micrographs of $MnFe_2O_4$ nanoparticles and CCMNCs showed the $MnFe_2O_4$ nanoparticles were well composited by chitosan, and the composites were around 300 nm. The Raman spectra of $MnFe_2O_4$ nanoparticles, chitosan and CCMNCs were first obtained to analyse the bond making of CCMNCs, indicating Fe(III) and Mn(II) of $MnFe_2O_4$ nanoparticles were chelated by functional group of chitosan.

9047 | Bridging nano- to macro-mechanical properties of an aerospace-grade mono-component epoxy reinforced with carbon nanotubes (19. Nano-Composites)

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The use of carbon nanoparticles as fillers of composite materials is investigated as possible solution for a large number of challenges in the aerospace field, ranging from advanced structures with multiple functionalities to electromagnetic shielding and sensing. In particular, the current trend is to create multifunctional composite structures to carry out tasks generally performed by several elements, with the additional critical objective of replacing heavy assembled systems with lightweight composite structures. Multi-walled carbon nanotubes (MWCNTs) are well known as reinforcing nanoparticles that enhance the mechanical properties of neat resins, particularly epoxy resin. Different methods and approaches can be found in the literature to fabricate composite structures reinforced by MWCNTs, mostly involving two-component epoxy resin systems. For all applications, a good dispersion of the nanoparticles in the polymer matrix is crucial to obtain the expected results. Unlike two-component resins, mono-component systems show a strong temperature dependent viscosity, but have the limit that, due to the premixed amine curing elements, crosslinking reactions occur if too much heat is transferred to the resin.
In this study we present an investigation of the mechanical and thermal properties, from the nano- to the macro-scale, of an aerospace-grade mono-component epoxy system (RTM6) reinforced with different weight percentage of multi-walled carbon nanotubes. The nanoindentation technique was used to determine the hardness and the modulus at the nanoscale of the MWCNT-reinforced epoxy system, whereas tensile tests were performed to determine the ultimate strain and the elastic modulus at the macro-scale. In addition, the thermal properties of the composite systems were investigated by measuring the thermal expansion coefficient so to determine the effects of the MWCNTs on the dimensional stability of the RTM6 composite structures.

9057 | Structure and optical properties of thin poly(p-xylylene) - silver nanocomposite films prepared by low-temperature vapor deposition polymerization (19. Nano-Composites)

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Low–temperature vapor deposition polymerization is a promising method for preparation of polymer – metal (semiconductor) nanocomposite films with high filler contents and uniform spatial distribution of inorganic particles in the polymer matrix. In this study, the crystalline structure and surface morphology of thin poly(p-xylylene) – silver nanocomposite films with Ag concentration up to 12 vol.% were addressed as a function of temperature in the range from room temperature up to +250 C by grazing–incidence X–ray diffraction, transmission electron and scanning force microscopy.

It was found that the predominant crystalline modification of PPX in the studied films is alpha–form, whereas beta–form prevails in thick PPX films deposited at liquid nitrogen temperature. The planar texture was observed in thin films with silver concentration from 0 to 12 vol.%, and it was found to improve on annealing. An irreversible alpha to beta1 phase transition occurs upon heating to +200 C. Based on GIXD and SPM data, one can conclude that thermal treatments can be used to control the crystalline structure of the polymer matrix, as well as the size and spatial distribution of the silver nanoparticles.

The optical properties of the synthesized PPX – Ag thin films were studied by UV–vis and IR–spectroscopy. All samples demonstrate surface plasmon resonance (SPR) with the peak wavelength within the range of 435 – 445 nm. A prolonged aging results in a redshift of the SPR maximum. This effect can be associated with growth of the silver nanoparticles size caused by aggregation. The main difference in IR spectra of PPX – Ag nanocomposite thin films and pure PPX thin films is the appearance of a new strong band in the spectral range of 1378 – 1389 cm-1 with intensity increasing with silver content. This band can be assigned to symmetric stretching of carboxylate groups anchored by their two oxygen atoms to silver. The intensity of the band is significantly enhanced due to the surface–enhanced infrared adsorption effect. A long–term storage under ambient conditions results in a redshift and a decrease of the band intensity, which can be explained by slow aggregation of the silver nanoparticles.

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9072 | The effect of different current types on the microstructure and tribological properties of Ni/Al2O3 composite coatings obtained by electrochemical methods (19. Nano-Composites)

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The paper describes an investigation of the nickel and nickel-alumina coatings. The layers was obtained from Watts bath with presence of nickel grain growth inhibitors by direct (DC), pulse (PC) and pulsed reverse (PRC) current plating. The study included the composite coatings of microcrystalline and nanocrystalline Ni matrix and nanometric Al2O3 particles. In order to ensure uniform co-embedding of disperse phase particles with nickel matrix and producing a stable suspension, the mechanical agitation was also used. The effect of the electroplating techniques on the microstructure (SEM, TEM, XRD) and tribological properties of Ni/Al2O3 composite coatings was investigated. The SEM studies on the worn surfaces were also conducted. The examined coatings exhibited different values of the friction coefficients depending on the applied plating current. Scanning electron microscopy studies of the worn surface reveal different delamination process of all examined coatings.
The completed studies have shown that the type of current significantly affects the structure of nickel and composite coatings, as well as its tribological properties.

9074 | Thermomechanical behaviour of epoxy matrix reinforced by titaniun oxide nanotubes (19. Nano-Composites)

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Composite materials based on polymeric matrices have today an increase in the use under adverse conditions. These materials must provide so especial thermal and mechanical properties combined with a low specific weight and high degradation resistance.
Polymer composites industry is currently placing emphasis on protective coatings, structural applications and reparability as part of the incorporation of such material in oil production systems. Epoxy matrices are the most used material for such applications. Some of the characteristics of epoxy resins are high chemical and corrosion resistance, good mechanical and thermal properties, outstanding adhesion to various substrates, low shrinkage upon cure, good electrical insulating properties, and the ability to be processed under a variety of conditions. Depending on the specific needs for certain physical and mechanical properties, combinations of choices of epoxy resin and curing agents can usually be formulated to meet the market demands. However, in terms of structural applications, epoxy resins are usually brittle and temperature sensitive. In fact, temperature is a key factor concerning for this material application.
However, the polymer matrix must support high mechanical loads; it is usually reinforced with fillers. The addition of different fillers favorably stiffens the material and may also increase the strength under load conditions previously determinate.
The modification of polymer properties through the addition of nanoparticles has lead to the development of the so-called nanocomposites. Polymer nanocomposites are usually defined as a combination of a polymer matrix and nano-sized particles. The possibilities to improve mechanical or thermal properties, developing a new material, by nanoparticles, have found applications in both academia and industry. Were performed several experimental and theoretical studies about micro and nanocomposites mechanical properties but there have been few studies on the thermo-mechanical properties of these materials. Nanoparticles embedded in polymer matrix have attracted increasing interest because of the unique mechanical, optical, electrical and magnetic properties displayed by nanocomposites. Due to nanometer size of these particles, their physicochemical characteristics differ significantly from those of molecular and bulk materials.
However, the nanocomposite properties can only be achieved, if the nanoparticles are well dispersed in through the polymer matrix. It is reported that a considerable amount of improvement in mechanical properties can be achieved using very low amount of nanopartcicles loadings.
Titanium dioxide nanocomposites are highly used for high mechanical, electrical, thermal and insulating properties. In other hand, nanocomposites based on thermosetting polymers reinforced with TiO2 are not well studied. The thermomechanical behavior and the mechanical properties of this kind of nanocomposites have been studied more extensively in the past decade with a focus in characterization of this material.
So many studies focused on the mechanical performance and the thermomechanical behavior of TiO2/epoxy nanocomposites. The addition of 1% by weight of the nanofiller presented the best results for tensile modulus, flexural modulus, glass transition temperature and thermal stability.
The effect of TiO2 nanotubes thermomechanical properties of epoxy based nanocomposites was studied in this work. Mass fractions varying from 1% to 5 % by weight of titanium oxide nanotubes produced different nanocomposites. Their thermomechanical behavior was analyzed by differential scanning calorimetry, dynamical mechanical analysis and thermogravimetry. The results provided the better amount of filler it is necessary to produce a nanocomposite thermomechanically superior than the neat epoxy, and compromised with the cost of the possible application of this composite on industry

9107 | Mechanical and thermal properties of multi-walled carbon nanotube reinforced polymer composites: A molecular dynamics approach (19. Nano-Composites)

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Present study is aimed to examine through molecular dynamics (MD) simulation, the mechanical and thermal properties of multi-walled carbon nanotubes-polycarbonate (MWCNT-PC) composite. MWCNT compositions in PC were varied by weight from 0.5% to 10% and also by volume from 2% to 16%. Forcite module in Materials Studio 5.5 was used for finding mechanical properties. A marked increase in the elastic modulus (up to 89%) has been observed even with the addition of small quantity (up to 2 wt %) of MWCNTs. Also upon addition of about 2 volume % of MWCNTs, the elastic modulus increases by almost 10%. This supplements the experimental investigation of these composites using nano-indentation techniques by Kumar et al [11]. Armchair MWCNT-PC composites exhibit highest values of moduli in comparison to zigzag and chiral MWCNT reinforced PC composites. To find thermal conductivity, MD simulations were performed with MWCNT volume fraction (Vf) varying from 0-0.16 and aspect ratio (l/d) was kept fixed at 10. Results were compared with other models. Because of the large band gap in chiral MWCNTs, the composites reinforced with these tubes display poor thermal conductivity. Longer CNTs with larger tubular diameter and more walls led to higher thermal conductivities in the composites.

9108 | Layered transition metal dichalcogenides and reduced graphene oxide hybrids for enhanced field emission applications (19. Nano-Composites)

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Graphene and analogous layered materials such as MoS2, WS2, SnS2 etc. have received tremendous attention from researchers owing to their potential applications in energy storage, energy conversion, catalytic activity and sensing devices. Field electron emission is the ejection of electrons by quantum mechanical tunneling from a conducting/semiconducting emitter upon application of a very high field. In view of their applicability as cold cathodes, metallic emitters are known for their inherent tendency to deliver high current densities whereas semiconductors are known for stable operation in the saturation regime. Reports on various semiconducting field emitters exhibit comparatively lower current densities though (due to limited conductivity), hence researchers are trying to explore field emission characteristics from other superior semiconducting field emitters. Recently efforts have been put forward by various groups for improving the electrical conductivity by preparing metal-semiconductor composites. Researchers are now interested in exploring the field emission properties of 2D nanostructures since their planar structure is ideal for flat, planar device technology such as electron sources in displays. We have studied field emission studies on WS2 and a WS2-RGO composite. The study revealed that WS2-RGO nanocomposites show superior field emission performance in comparison with their semiconducting counterparts. The turn on field required to draw a field emission current density of 1μA/cm2 is found to be 3.5, 2.3 and 2 V/μm for WS2, RGO and the WS2-RGO composite respectively. First-principles density functional calculations suggest that the enhanced field emission may also be due to an overalp of the electronic structures of WS2 and RGO, where graphene-like states are dumped in the region of the WS2 fundamental gap. Similarly, the p-doping in graphene with SnS2 exhibits superior field emission performance as compared with pristine SnS2 nanosheets. The turn on field for SnS2 nanosheets is 4.8 V/μm, whereas for the SnS2/RGO nanocomposite it is 2.65 V/μm. The enhancement in field emission properties in the SnS2/RGO composite is attributed to increasing emitting sites due to increased surface protrusions and lowering of work function of the composite due to p-doping as seen from the DFT calculations. Furthermore, the density functional calculations for a SnS2/graphene composite suggest that a reduction in the SnS2 work function of 1.47 eV, due to p-type doping of the graphene substrate, could also be contributing towards the enhanced field emission properties of the nanocomposite.

9110 | Fabrication and investigation of mechanical and physical properties ofnanostructured Al-4.5%wt Cu/ WC composite by mechanical alloying (19. Nano-Composites)

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Aluminum matrix composite have high potential for use in aerospace industries. Aluminum and Copper elemental powders were subjected to mechanical alloying (MA) to produce Al-4.5%wt Cu powder alloy. The morphological and micro structural changes during mechanical alloying process were studied. The MA was performed in attrition ball mill under argon atmosphere. The obtained powders were characterized by scanning electron microscopy, X-ray diffraction aiming to explore if the copper is present in solid solution or as small particles after milling. After producing the matrix, nano-particle of WC were added to Al-Cu alloy in different weight fraction to explore the role of reinforcement nano-particles on the properties of nano-composite. The result showed good dispersion of WC in nano-composite and formation of solid solution of Al-4.5%Cu via MA . Besides the composite performance in mechanical evaluation such as compression test labeled remarkable as the reinforcement fraction increased. Samples showed good wear resistance as the WC content increased.

9113 | Outstanding composites of the photovoltaic perovskite and carbon nanostructures (19. Nano-Composites)

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In the last few years, the organolead halide perovskite CH3NH3PbI3 and its derivatives have been found to be very efficient light harvesters and ambipolar semiconductors revolutionizing the field of solid-state solar cells. Its low temperature fabrication process allowed to design simpler solar cell structures (i.e. from mesoscopic to planar junctions) which yielded efficiencies approaching 20%.
We have shown that one can synthesize nanowires of this photovoltaic perovskite (Horváth et al, in Nano Letters DOI: 10.1021/nl5020684) which in association with carbon nanostructures (carbon nanotubes and graphene) makes outstanding composites with rapid and strong photoresponse. They can serve as conducting electrodes and as central components of sensors, detectors. The demonstration of the performance of several devices based on these composite structures will be given.
Acknowledgment: This work is done in collaboration with Endre Horvath, Massimo Spina, Andrea Pisoni, and Laurent Bernard.

9117 | Volatile organic compounds (VOCs) conversion over Pt/γ-Al2O3 catalyst (19. Nano-Composites)

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The emission of volatile organic compounds (VOCs) such as acetone, propylene, ethanol, n-butane in air from numerous sources including petrochemical and refining operations, food processing, pharmaceutical manufacturing, printing and a wide range of coating operations gives rise to deleterious health and environmental effects. Total oxidation is an attractive method in controlling these emissions due to the great amounts of energy saved if moderate temperature can be used. For wide application of catalytic combustion, thermally, mechanically and chemically stable catalysts are required. The operating costs for catalytic combustion are lower than those for thermal combustion and catalytic combustion is also more flexible compared to other means of VOC destruction. An innovation lies in the field of catalytic membrane reactors based on porous membranes which offer very attractive research opportunities to academic and industrial scientists working on catalysis.
In this work a catalytic membrane reactor has been developed and tested for VOC destruction utilizing a porous ceramic membrane over Pt/γ-Al2O3 catalyst for VOC destruction from air stream. A laboratory flow-through catalytic membrane has been used for the study. The influence parameters such as platinum (Pt) loading, total gas flow rate, VOC concentration, oxygen content and conversion temperature were examined.

9129 | Characterisation of composite mesoporous membranes using nitrogen isothermal measurements (19. Nano-Composites)

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The use of composite inorganic membranes for environmental gas separations to achieve high selectivity for desired target gasses has grown. To fully understand the transport mechanism of the silica membranes, single gas permeation measurements were carried out. In addition, the membrane was charecterised by the BET method. The hysteresis indicated the membrane was mesoporous and the Barrett, Joyner, Halenda (BJH) desorption method was used to determine the pore diameter of the membrane after first and second dip coating with silica elastomer which was 5.417 and 4.181 nm respectively. Specific surface area of the membrane showed an increase with each dipping from 7.662 m2g-1 to 9.556 m2g-1. Single gas permeation test with argon, helium, methane, nitrogen and carbon dioxide at a temperature of 293 K and 333 K and pressure ranging from 0.02 MPa to 0.1 MPa was carried out. The molar flux of the gases through the membrane was in the range of 10-6 molm-2s-1 with an average linear regression coefficient of 0.972. On the basis of the results obtained it can be concluded that the main mechanism governing the flow of gases through the modified mesoporous membrane was Knudsen flow although there is evidence that another flow mechanism was involved in the movement of the gases across the membrane. To achieve high selectivity of the target gases there is need for further modification of the membrane. Further permeation tests and characterisation will be carried out at varying temperatures. There is minimal amount of literature on the ideal conditions of membranes to achieve optimal selectivity of methane from carbon dioxide and inert gases. There is therefore the need for continuous research on the evaluation and characterisation of composite mesoporous inorganic membrane and the possibility of the use of this membrane for recovery of methane will be competitive.

9138 | Nanomechanical Characterization of Carbon Reinforced Polymer Composites (19. Nano-Composites)

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Fiber reinforced polymer composites (FRPC) are increasingly used in aerospace, automotive, marine industries due to their excellent specific mechanical properties compared to conventional materials. However, they are sensitive to environmental conditions such as humidity, temperature and UV irradiation. These environmental factors could affect the performance of FRPC, particularly the fiber/matrix adherence, which is a key parameter for FRPC mechanical properties.
In this work, we investigated the nanomechanical properties of fiber reinforced epoxy vinylester composites by means of nanoindentaion technic and atomic force microscopy. The objectives were to (i) characterize the mechanical properties of the fibers, their matrix and composite, and to (ii) investigate the evolution of the mechanical parameters as a function of the aging of the polymers. We characterized a sample aging naturally for 10 years. The first goal was partially achieved as we were able to measure the hardness (H) and Young's modulus (E) related to each compound (fiber, matrix and composite). However, the values deduced from our measurements [fibers: [H=(3±1)GPa; E=(41±8)GPa], matrix : H=(50±10)MPa; E=(5±1)GPa] and composite: H=(1.2±0.2)GPa; E=(12±4)GPa] are significantly different from those reported in literature suggesting that surrounding material influences the mechanical properties of the separated compounds.
The surface of the aging composite deteriorated as the polymer was partially removed leaving the carbon fibers at the surface. This deterioration was limited to 10 μm depth from the surface. At deeper areas, the mechanical properties of each compound do not evolved. These results reveal that carbon/epoxy composite is a stable material due to the chemical inertness of both constituents.

9157 | Synthesis and EMI properties Spinel Ferrite Nanoparticles and Polymer Nanocomposites Structures (19. Nano-Composites)

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Spinel ferrites-polymer composite structures serve as better EMI due to their dielectric and magnetic properties [1]. Ferrite materials display various properties of the complex permeability and the complex permittivity and they are important in determining their high frequency characteristics.

9160 | The New Generation of Composites Based on Nanopowders (19. Nano-Composites)

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It is wellknown that mechanical mixing of such non-agglomerated nanopowder with matrix component does not exclude the nonuniform distribution of filler particle phase. The main problem for nanocomposites manufacturing such as "ceramic-ceramic" is difficulty of creating a uniform distribution of the hardening phase due to the properties of nanopowders forming hard agglomerates. Authors developed a technology of composite oxide nanopowders by coprecipitation method using physical effects. The technology ensures the absence of nanopowders agglomeration and produces single-crystal particles with a given size in the range 6..30 nm, with controlled phase and chemical composition. In addition, the technology allows entering low concentrations dopants, and creating multicomponent and composite nanopowder systems. Control of the chemical composition is carried out with high precision and achieve a high degree of homogeneity of initial components is provided by the introduction of dopants through solutions. It is shown that in one integrated technology of oxide nanomaterials production through the use of physical and chemical methods of modification of cation sublattice of zirconia can create functionally-oriented and multi-component composite system. The mechanisms of influence of physical and/or chemical modification methods on structure and properties of nanoparticles are established. But particular importance, as shown by our study, doping of nanoparticles acquire in the creation of composites. It is established that even a slight amount from 0.3 to 5 mol.%. of doping elements leads to a significant change in the nanopowders properties and also substantially ceramics based on this nanopowders. Obtaining composites is considered for systems ZrO2-Y2O3-Al2O3 (ZYAl) and ZrO2-Y2O3-Cr2O3 (ZYCr), where Cr2O3 and Al2O3 have very low solubility <0.3 mol.%. In ternary systems detected competition between components of composites, leading to an increase in the concentration of the cation dopant on the surface of zirconia nanoparticles. Heating provides modification of nanoparticles and granules surface by doping of cations, which allows subsequently forming uniformly finely distributed phase in the matrix
Particles size and concentration of dopants is greatly affected on the structure and properties of the resulting composites. Our studies allow controlling the structure, phase composition and properties of ceramic composites due to the effects caused by nanoparticles sizes. Possible mechanisms of inhibition of cracks in the resulting nanocomposites estimated variation of the fracture toughness of composites and resistance to low temperature degradation in wet aggressive environment are discussed. We proposed model what illustrated the structure evolution of system ZrYCr at heating of powder system. At temperatures 600-800oC there is core-shell structure: core is ZY solid solution, shell is ZYCr solid solution. At 1000oC Cr2O3 nanoparticles precipitation is observed. At 1200-1350oC we can see Cr2O3 nanoparticles agglomeration but increasing of fracture toughness in 1,3 times. Effect of alumina on fracture toughness of zirconia/alumina composites is more high: the fracture toughness values increased sharply-in 1,8 times. For ZYAl composites obtained by traditional mixing method only a slight increase in fracture toughness were observed. We have reason to believe that increasing in the fracture toughness value for zirconia/alumina composites obtained from co-precipitated nanopowders is due to a formation of complex inter- intragranular structure of alumina inclusions with effect of alumina segregation on zirconia grains boundaries during sintering. Nanoparticles of alumina on zirconia grains boundaries and inside zirconia grains lead to enhancing of crack interaction with zirconia grains. The penetration of crack inside grains leads to crack breaking and increasing the fracture toughness of zirconia ceramics.

9190 | Development and characterization of functionalized mullite fiber reinforced sulphone ether linked tetra glycidyl epoxy matrices and nanocomposites (19. Nano-Composites)

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The objective of the present work is to synthesize 1,4'-bis (4-amine-phenoxy) benzene epoxy resin (TGBAPSB) via 1,4'-bis (4-amine-phenoxy)sulphonebenzene (BAPSB) and epichlorohydrin. The amine functionalized mullite fiber (F-MFI) was synthesized via the sol–gel method and its surface was modified with 3-glycidoxypropyltrimethoxysilane and has been confirmed by FT-IR. The TGBAPSB epoxy resin was further reinforced with varying weight percentages (1-5wt %) of F-MF and cured with diaminodiphenylmethane (DDM). Thermal and thermo-mechanical behaviour of TGBAPSB epoxy matrices and nanocomposites were examined by TGA, DMA and DSC. The surface morphology of the epoxy nanocomposites was investigated by XRD, SEM and AFM studies. Data obtained from the mechanical, thermal and thermo-mechanical, dielectric and water absorption studies indicate a significant improvement in the resultant epoxy nanocomposites, which appear to be an ideal candidate for advanced high performance applications when compared to those of neat epoxy matrix

9216 | The effect of titanium aluminides reinforcement particles on microstructure and properties changes of AMC's (19. Nano-Composites)

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Powder metallurgy (PM) combined with (MA) offers innumerable advantages over casting metallurgy, making possible to improve the existing properties but also conferring new properties. Results presented in this paper were obtained in such processes. Experiment have been developed to improve the characteristics of aluminium matrix composites, because of produced fine and uniform dispersions of reinforcements particles. Applying mechanical alloying route of composite powders production, makes it possible to obtain diminution of reinforcing particles size as well as homogenous reinforcement particles distribution. As was expected mechanical milling process has improved the reinforcement distributions throughout the whole particle. Extruded composites are characterized by a very homogeneous distribution of intermetallic particles and the absence of any reaction and with good cohesion at the matrix/particle interfaces Observed changes in the microstructure, influence on the mechanical properties of composite particles obtained.

9298 | Preparation and Properties of Poly(vinyl alcohol) Composite Nanofibres Containing Multi-Wall Carbon Nanotubes Produced by Electro-Spinning Technique (19. Nano-Composites)

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In this study, polyvinyl alcohol (PVA) nano fibers and PVA nano mats with 1-3-5% by weight multi walled carbon nano tubes (MWCNT) were produced by electro spinning method. The characteristics of PVA nano fibers and PVA nano fibers reinforced with MWCNT were investigated by using Fourier transforms infrared spectroscopy (FT-IR), differential scanning calorimetry (DSC) and scanning electron microscopy (SEM). SEM results of PVA nano mats with 1 % wt. MWCNT revealed that the fiber diameters ranged between 154-335 nm and they were linear, continuous, homogenous and free of beads. But fiber diameters decreased and beads started to form by increase of MWCNT wt. ratio. DSC thermograms indicated that the addition of 1% wt.

MWCNT increased glassy transition (Tg) to 85 C and melting temperature (Tm) to 225 C.

9348 | Fabrication and Characterization of Functionalized Silica-Epoxy Based Composite (19. Nano-Composites)

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Epoxy/silica composites samples were successfully fabricated by uniformly dispersing the produced silica into epoxy polymer mainly using a mechanical, sonication, and solvent compounding methods. The tensile properties of silica-epoxy composite exhibited improved resin strength and fracture toughness than those of the bare epoxy polymers at room temperature, respectively. Electrical properties and crosslink density of epoxy/silica composite were noticeably improved by addition of silica. Functional silica-epoxy based composite were investigated by dynamic mechanical analysis(DMA), scanning electron microscopy(SEM), atomic force microscopy(AFM), fourier transform infrared spectroscopy(FTIR), thermal gravimetric analysis(TGA), and differential scanning calorimetry(DSC).

9349 | Fabrication and Characterization of Glass fiber-Epoxy Based Composite (19. Nano-Composites)

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Epoxy/glass fiber composites samples were successfully fabricated by uniformly dispersing the produced glass fiber into epoxy polymer mainly using a mechanical, sonication, and solvent compounding methods. The tensile properties of glass fiber-epoxy composite exhibited improved resin strength and fracture toughness than those of the bare epoxy polymers at room temperature, respectively. Electrical properties and crosslink density of epoxy/glass fiber composite were noticeably improved by addition of glass fiber. Functional glass fiber-epoxy based composite were investigated by dynamic mechanical analysis(DMA), scanning electron microscopy(SEM), atomic force microscopy(AFM), fourier transform infrared spectroscopy(FTIR), thermal gravimetric analysis(TGA), and differential scanning calorimetry(DSC).

9358 | Influence of Granule Size on Thermal Characteristics of Protein Based Silica-Aerogel Composites (19. Nano-Composites)

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Silica aerogels are light and highly porous nanomaterials offering excellent thermal insulation properties. Thermal conductivity of the silica aerogel granules that are commercially available typically ranges from 0.013 to 0.024 W/m-K at 300K for the granules sizes ranging from 0.01 to 4.00mm. This thermal conductivity range can be influenced by effectively controlling the granule sizes in a sample. This is especially crucial in applications where the tolerance for thermal conductivity is +/- 0.002 W/m-K.
In order to enhance the applicability of the granules, binder-treated gelatin silica aerogel-sodium dodecyl sulfate (GSA-SDS) composites were specially envisaged and developed. The influence of aerogel granules sizes on the thermal conductivity is investigated on GSA-SDS composites fabricated using the aerogel granules of different sizes. The thermal conductivity of silica aerogel granules, 〖(λ〗 _a (d,T_m)), and of GSA-SDS composites, (λ_gsasds (d,T_m)), was evaluated with several mass ratios of the composite mix for 1-D steady-state heat transfer at mean temperature (Tm= 300-370K) using Lee's Disc method. The experimental thermal conductivities of the silica aerogel granules were in range from 0.021 to 0.038W/m-K within the tolerance of +0.0023/-0.0018W/m-K. Thermal conductivities of GSA-SDS composite blocks were in the range from 0.021 to 0.040W/m-K with the tolerance of +0.0015/-0.0038W/m-K. A predictive model is developed to determine the optimal granule size and thermal conductivity of the granules based on measured data from the experiments. The model, as a function of; a) the distribution of aerogel granule size based on two-term Gaussian function, b) thermal conductivity factor (T_f) and, c) the mass ratio of the constituent materials exhibited exponential behavior according to the various granule sizes. The predictive model for 〖(λ〗 _a (d,T_m)) based on the measured data showed R2 > 0.93 fit. The results indicate that the size of silica aerogel granules does have effect on thermal characteristics of GSA-SDS composites. Smaller granules offer better insulation with little variation in thermal conductivity as compared to larger granules.

9366 | Electric-field-induced resistance behavior in Al/a-C:Co/FTO sandwich structures (19. Nano-Composites)

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For its sub-ns operation speed, low energy consumption, high endurance and proved excellent miniaturization potential, resistive random access memory (RRAM) has been investigated intensively as a promising nonvolatile memory in recent years. Due to their diverse forms with electronic properties ranging from metallic to insulating，carbon based materials seem to be ideal resistance-change materials. Resistive switching (RS) behavior has been observed in carbon-based materials, including carbon nanotube (CNT), graphene oxide, fullerene, amorphous carbon (a-C) and carbon/organic composite. Different switching mechanisms have been proposed, including thermo-chemical sp2 carbon chain forming/ruptureelectrochemical metallization and valence change. Nowadays, few study of the RS property has been done on doped-carbon films. As we know, Co and C are immiscible and the metastable Co carbides (Co_2C and Co_3C) can easily decompose into Co and C. Co-C composite films therefore form an interesting storage layer to be investigated.
In this work, we investigated the RS characteristics of α-C:Co films prepared by RF magnetron sputter deposition technique for nonvolatile memory application. Commercial glasses capped by a 100 nm thick F-doped SnO_2 (FTO) layer were used as substrate and simultaneously bottom electrode. Before film deposition, the FTO layer was etched into 1 mm width strips as bottom electrodes. Amorphous Co-doped carbon (α-C:Co) films of 300 nm were sputtered from a 4at % Co doped carbon target on the FTO-glass substrates. The substrate temperature was kept at 300 °C and the Ar pressure was maintained at 0.65 Pa during the deposition. Electric-pulse-induced reliable and reproducible switching behavior of Al/α-C:Co/FTO were obtained. The on/off ratio is over 10 with read voltage (1 V). The RS behavior is consistent and reproducible up to 300 cycles and 10000 s. Based on the observed features, the clustering of existing sp2 sites with the sp3 matrix and the formation of conducting nanochannels in Co-C composite films are believe to

related to the RS between HRS (high-resistance state) and LRS (low-resistance state).

9424 | Synthesis and Tribological Properties of Copper-alumina Nanocomposites Prepared by Coprecipitation Technique (19. Nano-Composites)

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Copper-alumina nanoparticles were synthesized by coprecipitation method to prepare the nanocomposites and investigate their mechanical performances. The effects of calcination temperature on the average size of composite particles and the chemical composition after calcination were analyzed. The sintering parameters including sintering temperature, hot pressure and packing time were optimized to fabricate the alumina nanoparticles reinforced copper matrix composites (CMCs). The density, microhardness and tribological properties of CMCs reinforced with 1, 2, 3, 4 and 5wt% of alumina nanoparticles were investigated respectively. The results showed that the optimized preparing parameters for the composites were: hot pressing temperature of 900C， hot pressure of 27.5MPa and packing time of 2 hrs. The composites reinforced with 2wt% alumina nanoparticles had the lowest wear rate, with the relative wear resistance of 3.13.

9473 | Preparation and Properties of poly (acrylamide-co-alginate)/gold nanocomposites for inactivation of bacteria (19. Nano-Composites)

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A facile and efficient approach to prepare uniform gold nanoparticles (Au NPs) in hybrid hydrogel consisting of acrylamide (AM) and alginate (SA) for antibacterial applications is reported. In this study, reduction of gold ions by acrylamide and alginate (AM–SA) occurred before the polymerization and as-obtained gold colloids are stabilized by AM–SA immediately in the absence of commonly used reducing agents and protective reagents. Via transmittance electron microscopy results, we can conclude that the obtained gold nanoparticles in hydrogel are well dispersed. Furthermore, ultraviolet–visible absorption spectroscopy. Fourier transform infrared and thermogravimetric analysis were used to characterize the structure and composition of the synthetic nanocomposites. Our approach provides well-dispersed nanoparticles around 8 mm in size. It is important to underline that nanoparticle aggregation was not observed during and after gel formation. The prepared Au NPs exhibited remarkable stability in the presence of high pH s, and a range of salt concentrations. Importantly, the hydrogel/gold nanocomposites showed a non-compromised activity to inhibit the growth of a model bacterium, Escherichia coli. With their excellent mechanical behavior, as well as the remained antibacterial activity, the nanocomposites should get various potential applications in the fields of pharmaceutical science and tissue engineering.

7534 | FRACTURE PROPERTY DETERMINATION IN NATURAL FIBRE COMPOSITES (20. Natural Fibre Composites)

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Adhesive bonding has become more efficient in the last few decades due to the adhesive developments, granting higher peel and shear strengths, and also increased ductility. As a result, bonded joints are replacing conventional methods. On the other hand, natural fibre composites have recently gained interest and application due to the low cost and density. It is therefore essential to predict the fracture behavior of joints between these materials, to assess the feasibility of joining during the fabrication process of components, of joining cured parts of a structure, or even for repairing. In this work, the tensile fracture toughness (Gnc) of adhesive joints between natural fibre composites is studied, by bonding with a ductile adhesive and co-curing. Conventional methods to obtain Gnc are used for the co-cured specimens, while for the adhesive within the bonded joint, the J-integral is considered, to accurately account for the large adhesive plasticity. For the J-integral calculation, an optical measurement method is developed for the evaluation of crack tip opening and adherends rotation at the crack tip during the test, supported by a Matlab sub-routine for the automated extraction of these quantities. As output of this work, a comparative evaluation of the two bonding methods is carried out and fracture data in tension is provided for the subsequent strength prediction of joints in natural fibre composites.

7551 | Behaviour of composite soil reinforced with curauá treated fibers for use in asphalt pavements (20. Natural Fibre Composites)

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This paper discusses the geotechnical behaviour of two tropical soils reinforced with the random inclusion of the short and superficially treated curauá fibers with EPS (Expanded polystyrene) for use in pavement structures. The vegetal fibers were mixed to the natural soils to evaluation the influence of such materials on the improvement of the mechanical properties of the composites. In order to characterize the performance of these fibers, scanning electron microscopy (SEM) and dynamic mechanical analysis (DMA) were employed. The characterization and classification soil tests were gradation, Atterberg limits, mini-CBR (natural and after inundation), mini-MCV compaction and mini-Proctor compaction. The geotechnical behaviour of reinforced and non-reinforced soil samples were analyzed by unconfined compression test (UCS) and diametral compression (Brazilian) test. The test results indicated that the inclusion of fiber reinforcement within tropical soils caused a significant improvement on the mechanical properties of these soils, and it was shown the curauá fibers potential as soil reinforcement for use in asphalt pavements structures.

7552 | Mechanical Properties of Tropical Soils reinforced with Treated Jute Fibers (20. Natural Fibre Composites)

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Ecological concern has resulted in a renewed interest in natural materials for their recyclability, light weight and non pollution. Lignocellulosic natural fibers such as curaua, sisal and jute are an interesting, environmentally friendly alternative to the use of artificial fibers as reinforcement in engineering composites because of the benefits that these fibers provide over conventional reinforcement materials. However, the rapid absorption of water and degradation of vegetal fibers can represent negative characteristics. Thus, a study of the effect of surface treatment on jute fibers in order to increase its durability is necessary for these fibers can successfully replace synthetic fibers. In this context, the aim of this work was analyze the geotechnical behavior of two tropical soils reinforced with the inclusion of short and superficially treated jute fibers with EPS (Expanded polystyrene) for use in asphalt pavement structures. These fibers were mixed in the tropical soils in order to evaluation their influence on the mechanical properties improvements of the soils. A series laboratory geotechnical tests were performed to determine the mechanical behavior response of the composites. The results demonstrated that the addition of treated jute fibers presented significant improvements on the mechanical properties of these soils and showed its potential as soil reinforcement for use in pavements structures.

7712 | NUMERICAL STUDY OF THE BEHAVIOUR OF NATURAL FIBRES COMPOSITES UNDER LOW-VELOCITY IMPACT

(20. Natural Fibre Composites)

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Composite material are characterised by the combination of at least two materials, usually polymer matrix reinforced with carbon of glass fibres, with the intention to get properties that cannot be achieved using the constituent materials separately. In the last years, numerous researchers have introduced natural fibres as reinforcements to increase the biodegradability of composites. The works that have studied biocomposites made of natural fibres as jute, hemp, linen or cotton have shown promising results related with their mechanical properties. Also natural matrixes are used to fill the fibres. PLA is the most common one, which shows good mechanical behaviour.
The most of the research done on biocomposites are focused on their quasi-static behaviour, there are also several remarkable works that study their impact behaviour. Impact properties of biocomposites are extremely important to find industrial applications e.g. in automobile structures, but these properties are difficult to quantify. Impact testing of materials is performed to determine the amount of energy that can be absorbed during a suddenly applied force. Impact testing is usually performed by Charpy or Izod test machines. Charpy and Izod tests, originally designed to determine ductile–brittle transitions in metals, most often assume a pre-existing notch, which is not suitable for testing composite materials.
An alternative method is the drop-weight test, in which a known mass is dropped from a given height onto a flat, un-notched sample. The drop-weight test is a more realistic test of what a structural component would experience in its service life. Drop-weight tests have proven to be valuable source of information about the impact behaviour of woven composites, tape laminates, and sandwich beams. However, the use of these tests on biocomposites has not received comparable attention in scientific literature. In this work, a drop-weight test was made on a biocomposite.
The development of theoretical models to predict the impact behaviour of composites has shown to be useful tool to get a better understanding the failure modes and the energy absorption mechanisms. However, the modelling of biocomposite structures is an almost unexplored field. This work is focussed on the development of the first numerical model to predict the low-velocity impact behaviour of biocomposite plates using finite element method (FEM). The numerical model was validated with experimental data from drop-weight tests. Moreover, the FEM model was used to analyse the influence of impact energy on the peak force and absorbed energy during impact.
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7739 | ANALYSIS OF THE MANUFACTURING PARAMETERS ON THE MECHANICAL PROPERTIES OF NATURAL FIBRES COMPOSITES **(20. Natural Fibre Composites)**

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Composite materials are present everywhere in nature, for example, muscles are made of proteins girded by myoglobin and other components. This nature configurations take the best from every component, so that, man-made composite materials are characterised by the combination of at least two materials, usually polymer matrix reinforced with carbon or glass fibres, with the intention to get properties that cannot be achieved using the constituent materials separately. During the last years, numerous researchers have introduced natural fibres as reinforcements and natural plastics as matrix to increase the biodegradability of composites because friendly environmental materials are needed. In this work, biocomposite refers to a totally biomass resource composite material.
The works that have studied biocomposites made from natural fibres as jute, hemp, flax, kenaf or cotton have shown promising results related with their mechanical properties. New fully biodegradable bioplastics derived from the biomass and processed to a final plastic as PLA (poly-lactic acid), PHB (Polyhydroxybutyrate) or chitosan are being used to made new composite materials. The hydrophilic behaviour of biopolymers sets them as the better option. The advantages of a biodegradable material are not only to reduce contamination, but also to obtain a renewable material, which could be reused at the end of the product cycle life.
The applications of a biocomposite reach a high range of possibilities, from the automotive sector to boats. It´s mechanical properties call this material to replace most of non-renewable materials as traditional fibre glass composites possibilities. Usually in bibliography, the quantity of filler part exceeds reinforcement parts, being a typical value a 60-70% the matrix percentage. The typical temperature of fabrication during the compression moulding is around 160-180 ºC, while the melting point of matrix usually rounds 150ºC. However, these are new materials and there is a lack of studies about the influence of the main parameters of the manufacturing process.
In this work, the influence of temperature, pressure, percentage of reinforced volume and number of layers on the mechanical properties of biodegradable composites made of natural fibres is studied. The influence of these parameters was studied for different fibres as flax, cotton and jute. PLA was used as matrix.
Authors gratefully acknowledges the support of Spanish Ministry of Economy under the project DPI2014-43994-R.

7742 | Effects of cellulose fiber content on physical properties of polyurethane based composites (20. Natural Fibre Composites)

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For the sake of environmental protection and public health, the utilization of natural fibers in industrial application composites provides challenges for researcher to develop suitable techniques to produce good quality fibers for use as reinforcement for polymer composites. Cellulose fibers are renewable resources with many advantages. They are abundant, inexpensive, light in weight, strong and non-abrasive, they can serve as an excellent reinforcing agent for plastics such as PU to replace or to reduce utilization of synthetic fibers in different applications.
Cellulose extracted from Alfa stems was used as reinforcement of polyurethane (PU) based composites. The dispersion of the fillers within the polymeric matrix was investigated by scanning electron microscopy, and results showed a relatively homogeneous dispersion of the cellulose fibers and the existence of agglomerates at high fiber content. Infrared spectroscopy clearly revealed the existence of hydrogen interactions between matrix and reinforcement. We focused our attention on the changes in the mechanical and the electrical properties of the composite, when the thermoplastic matrix is filled with cellulose fibers up to 30 % by weight. The mechanical properties show gradual changes, with a marked improvement in rigidity of the composite, when the embedded fiber content increases. However, the cellulose concentration-dependence of the electrical properties of the composites, especially resistivity and capacitance, show a percolation behavior beyond a critical concentration of 10% cellulose fibers [1]. These features are correlated with the cellulose concentration-dependence of charging effect of the composite under electronic beam irradiation in a scanning electron microscope. The results indicate that the leakage current and the trapped charge as well as the kinetics of charging process significantly change beyond the critical concentration of 10 % cellulose fibers [2]. Poor dispersion of the fibers and their agglomeration when their concentration exceeds a threshold of 10% and their consequences on dipole concentration may explain such cellulose concentration-dependence.

1. Effects of Cellulose Fiber Content on Mechanical and Electrical Properties of Polyurethane Based Composites
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J. Mat. Sci. Eng. A 3 (2013) 398–406.

2. Charging process of polyurethane based composites under electronic irradiation: Effects of cellulose fiber content
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7772 | Experimental and Numerical Investigation of Paperboard Creasing (20. Natural Fibre Composites)

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Laminated paperboard is widely used in packaging products. It usually consists of multiple layers bonded to each other by starch or adhesion. The indentation of fold lines (creasing) plays a crucial role during the folding process. It is important to control delamination and other damage effects to create high quality commercial cartons. Thus, the aim of this study is to describe the material behavior of a laminated paperboard during the creasing process. The paperboard was considered to be a laminate of three distinct layers, and each was modeled separately with an anisotropic elastic-plastic material model while a cohesive zone approach described the opening behavior between layers. The initial yielding was given by Hill's 48 yield criterion, while the isotropic strain hardening was described by a power law hardening function. To calibrate the material parameters, a sequence of tensile, compression, Double Cantilever Beam (DCB) and End Notched Flexure (ENF) tests were conducted for each layer in different directions to account for the material's anisotropy. Finally, the creasing process was investigated using a two-dimensional plane strain finite element model.

8036 | Properties and evaluation of structural changes of thermoplastic polymer composites with renewable plant materials after accelerated weathering tests (20. Natural Fibre Composites)

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The range of application of composite materials with plant fillers, including construction materials, depends on, among others, resistance to atmospheric factors. The scope of processes leading to disintegration and/or photolytic degradation of materials triggered by a complex of environmental conditions is known as weathering. The susceptibility of polymer materials to degradation processes is a result of, among others, polymer's structure and molecular weight, material's physicochemical properties, as well as the type and intensity of factors responsible for degradation. The synergistic activity of atmospheric factors (temperature, humidity, UV radiation) may result in a change of color and/or changes in the material's structure and, consequently, the loss of desirable mechanical properties [1-3].
The aim of this paper was characterizing and comparing the structure and properties of polymer composites containing plant fillers of various types. The following plant materials were used: pine wood flour, beech wood flour as well as wood flour from osier and pine needles (the last two had not been used before for such proposes). The impact of mercerization of the fillers on the alteration of the composites' properties was specified [4]. Furthermore, a weatherometer was used in order to characterize and compare the properties of the composites under exposure to atmospheric factors. The weathering process of the materials exposed to destructive factors was evaluated by analyzing the structural (ATR-FTIR, DSC), topographical (SEM), rheological (MFR) and mechanical changes of the aged samples.
A thorough analysis has indicated that the introduction of a plant filler into polymer matrix increases its resistance to atmospheric factors.

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6. Patent applications nr 408425
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8050 | Fungal biocorrosion as a reason of the changes in the structure of thermoplastic polymer composites reinforced with plant fillers (20. Natural Fibre Composites)

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Growing demand for composite materials that contain renewable plant resources has become visible over last years. The main reasons for this are diminishing supplies of substrates of petrochemical origin, and commonly accepted concerns for the natural environment, especially important in the light of serious difficulties in managing the wastes of polymers. Of a great meaning are growing prices of the limited resources of oil and gas, what consequently leads to an increase in prices of commercial polymers. The major advantages of composites reinforced with plant fillers comprise their at least partially renewable nature, relatively low price and widespread availability. Due to usually good functional properties, composites containing plant fillers possess a wide range of applications in industrial and home construction, as well as, in car industry [1].
However, all materials that contained natural substances as components are characterized by varied susceptibility to destructive activity of biological factors. Simultaneously, this particular property determines the potential scope of application of every product, which is made from such composites, because the presence of plant resources shortens their lifespan, thus making them vulnerable to biocorrosion triggered by microorganisms, in case of our research - filamentous fungi [2,3].
The omnipresence of microorganisms, a large diversity of species, as well as their high enzymatic activity, contribute to biocorrosion and biodegradation of various materials and substances. A considerable threat to the lifespan of composites with plant fillers is often caused by filamentous fungi that in favourable growth conditions (high humidity), may change the physical-chemical structure of composites on the way of biocorrosion [4].
This contribution presents the results of the study on the resistance of composite materials towards selected filamentous fungi (e.g. Aspergillus niger), existed in compost and post-mushroom peat. The susceptibility of the tested materials to infestation and/or biocorrosion was determined on the basis of macroscopic evaluation of area of growing mycelium, or on the basis of mycelium mass balance. Furthermore, the progress of degradation was evaluated by analyzing the changes in structure (ATR-FTIR, DSC) and surface morphology (SEM) of the samples.
The obtained results clearly show that renewable plant resources in composites (its type and share) was crucial to the process of its degradation under the influence of filamentous fungi. Moreover, the conditions and environment of this process have become equally responsible for the pace of degradation. The conditioning the samples in the compost caused major structural changes of tested composites and the progress of deterioration. That aspect has been proven through changes in the crystallinity of samples and their structure, confirmed by analyzing IR spectra.

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8190 | Filler component to precast slabs produced with short sisal fiber cement based composites (20. Natural Fibre Composites)

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Precast unidirectional slabs can be defined as structural elements with a ribbed section, consisting of longitudinal ribs, arranged in a single direction. They can be formed by precast elements, called beams, normally interspersed with ceramic or EPS components, called tiles and a “concrete cover” laid in situ. In this study, the substitution of ceramic and EPS components by short sisal fiber cement composites, used as an in fill material for semi-precast slabs, was investigated experimentally. Strip of slabs were produced in full scale, with mean measurements of 0.5 m (width) x 2 m (length). The flexural behavior of fill component was determined using three point test under displacement control. The slabs were characterized according to flexural strength. The sisal-cement fill component show a multiple cracking with flexural hardening and a higher flexural strength (1.20 kN) than ceramic (1.1 kN) or EPS components (0.7 kN). The flexural strength of the composite slab (sisal-cement component) was higher than EPS slab and reference slab (ceramic fill component) and less density than later. These results indicate the feasibility of using short sisal fiber cement composite as a constructive element in the production of slabs.

8274 | A comparison of the microstructure of wood-based carbon fibers activated by steam and disodium hydrogen phosphate (20. Natural Fibre Composites)

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Activated carbon fibers were prepared from liquefied wood through steam and disodium hydrogen phosphate activation with different temperatures. Their crystal structure, pore structure, and surface chemistry structure were studied using analysis of X-ray diffraction, nitrogen adsorption-desorption isotherms, and X-ray photoelectron spectroscopy, respectively. The results showed that the steam at the concentration of 3.0 ml/min had a more serious damage to the crystal structure of fibers compared with the disodium hydrogen phosphate at the concentration of 5 wt%. Therefore, the BET specific surface area and total pore volume of activated carbon fibers activated by steam were larger than those of activated carbon fibers activated by disodium hydrogen phosphate. However, more mesopores were found in activated carbon fibers activated by disodium hydrogen phosphate. Meanwhile, the samples activated by disodium hydrogen phosphate possessed more element oxygen and less of element carbon.

8669 | PRODUCTION OF CELLULOSE BASED BIOCOMPOSITES WITH HYDROXYAPATITE FOR MEDICAL APPLICATIONS (20. Natural Fibre Composites)

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Nowadays tissue engineering is assumed as an alternative and very promising approach for biological tissues regeneration. Three-dimensional (3D) polymeric scaffolds are used as a support for biological cells transplantation, adhesion, proliferation, and differentiation or as a reservoir for different molecules and cell mediators [1-5]. Scaffolds must be, therefore, biocompatible, bioactive and biodegradable to avoid tissue rejection and to promote space for the new regenerated tissue [4].
Materials as blends of natural or synthetic polymers, as Poly(ε-caprolactone) (PCL), reinforced with ceramics such as hydroxyapatite (HA) have been widely used for repair and regeneration of biological tissues, mainly bone tissue. HA is used as reinforcement of PCL matrix for improving the mechanical and biological properties. The addition of natural biopolymers is pointed out as a way to enhance the control over the degradation of polymeric scaffolds and improving additionally cell adhesion and proliferation [1 - 4]. Regardless of its origin, nanocellulose has great potential as a reinforcement element in composite research areas, because of its exceptionally superior mechanical properties and biocompatibility. However, due to its hydrophilicity, proper interface compatibilization between a hydrophobic polymer matrix and nanocellulose must be ensuring [6-8].
In this research work biocomposites of PCL, HA and carrot nanocellulose (NC) were prepared, in order to evaluate the influence of different NC contents on the produced biocomposites.
Concerning to biocomposites processability, scaffolds can be produced by the conventional techniques, e.g. freeze-drying, thermally induced phase separation, gas foaming and so on, but if the purpose is to produce complex free form geometries, such as the ones required for medical applications, additive manufacturing techniques based on extrusion technology are the solution [2, 5]. With this purpose scaffolds of PCL/HA/NC were manufactured using a BioExtruder equipment.
Chemical, thermal, morphological, and mechanical compression tests were performed on the produced scaffolds to investigate the effect of different nanocelulose contents and HA on the PCL matrix.
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8716 | Composites from sugarcane bagasse: particles granulometry (20. Natural Fibre Composites)

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The search for alternative raw materials for composites manufacture, which will mitigate the use of forest resources and add value to fibrous often considered as waste, must be a constant in the research development of new products more sustainable and opens front to use raw material availability and with great potential, such as sugarcane bagasse in Brazil. In these new panels, all the technological performance is related to the conformation and aspects initially granulometric particle used, with a clear need for detailed classification of the fibrous raw material used. In this paper we report classification percentage of bagasse particles suitable for new composite manufacture mixed with eucalyptus fibers, and illustrated morphological details on the visual aspects and through the interpretation of images obtained under scanning electron microscopy (SEM).

8717 | Prospects of using Amazon fibers as reinforcement in multilayer composites (20. Natural Fibre Composites)

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The research of the last decade have evaluated the application of fibrous raw materials of agricultural crop residues for composites manufacture in different regions of the world, with satisfactory results, and the development of composite materials with natural fibers or waste agroindustrial arouses interest in academic and industrial circles for questions and associated technological possibilities of being environmentally friendly and competitive mechanical properties of materials, and can also contribute to greater sustainable development. In this context, this evaluation included the insertion of curauá fibers (Pineapple erectifolius) and jute fibers (Corchorus capsularis) in the inner layer of low density particleboard from bagasse in order to increase performance mechanical in properties panels. The panels were made of multilayer, similarly to the MDP panel and containing: (i) outer layers (CE) and fine particle dose of 15% based on castor oil resin and (ii) the inner layer (CI), grain size coarser and 12% dosage of resin, which received the addition of curauá and jute fibers in a percentage of 20%. Preliminary results indicate the necessity of prior particle size distributions in fiber alternatives to better match the matrix of sugarcane bagasse, with the inclusion of jute fibers promoted significant increase in the values of MOR and MOE compared to panels made with only sugarcane bagasse, this satisfactory performance which can guide the further research aiming adjustments in the production process and the use of other fibrous matrices.

8732 | Mechanical properties of Napier Grass Fibre Reinforced Unsaturated Polyester Composites (20. Natural Fibre Composites)

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This paper presents the investigation on the mechanical properties of Napier grass fibres reinforced polyester composites. The Napier fibres were extracted from the grass internodes by the conventional water retting process. Extracted fibres were treated with 5%, 10%, 15%, and 20% sodium hydroxide (aq. NaOH) solutions to remove the surface impurities from the fiber strands. The morphology of the fibres before and after alkali-treatment was observed by field emission scanning electron microscopy. The results indicate that 10% alkali-treated Napier grass fibres yield the highest strength. The Napier grass fibre is then used as reinforcement to produced polyester reinforced composite, where their tensile and flexural properties were studied. The mechanical properties of composites produced are highly influenced by the interfacial adhesion between the matrix and the fibres. In general, the tensile and flexural strengths of the Napier/polyester composites increased with increase of fibre volume fractions, up to a maximum or to an optimum value, before starts to degrades .

8754 | INFLUENCE OF RTM, HAND LAY-UP AND AUTOCLAVE MANUFACTURING PROCESSES IN VEGETABLE FIBRE-REINFORCED COMPOSITE MECHANICAL PROPERTIES EXPOSED TO UV RADIATION (20. Natural Fibre Composites)

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Vegetable fibres exhibit potential advantages when used as a substitute for glass fibres in composites. Glass fibre-reinforced composites are materials widely used in applications such as blades for wind turbines, construction structures, boat hulls, automotive components, etc. In these applications the composite parts are exposed to environmental factors such as light, heat and water. Therefore, the study of the exposure of such materials/parts to environmental conditions such as varying temperature, humidity, ultraviolet (UV) radiation, etc. is of utmost importance, in order to assess the impact of these important ageing factors on their mechanical behaviour [1, 2]. To replace glass fibres with vegetable ones as reinforcement in composite exterior applications, the study of the influence of environmental conditions on their behaviour becomes crucial. Additionally, each manufacturing method can sometimes result in different performances of finished composite parts, especially so when vegetable fibres are used, so a study of the influence of the manufacturing process on the final properties of the composite is also important.
In the present study, the influence of the manufacturing method on the mechanical behaviour of jute fibre reinforced composites when exposed to UV degradation is assessed. The jute fibre-reinforced composites were obtained by three manufacturing processes: RTM, Hand Lay-up and Autoclave. The composites were produced in two configurations (Random mat (JRa) and Bi-axial (JBi)). The UV degradation of the composites was performed using a variation of ASTM standard (D2565-08) for accelerated tests, applying UVB (wavelength between 280 nm and 320 nm). The UVB was chosen because it is the most harmful UV radiation to reach the earth surface, and most polymers have their bond dissociation energies close to its wavelength (290-400 nm) [3].
To account for the changes in the mechanical properties of the degraded jute fibre-reinforced composites, 4-point bending (ASTM D6272-02) and experimental free vibration modal analysis tests were performed. The enhanced capacity of vegetable fibres to attenuate vibration is one of their most important advantages. In this sense, the analysis of the changes that can occur in their damping factors (attenuation of vibration capacity) is very important. For this purpose, the plates, suspended by wires, were excited by an instrumented hammer at different points, and from the recorded FRF's the natural frequencies and the damping factors identified by the Global Rational Fraction Polynomial (GRFP) method [4].
Additionally, to correlate the mechanical behaviour changes with the chemical modifications, two chemical analysis - Simultaneous Thermogravimetric and Differential Thermal Analysis (TG – DTA) and Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy were performed.
The differences found between composites produced by the different methods confirm the fact that the manufacturing process and conditions will

influence the composites' mechanical and environmental performance. For instance, the composites produced by the method using higher curing process temperatures (Autoclave processing) resisted better the degradation than the RTM ones, where lower curing temperatures were involved.
It can be concluded that damping is more sensitive to degradation exposure levels (UV exposure) than elastic properties. The damping capacity of jute fibre composites decreases with an increase of UV exposure.

8760 | Composites manufacture with alternatives products in Brazil (20. Natural Fibre Composites)

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In Brazil, there is growing demand for use of alternative resources fibrous face availability, low cost and ability to obtain products with higher added value The agricultural and forest cultures are, also, characterized by the productin of high amount of biomass after-harvest or deriving of the industrial processing, which may be allocated to the recycling, the incorporation and enrichment of the ground, the primary burning for the energy generation, and others.
Recently, research has been intensified concerning the manufacture and performance analysis of available low cost fibrous raw material panels, compared to the wood-panels from forest species, with additional tendency of increased agricultural waste availability.
However, alternative sources of lignocellulose fibres in the MDF manufacturing process have been explored, namely by using agricultural and forestry waste, in a policy of better preservation and management of the available natural resources
In the present work, the analysis of the potentiality of application of this kind of residues in composites is made, with emphasis in the biomasses from sugarcane, bamboo and cement-wood, presenting initial results that indicate its viability of uses. Local experiences and the advances in the research on the production and the quality of composites will be showed.

8811 | Bond behavior of flax-FRCM and PBO-FRCM composites applied on clay bricks: experimental and theoretical study (20. Natural Fibre Composites)

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The application of composite materials as structural strengthening requires the use of special adhesives. The choice of the adhesive depends on several factors, one in particular is related to the characteristics of the support (concrete, masonry or wood). Usually, the technical data sheet for the FRP-based structural strengthening give specific instructions about the type of adhesive to be used depending on the type of work to be performed. There are many types of natural and synthetic adhesives: the most suitable adhesives for composite materials are based on epoxy resin; adhesive-based on mortar are currently the topic of several researches in order to ensure sustainability and to use renewable technologies also in the field of civil engineering. The well-known problems of debonding, especially in the structural applications, depend precisely from the relationship between the adhesive and the mechanical properties of the substrate. The bond failure of polymer matrix-based composites usually occurs with detachment of part of the surface, so called "peeling". Consequence of this, the mechanical properties of the support play a role of primary importance, as said: the maximum adhesion stress is, with good approximation, linearly proportional to the tensile strength of the support, and the fracture energy is, linearly proportional to the square root of the tensile strength of the same support.
In this paper an experimental investigation dealing with the use of natural fibers applied to masonry substrate, was carried out in the Civil Engineering Laboratory of the University of Calabria. The experimental investigation was organized in two parts: experimental tests and theoretical approach. For this purpose, single-lap shear bond tests were carried out on typical masonry clay brick, with dimensions of 200x12x50 mm3, externally strengthened with composite materials using special steel formworks. In particular two different composite materials were manufactured in order to strengthen the bricks: flax fabric-reinforced cementitious matrix (flax-FRCM) and PBO fabric-reinforced cementitious matrix (PBO-FRCM). About the specimens characteristics, it still does not exist a specific standard that gives recommendation about natural fibers-based composites, indicating geometric properties or special configurations of the specimens or of test machine. Consequently to this, the typical configuration of tests used for masonry substrate reinforced with GFRP or CFRP was made reference. Regarding the bond length for each specimen, two sizes equal to 50 mm and 100 mm were used, taking into consideration the design procedure suggested by the standards. The results obtained were compared both from the point of view of the material used (natural and synthetic) in terms of failure modes and adhesion strength, and from the mechanical properties point of view, in terms of the maximum load capacity, fracture energy and bond stress. The interfacial bond stress–slip laws have been analyzed comparing the different specimens built and composite materials used. At the end, a comparison between the experimental results achieved and that one proposed by Italian design code CNR 200 R1/2012 was performed, which currently represents the Italian normative reference on design and construction of externally bonded FRP systems for strengthening existing structures, picking out some relevant aspects about design procedures.

8832 | A Study on the Structural Performance of Jute Fiber-Based Composite Tubes under Axial and Transverse Loadings (20. Natural Fibre Composites)

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Natural fiber-based composites such as jute-polyester composites have the potential to be more cost-effective and environment-friendly substitutes for glass fiber-reinforced composites which are commonly found in many applications including automotive body structures. This paper focuses on the behaviors of woven jute-polyester composite tubes of square and double-hat shaped sections subjected to axial quasi-static and impact loads. In order to make an assessment of load carrying capacity of such tubes and the axial deformation that they can undergo, by theoretical or numerical means, the mechanical properties of the laminates that the tube walls are made of would be necessary. Hence, mechanical characterization of jute-polyester laminates of different fiber volume fractions is carried out in the form of determining tensile and compressive stress-strain curves till failure from coupon tests. The basic material characterization of jute-polyester laminates is followed up with axial quasi-static testing of jute-polyester tubes of cross-sectional shapes mentioned above and obtaining the load-displacement curves. It is noted that for each cross-sectional profile, tube laminates of two different ply

counts were considered. Experiments were then conducted on similar components in an instrumented drop-weight impact testing device to investigate crash performance characteristics such as mean crush load, absorbed energy and specific energy absorption. A comparison is made between the performances of square and double-hat section tubes in quasi-static and impact tests. Additionally, the load-displacement behaviours of tubes of a given sectional profile obtained through quasi-static and impact tests are compared. As many structural applications involve transverse loading of components, the behavior of double-hat jute-polyester components under transverse impact loading is investigated. Finally, a comparative study is done between jute-polyester and glass-polyester components of double-hat sectional profiles subjected to axial quasi-static and impact dynamic loading, as well as transverse impact loading. The failure modes of jute-polyester and glass-polyester tubes under axial loading are discussed. At the end, it could be concluded that double-hat section jute composites tubes perform in a similar manner as compared to their square section counterparts, and jute composite tubes can be a structurally effective alternative to geometrically similar components made of well-established glass fiber composite material.

8864 | Low impact behaviour of hemps fibre reinforced epoxy composites (20. Natural Fibre Composites)

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In this study, the behaviour of hemp fibre epoxy composites subjected to a low-velocity impact loading using an instrumented falling weight impact equipment, is presented.
Two types of hemp reinforcements were used: unidirectional with a weight of 340 g/m2 and bi-directional fabric with a weight 362 g/m2. Three types of balanced laminates (0°/90°) were studied: 4 plies, 8 plies, 12 plies.
The laminates were fabricated by RIFT process. The reached volumetric fibre percentage Vf was not too high. It assumed a value of 30% for the unidirectional reinforcement and an average value of 28% for the bidirectional one. It is due to the fact that the hemp reinforcement presents a large mesh that inhibit the possibility to have high values of Vf with RIFT process.

The impact behaviour was analysed carrying out tests impacting the square specimens, 100x100mm, cut from the laminates with a hemispherical tup geometry with a diameter of 19.8 mm and a velocity of 4.0 m/s. Both penetration and indentation tests were performed at the aim to investigate about the damage start and evolution.
The damage was observed by an optical microscope: an interesting compressed central zone of the laminate under the impact point was noted.
By the analysis of the results, it is possible to assert that natural fibre composite has a potential to be widely applied alternatively to a fibreglass composites in sustainable energy impact absorption structures.

8927 | Preliminary investigations on Sisal Fibre Reinforced Aluminium Laminates (20. Natural Fibre Composites)

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Fibre Metal Laminates (FML) have been widely used to manufacture airframe components. Sisal fibre Reinforced Aluminium Laminates (SiRALs) have been fabricated by cold pressing and evaluated under tensile testing. The results were compared with a commercial FML constituted of polyethylene core and aluminium (PEFML) prepared via hot pressing. The pristine sisal fabric and the sisal laminate composites were also tested to better assess the properties achieved by the SiRALs. A commercial sisal fabric provided acceptable mechanical properties for the fabrication of laminate composites, and consequently, sisal fibre reinforced aluminium laminates (SiRALs). A delamination of the composite (core) was often observed during the tensile testing of SiRALs, which can be attributed to the weak interfacial adhesion with the aluminium sheets. The polyethylene based fibre metal laminates (PEFML) did not exhibit delamination, indicating a good interfacial adhesion. The SiRALs achieved superior mechanical properties compared to the PEFMLs, revealing a promising sustainable material for many applications in engineering. A chemical treatment of the sisal fabrics and the aluminium sheets will be the scope of future investigations in order to enhance the interfacial adhesion and the mechanical properties of the sandwich structures.

8989 | MECHANICAL CHARACTERIZATION OF REINFORCED COMPOSITES WITH UV-IRRADIATED BANANA FIBERS (20. Natural Fibre Composites)

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Surface treatments in banana fibers (BFs) can generate significant superficial and structural changes enabling the production of mechanically stronger composites. In this way, the objective of this study was to evaluate the mechanical properties of polyester composites reinforced with UV-irradiated (λmax = 400 nm) banana fibers. Possible structural changes in the fibers and the consequent influence on their mechanical performance through tensile test on fibers, based on ASTM C1557-03, were investigated. Thermal and surface characterizations for non- and irradiated fibers were performed by Differential Thermal Analysis (TG/DTA/) and Scanning Electron Microscopy (SEM), to investigate the influence of UV irradiation on the BF surface. Polyester composites were subjected to the impact test based on ASTM D6110-10 to evaluate the adhesion matrix/fiber. Mechanical characterization shows that rupture stress and Young's modulus increased for treated fibers and the SEM showed an increase of surface area of the irradiated fibers, which can improve the mechanical anchoring with the polymeric matrix.

9018 | Effect of Alkali Treatment on the Thermal Stability of Alkali Treated Water Hyacinth/Multi-walled Carbon Nanotube/High Density Polyethylene Composite (20. Natural Fibre Composites)

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This article studies the effect of alkali treatment on the thermal stability of alkali treated waterhyacinth and multi-walled carbon nanotube (MWNT) filled high density polyethylene (HDPE) composite. The composites were prepared by internal mixing process. The ratio of water-hyacinth fibre to HDPE was fixed to 1: 4, while the content o f MWNT was 2 mass % of the composite. Thermal stability of the composites was determined by means of thermogravimetric analysis. The composites were alkali treated at various alkali concentration (2, 4, 6, and 8 mass %, respectively). The results show that thermal stability of the composites slightly increases with the increase of alkali concentration.

9030 I Effect of pressing parameters and chemical modifications of flax fabrics on microstructure and mechanical properties of natural fiber-reinforced composites (20. Natural Fibre Composites)

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Natural fiber-reinforced composites have been applied mainly in the automotive industry, replacing primarily glass fiber-reinforced plastics. Apart of the obvious environmental issues, the major motivation for natural fiber application is the potential for weight saving, since natural fibers have lower density than glass counterparts. However, the use of natural fibers implies several challenges, especially with regard to reproducibility of material properties, aging or fire behavior. In this context, the fiber preparation and further processing of the natural fibers play a crucial role. For good composite quality, the structure of the fiber bundles and the resulting fiber-matrix adhesion are of special importance. This requires specific solutions, depending on the types of fiber and matrix used.

A typical method for processing technical textiles is resin transfer molding (RTM) and its modifications. In this method fiber fabrics are placed in a mold, which is then closed and clamped. Low-viscosity resin is pumped in under pressure, displacing the air and venting it at the edges, until the mold is filled. RTM process is suitable for medium volume production. A competitive method to RTM has been developed at ILK TU DRESDEN, i.e. resin powder molding (RPM) and thermoset sheet forming (TSF) based on pressing process. An unique feature of these processes is their high efficiency. Both techniques work with a new formula of powdered, single-component epoxy resin (A.S.SET® Powder). A.S.SET® Powder is solid at room temperature and liquefies when subjected to an increase in temperature before hardening in a short time. It is the first known thermoset material that can be processed like thermoplastics. RPM and TSF are therefore distinguished by a rapid processing speed known from thermoplastic composite production. What is more, the additional systems previously used to prepare, dose and inject thermoset resin components are no longer required.

In this paper, the effect of RPM and TSF processes parameters (temperature, time and pressing force) on microstructure and mechanical properties of flax fiber reinforced plastics (FFRP) has been shown. The goal of the performed investigation was selecting the most favorable parameters of pressing to manufacture natural fiber-reinforced composites characterized by high quality, good mechanical properties and low amount of defects in the structure. Microscopic and computed tomography analysis have been carried out to describe the microstructure of produced samples and to assess their quality. Mechanical properties of investigated materials have been determined in standard strength tests. In addition, different chemical modifications of surface of flax fibers has been conducted to improve the adhesion between reinforcement and composite matrix and thus to increase the strength parameters. The obtained results allowed to manufacture high quality natural fiber composites in highly efficient, one-step, automated RPM and TSF processes.

9037 I Improving the Strength and Service Life of Jute/Epoxy Laminar Composites for Structural Applications (20. Natural Fibre Composites)

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Natural fibers are lighter, less expensive, and less abrasive than synthetic fibers such as glass or carbon, and provide a resource that is both annually renewable and biodegradable. This study will use surface treatments and Z-axis reinforcement technology to improve the strength and fracture properties of natural fiber composites (NFCs), thus increasing its ability to bear loads. This enhancement of performance properties will expand applications of the NFCs in industries such as automotive and housing construction industries, and will provide a more sustainable, environmentally friendly, and inexpensive alternative over traditional glass or carbon fiber composite materials.

9078 I Study on mechanical properties and bio-degradability of matrix modified banana fiber/ Polyester composite (20. Natural Fibre Composites)

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Composites comprise of two materials binder and reinforcing agent. The binder act as stress distributor and reinforcing agent as the load bearer. These are used for structural and load bearing applications due to their high strength. Presently natural fibers are used in the composite preparation along with the polymeric material as the matrix to overcome the problem associated with limited global petroleum feedstock and voluminous waste generated after disposal of the composite material. The natural fiber used in composite gets biodegrade after use when disposed to the environment but the polymeric materials are generally non-degradable and remains as such for long-time after disposal. The use of natural fiber and natural resin modified polymer or plant based natural resin, as matrix in the composite preparation will reduce the waste accumulation after disposal.
In the present study Euphorbia coagulum, a natural resin, modified polyester-banana fiber composite were prepared. We had prepared composite by

adding 40% banana fiber in unsaturated polyester resin and subsequently cross linked using methyl ethyl ketone peroxide and accelerator cobalt octoate. 40 % of Euphorbia coagulum was also added to the polyester resin to modify the matrix during the composite preparation. The physico-mechanical properties such as water absorption, izod impact, flexural strength and flexural modulus of composites were characterized. The composites were also characterized bio-degradation by estimating of CO2 generated. Results shows that the addition of Euphorbia coagulum decreases the water absorption by 20% whereas izod impact, flexural strength and flexural modulus increases by 8%, 25% and 8% respectively as compared to composite without Euphorbia coagulum. The microbial growth of the Euphorbia coagulum modified polyester composite shows that due to the presence of coagulum in coagulum modified composite the growth of the A. nigar was found on the cut as well as skin surface where as in case of polyester composite the growth was only on the cut surface where banana fiber is exposed because polyester resin resists the growth of A. nigar. The bio-degradability study of the Euphorbia coagulum modified polyester banana fiber composites shows that the bio-degradability of the Euphorbia coagulum modified polyester banana fiber composite are around 40 % within the test duration 90 days in comparison to the reference material i.e. cellulose which degrades around 90% within same duration. This shows that developed Euphorbia coagulum-polyester-banana fiber composite will get degraded when exposed to the land filling sites.

9087 | SURFACE PROPERTIES OF PAPERS COATED WITH THE STYRENE-ACRYLATE BASED COPOLYMERS (20. Natural Fibre Composites)

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The surface resistance of papers to the liquids is very critical and needs to be improved by different treatment techniques. Surface sizing is one of the widely used methods of those treatment techniques. Surface sizing of the paper is simply defined as drying the surface partially, then wetting of paper with sizing materials and re-drying of paper. Large amount styrene-acrylate based copolymers are used in paper industry for surface sizing. Surface sizing are able to resistance to penetration of the liquid on the paper, improves the surface properties of the paper and the physical properties such as the internal bonding. The surface prevents plucking and dusting, thus, it can be possible to control the penetration of the ink and water. Surface sizing also improved paperboard folding and impact resistance. In addition, this sizing process is also help flame, bacteriological and oxidation resistances of the paper.

In this study, styrene-2-ethyl hexyl acrylate copolymer based surface sizing materials were synthesized by emulsion polymerization. Four different emulsifier (E-1, E-2, E-3 and E-4) and two different initiator (potassium per sulfate(K) and 2,2'-Azobis (2-methylpropionamidine) dihydrochloride (A)) were used and twenty-four different copolymers were produced. Papers used in the study were prepared by using Estanit (GmbH) paper machine. Produced papers were cut in 12x12 cm sizes for characterization tests. Coating process was performed by using Mathis SVA-IR-B 605 size press. Papers which were surface coated were characterized by using contact angle measurements, mechanical tests, Cobb tests and SEM. Samples with coated copolymers with initiator A had more hydrophobic surface than samples with coated copolymers with initiator K (θc > 90o). The lowest water penetration value was obtained by Cobb for the emulsifier E-3 and initiator A.

9106 | The use of Kenaf fiber reinforced polymer to confine the concrete cylinder (20. Natural Fibre Composites)

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Recently, Fiber Reinforced Polymer (FRP) wrapping technique has been used as an alternative to retrofit concrete members especially in columns. FRP based on natural fibers are new materials used in wrapping technique and are an alternative to synthetic fibers. The ability of natural fibers based FRP (bio-composites) as an element to wrap concrete columns was studied in this study. This research is a laboratory experiment conducted on the performance of concrete columns subjected to axial compression loading. Many samples of plain concrete cylinders were prepared for testing which consists of unwrapped samples, samples wrapped with glass FRP, and samples were wrapped with Kenaf FRP. Then, the results from tests and a confinement theoretical model will be surveyed.

9127 | Structure and Properties of Novel 2D composites of Sericin- starch using cross- linkers. (20. Natural Fibre Composites)

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Silk protein sericin / starch composite films were prepared by casting.This research were focused on the exploration of waste protein sericin blended with starch for useful product. Two cross linking agents, namely glycerol and PEG wre used and casting was done to produce thin films. Surface analysis was studied by SEM, showing a rough and porous surface in sericin- starch films, application of cross linkers rendered the surfaces intact and smooth. Secondary structure determination by FT-IR and XRD showed the native structures of sericin and starch as well as the films, with a reduction in crystalline β sheet conformations after the cross linking. Thermal properties of the films also showed better thermal stability of the cross linked films compared to the non- cross linked one. This study reveals that cross linking of sericin with starch is possible with PEG and glycerol. The findings also showed PEG to be a better cross linker than glycerol. This study provides insights into using sericin- starch composites as biomaterials in biomedical and allied fields and also utilizations of waste materials.
Keywords- ASericin,Starch, Thin films, . Thermal properties, . Surface analysis, . casting, cross- linkers.

9131 | EFFECT OF DIFFERENT SURFACE TREATMENT METHODS on PHYSICAL PROPERTIES of BANANA FIBERS (20. Natural Fibre Composites)

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Banana is one of the earliest and important fruit crops cultivated by man in Mediterranean zone. Banana is distributed in more than 120 countries, over an area of 48 lakh hectares. Banana farming generated huge quantities of biomass all of which goes as waste due to non-availability of suitable technology for its commercial utilization.
Normally this biomass is used for animal feed and fuel. Banana fibre is a lignocellulose based fibre and it has excellent sound absorption and mechanical properties. Therefore it is used in composites as reinforcement material in automotive industry
After cultivation of banana fruits tons of banana fibre waste are remained from banana trees in Turkey.
In this study, Banana fibres were treated with 99% formic acid by using conventional (15, 20, 30 minutes, 600C) and microwave energy (1, 3and 5 minutes) methods. Elongation (%), tensile strength (MPa) and weight loss (%) properties of treated banana fibres were investigated.

Keywords: Banana fibres, surface treatment, microwave energy, physical properties

9132 | Effect of Ecological Methods on Surface Treatments of Cotton-Polypropylene Waste Fiber Reinforced Polymer Composites (20. Natural Fibre Composites)

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Assortment is very important and sensitive process for the ready-made garment production companies however tons of fabrics are wasted during the garment production every year. Generally waste fabrics are collected and sent to the waste fiber production companies to get waste fiber to be used for the insulation and decoration purposes.
In this study, ready-made garment waste cotton and polypropylene fibers were used. Waste fabrics were collected from garment production companies. And these fabrics were processed by Punteks and transformed into fiber form. Then surface treatment process was applied by using ultrasonic and microwave methods to ready-made garment waste cotton fiber with NaOH, acetic and formic acids then treated cotton fiber mixed with ready-made garment waste polypropylene fibers. Finally polymer composites were produced from these treated cotton/polypropylene blend by using thermoset polyester resin as matrix. Waste fiber reinforced polyester composite structures were produced by using vacuum infusion method. Tensile strength and charpy impact strength properties of treated waste cotton/polypropylene fiber blend reinforced thermoset polyester composites were investigated. Higher tensile and charpy impact strength results were obtained from microwave treated cotton - polypropylene waste fiber reinforced composites.

9159 | Fracture mechanics property of high strength concrete reinforced with basalt fibers (20. Natural Fibre Composites)

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Basalt fiber is a new reinforced material for concrete, and is made of pure natural basalt ore by melting wiredrawing under high temperature. Basalt fiber, a typical of silicate fiber, has higher cost performance, high tensile strength, corrosion resistance, high temperature resistance and high stability, so it is a good substitute for other kinds of fiber. In addition, basalt fiber possesses extremely low coefficient of thermal conductivity, good sound insulation, insulation, explosion protection and good flame retardant. Basalt fiber has a wide and optimistic application prospect in the field of civil engineering because of the above advantages.
This paper presents the research on fracture mechanics property of high strength concrete reinforced with basalt fibers. The process of three-point bending test for notch concrete beam, the load-displacement curves and the load-opening width curves are given. The fictitious crack model and the fracture mechanics are applied to analyze the experimental results and study the basic mechanics and fracture behavior. To discuss the influence of basalt fiber on the fracture behavior, and give the influence rule of basalt fiber on the fracture parameters including fracture energy, fracture toughness and cracking subcritical extension. Based on the above research, this paper discusses the process and mechanism of fracture, and analyzes the mechanism of reinforcing and toughening effect of basalt fiber.

9183 | SYNTHESIS OF MICROCELLULOSE (MCC) AND NANOCELLULOSE (NCC) FROM EUCALYPTUS KRAFT ssp PULP (20. Natural Fibre Composites)

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Natural fibers have been attracted significant interest due to its renewable nature, its vast source of raw material, besides having good mechanical properties and low cost. The cellulose present in cell walls of plants can be purified and isolated, acting as a reinforcing agent in polymer composites, in order to obtain lighter, resistant and biodegradable composites. The techniques of acid hydrolysis are methods used to isolate crystals of cellulose, using different acids, resulting in different materials. In this study it was possible to verify the effect of the acid hydrolysis process, with hydrochloric acid (HCl) and sulfuric acid (H_2SO_4), resulting in MCC and NCC by one hydrolysis step, and then were analyzed for its chemical and morphological characteristics, presenting significant improvements on these properties.

Keywords: cellulose, composites, microcellulose, nanocelulose, hydrolysis, fibers.

9203 | Mechanical and water absorption behavior of surface modified banana/sisal fiber reinforced poly(lactic acid) bio-composites (20. Natural Fibre Composites)

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The objective of this study is to investigate the effects of fiber surface treatment on tensile, flexural, impact and water absorption properties of neat PLA and UT-BSF/PLA & AA-T-BSF/PLA bio-composites. Bio-composites were prepared by mixing 70% of biodegradable poly (lactic acid) (PLA) with 30% weight short banana/sisal fibers (BSF). The chemical modification of BSF was done by sodium hydroxide (NaOH) followed by acrylic acid (AA) to augment the compatibility. PLA and BSF in the combination of UT-BSF & PLA, AA-T-BSF &PLA and neat PLA were mixed in twin screw extruder and processed by injection molding machine. Mechanical and water absorption properties of PLA and BSF composites were also examined. Scanning electron microscopy (SEM) images of fractured surfaces of BSF and composites validate the enhancement in adhesion between BSF and PLA matrix. Results obtained by water absorption analysis and SEM showed that addition of AA-T-BSF in PLA increased the mechanical properties of AA-T-BSF/PLA composites to a greater extent than UT-BSF/PLA composites and neat PLA. The results obtained from the study are discussed in detail.

Keywords: poly (lactic acid), banana/sisal fibers, acrylic acid, Mechanical properties, water absorption properties

9230 | An Experimental Investigation into the Enhanced Mechanical Performance of A Hybrid Jute-Steel Composite (20. Natural Fibre Composites)

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Although jute-polyester composites have been studied in the past, the effect of adding relatively inexpensive and recyclable steel wire-mesh (SWM) to such composites on mechanical properties of the resulting hybrid composites does not appear to have been reported earlier. In the present work, a comparative study has been carried out between jute-polyester and jute-SWM-polyester composite laminates with similar volume fractions of the polyester resin. Initially 10-ply jute-polyester laminates were prepared using commercially available woven jute mats. By keeping the total number of plies as constant, jute-SWM-polyester hybrid composites were made with 6 plies of woven jute mat and 4 plies of SWM. The volume fraction of polyester resin was maintained in a range of approximately 60-70% by changing the thickness of laminates during fabrication using a compression molding setup. Key mechanical properties such as stiffness modulus and strength under tensile, compressive and flexural conditions were determined experimentally using coupon specimens in a UTM under quasi-static conditions. It has been found that jute-SWM-polyester hybrid composite has higher stiffness and tensile strength as well as substantively higher flexural strength as compared to plain jute-polyester composite of same number of plies and similar volume fraction of matrix. SEM (Scanning Electron Microscopy) images were used to gain insights into the failure mechanisms of hybrid composites in tensile tests. The micrographs indicate that steel wires bond well with polyester-based matrix and fail by snapping under tensile load instead of being pulled out of the matrix.

9352 | Numerical simulation of composite hemp fibers behavior Application to automotive part forming (20. Natural Fibre Composites)

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Hemp fibres are using as reinforcement for compounds based on polymer in different industrial manufacturing (aerospace and automotive) for their interesting mechanical and ecological properties. The hemp fibres present a non-constant cross section and complex geometry that can have a high effect on their mechanical properties. In this study, a micro-traction test coupled with a numerical imaging treatment and a finite elements method are used. The mechanical tensile test allows to determinate the evolution of the traction load in function of the displacement until the fibre crack. The used fiber are incorporate in plastic material is order to obtained PP/hemp reinforcement composite part. Static and dynamic tests are proposed in order to study the simulation of green material behavior subjected to forming load.

9355 | Characterisation of hybrid flax carbon fibre composites (20. Natural Fibre Composites)

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Carbon fibre composites have found many applicaitons in the automotive and motorsports industry. The vibration characteristics of the composites can be improved by using natural fibres like flax. They hybrid compoiste (flax-C fibre) should be able to damp vibrations effectively. In this study the mechanical and damping properties of CF, (FF) and hybrid composites layups were examined. The hybrid layups consist of two different solutions: "sandwich" (C3F6C3), in which six layers of FF were placed in the middle of the specimen, with three layers of CF were placed at each side of them, and "alternate" (((C/F)3)s), in which alternate layers of CF and FF were used, with two of FF in the middle. The damping behaviour of the specimens was examined using Centre Impedance Method (CIM) and the loss factor n of each specimen was measured. As expected, FF specimens showed greater damping performance than CF. C3F6C3 and ((C/F)3)s damping behaviours were pretty close, with both of them performing significantly better than the CF. The mechanical testing consisted of tensile and flexural testing, in which C3F6C3 behaved better than the ((C/F)3)s in both types of testing. In addition to this, C3F6C3's flexural results were quite close to the CF ones. These results shows that C3F6C3 layup is a promising solution to achieve vibration damping with an acceptable compromise in mechanical properties.

7526 | A non-intrusive automated procedure based on active thermography for defect localization in plane composite.

(21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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This communication is focused on the implementation of a local pulsed thermography method in order to locate a defect in a plane composite. For such a local approach, the investigated plane composite is periodically heated on a small surface (several square centimeters) and thermal waves propagation is observed up to three thermal diffusion length on the same material surface (in reflexion). Both modulus and phase lag of the measured periodic signal are modified by the defect neighborhood and the seek for the most effective area leads to the defect localization. The contrast between the composite thermal behavior with or without defect is a relevant tracker of the defect proximity. Several criteria are proposed in order to quantify the contrast. Issued from cartographies differences, they are based upon usual functional norms and do not induce the same sensitivity to defect neighborhood. A simplex method is proposed for the automated procedure leading to the defect localization. Such method is based on an iterative process in order to explore the material surface (using an infrared camera) considering the investigation of new points (potentially better candidates for the defect location). New point coordinates are calculated from the previous points which are weighted considering the above mentioned criteria. Experimentations are performed according to the following steps : heat flux calibration, reference measurements, heat source shifting for automated scan.

7633 | Non-destructive evaluation of satin woven fiber reinforced polymer matrix composites **(21. Non-destructive Inspection Techniques for Composite Materials and Structures)**

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The aim of this study is to utilize infrared thermography to assess the critical damage states, and to capture the evolving damage processes, of 5HS and 8HS woven carbon fiber/epoxy composites subjected to uniaxial in-plane tensile quasi-static and fatigue loading. Quasi-static test results revealed that the dominant damage mechanisms were matrix cracks contained within the weft yarns, which initiated at the thermally-detected material thermoelastic limit and were confirmed through SEM observations. An established thermographic technique was also used to confirm the existence of a high cycle fatigue limit, which may in fact be a characteristic of all fabric reinforced polymeric composites. Temperature profiles captured during cyclic testing directly correlated with corresponding stiffness degradation profiles, providing support for thermography as an accurate fatigue damage metric. The infrared camera was able to detect the evolution of weft yarn cracking during the initial stage, as well as the initiation and growth of interply delamination cracking during the final stage of three-stage cyclic damage evolution. The reported results and observations provide an important step in the validation of thermography as a powerful non-destructive tool for assessing the development of damage, as well as predicting the critical damage states of fiber reinforced polymeric composite materials.

7674 | Identification of dynamic stiffness distribution of fatigue loaded polymer concrete through vibration measurement **(21. Non-destructive Inspection Techniques for Composite Materials and Structures)**

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Experimental methods to measure the stiffness distribution of the fatigue loaded polymer concrete was proposed. The fatigue life of the polymer concrete which is a mixture of epoxy resin and aggregates was measured by increasing load cycles. To investigate the fatigue life change, frequency dependent dynamic stiffness of the polymer concrete was obtained by measuring the transfer function of concrete. The sensitivity function of the dynamic stiffness was also calculated. The dynamic stiffness distribution with location was derived using the frequency dependent stiffness and the sensitivity function. To verify the proposed methods, the micrograph of the concrete cracks was observed by an optical microscope. Consequently, the durability of the polymer concrete was validated in comparison with the cement concrete. The result of this study will be useful for identifying fatigue strength properties of structures under dynamic loads.

7769 | Evaluation of residual strain field and temperature mapping in 3D printed layered polymer plates **(21. Non-destructive Inspection Techniques for Composite Materials and Structures)**

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The technological advancements have resulted in the generation of new manufacturing methods for the production of innovative and advanced components. In our days, such a novel manufacture technology is the Additive/Rapid/Layered Manufacturing (AM/RM/LM) which has as basic operating principle the deposition of layers one upon the other. A major benefit provided by AM techniques arises from the potentiality of building functional parts with intricate design features and locally defined mechanical properties (high strength, stiffness, lower weight, etc.). Given the flexibility of the additive process, these techniques can be used in the design and manufacturing of composite parts.

Fused deposition modeling (FDM) is a layered manufacturing technology that produces parts of complex geometry by the layering of extruded materials, such as Acrylonitrile-Butadiene-Styrene (ABS) thermoplastic. The ABS material is initially in the raw form of a flexible filament which is then partially melted and extruded through a heated nozzle in a prescribed parallel road pattern onto a platform, layer by layer at chamber temperature. The deposited material (individual roads) cools, solidifies, and bonds with the neighboring material. In FDM, as in other LM processes, the heating and rapid cooling cycles of the work materials will aggravate non-uniform thermal gradients and cause stress build-up that consequently result in part distortions and dimensional inaccuracy. Once the building process is completed, the FDM built part can be viewed as a laminate composite structure with anisotropic material properties. The mechanical properties of FDM parts are not only controlled by the build material, but also influenced by the selected fabrication

parameters. Analysis of past research suggests that quality of FDM parts relates to component strength, surface finish and dimensional accuracy and it depends significantly on few primary control factors such as layer thickness, deposition direction of filament roads, road (raster) width, air gap sizes between filaments and stacking sequence of the vertically deposited layers of bonded fibers.

This paper presents the work done on investigating residual strains accumulation in FDM-built structures as a function of part orientation on the building platform. The developed residual strains at the end of the fabrication process were recorded using a series of optical sensors, with a short fiber Bragg grating (FBG), embedded at various locations within the middle plane of thin plate specimens. In addition, temperature mapping of the fabricated specimens during the deposition process was performed. An effort was put to compare the FBG-based findings to the ones using a full-field measurement technique such as Digital Image Correlation (DIC). To assess the strain development without constraining effects from any adhesion to the building platform surface, measurements were taken at free-standing state at the end of the fabrication process. It is demonstrated that the magnitude of the solidification induced residual strains is significant and depends on the selected material deposition direction.

7781 | On the use of Laser-spot Thermography for the Nondestructive Inspection of Composites (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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In the study presented in this paper we applied a fractal analysis to analyze raw thermal infrared images obtained using the nondestructive evaluation method of the laser spot thermography, that aims at detecting the presence of surface defects. A laser was used to scan a test specimen through the generation of single pulses. The temperature distribution produced by this thermoelastic source was measured by an infrared camera and processed with an algorithm based on fractal analysis. The algorithm was first proven by analyzing simulated thermal images and then it was experimentally validated by scanning the surface of a CFRP composite plate with impact-related defects. We found that the method allows for the detection of damage. Some of the advantages of the proposed method with respect to existing approaches include automation in the defect detection process.

7782 | Dispersion analysis of Lamb waves in composite laminates based on Reverberation-ray theory (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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On the basis of Reverberation-ray theory, this article presents the development of a new mode tracing method using which the dispersion curves of Lamb waves in composite laminates can be calculated efficiently. The dispersion relations are built by Reverberation-ray formulas in three-dimensional Cartesian coordinate, and the transcendental equations are numerically solved by the improved mode-tracing method. Compared with conventional mode-tracing method, a slope control algorithm is adopted in the new approach to avoid the switch of tracer from one mode to another around the cross point of dispersion curves, and the problem of solution loss can be solved. Numerical verifications are conducted to assess the performance of the proposed method and the good agreement with the existing experiment results demonstrate that the proposed method is efficient and robust for the dispersion analysis of Lamb waves in composite laminates with arbitrary lay-up. In experimental study adopt two-dimensional FFT method to get the relations of frequency and wavenumber directly. In addition, combined with this method, the propagation characteristics of Lamb waves in defective composite laminates is further investigated and the potential of this method in nondestructive evaluation (NDE) is discussed.

7820 | Direct Estimation of the Elastic Constants of CFRP Plates by using Lagrange's Equation (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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This investigation takes a closer look onto a method of estimating the elastic constants of unidirectional carbon fiber reinforced plastic (CFRP) rectangular plate samples by using the geometrical shapes, densities and eigenfrequencies of a sufficient number of experimental measured vibration modes as input parameters. The measurement of the eigenfrequencies and the identification of the mode shapes have been done by four different experimental setups to compare the influence of different boundary conditions. The computational procedure uses an analytic equation for the bending of orthotropic plates. The solution for the free-free boundary condition serves the input for the lagrange's equation of motion. By separation of variables, a solution for the nth eigenfrequency of the nth mode shape can be found that is used to set up a least squares estimation, with n used vibration modes, to estimate the elastic constants of the measured plate. These constants are then used in a finite element simulation to proof the accuracy of the estimation by a sensitivity analysis. It has been found that there is a strong dependency on which modes are used for estimation. The method has been performed on aluminum and different CFRP plates to study the orthotropic material behavior. This method is a fast, easy to use and non-destructive way to identify the elastic constants compared to ordinary tensile tests which have been performed afterwards to proof the method in an experimental way.

7843 | Nondestructive evaluation technique of multiple-delaminations in glass fiber reinforced composites using terahertz spectroscopy (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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The glass fiber reinforced composites are being widely used as structural components in various industries because they provide higher specific strength and superior impact characteristics to the structure compared to the conventional metallic materials. However, its reliability and mechanical properties can be much weakened by various hidden defects and damages. Therefore, appropriate nondestructive inspection techniques are required to detect and characterize hidden damages in their inside in order to ensure the safe use of composite structures. Terahertz (THz) wave has recognized as one of the new powerful nondestructive evaluation (NDE) technique for fiber reinforced composite structures because it has many advantages which can overcome the limitations of conventional NDE techniques such as x-rays or ultrasound. The THz radiation (0.1-10THz) can penetrate common nonmetallic materials, and offers a noninvasive, noncontact, nonionizing method evaluating composite damages, also it gives a broad range of information about the material properties. In this study, the pulse type THz spectroscopy imaging system was devised and used for detecting and evaluating of hidden delamination in the glass fiber reinforced composite laminates. The interaction between THz and the glass fiber composite was analyzed respect to the type of delamination, including their thickness, size, depth and numbers of overlaps among multiple-delaminations in through-thickness direction. Both of transmission and reflection configurations were used for evaluation of hidden delamaniations and THz wave propagations through the delaminations were also discussed. From these results, various hidden delaminations inside of the glass fiber composite were successfully detected using time-domain THz spectroscopy imaging system and also compared to the results of C-scan inspection. It is expected that THz NDE technique can be widely used to evaluate the reliability of composite structures.

7916 | Edge-illumination X-ray dark-field imaging for imaging defects in composite structures (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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We report on a novel X-ray imaging technique enabling the detailed visualization of the consequences of impact damage in composite materials. The system is based on edge-illumination [1] and can be implemented with conventional X-ray equipment, namely a rotating anode source and a digital detector, with the addition of two achromatic optical elements [2]. It is robust against vibrations and thermal stress and works well with a polychromatic energy spectrum. The system is multi-modal and provides three representations of the sample: absorption, differential phase and dark-field [3]. The latter is of particular interest to detect cracks and voids of dimensions that are smaller than actual spatial resolution of the imaging system. An example of application to a carbon fibre laminate plate consisting of 8 layers with a symmetric layup sequence of [0/90]2s will be shown. Low-velocity impact damage was induced using standard drop weight procedures. The plates and impact damage were initially characterized using ultrasonic measurements. Depending on the severity of the impact, fiber and matrix breakage and delaminations occurred. Future developments of the testing technique will also be discussed, which will include the implementation of quasi-3D approaches such as laminography, in order to separate the contribution to the projected image coming from separate planes in the composite structure.

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7917 | Spectromicroscopic characterization and magnetic properties of submicron Ni rod arrays in silicon dioxide matrix (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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Arrays of Ni particles embedded in a dielectric matrix with the enhanced magnetoresistance effect tunable by electric field is a potential candidate for magnetic field sensing applications (e.g. magnetic tomography 2D matrixes) and other novel electronic devices. The present work aims at microscopic and spectroscopic characterization of the morphology and local electronic structure of submicron Ni rods distributed on Si substrate inside SiO_2 layer as well as demonstration their transport properties.
Ni rods with ~ 350-500 nm diameters, embedded into the n-Si/SiO_2 porous template, were created by selective etching of swift heavy ion tracks (Au ions, 380 MeV) in a SiO_2 layer with the following electrochemical filling with nickel nanoparticles. The study of the carrier transport and magnetotransport in such nanostructures was performed over the temperature range 2 – 300 K and at the magnetic field induction up to 8 T. The obtained samples of Ni/SiO_2/Si structures was studied by the scanning electron microscopy and atomic force microscopy. Photo Emission Electron Microscopy (PEEM) technique were applied to investigate morphology and electronic structure of samples surface and interfaces between Ni rods and surrounding SiO_2 matrix at the room temperature. Synchrotron radiation of the Helmholtz Zentrum Berlin BESSY II storage ring were used for PEEM measurements performed at the Ni $L_{2,3}$ core level resonance. Ni $L_{2,3}$ X-ray absorption near edge structure (XANES) data extracted from PEEM imaging were used for samples surface and interfaces electronic structure characterization with energy resolution ~ 0.1 eV.
PEEM study allowed us to identify the predicted partial oxidation nearby individual Ni rods and to show the formation of 50 nm length bridges between Ni rods in their small groups. 20-50 nm transition area around each rod contained the metallic Ni as well as its defective residual nickel oxide pollutions were observed. Figure 1 demonstrates the PEEM image from the investigated sample as well as different XANES Ni $L_{2,3}$ absorption edges taken from different regions of interest consist of metallic Ni as well as residual surface oxidation products.
The observed huge magnetoresistance between 17 – 27 K (up to 40 000 %), which was tuned with transversal electric voltage applied, was attributed to the impurity avalanche mechanism at Schottky barrier formed at the interface Ni/Si.
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8060 | Using the Flexural Rigidity to Detect the Presence of Defects in Composite Sandwich Beams (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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A constant challenge to the composites industry is to determine the presence of defects in composite structures and by doing so prevent potentially catastrophic failures of critical components. A number of non-destructive testing techniques exist and include tap testing methods, ultrasonic scans, infrared thermography, optical inspection and interference techniques, as well as X-Ray techniques. An alternative defect detection approach proposed in this paper is to investigate the feasibility of using the magnitude of the flexural rigidity of composite sandwich samples as an indicator for the presence of defects.

Previous work has determined that the combined flexural rigidity of composite sandwich structures can be determined experimentally using Electronic Speckle Pattern Interferometry applied to loaded cantilever beams as well as PVDF sensors applied to vibrating beams, and that their results compare favourably with theoretical predictions.

To this end, a number of composite sandwich beams were manufactured and during the manufacturing phase delaminations introduced between the core and skin layer of the composite sandwich beams. Each beam manufactured included one defect and beams were grouped into sets containing same sized defects but at different locations, as well as different sized defects located at the same position in the composite beams. In order to verify the size and location of the man-made defects, a woodpecker tap tester was used. The beams were then clamped at one end and placed into vibration mode using an instantaneous force. Using PVDF sensors the beam’s natural frequency was recorded. The beams were then treated as cantilevers, subjected to an out of plane force and Electronic Speckle Pattern Interferometry was used to determine their displacement profile.

For both sets of investigations the flexural rigidity of the beams was determined and compared with the flexural rigidity of identical composite sandwich beams without defects. The results obtained from both inspection methods are presented and their viability in determining the presence and magnitude of a defect discussed.

8084 | DAMAGE ASSESSMENT OF HYBRID FIBRE REINFORCED LAMINATES (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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The characteristics of fibre reinforced laminates have widened their use from aerospace to domestic appliances. New possibilities for their usage emerge almost every day. Their ability to be tailored for use and endless possibilities provided by the combination of reinforcements together with their alignment and fiber fraction, allow design engineers to have almost total freedom in the design of new parts. Unique properties such as low weight, high strength and stiffness are normally referred to whenever the advantages of these materials are listed. In the later stage of parts production, machining operations like drilling are frequently needed in composite structures, as the use of bolts, rivets or screws is required to join the parts. Generally, machined parts have poor surface appearance and tool wear is higher. One of the problems related with composites’ machining is the nature of the fibre reinforcement, which is usually very abrasive and causes rapid tool wear and deterioration of the machined surfaces. The special characteristics of these materials make them difficult to machine when compared to traditional materials. It is known that a drilling process that reduces the drill thrust force can decrease the risk of delamination thus increasing reliability. Delamination is the most usual damage and can reduce the bearing capacity of the plate. For that, damage assessment methods based on data extracted from images of drilled plates are of primordial importance.
The use of solid wastes as dispersive phase into polymeric composites has been investigated not only as a recycling proposal but also as an innovative material for specific engineering applications. In this work a batch of hybrid composites constituted of waste rubber particles and sugarcane bagasse fibres into a thermoset composite material are drilled to determine the effect of rubber particle addition (25 and 50wt%), rubber particle size (50-80 and 100-200US-Tyler), sugarcane fibre addition (3 and 5wt%), sugarcane fibre length (5 and 20mm) and fibre chemical treatment (with and without) on damage extension and related mechanical properties.
Damage extension is determined by enhanced radiography and images are then processed for damage measurement – diameter and areas.
A number of published criteria for damage assessment are compared and correlated with mechanical test results—bearing test and open-hole tension test.
The results demonstrate the effect of the rubber and fibre additions on mechanical properties of the composites enhancing specific properties for structural applications, the importance of an adequate assessment of damaged area and proper selection of machining parameters to extend the life cycle of these laminates as a consequence of enhanced reliability.

8115 | LIFETIME OF FIBROUS CARBON/CERAMIC COMPOSITES SUBJECTED TO A CYCLIC LOAD (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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The development of advanced structures requires new low cost materials, which could work under dynamic load at elevated temperature. Carbon fibers-reinforced carbon composites are candidates for such applications. They retain their high strength and stiffness at high temperatures (even at 2000oC), and due to low CTE and high heat of sublimation they have good ablation resistance. Other advantages include thermal shock resistance and chemical resistance in non-oxidizing atmosphere. The main disadvantage of carbon-based materials is their low oxidation resistance [1]. For this reason, ceramic materials characterized by good oxidation resistance have been progressively incorporated in the carbon-based materials in order to protect them against

the environment [1]. Nevertheless, high manufacturing costs of carbon fibers-reinforced carbon composites modified with ceramics prevents them from wider application.
The aim of this work is to compare fatigue behavior of phenol-formaldehyde resin-derived CCC (carbon) composite with CCC/ceramic (carbon/ceramic) composites obtained by the impregnation of CCC composite with commercially available polysiloxane-based solutions of preceram and their subsequent heat treatment at 1000 oC, 1500 oC and 1700 oC. CCC/ceramic composites heat treated at 1000 oC and 1500 oC contain silicon oxycarbide [2] and CCC/ceramic composite heat treated at 1700 oC contains silicon carbide [2]. As a reinforcement HTS 5131 carbon fibers (Tenax) in a form of roving were used. Phenol-formaldehyde resin (Organika-Sarzyna, Poland) and Lukosil 901 polysiloxane substrate (Lucebni zavody, Czech Republic) used in this experiments were inexpensive (cost about 10$/kg).
In order to determine conditions of fatigue tests, mechanical parameters in static conditions were measured. The composite samples were investigated in three points bending test. The strength and Young’s modulus were calculated from strain-force relationships. On the basis of results obtained in the test, parameters of dynamic test were set up. Deflection in fatigue three point bending test was 50% of the deflection measured in static three point bending test. Composite were subjected to fatigue with the frequency of 11.7 Hz. After every 10 000 cycles, ultrasonic wave velocity in three directions of sample was measured. CCC composite was used as a reference.
Differences in mechanical properties in static conditions between CCC reference sample and CCC/ceramic samples were observed. Bending strength for all samples varied from 210 to 260 MPa and Young’s modulus - from 40 to 70 GPa. Composites subjected to heat treatment at 1500 and 1700oC exhibited lower values of Young’s modulus. At these temperatures, due to heat treatment of the composite samples, decomposition of impregnate occurs [2].
In comparison to the reference, namely to CCC composite, CCC/ceramic composite heat treated at 1000oC exhibited similar fatigue properties - number of cycles until destruction for these composites were 450 000 - 470 000. CCC/ceramic composite heat treated at 1500oC exhibited 20% lower fatigue resistance than CCC reference and CCC/ceramic composite heat treated at 1700oC exhibited 40% lower fatigue resistance than CCC reference. Decrease of fatigue resistance, especially in the case of composite heat treated at 1700oC, is caused by subsequent heat treatment. During the treatment, release of decomposition product from ceramic phase occurs [2], what changes the fibre-matrix interface.

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8137 | Nondestructive evaluation of carbon fibre reinforced composites with infrared thermography and ultrasonics (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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Carbon Fibre Reinforced Polymers CFRP are increasingly used in aircraft primary structural components. However, as most types of composites, they exhibit different problems when compared to metallic materials. A main weakness is their vulnerability to low velocity/energy impact; in particular, important damage may arise inside the material thickness without any perception on the impacted side. The duration of a metallic component is dependent on the possible formation of a crack and its growth, which can be somehow predicted by the linear elastic fracture mechanics. On the contrary, CFRPs are strongly inhomogeneous and their behaviour under impact is complex and difficult to be modelled. In addition, CFRPs, as all composites, are susceptible, during fabrication, to formation of defects and slag inclusions which may affect their performance in service. So that, the availability of any valuable experimental data, to get information on the failure starting point and its propagation, is of great importance.
In the present work we use infrared thermography and a phased array system to detect defects in CFRPs as well the damage caused by impact events. In particular, infrared thermography, apart from its use as nondestructive evaluation technique, it is also used to take a video during an impact event. In particular, visualization of thermal signatures, caused by local dissipation of impact energy, allows gaining information about the material response to impact. The material may display three different features: only thermoelastic effects meaning that no damage occurred, or small temperature variations to account for delamination, or abrupt temperature rise in correspondence of any breakage. In addition, the overall warm area allows measuring the extension of delamination.

8365 | Probing the Characteristic Free-Volume, Void, and Elemental Composition within a Polyamide Composite Membrane by Age-Momentum Correlation Spectroscopy (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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Positron annihilation spectroscopy (PAS) is highly sensitive to measuring free-volumes in membranes, with sizes as small as 0.1~1 nm, but it is unlikely to measure voids bigger than 1 nm and to provide information about the elemental composition within the membrane. In regard to this limitation, this study established positron annihilation agemomentum correlation spectroscopy (AMOC) in conjunction with a variable mono-energy slow positron beam. The integration of AMOC with conventional methodologies, such as transmission electron microscopy (TEM) and quantum chemical calculations (QCC), enabled the investigation of free-volumes, voids, and the elemental composition in the ultra-thin selective layer of a polyamide composite membrane, as well as the relationship among these three properties. Based on AMOC results, the free-volume size in the polyamide layer ranged 0.42-0.68 nm in

diameter, corresponding to the free-volume amount of 9-13%; the voids diameter and amount were 7.2-14.1 nm and 12-18%, respectively. TEM results indicated that the polyamide layer consisted of a continuous dense polyamide structure and a discrete voids structure, with the size distribution of voids ranging from 5 to 20 nm. In support to AMOC results, QCC data confirmed that the highly electronegative environment in the membrane could inhibit the formation of positronium. This study not only established a technique using PAS that increased the range and the accuracy of voids measurement, but it further provided information on the physical and chemical properties of a polyamide composite membrane and the correlation between them.

8379 | Passive wireless sensors with metamaterials for SHM (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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Implementing a process of damage detection and characterization strategy for engineering structures is referred to as structural health monitoring (SHM). Here, we understand by damage a change in the material and/or in geometric properties of a structural system. These changes involve the modification of the boundary conditions and system connectivity which adversely affect the system's performances.
The SHM process involves the observation of the system over time using periodically sampled dynamic response measurements from a sensor or an array of sensors, the extraction of damage sensitive features from those measurements and the statistical analysis of these features to determine the current state of the system health.
On long term, SHM updates the information about the ability of the structures to accomplish its functions, knowing that the determination and the loss of performances are inevitable in the working environments.
This paper proposes the use of passive wireless strain sensors for monitoring wind turbine blades (WTB), based of metamaterials type Split Ring Resonators (SRR), tuned on the frequency which frames into the allocated bandwidth. The sensitive element of the capacitive sensor is a capacitor obtained by a nanotechnology scheme, namely the obtaining of carbon nanotubes – polyelectrolyte nanocomposites thin films that are coupled with SRR. The algorithm for identification of sensor in which strain/stress was exceeded from the sensors network is analyzed and presented. A RFID tag for the identification of the sensor will be developed using an inductive SRR coupled with a planar waveguide.

8648 | Analysis of damage mechanisms in drilling of composite materials by acoustic emission (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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Conventional methods for analysis of drilling of composite materials usually study the amount of damaged area and effective parameters. However, these methods do not provide investigators with sufficient information regarding drilling induced damages. In this paper, a procedure for discrimination and identification of different damage mechanisms based on the analysis of acoustical signals emitted during the process is presented. Using principle component analysis for data reduction and unsupervised pattern recognition analysis, drilling process was divided into three main stages; entry stage, cutting stage and exit stage. Then different methods of signal processing were used to identify and discriminate the most active damage mechanisms in each stage. As a result matrix cracking, delamination, fiber pull out and friction were discriminated and frequency distribution of each were identified.

Keywords: Drilling, Composites, Damage mechanisms, Acoustic emission, Signal processing

8758 | Importance of density profile for quality composites (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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The innovation in the development of different materials in our society has caused a major impact on technology. Brazil has a strong agro-industrial economy, where the improvement of composites with natural fibers or agro-industrial waste can become a significant factor for the development of the country
The development of composites using natural fibers or agroindustrial residues calls the attention of scientific and technological communities as they are environmentally friendly while showing competitive mechanical properties if compared to other composites reinforced with synthetic fibers.
In this way, obtaining density profile in fibreboard and particleboard is essential to control production, becoming an important measure of its quality and application.
The objective of this study was apply the technique of X-ray densitometry in obtaining density profiles, testing fundamental in the analysis of quality of reconstituted wood panels, along the thickness of new composites made from eucalyptus fibers and sugarcane bagasse particles.
The results indicated that the dosage of resin it's very important in the form of profiles, which refer to performance as the internal bond, and the density profiles along the thickness showed variations of the panel frame and provided important quality informations, applied in setting press cycle and indications of its technological performance in use.

8913 | SPARSE REPRESENTATION FOR NON-DESTRUCTIVE TESTING OF GLASS-EPOXY COMPOSITES (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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In this paper we propose to investigate a sparse representation technique for the purpose of identifying damage mechanisms from acoustic emission (AE) signal which occurs during non destructive test applied to composite materials. In particular we introduce a new approach based on the sparse representation of signals for clustering (AE) data occurring during the fracture process of glass fibre reinforced polymer (GFRP) plates. The proposed sparse representation used a redundant dictionary specific to damage mechanisms which may appear in the composites. Experiences were performed on model specimens of GFRP composite in order to generate the specific damage modes. An analysis of the recorded signals by advanced signal processing methods has enabled us to distinguish the different acoustic signatures as well to gather signals having similar characteristics. The latter are used in the construction of the dictionary. The proposed classification procedure was examined on the signals of learning as well on the test signals. This study has shown the interest provided by the sparse representation of signals to follow the damage mechanisms in composites.

8934 | APPLICATION OF ULTRASONIC GUIDED WAVES FOR DEFECT DETECTION IN HONEYCOMB (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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In recent years, the novel lightweight honeycomb sandwich structures have been applied in a wide range of industries. However, daily operational conditions, fatigue, as well as various defects developed during exploitation lead to the risk of structure failure. To meet safety and economical requirements, such structures must be tested. The ultrasonic pitch-catch technique based on ultrasonic guided waves (UGW) for detection of defects in honeycomb sandwich structures is proposed. The parameters of UGW propagation are sensitive to structural changes, therefore UGW make it possible to detect defects and evaluate their size.
As an object for investigation, a sandwich structure, composed of two thin carbon fibre reinforced plastic skins (CFRP AS/48552) and an aluminium honeycomb core had been selected. The simulations were carried out on honeycomb sample (172 mm×114 mm×21 mm) that consisted of two 2.5 mm thickness CFRP skins and a hexagonal aluminium core having thickness of 16 mm. In order to simulate the structural damage in honeycomb sandwich structure, a part of the core was cut at the junction points to the skin while both skins (external and internal) remained undamaged. A defect of circular shape, 30 mm diameter, was constructed at the distance of 30 mm away from the edge of the sample. The excitation of UGW was performed applying the normal force to the area of 2 mm on the surface of the skin. The excitation pulse had a Gaussian envelope of 3 periods and frequency of 100 kHz.
The main parameter which is related to the presence of structural non-homogeneities is the velocity of UGW and the method which can be used for measurements of phase velocity variations is based on the zero-crossing approach. This technique was applied to measure the time of flight values of the multiple zero-crossing points for each A-scan signal in the entire B-scan image. The results obtained demonstrated that in the defect-free zone the average phase velocity of the A0 mode is 1550 m/s. Still, in the defective zone the phase velocity drops down to an average value of 1280 m/s, due to changes in the overall thickness of the sample. The variations of the phase velocity can show the regions with the delamination or disbond type defects and this method can be used for detection of such defects.

9077 | Thermographic Interpretation of Failure Mode in Polymer Matrix Composites (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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The fracture behavior of glass fiber reinforced epoxy polymer matrix composites (PMCs) was investigated during tensile testing. The PMCs have been used for railway bogie materials application for the purpose of lightweight in bogie. In order to monitor tensile damage evolution of PMC sample, a high-speed infrared (IR) camera was used to measure surface temperature changes during tensile testing. The high-speed IR camera also provided clear thermographic images at the time of failure. Through the thermographic image analysis, crack initiation and propagation were qualitatively monitored. Based on tensile testing results, the failure initiated at the epoxy matrix, and the brittle failure mode was observed. Moreover, the microstructural characterization using scanning electron microscope (SEM) was performed to correlate the mechanical failure mode with thermographic results. In this investigation, an IR camera and SEM investigation were used to facilitate a better understanding of damage evolution and failure mode of PMC materials during tensile testing.

9175 | Inter-laminar fracture toughness measurement of the mixed-mode delamination using acoustic emission technique (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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In this paper acoustic emission (AE) technique was used to evaluate the inter-laminar fracture energy for the initiation of delamination, Gc, in mode I, mode II and the combination of these pure modes in glass/epoxy composites. The AE signals are transient waves originated from the damage mechanisms such as matrix cracking, fiber failure, etc. during a delamination phenomenon. These AE signals are used to evaluate the Gc values and the results are in good agreement with the values estimated by means of the standard ASTM procedures. The results indicate that different interface lay-ups and different GII/GT modal ratio values indicate different AE signals and mechanical behaviours. In addition, the proposed methods for measuring the Gc is precise and successful, especially in mode II and mixed-mode conditions where there is unstable crack growth which prohibits a rigorous measurement

of Gc. The main advantage of the suggested method, with regard to those in the literature, is the simple and practical identification of the initiation stage and high sensitivity of the AE method to the failure mechanisms.

Keywords: Mixed mode delamination, Fracture toughness, Glass/epoxy composite, Acoustic emission

9343 | Nondestructive Testing Method for Curved Composite Surface Based on twin-robot technology (21. Non-destructive Inspection Techniques for Composite Materials and Structures)

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A curved surface path planning method base on multi-Gaussian beam model is proposed in this paper. Multi-Gaussian beam model for multi layers composite is introduced into the curved composite ultrasonic testing system. The mathematical model of receive beam field to composite is established to analyze the effect of different testing parameters for the receiving transducer. The simulation and experiments illustrate the validity and effectiveness of the proposed method. Imitating surface with bi-cubic B spline curves for complex curved surface. The normal vector can be calculated out to achieve transmitting transducer position and orientation. The acoustic length in water of receiving transducer is decided by the receiving beam field. By coordinate transformation, the position and orientation of receiving transducer can be achieved. Experiment results indicate the receiving signal is stronger, measuring accuracy is more accurate with the proposed method. The C-scan image results verify the effectiveness of the proposed method. It is believed that our method provides an effective solution to curved composite surface part, and it will greatly benefit industrial development.

5440 | A new method for designing of metal-matrix composites with particle reinforcement (22. Optimization techniques and methods)

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Using the methods which are applied for estimating strength and toughness of composites reduces trial-and-error rate in their design. One of the mechanisms for strengthening and increasing toughness of composites is through reinforcement debonding mechanism. Interface strength of reinforcement with matrix and effective surface of debonding greatly affect toughness and strength of these types of materials. In this study, a model was proposed to estimate the effect of interface and matrix strength of composites in increasing tensile toughness and strength. Then, interface strength and its effect in increasing tensile toughness and strength were calculated in a case study of composites containing particle reinforcement in matrix of tool steel.

6889 | General Method for optimizing composite patch repairs. (22. Optimization techniques and methods)

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Abstract :
The aim of this work is to define a general method for the optimization of composite patch repairing. Fracture mechanics theory shows that the stress intensity factor tends towards an asymptotic limit $K\infty$. This limit is given by Rose's formula and is a function of the thicknesses and mechanical properties of the cracked plate, the composite patch and the adhesive. The proposed approach consists in considering this limit as an objective function that needs to be minimized. In deed lowering this asymptote will reduce the values of the stress intensity factor hence optimize the repair. However to be effective this robust design must satisfy the stiffness ratio criteria. The resolution of this double objective optimization problem with Matlab program allowed us determine the appropriate geometric and mechanical properties that allow the optimum design; that is the selection of the adhesive, the patch and their respective thicknesses.

Keywords: General method, optimization, patch repair, objective function, stress intensity factor

7592 | A Sensitivity Analysis of Material, Geometry, and Process Parameters in Roll Forming of Polypropylene/E-glass Woven Fabric Laminates (22. Optimization techniques and methods)

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Fiber reinforced thermoplastic composite materials are rapidly attracting an increasing market share in a number of applications in leading industries such as automotive and transportation. In particular, recent developments in fabricating commingled fabric architectures as well as new rapid forming processes have allowed thermoplastic matrix composites to be competitive alternatives to thermoset composites. One traditional challenge during fast thermo-forming of these materials, however, is the presence of large spring-in deformations where the final part shape is different than the original/tool shape. These deformations can be particularly significant for large components, in assemblies, or when strict dimensional tolerances are required. In addition, there is an inherent uncertainly in composite raw materials along with uncontrollable factors during manufacturing stages, which in turn poses an extra challenge for manufacturers for quality control of their final products. This article using a previously developed finite element model of a composite roll-forming process, aims at a factorial design based statistical analysis for (a) predicting the variation in spring-in angle in forming of a typical woven Polypropylene/E-glass thermoplastic laminate, and (b) identifying the main material, geometry and process factors that govern this variation. Selected design factors include the relative crystallinity of the polymer matrix, the through-thickness coefficient of thermal expansion, thermal cycle applied in the forming process, the corner inner radius of parts, the laminate thickness, and the material's elastic modulus. Results of both modeling and sensitivity analysis are discussed and practical recommendations are made.

7648 | QUALITY ASSESSMENT OF 2D BRAIDED COMPOSITES WITH OPTICAL MEASUREMENT TECHNIQUES (22. Optimization techniques and methods)

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In recent years, 2D-braided carbon-fiber composites have been becoming increasingly popular due to their potential of realizing parts with complex hollow geometries and high load-bearing capacities. A common technique used for manufacturing braided composites is the circular braiding process with radial braiding machines. By robotically guiding a mandrel through the center of the braider with a defined speed, the fiber architecture can be adjusted along the axis. The braid pattern mainly evolves from a complex interaction of the yarn movement along the circumference of the machine, the yarn configuration, the mandrel geometry and the robot-controlled path of the mandrel.

Most of the visual braid attributes, such as the braiding angle and braid coverage, are directly linked to each other within the process and it is not possible to choose them independently. Since these visual properties strongly correlate with the mechanical performance of the composite material, it is crucial to analyze the fiber architecture and to know the potential impact of each parameter.
One of the correlations between fiber architecture and mechanical properties highlighted in the presented work is the effect of the cover factor of 2D biaxial and triaxial braided composites. Potentially, large gaps between the fibers can lead to strongly reduced mechanical properties due to local resin accumulations and reduced fiber volume content. However, the results show that the influence of the cover factor also strongly depends on the type of braid and the applied resin system.

Depending on the geometry of the part, the braid coverage and other fiber architecture attributes can significantly vary along the radial and axial direction of the mandrel. If the effects of the fiber architecture shall be considered for the quality assessment of a real part, it is therefore necessary to evaluate it over the entire part surface. A new machine vision system is shown that allows for capturing and analyzing the fiber architecture of complex-shaped 3D preforms area-wide. Single images are captured by a camera sensor which is robotically guided over the preform surface. By connecting the single images with their position in relation to the part, it is possible to display all attributes in the form of a digital 3D surface map. The system is illustrated by showing typical braid parts and their corresponding fiber patterns.

The presented work shows that by integrating optical measurement techniques into braid manufacturing, it is possible to apply mechanically based quality criteria, to optimize process parameters and to validate process simulations, which are key issues to further increasing the lightweight potential of composite parts.

7770 | Fabrication and properties of steel-TiB2 composites (22. Optimization techniques and methods)

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Methods for the production of steel matrix composites reinforced with TiB2 involve ingot casting and powder metallurgy (PM) processes. The powder metallurgy is ideal to obtain this composites because it provides the dispersion of fine particles. Technological progress, as well as economic and ecological considerations make the search for new manufacturing techniques of composite materials constantly growing. Spark plasma sintering (SPS) is a new technique to rapidly produce ceramic, metallic and composite products. SPS process is a recent development of an advanced sintering technology that combines axial pressure with direct electrical current through a die and a sintered body.
In the present study, the effects of TiB2 ceramic on the microstructure, mechanical, wear and corrosion resistance were investigated. The steel/TiB2 composites were prepared by Spark Plasma Sintering (SPS). The phase composition and microstructures were characterized using scanning electron microscopy and transmission electron microscopy using EDS, WDS and EBSD analysis. For the tested composites, the relative density, Young's modulus, microhardness, compressive strength, wear and corrosion resistance were measured. The best densities were obtained for composites sintered at 1100□C. The microstructure investigation reveals that fine TiB2 particles are homogeneously distributed in the steel matrix. Additionally, formation of new fine phases in steel matrix was observed. The addition of hard TiB2 particles to steel leads to increase of hardness and compressive strength. Furthermore, the wear resistance of the composites was better for higher TiB2 contents.

7850 | Cast aluminium matrix composites modified with using plastic deformation process – changing of the structure and mechanical properties (22. Optimization techniques and methods)

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The aim of this study was to explain the influence of the plastic deformation generated in friction stir processing on the changing size and distribution of reinforcement particles in the cast composite A339/SiC/p, as well as determine its mechanical properties.
A339 aluminum alloy reinforced with 10 % vol. SiC particles was modified using friction stir processing method. Changing of distribution and size of the reinforcement particles were analyzed using new mathematical Mitiouhev RVE theory. The mechanical properties were determined on the basis of compression tests. In the resulting observed significant changes in the distribution of particles, precipitation which were characterized by macro-heterogeneity. However, in micro scale, a few typical distributions and areas of fragmentation of the reinforcing particles were identified. Differences in the sizes of the ceramic particles were about 15 microns in the initial material and about a few micron in the modified material, respectively. Mechanical testing of selected deformed areas showed significant differences in the values of the plastic flow stress in thermomechanical hardening areas, approximately from about 30%
The obtained results can be used to optimization of the modification process of cast composites by friction stir processing. In addition, the analysis results may be used to design new methods to modify aluminum matrix composites reinforced with ceramic particles.

7887 | Methodology for the Product Engineering of Lightweight Structures in Multi-Material Design (22. Optimization techniques and methods)

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To realise cost-effective lightweight structures, components in multi-material design with locally adapted properties are a very promising approach. One example is the combination of press-hardened steels with fibre-reinforced plastics. On the one hand, this design is cost effective, for example because of the high material utilisation. On the other hand, their development is highly complex and expensive, because it is marked by strong dependencies between product, manufacturing technologies and production system.

Against this background, products, manufacturing technologies and production systems have to be developed in a close interplay from the beginning. Furthermore, it is not sufficient to develop product and production system only from the present point of view. It is necessary to foresight possible future developments and to anticipate the product lifecycle. Today, these points are not considered adequately. This leads to time-consuming and cost intensive iteration loops during the development process. The results are expensive and not optimal components, which do not fulfil the future market requirements.

At the Institute for Lightweight Construction with Hybrid Systems a methodology for the product engineering of lightweight structures in multi-material design is developed. It consists of a procedure model, methods and IT-tools, a specification technique as well as a knowledge base. The procedure model defines the steps that have to be conducted in the product engineering of lightweight structures (e. g. experimental work). The methods support the product engineering process. Methods of forecast (e. g. Trend Analysis) enable the anticipation of the product lifecycle and the identification of chances and risks. Evaluation methods enable the early assessment of manufacturing and life cycle costs, the robustness of the product and the production system as well as the recyclability. The specification technique is used for the integrative description of the product and the associated manufacturing process and production system. Thereby, the dependencies between product and production systems are considered and information for the evaluation is provided (e. g. between process parameters and mechanical properties). The knowledge base can be used for the synthesis of process chains. It contains knowledge about future developments (e. g. market or regulatory requirements) and domain specific knowledge of lightweight design (e. g. design rules).

The present paper focuses on the procedure model. It coordinates the work of the involved developers from different domains during the whole development process of hybrid structures. Furthermore, it controls the use of the methods and IT-tools. The procedure model describes commonly understandable the activities to be carried out. It is divided into several main steps. In the first step, the considered component is analysed for example regarding automotive requirements like loads or mechanical characteristics. This includes the decomposition into function owner and the specification of requirements. Especially for hybrid systems it is necessary to specify the natures of loads and the direction (isotropic or anisotropic) to achieve an optimal lightweight structure. In the next step, partial solutions for the functional owners are identified. Thereby, material, geometry as well as manufacturing and assembly technologies must be taken into account. The partial solutions will be combined into a total solution. The large number of possible combinations ensures that this step results in a number of alternative solutions. Finally, the alternative solutions have to be evaluated to provide the best fitting solution.

An automotive b-pillar is used as a demonstrator to validate the developed procedure model. This component is produced in high quantities and is characterised by extensive requirements (e. g. energy absorption, manufacturing costs or adapted material properties).

7896 | Crashworthiness optimization of metal-composite energy absorption devices (22. Optimization techniques and methods)

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Fuel efficiency and occupant safety are fundamental requirements in vehicle design today. The combination of metal and composite materials in crash-absorbing parts is a good solution to improve the crashworthiness response of a vehicle without increasing its mass significantly.

New designs arise from the multiple possible combinations of cores made of carbon or glass fiber composites with steel or aluminum enclosures. While the composite cores provide specific strength and stiffnesses, the metallic enclosure adds a ductile and progressive collapse mechanism to the final design.

The advances in finite element analysis codes have allowed not only accurate and affordable simulations of crash events but also the possibility of applying optimization strategies to these new designs. This is not an easy task due to the inherent characteristics of finite element impact simulations, due to the presence of noise in the responses and the high computational cost of each simulation.

This work presents a procedure for crashworthiness optimization of metal-composite energy absorption devices. These devices consists of a hollow metallic tube filled with a core structure made of composite material.

Surrogate-based optimization techniques are used to smooth the noise in the responses and to decrease the computational cost of the numerical simulations. Three objective functions are chosen: mass, absorbed energy and peak load. These functions are approximated by two surrogate models: multivariate adaptive regression splines and gaussian process. The geometrical dimensions and the shape of the core are selected as design variables. Results show appreciable improvements on the objective functions compared with the original design. The peak load is reduced with respect to designs with similar mass and absorbed energy, and the specific energy absorbed is increased compared with specimens with a similar peak load.

7941 | Silica carbon composite modified with glucose oxidase used as biosensor for glucose determination (22. Optimization techniques and methods)

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Silica-carbon composites have received growing attention in recent years. These materials can be obtained by sol-gel method through doping of silica matrix with carbon (graphite or nanotubes). The advantage of this synthesis method is the possibility to obtain materials with different characteristics, allowing their use as electrochemical devices. The silica-carbon materials can present high surface area and conducting properties allowing their use as electrochemical devices. The immobilization of electroactive species, such as enzymes, inside the porous structure attributes higher sensitivity and selectivity to the system. Glucose oxidase (GOx) is an enzyme widely used in food industry and it is also applied as sensor in the Diabetes Mellitus control. In this work, two silica-carbon composites were obtained with different pore size, by varying the sol-gel synthesis conditions. The materials were assigned as S1 and S2. These materials were functionalized in sequence with 3-aminopropyltrimetoxysilane (APTMS), glutaraldehyde (GA) and glucose oxidase enzyme (GOx). The S1 and S2 materials were characterized by N2 adsorption-desorption isotherms, thermogravimetric analysis and cyclic voltammetry. Afterwards, they were used as biosensor for glucose determination using chronoamperometry technique. From the N2 adsorption-desorption isotherms, it was obtained BET specific surface area of 273 and 73 ± 5 m2g-1 for S1 and S2, respectively. The pore size distributions obtained by BJH method were in the mesoporous region, with a maximum at 7 and 20 nm for S1 and S2, respectively. The functionalization of these matrices with APTMS does not produce significant changes in the surface area, neither in the pore size distribution. However, after the GA immobilization, the specific surface area of S1 material decreases to 184 m2g-1, while S2 material maintains its value constant. The GOx immobilization does not produce significant change in the S1 and S2 surface areas and porosities. From the thermogravimetric analysis, it was possible to estimate the amount of enzyme immobilized as 13.8 and 30.0 mg per gram of material for S1 and S2, respectively. Although S1 presents high surface area, the enzyme immobilization was more effective for S2 material, indicating the pore size is a determinant factor for the amount immobilized. This fact was interpreted considering the size of the enzyme and its access into the pores. The cyclic voltammetry essays show anodic and cathodic peaks assigned to the presence of GOx for both materials. However, for S2 material the current intensity (78.2 and -154.0 μA) was higher when compared with the S1 material (-8.7 and -55.47 μA), probably due to the higher GOx amount immobilized inside of the pores. Considering the above results, the S2 material was chosen to develop a biosensor for glucose. The system shows a linear response between current peak and glucose concentration in the range from 0.39 to 5.36 mmol L-1, under argon atmosphere. The sensitivity, obtained by the slope of the curve, was 0.33 μA (mmol L-1)-1 cm-2. The detection limit was calculated by the ratio (3×SDb/Slope), where SDb was the standard deviation of blank measures (n=10) and the obtained value was 0.93 mmol L-1. These results show the system is very promising to be applied as electrochemical biosensor for glucose.

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7986 | An efficient semi-automated optimization algorithm for (lattice) composite structures: implementation and application (22. Optimization techniques and methods)

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Composite grid-stiffened (GS, lattice) structures have long been of interest as a replacement for honeycomb sandwich, aluminium isogrid and skin-stiffener-frame structures for aerospace applications. Such interest is caused by the multiple advantages of this structural architecture amongst which the cost per unit weight is the most attractive one. Apart from the numerous challenges related to lattice structures manufacturing, analysis correlation, certification, fatigue, impact, load introduction and attachment regions the structural optimality plays an important role in paving the way towards a broad application of the lattice architecture in real-life structures. Multiple optimization approaches for GS structures have been proposed and investigated in the past however none of these offer a good balance between their universal applicability, accuracy and computational speed. In an attempt to obtain an efficient way of optimizing lattice structures without stringent constraints on geometry and loading a semi-automatic optimization algorithm for composite structures has been set up. The optimizer uses automatically generated parametric CAD and FE models to assess the fitness of the design. A genetic algorithm linked to the CAD and FE framework is employed for optimizing the structure based on the fitness data. Due to the automation of all model generation procedures and computations the algorithm performs the optimization by solving the corresponding FE models without having to rely on less accurate analytical approximations for composite structures to determine the design fitness. This is especially beneficial for the cases where a complex structure or complex loading scenario are present (e.g. grid-stiffened structures). This setup significantly facilitates the design space exploration since no additional FE model preparation is necessary and thus any entry of the design space is readily accessible by the algorithm.

The validation of the lattice structures FE analysis methodology used in the automated optimization approach has been confirmed by a testing and validation campaign for composite lattice panels.

A number of test cases for grid-stiffened structures have been investigated with the developed optimization algorithm. These include an idealized fuselage barrel, launcher interstage structure, several satellite structures as well as some simpler test cases without lattice stiffening architecture. Main design trends, lessons learned and conclusions from some of these test cases are presented.

8012 | Torsion induced buckling design of a variable stiffness composite cylinder made by fiber steering (22. Optimization techniques and methods)

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With the advent of Automated Fiber Placement (AFP) machines, it has become possible to continuously change (steer) the orientation angle of the fibers/tows to manufacture composite laminates with spatially variable mechanical properties. The resulting so called variable stiffness (VS) composite component has spatial stiffness properties that can create an efficient path between the loading points and the supports. These VS laminates allow the designer to fully exploit the directional properties of composite materials. In designing components made of these laminates, the design space is extended so that structural components with significantly higher performance and/or lower weight compared with constant stiffness structures can be made.

As a continuation of our previous work [1-4], in this paper, a variable stiffness composite cylinder made by fiber steering is designed and optimized for maximum buckling load due to torsion. A multi-step design optimization procedure is developed to get the maximum potential improvement in torsion induced buckling. High fidelity finite element (FE) analyzes are substituted by low-cost and computationally inexpensive surrogate models based on Radial Basis Functions (RBF) to improve the computational efficiency of the design optimization process. Different RBF formulations are also studied and

compared with each other in terms of their accuracy. The torsion induced buckling load of the optimized VS composite cylinder is also compared with its constant stiffness counterpart to evaluate the potential improvement the VS composite cylinder can offer in terms of the structural performance.

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8069 | THE INFLUENCE OF EXPANSIVE AGENTS ON THE PROPERTIES OF FIBER REINFORCED CEMENT-BASED COMPOSITES (22. Optimization techniques and methods)

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Mortar and concrete are the most widely used construction materials because they develop high strength, high toughness and long durability. However, drying shrinkage ant the related cracking are two important properties, which can reduce the durability. It has been proved that incorporating fibers into cementitious materials can effectively improve their thoughness and ability of resisting crack.
In this work several Fiber Reinforced Cement-based Composites (FRCCs) were studied. The effectiveness of two different kinds of metallic fibers was tested: brass-coated hooked steel fibers (Hook), and flat and flexible amorphous metallic fibers (Flex). Fibers were separately added to superplasticized cement-based mixtures, at a rate of about 1.9% and 1.4% by volume of FRCC, respectively. Moreover, special FRCCs were also manufactured by adding a low dosage of CaO-based expansive agent (20 kg/m3) in order to help in reducing the risk of cracking induced by drying shrinkage and make more reliable materials from the durability point of view.
All the FRCC mixtures were characterized by the same w/c ratio of 0.30 and the same inert/cement ratio of 2.3, as well as the same amount of a polycarboxylate-based superplasticizer (3.2% by weight of cement). A control superplasticized mixture with expansive agent (EA), with the same w/c, the same inert/cement ratio, but without fibers was manufactured and studied. Finally, two control superplasticized mixture with either hooked steel fibers (Hook) or flexible flat metallic fibers (Flex), with the same w/c, the same sand/cement ratio, but without expansive agent were manufactured and studied.
All the FRCC mixtures were characterized for the workability in the fresh state (where they showed approximately the same plastic consistency), and in the hardened state by measuring compressive and flexural strength, as well as length changes under drying shrinkage test. Moreover, their microstructure was investigated by means of Mercury Intrusion Porosimetry (MIP) and Scanning Electron Microscope (SEM) observations.
The effect on mechanical performance of a thermal pre-treatment at 80°C for the first 24 hours of curing was also evaluated.
The results obtained confirmed the effectiveness of CaO addition (even at low dosage) on mortar stability under drying shrinkage, moreover it proved to be extremely effective in terms of flexural strength improvement if used with brass-coated fibers (+50% after 1 day, +43% after 7 days, and +33% after 28 days). The reason of this synergy probably lies in the formation of calcium-hydroxy-zincate crystals at the interface between fibers and surrounding cement mortar; this phenomenon is promoted by dezincification of brass in alkaline environment (due to the presence of high amount of Ca(OH)2 formed when CaO comes in contact with water). These hydroxy-zincate crystals, as observed by SEM, are likely able to significantly improve the quality of the interface fiber-matrix by increasing the adherence.
In conclusions, in this work FRCC mixtures were designed showing very high performance in bending, close to those obtained by using Ultra High Performance Concrete (UHPC). The advantage of the FRCC mixtures studied in this work with respect to UHPC is that some very expensive ingredients such as silica fume and microsilica were not used. Their final cost will be about 3-4 times with respect to ordinary mortars (mainly due to the cost of the high amount of metallic fibers introduced in the mixture), while for UHPC is more than 10 times (usually 15). Therefore, the ratio between flexural performance and cost of these FRCCs is very high, and they use for producing structural elements is certainly promising.

8118 | STACKING SEQUENCE OPTIMIZATION OF SMALL COMPOSITE WIND TURBINE BLADES BY FEM AND SCE (22. Optimization techniques and methods)

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A technique and an application for the design optimization of composite laminated wind blades are presented in this work. The optimization is performed combining the Finite Element Method (FEM) for the structural analysis and the Shuffled Complex Evolution (SCE) algorithm for the numerical optimization. The structural analysis model considers composite shell elements and different load cases applied to a small wind turbine blade. The blade geometry is designed with the MH-110 aerodynamic profile, considering a constant angle-of-attack to comply with power limits. Geometric nonlinearities are considered. The optimization is performed in order to minimize displacements at the tip of the blade for multiple static load cases. Failure criteria and design limitations are considered as constraints for the numerical optimization through the use of penalized functions. Numerical examples are evaluated to validate the present framework and application.

8286 | Influence of SiC particles on tribological properties in aluminum based composites (22. Optimization techniques and methods)

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The paper presents the tribological and microstructural characteristics of composite materials produced by spark plasma sintering method. Composite powders containing 10, 15, 20 % SiC particles were produced by mechanical alloying in planetary ball mill. High energy during powder preparation led to fragmentation of matrix particles down to average size of 3 mikrons. During that process good mechanical bonding between SiC reinforcement and AlSi5Cu2 matrix was obtained. The microstructure of spark plasma sintered powders was examined by scanning and transmission electron microscopy. Composites reveal uniform distribution of SiC particles in aluminum matrix. The tribological properties were measured during at room temperature and conducted by the ball-n-disc method, at a distance of 200m, with a load of 4N. The analysis of the tribological results revealed the desirable influence of the SiC particles on increasing the average value and stabilization of friction coefficient.

8330 | Composite materials based on carbon fiber used to manufacture automotive parts with complex geometry (22. Optimization techniques and methods)

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Based on the requirements of achieving lightweight components and mechanical performance, the paper aims to present the structure of technology for use fiber reinforced plastics, especially plastics reinforced with carbon fiber using the new winding space technology.
Composite materials based on carbon fiber used to manufacture automotive parts with complex geometry, especially steering column console are presented in the paper.

8572 | Maximization of the fundamental frequency of composite plates and cylinders using genetic algorithms (22. Optimization techniques and methods)

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This work deals with the maximization of the fundamental frequency of laminated plates and cylinders by finding the optimal stacking sequence. Only symmetric and balanced laminates are considered. Instead of using the angle at each ply the so-called lamination parameters are used as design variables. Results for the plate problem are compared to those by Bert in 1977 and some improved results are found. The cylinder problem is solved for many combinations of thickness and radius-to-length ratio. Values of the optimal stacking sequence are given considering the angle can take any value between 0º and 90º or the case when the angle can only take a discrete set of values.

8581 | Experimental study and validation of computational optimised, endless fibre reinforced thermoplastic parts (22. Optimization techniques and methods)

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Endless fibre reinforced polymer matrix composites show remarkable thermomechanical properties. However their anisotropic material behaviour exhibits a challenging task for engineering applications. To fully exploit composite structures new concepts for component design have to be developed targeting for stiffness and strength improvement or for weight reduction of composite materials.
Computational methods for variable stiffness design have been developed by numerous authors. A good overview can be found in [1] and [2], e.g., a coupled procedure by hybridisation of principal stress and thickness optimisation has been developed by the authors and has been presented in [1]. Further improvements and validation of an optimisation algorithm are shown in [3]. There an algorithm with hierarchical order is developed by using different space scales.

The optimisation can be addressed by the following points:
1. A global laminate position considers the interaction between a globally defined straightline fibre format groundstructure with the reinfocement layer. The interaction is considered as a displacement boundary condition.
2. On a local laminate position optimisation of fibre direction in the reinforcement layer is done by a principal stress optimisation resulting in locally varying fibre angles Theta and Theta + 90.
3. On a local ply position Theta and Theta + 90 plies are optimised regarding material distribution. This is done by density optimisation using a gradient based technique.

During the optimisation it is iteratively switched between 2 and 3. As a result continuous fibre paths are obtained in specific regions of the structure following major principal stresses or minor principal stresses. Since continuous fibre paths are detrimental for high throughput production special designed post processing steps for patch placement are developed.
The post processing step focuses on Multi-Linearisation of the obtained stress trajectories. Therefore a conformity analysis of the structural component is implemented, based on a xyz-position information and local fibre angels of the FE-discretisation. First a conformity analysis of similar global fibre angles is conducted, this leads to fields with correlated fibre angles. Similar global fibre angles refers to a range of angles, e.g. -5 to +5 degrees. With this information another conformity analysis is conducted focusing on neighbourhood of the elements. As a result discrete fields with an averaged, linearised fibre angle are
obtained. Constraints can be inserted limiting the discrete areas to a specific geometry, e.g. of rectangular shape.

The overall process, optimisation and postprocessing, is validated on various comnponents in the 2 and 3 dimensional space scale. The obtained optimisation and postprocessing geometry is manufactured by a tape laying process and mechanically tested with a component testing machine.

The authors present the overall optimisation process including the post processing step with the verification of the components. The concept is well suited for fabrication of tailored composite parts by tape laying and the application in high-throughput manufacturing.

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8667 | Concepts in the Design of Lateral-Load Systems in High Rise Buildings to Reduce Operational Energy Consumption (22. Optimization techniques and methods)

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The location of the main lateral-load resisting system in high-rise buildings may have positive impacts on sustainability through a reduction in operational energy consumption, and this paper describes an assessment of the accompanying effects on structural performance. It is found that there is a strong influence of design for environmental performance on the structural performance the building, and that systems selected primarily with an eye towards energy use reduction may require substantial additional structural stiffening to meet safety and serviceability limits under lateral load cases. We present a framework for incorporating the environmental costs of meeting structural design requirements through the embodied energy of the core structural materials and also address the issue of economic cost brought on by incorporation of environmental concerns into the selection of the structural system. We address these issues through four case study high-rise buildings with differing structural morphologies (floor plan and core arrangement) and assess each of these building models for cost and embodied energy when the base structural system, which has been suggested by architect Kenneth Yeang based on environmental concerns, is augmented to meet lateral drift requirements under the wind loads prescribed by ASCE 7-10.

8733 | Simultaneous Analysis and Design of Composite Structures (22. Optimization techniques and methods)

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The optimisation of composite structures is mostly performed using nested analysis and design (NAND). NAND formulations have the response variables as implicit functions of the design variables and these variables are related by state equations, and design variables are the only optimisation variables. The optimisation and the analysis, which may for example be a finite element analysis, are performed independently of each other. In gradient based design, the gradients of the objective and the constraints have to be calculated with respect to the design variables. This is complicated due to the implicit relationship between the design and response variables. A computationally demanding sensitivity analysis is required to calculate these gradients. With SAND formulations, the optimisation variables are both the design variables and the response variables. They are considered independent during the optimisation and this simplifies calculation of the gradients.

The state equations are included as equality constraints. This obviates the need for the analysis of trial designs after each iteration step which may be computationally expensive.

An illustration of these methods is performed using the optimisation of a composite tube subject to various loadings. Firstly, a NAND formulation is used with the orientation angles as the optimisation variables, where after a SAND formulation, which includes the in-plane strains as optimisation variable is used. A sequential approximation optimisation (SAO) algorithm is used to approximate the objective and constraint functions. Various objective functions are investigated for their suitability with SAND namely, compliance and quadratic failure criteria such as Tsai-Hill and Tsai-Wu.

8747 | Systematic search for optimums using a methodical ap-proach coupled with genetic algorithm (22. Optimization techniques and methods)

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One of the major advantages of sandwich structures is the infinite possibility of combining different kinds of materials to achieve specific properties. Despites this sandwich structures remain rarely used in the mechanical engineering industry. One reason for this scarcity of use is the lack of a systematic approach to arrange the various parameters, which are different materials and different thicknesses for skin and core. One of the research areas of the workgroup “multi-materials structure” of the institute for engineering design at the RWTH Aachen University is to develop a systematic approach to solve this problem.
For this preliminary work, the workgroup has focused on a simple and symmetrical structure. It is composed of two identical face materials with same thicknesses, which surround a continuous core. These face materials are bonded to the core by a suitable adhesive.

In the context of the experiment, five different materials are selected; two face materials and three core materials. The thickness of the individual layers is used as another variable. However the overall thickness is set as a fixed parameter. Therefore the core thickness is dependent from the thickness of the two face materials. Besides the variable parameter, objectives functions in order to optimize the structure are defined. The goal of this work is to maximize the bending stiffness and to minimize the cost and the mass of the sandwich structure. These functions are not restricted by any constraints of optimization. In order to evaluate the objectives functions, it was imperative for the further work to establish thoroughly mathematical functions, in which the objectives functions are expressed in terms of the variables parameters. These mathematical functions are used in the further process, in order to evaluate different alternatives from which the set of non-dominated solution are defined, the so called Pareto-optimal solutions.
Due to the fact, that the addressed problem considers a multi-objective optimization (MOO), deterministic methods are not taken into account since they are not suitable for multiple optimums. Among the stochastic methods, which are adapted for this kind of problem, genetic algorithms (GAs) are used to solve the problem addressed in this work. The chosen GAs offer the following advantages: GAs work well on mixed discrete/continuous problems; they are simple to understand, set up and implement and they are very robust.
For the validation of the results of the programmed algorithm, a parallel calculation is done "manually". In order to make a simple and easy comparison of the different results, a group of non-dominated solu-tions is formed on the one hand for the manual calculation and on the other hand by the algorithm.
In conclusion, the method chosen for this experiment is effective due to the fact, that after comparing the results of the two calculations, a perfect similarity is obtained. Despite the satisfactory results a certain number of questions arise though: Is this method still effective for problems of larger size (a number of alternatives nearby 1000 alternatives for example)? And is this method satisfactory if the objectives are constrained? Future works will help to answer this questions.

8977 | Optimum design of shape and reinforcement of oval cut-out in fiber-reinforced composite laminates (22. Optimization techniques and methods)

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Stress concentration and reinforcement of cut-outs in fiber-reinforced composite laminates are of great concern in aeronautical engineering. Available elastostatic solutions and optimum designs for cut-out reinforcements are mostly devoted to circular and elliptic holes in isotropic and anisotropic plates with the purposes to calculate and reduce the stress concentration. In this paper, first, we seek the optimum shape of an oval cut-out, which is described by a simple function and more flexible than its degenerate cases (circle and ellipse), in an infinite composite laminate that is subjected to in-plane bi-axial tension or shear. We introduce a failure index for the laminas in the laminate, instead of the stress concentration, as the objective function. By using the analytical complex potential method to calculate the stress field, the optimum shape is easily obtained. Second, we study the optimum reinforcement around the cut-out by combing a new targeted mesh method for the finite element computation with the annealing simulation algorithm. The mesh method greatly reduces the computation and thus expedites the optimum design. Optimum shape of the reinforcement is obtained for a given reinforced area, and it is found that the smaller the area of the reinforcement, the more effective the optimum design. Thus, this work presents a highly efficient method for optimum design of shape and reinforcement of oval cut-outs in fiber-reinforced composite laminates.

8986 | Lightweight design of composite plate and shell strusctures in vibration environments (22. Optimization techniques and methods)

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The composite plate and shell structures, applied to the aircraft, spacecraft and automobile industries, are often working in the vibration environments. The lightweight design of such composite structures can be one of the possible solutions for reducing the rate of CO2 emissions and benefit the living environment of human being. The purpose of the research is to develop the lightweight design methods for the composite plate and shell structures in vibration environments. The efficient gradient-based optimization methods are employed to implement the lightweight design of composite structures because the dynamic analyses including the frequency, mode and dynamic response of such large scale composite structures require very much computational effort. First, the first derivatives of the frequency, mode and dynamic response with respect to design parameters (thickness of laminate, fiber volume fractions and fiber orientations) are carried out based on finite element methods. Second, the optimization model of the composite plate and shell structures in vibration environments is built to minimize the weight of the structures subject to the constraints of dynamic characteristics and responses. Third, the inequality constraint problem is converted into a sequence of appropriately formed unconstrained problems using the penalty function methods. The sensitivity of the objective functions of the unconstrained problems are obtained by using the first derivatives of the frequency, mode and dynamic response with respect to design parameters. The conjugate gradient method, a gradient-based optimization method, is used to obtain the lightweight design of the composite plate and shell structures by solving a sequence of unconstrained problems. Finally, two examples (plate and shell) are demonstrated by the proposed methods in this paper and other non gradient-based methods.

9016 | On design of anisotropy distributions, applying lamina formulas for result visualization (22. Optimization techniques and methods)

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In rotational transformation of constitutive matrices, some practical quantities are often termed invariants, but the invariance relates to an unchanged reference direction. Rotating this reference direction, the practical quantities do change and this point is clarified with derived rotational transformation for the practical quantities. The results are applied in a 2D visualization of optimized constitutive matrices, that are distributed in a finite element (FE) model where each element has a specific reference direction. The visualized distributions of physical quantities are; stiffest material direction, material stiffest longitudinal constitutive component, level of anisotropy, relative shear stiffness and orthotropy test.

In free material optimization (FMO), the components of the constitutive matrices are optimized and they change in the space of a finite element (FE) model, i.e., they are distributed. The constraints for the non-dimensional description of these matrices are; symmetry, positive definite and normalized to unit trace. The optimized constitutive matrices should be visualized, but this is not an easy task and different techniques are applied in the literature. From the authors point-of-view the visualization should be related to the most important physical quantities, and for 2D problems the traditional lamina analysis is found valuable.

Analysis and optimization may be performed without rotational transformations in a common coordinate system with the x-direction as reference. However, the visualizations of the optimized results involve rotational transformation of material behavior, i.e., of the constitutive matrices. For each element in a FE model, the direction of stiffest material direction is taken as reference direction with stiffest direction defined as the direction of largest longitudinal components in an optimal constitutive matrix, here termed $(\alpha_{1111})_\theta$ with θ being the angle counter-clockwise from the common x-direction to the θ-direction.

The traditional lamina formulas are well suited for localizing θ for a specific element. With $\theta, (\alpha_{1111})_\theta$ determined for all elements the available further physical information is calculated, applying the practical parameters $(\alpha_2, \alpha_3, \alpha_6, \alpha_7)_\theta$ as evaluated for element e in the specific reference direction θ_e. In the present note the non-dimensional, normalized practical quantities are given notation α, as alternative to the often preferred notation Q for corresponding dimensional quantities. The note shows that the name invariant is not a god choice. The practical parameters depend on the reference direction and the relations to the common x-direction are presented.

The note ends with a suggested visualization for the optimal constitutive design (obtained in recent research, see [1]).
Although written in relation to 2D constitutive matrices, the approach is also valid for; 2D structural stiffness matrices $[S]$, 2D structural flexibility matrices $[F]$, and 2D strength matrices in stress space $[H]$ or in strain space $[G]$. Also laminate stiffness sub-matrices and laminate flexibility sub-matrices may be analyzed similarly.

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9124 | SIMULTANEOUS SHAPE AND MATERIAL OPTIMIZATION OF SANDWICH PANELS WITH HONEYCOMB CORE FOR ADDITIVE MANUFACTURING (22. Optimization techniques and methods)

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This works deals with the problem of the optimum design of a sandwich plate composed of CFRP faces and Al honeycomb core.The proposed design strategy is a multi-scale numerical optimization procedure that does not make use of any simplifying assumption to find a global optimum configuration of the system. The goal of such a procedure consists in simultaneously optimizing the shape of the unit cell of the honeycomb core (meso-scale) and the geometrical as well as the material parameters of the CFRP laminated skins (meso and macro scales). To prove its effectiveness, the multi-scale optimization strategy is applied to the problem of the least-weight design of a sandwich panel subject to constraints of different nature: on the positive-definiteness of the stiffness tensor of the core, on the admissible material properties of the laminated faces, on the local buckling load of the unit cell of the core, on the global buckling load of the panel and geometrical as well as manufacturability constraints linked to the fabrication process of the honeycomb core.
This study can be placed within the conceptual framework of the work originally proposed in [1,2] and can be seen as a generalization and also as an extension of that work. Indeed, the main questions which inspired this work were the following ones: is the hexagonal shape the optimum shape of the unit cell of the honeycomb core for a given application? In addition, if other (more effective) shapes exist is it possible to fabricate them with a current modern fabrication process as additive manufacturing? In which manner the considered fabrication process affect the final optimum configuration? How to take into account these aspects within the design phase (i.e. the optimization process)? To answer to these questions we developed an optimization procedure which is articulated into two distinct (but linked) problems.
The aim of the first level problem is the determination of the optimal shape of the unit cell (described in the mathematical framework of NURBS curves [3]) together with the material and geometric parameters of the laminated skins in order to minimize the weight of the structure and to satisfy, simultaneously, the full set of optimization constraints. At this level each skin is modeled as an equivalent homogeneous anisotropic laminate whose behavior at the macro-scale is described in terms of laminate polar parameters, see [2]. Concerning the model of the honeycomb core, the first-level problem involves two different scales: the meso-scale of the repetitive unit cell characterized by its geometric variables, as well as the macro-scale where the core itself is modeled as a homogeneous orthotropic solid whose equivalent material properties depend upon the geometric parameters of the unit cell. Therefore, the link between these two scales is represented by the homogenization phase of the honeycomb core, see [1,2].
At the second level of the strategy, we have to determine the optimal lay-up for both skins (the skin meso-scale) meeting the optimal combination of their material and geometrical parameters provided by the first level of the strategy. The goal of this phase is, hence, to find at least one stacking sequence which has to be quasi-homogeneous, fully orthotropic and that has to satisfy the optimal polar parameters resulting from the first step. At this level of the strategy, the design variables are the layer orientations, see [2].
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9146 | Optimizational Design and Analysis for Composite horizontal axis tidal turbine blades (22. Optimization techniques and methods)

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Tidal turbine blades are subjected to significant thrust and torsional loadings due to the high density of the seawater in which they operate. These thrust loadings lead to high bending moments at the blade root, which can prove to be a serious design constraint for these devices. This work presents a combined hydrodynamic-structural design methodology for a commercial scale (200KW) tidal turbine. Based on Computational Fluid Dynamics (CFD) and three-dimensional numerical flow analysis, power and torque of a composite water turbine at different rotating speeds were calculated and analyzed for a specific flow speed. A hydrodynamic analysis of the blade is carried out to determine pressure distributions along the blade span under normal and extreme operating conditions. The results showed that pressure at the tip of blade is higher than pressure at other position when blade rotated under

water. The pressure at spar caps is higher than blade's edge when water flowed through blade.
Parametric programm for computing blade structural properties is used to determine the stress ans strain distribution along the blade spar caps. Section shape such as box spar and I shape web was analyzed. The results showed that height of web should be considered during hydrodynamic analysis for blade profile and its strength and stiffness were enough for undertaking water pressure.

9188 | Efficiency optimisation of composite hydrofoils and cavitation tunnel experiments (22. Optimization techniques and methods)

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Traditionally marine propellers are manufactured using Nickel Aluminium Bronze (NAB) alloys or Manganese Nickel Aluminium Bronze (MAB) alloys. However, more recently, using composites to manufacture marine propellers has been extensively investigated and attempted in practice. This is mainly due to the favourable qualities of composites over metal alloys, such as, light weight and reduced inertia, reduced corrosion, ease of repeatable manufacture, lower noise generation, reduced lifetime maintenance costs and increased lifetime. In addition, one of the main advantages of composite propellers is their potential shape adaptability to ensure a higher efficiency over a large range of operating conditions compared to traditional alloy propellers and hydrofoils.

Designing shape adaptive composite hydrofoils is considerably difficult due to the complex interaction between the fluid domain and the hydrofoil and the resulting structural response. Furthermore, the variety and complexity of material selection and lay-up strategies are critical issues to be addressed in order to obtain optimum performance out of such blades. A genetic algorithm based optimisation technique has been developed by the authors to achieve layup optimisation of composite marine propeller blades [1, 2] to improve the Lift/Drag (L/D) performance by using bend-twist coupling driven shape-adaptive properties of composites. This paper presents the optimisation technique used to optimise the layup of the hydrofoils to maximise L/D performance, the process of manufacturing composite blades and experimental validation at the cavitation tunnel facility in Tasmania, Australia.

The developed in-house optimisation technique is based on the genetic algorithm coupled with Cell-based Smoothed Finite Element Method (CS-FEM) using 3-noded triangular elements using first order shear deformation theory [2]. The FEM technique is enhanced to take into account ply terminations required to accommodate the thickness variation of the blade. The optimisation is performed in both continuous ply angles and mixed-integer ply angles. The optimisation scheme multi-objective (pareto) with the intention of eliminating the possibility of layup schemes that are too flexible and deemed unreliable. The unloaded shape is obtained as a part of the optimisation process, which the mould for resin infusion is based on. Pressure distributions used in the optimisation is a result of past experiments in the cavitation tunnel on fixed hydrofoils. These pressure distributions have been validated using CFD analysis using ANSYS CFX. The paper discusses about the validation process in CFX and the Delaunay Triangulation based interpolation used to transfer loads from the CFD domain to the in-house structural optimisation code.

The manufacture of hydrofoil blades using vacuum assisted resin infusion inside a fully closed mould is also discussed in the paper. The blades are predominantly made using Carbon fibre composites. Cavitation tunnel tests were performed at various Reynold's Numbers with a number of different incident angles ranging from 0° to 10°. As a part of the experiments, the lift, drag and pitching moment were measured. The main parameter discussed in the paper will be the ratio between Lift and Drag as it was the main objective of optimisation. The paper will also discuss the L/D variation with Reynolds number for the same incidence angle.

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9304 | Sintering of High Performance Silicon Nitride Ceramic Composite under Vibratory Pressure (22. Optimization techniques and methods)

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To improve mechanical behaviors of silicon nitride ceramics, here we introduced a novel external field — vibratory pressure into the sintering of Si3N4 ceramics with advantages of higher density, more uniform distribution of interfacial phase, higher sintering motivation in the width direction, and therefore more favorable mechanical properties than traditional sintering methods. Grain size and aspect ratio of the two ceramics were investigated with linear intercept method. Flexural strength of the vibratory-assisted hot pressing (VAHP) specimen increased from 936±27.2 MPa to 1247±28.9 MPa, and an increase of 10% was achieved in fracture toughness. It is believed that such VAHP method can provide a universal approach and new opportunities for the fabrication of covalent-bonded ceramics or composites with enhanced performances.

9336 | Optimal and robust design of glass and carbon fibre reinforced hybrid composites under flexural loading (22. Optimization techniques and methods)

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Introduction
Hybrid composites consisting two or more types of fibres in a common matrix have attracted increasing interests [1]. An optimal and robust design of glass and carbon fibre reinforced hybrid composites under flexural loading is presented in this paper. It is shown from one of our previous studies [2] that fibre volume fractions and stacking sequence have significant effects on the flexural performance of S-2 glass and TR30S carbon fibre reinforced epoxy hybrid composites. This study further investigated the effects of fibre volume fractions and hybrid ratio on the strength and robustness of the hybrid composites.

The main objective is to provide an approach to designing laminates with improved flexural strength and robustness by adjusting the design variables. The results show when the fibre volume fraction for glass lamina is higher than that for carbon fibre lamina, the strength will increase and is less sensitive to manufacture uncertainties.
Model Development
The lamina properties, including the longitudinal, transverse and shear modulus are derived by Hashin's model [3]. The strain and stress distribution is determined based on Classic Laminate Plate Theory. Lo-Chim model [4] was used to predict the longitudinal compressive strength of the laminate and the longitudinal tensile strength was estimated to be equal to the stress in the lamina at the tensile rupture of the fibres. For hybrid composites, the maximum stress may not always occur at the outermost layer. Thus, the factor of safety for each layer, which is defined as the ratio of strength to maximum stress, is evaluated. The external load is increased until one of the factors of safety reaches 1, and the flexural strength is calculated accordingly.
Parametric Study
The fibre volume fractions of carbon/epoxy and glass/epoxy plies were chosen to be the design variables. For each variable the range of 30% to 70% was chosen. The laminate thickness was kept constant with the glass/epoxy layer being put on the compressive side. The thickness of glass/epoxy layer was varied and the stacking configurations with maximum flexural strength and maximum robustness were then found.
Results
When the stiffness of the carbon layer is similar to that of the glass, the flexural strength curve is relatively flat and in some cases the strength is higher. This will be achieved by choosing proper value for the carbon fibre to glass fibre volume fraction ratio less than 1. For instance, when both carbon and glass fibre volume fractions are 50% , the maximum flexural strength is 1429MPa, and when carbon fibre and glass fibre volume fractions are 35% and 65% respectively, the strength increases to 1436MPa. But the most flat curve (most robust design) will be achieved when the fibre volume fraction of carbon fibre and glass fibre are 33% and 70%, respectively. In this case the maximum strength is 1409MPa.
Conclusions
An approach to optimal and robust design of hybrid composites with respect to the flexural strength is presented. For carbon and glass fibres, it is found that when the outermost top carbon/epoxy layers are replaced by glass/epoxy ones of higher volume fractions, the strength and robustness of the composite will be increased in a certain range of hybrid ratio and fibre volume fraction ratio.
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9369 | Fabrication of complex-curved composite parts by using shape memory polymer mandrel (22. Optimization techniques and methods)

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Nowadays, the composites components and structures in the aerospace industry are increasing to reduce the weight of aircraft, in which the simple shapes can be fabricated by classical plate mandrels. However, the complex-curved shapes are difficult to realize by classical methods. Although there are two types of advanced fabrication technologies for complex-curved composite parts: Multi-piece metal mandrels and water-soluble mandrels, some inherited disadvantages of these methods hinder the development of composite manufacturing industry, such as long cycle and high cost. Based on the significant stiffness change between high temperature (higher than transition temperature) and room temperature of shape memory polymer (SMP), a new kind of styrene-based SMP deformable mandrel is developed and designed to fabricate the complex-curved composite parts and improve the development of composite manufacturing industry. There are mainly consists of six steps for materials selection to fabricate composite parts: (1) Measure the basic dynamic mechanical properties, such as storage modulus, loss modulus and loss factor and make sure the transition temperature of SMP; (2) Tensile the SMP samples under different temperatures from low temperature to high temperature in every 10oC interval to find out maximum deformation ratio of SMP; (3) Fabricate the original SMP mandrel state, heat to high temperature, put into the outer steel mold and inflate, the SMP mandrel will become replica the inter surface shape of outer mold; (4) Cool the temperature to room temperature and the mandrel will keep the temporary deformed state; (5) Filament winding on the surface of deformed SMP mandrel to form composite part and cure at room temperature; (6) Reheat the SMP mandrel above the transition temperature, the mandrel recover the original shape and easily removed to obtain the composite part without liner. In order to evaluate the feasibility of SMP mandrels, a kind of bottle-shaped composite parts with maximum deformation ratio 25%, 50%, even up to 120% are designed and fabricated. Moreover, a complex-curved SMP inlet mandrel is also fabricated, which can change the shape from circular section to square shape between two end cross-sections. These experimental results that SMP mandrels own significant potential for the future composite manufacturing industry.

9470 | An advantageous technique for the optimal reinforcement design (22. Optimization techniques and methods)

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The adoption of Fibre-Reinforced-Polymer (or FRP) materials in the construction field is young as regards to other refurbishment techniques. However their use relevant to ancient buildings cannot consist of strips glued in a rather unordered way along casual (horizontal, vertical plus diagonal) directions. On contrary, the optimally effective distribution of the FRP strips or textiles should take into account the technical characteristics of the refurbishment materials and the artistic and monumental value of the building at the same time. Apart from some economical and technological features, the mechanical function of FRP is substantially independent on the material constitution. Usually, the task is to confer to masonry (as well as in reinforced concrete) some tensile strength that can be very useful to drastically improve its performance, especially under seismic loading.
The behaviour of the masonry structure can be successfully modelled by means of the no-tension (or NT) material, that behaves very well in compression, but is not able to resist tensile forces, similarly to the masonry material. The FRP reinforcement acts when the tensile forces born. So that it must be used after having the deepest knowledge of the behaviour of the structure where the intervention is coming on and after having projected the FRP application.

In absence of one or both of them, the advantage of the refurbishment could be null or quite negative.
It is true that if the models for the prevision of the masonry behaviour are sufficiently reliable, on the contrary the studies about the optimization of the refurbishment intervention are discontinuous and not validate by a large experience.
Since some years, by means of the basics of the topology optimization [1-3] the authors search a simplified, and more advantageous, technique for the application of FRP materials to damaged masonry structures [4-5]. In the area of computational variable-topology shape design of continuum structures, the methods that employ a material distribution approach for a fixed reference domain, seem to fit very well the objective, in combination with a finite-element model of the structure, yielding a partition of the wall surface under examination with the areas where the reinforcement should be applied. The problem is approached by defining a performance index of the reinforcement, that mixes both fractures and reinforcement in the objective function, thus reducing the number of constraints in the minimization process.

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9617 | Ply optimization of variable stiffness composite laminates based on density distribution curve method (22. Optimization techniques and methods)

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A gradient based optimization method for variable stiffness design of composite laminates was proposed in this paper. The optimal element density and fiber orientations were determined in the optimization process. In order to attain industrial relevance, the manufacturing constraint should be satisfied and candidate fiber orientations were limited to a finite set. For the purpose of eliminating the number of constraints and design variables in optimization model, the density distribution curve method (DDCM) was established to parameterize element density. The element material properties were determined on basis of interpolation scheme in BCP method. Compliance and volume of laminates were treated as objective and constraint respectively in optimization model. The optimization problem was solved by the convex programming dual algorithm. Numerical examples demonstrate validity and efficiency of DDCM.

6845 | Damage growth characteristics in composite glass-epoxy plate by Vibration analysis (23. Finite elements)

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The aim of this paper was to presents a identification of dynamic behavior and response analysis of a glass-epoxy plate.
The numerical simulation were carried out on model plate made of glass-epoxy, and the corresponding frequency response functions have been calculate. An initial study into the dynamic loads of this method has been considered, the use of the finite element method makes it possible to develop the model of the plate, the Abaqus software is used to evaluate the maximal (displacement, strain and stress) and the natural frequencies , mode shapes of plate in composite glass-epoxy under damage condition.
The stress should be increased to improve the strength of the plate. These results can provide a reference for analysts and designers of composite material in aeronautical systems.

6919 | VIBRATION CONTROL BEAM USING PIEZOELECTRIC BASED SMART MATERIALS (23. Finite elements)

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The vibrations of bituminous beam are traditionally passively damped by the inherent damping properties. This sort of passive damping is effective for the high frequency vibrations only and is not effective for the low frequency vibrations. Recently, the use of smart materials for vibration control has become an alternative to the traditional vibration control techniques which is usually heavy and bulky, especially at low frequencies. This research is about the study of vibration control with smart materials with the ultimate goal to reduce the vibration of the bituminous beam. The study focused on the passive piezoelectric vibration shunt control technique. The Finite Element Analysis (FEA) was used in order for the analysis, optimal design and for determining the location of piezoelectric transducers. Finally, the analytical study of the passive piezoelectric vibration shunt control of cantilever beam is undertaken. The equation of motion of a composite beam which consists of a cantilever beam bonded with a PZT patch using Hamilton’s principle and Galerkin’s method was derived.

6973 | Experimental and Numerical Investigation of Masonry Walls Strengthened With Reinforced Fiber Plaster (23. Finite elements)

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The topic of this study is to investigate behaviors of masonry walls strengthened with reinforced fiber plaster under diagonal tensile loads. Full blend brick 100x50x30 mm in dimensions were used to make masonry walls with dimensions of 400x400x100 mm. Three different samples were manufactured by plastering masonry walls with traditional style, with 3% polypropylene or with 5% steel fiber. All the samples were tested using ASTM 1391- 81 standards. The propagation of damage on samples caused by diagonal tensile load was observed and load-displacement graphs were plotted for each sample. A finite element software (ABAQUS) was used to obtain numerical values for all samples and crack patterns and load-displacement responses were obtained. Experimental and numerical results were compared.

7576 | Evaluation of structural integrity of Type III hydrogen pressure vessel under impact loading by using finite element analysis **(23. Finite elements)**

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Aim of this paper is evaluate the structural integrity of Type III Full-wrap hydrogen pressure vessel, composed of an aluminum liner and carbon/epoxy composite layers, under impact loading condition by using finite element analysis. In order to develop analysis technique predicting accurate material failure under loading condition tensile test was simulated with user subroutine programmed by a commercial finite element code ABAQUS 6.10-1. The accuracy of the user subroutine program was verified by the experimental test results. The 3-dimensional model of a Type III hydrogen pressure vessel fabricated by filament winding process was constructed using ‘Composite Lay-Up’ function provided by ABAQUS 6.10-1 and every single ply was separately modeled. By the previously developed modeling technique the dome part was modeled considering spatially varying winding angle, and local coordinate was used to impose the exact material properties on each finite element of the dome part along each principal axis. Weight drop analysis was carried out to check the possible material failure of the pressure vessel following the international regulation of EIHP II. To implement property changes due to partial failure of the composite structure a user subroutine was programmed by using Hanshin criterion. The filling cycle pressure (1.25 x service pressure) of 87.5MPa was applied to the inside of the pressure vessel. The stress analyses of the pressure vessel before and after impact loading were carried out, and the possible material failure and the corresponding failure modes were closely investigated. Those finite element analysis results were used to estimate the structural integrity of the Type III hydrogen pressure vessel.

7714 | Free vibration and buckling analysis of laminated composite plates with cutout using isogeometric analysis **(23. Finite elements)**

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An isogeometric finite element method based on non-uniform rational B-splines (NURBS) basis functions is developed for free vibration and buckling analysis of thin laminated composite plates with cutout based upon the classical plate theory. The displacement fields and geometric description are approximated with NURBS basis functions. The essential boundary conditions are imposed with an improved Lagrange Multiplier Method, in which the system equations are split into boundary and interior groups, thus the size of the system equations of standard Lagrange multiplier method (LMM) is reduced and the shortcoming of the LMM is eliminated. The accuracy and the efficiency of the proposed method are thus demonstrated through a series of numerical experiments of laminated composite plates with different cutouts, boundary conditions, fiber orientations, lay-up number, eigen-modes, etc. The obtained numerical results are then compared with other available ones, and excellent agreements are found.

7794 | Numerically evaluation of strength for open-hole composite laminates from smooth laminates properties **(23. Finite elements)**

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NCF Composite laminates became attractive to structural applications due to its post-impact properties, higher manufacturing speed and more freedom on fiber orientation design. Techniques that are more recent allowed manufacture thin-ply lamina with reduced waving, achieving stronger and thinner laminates. Mechanical properties of NCF are discussed, as well its mechanical response to tension and compression. The stitch thread that keeps laminas together is responsible to introduce stress concentration sites. Manufacturing processes affects substantially the final properties of NCF, what address importance on development of new processes that minimize its impact. Finally, a finite element analyze on open-hole laminates is conducted to compare the results to previous NCF experimental data. For this, all input data was acquired from smooth laminates experimental mechanical response.

7837 | Modelling of beam – column composite joints at elevated temperature **(23. Finite elements)**

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The paper presents a numerical study on two composite cruciform beam-column joints with flexible end-plates subjected to fire. Joint-1 was 356x171x51 UB connected to 254x254x89 UC and the joint-2 was 610x229x101 UB connected to 305x305x137 UC. The results were verified using existing experimental data. Numerical experiments were performed to estimate moment capacity of the joints at ambient temperature. Four load cases for joint-1 and three for joint-2, with applied moment varying between 30 % - 70 % of the joint moment capacity were investigated to understand joint behaviour under fire. Heating was applied linearly at a rate of 10°C/min. Utilizing biaxial symmetry, only one fourth of the configuration was modelled in ABAQUS. The bare steel components of the joints were modelled using a four-noded tetrahedral element (C3D4T) capable of coupled thermal displacement analysis. The concrete slab was modelled using damaged plasticity. EC3 recommendations for degradation in strength and stiffness of steel were

employed to model material behaviour. Based on temperature-rotation relationship, the predicted results showed good agreement with experiment data in the elastic range while slight overestimates were observed in the plastic range. The results indicated high stress concentration in the top bolts and lower portion of the web close to end plate. The base of the embedded shear studs were heavily stressed as well. The failure modes of both joints in all loading cases were well predicted in simulation.

7935 | Structural analysis of composites under manufacturing constraints (23. Finite elements)

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An improvement of a structural simulation is realized with data sets from process simulations. A main challenge is to provide a mesh-independent interface for FE data conversion. In this work, FE data conversion for structural analysis is proposed. All relevant material parameter and model data can be exchanged with a mesh-independent method, between different process simulation tools and simulation tools for a subsequent mechanical analysis using structural simulation. This approach based on mapping algorithms and common data format definition.

The mapping algorithms search representative elements of a source mesh for nodes of a target mesh. An approximated FE field value is transferred into the target mesh with respect to coordinate system and setup of composites. Different material models are considered to analyse an influence of thickness and fiber orientation distributions onto material characteristics.

Validation results for using material models are demonstrated on a sheared textile AIRBUS material.

Joint work with Prof. Klaus Drechsler, Mr. Dr. Roland Hinterhölzl (TUM LCC), Mr. Dr. Tamas Havar and Mr. Jens Prowe (AGI).

Projects: MAI Design / MAI Carbon (BMBF)

7956 | Numerical Analysis of the Influence of Ply Waviness on the mechanical Behaviour of Composite Laminates by using laminated RVE (23. Finite elements)

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In recent years, fiber composites are widely used in mission-critical components. However, the manufacturing processes of these composites are known to introduce anomalies and imperfections that are difficult to eliminate, such as ply waviness, i.e. local undulations in the layers, which can produce significant decreases of stiffness and strength of composite structures. Accordingly, there is a demand for more accurate models to study the effects of such imperfections on the mechanical behaviour of these structures. For that purpose, a finite element model, based on laminated representative volume element (RVE) method, is developed in this work to investigate the influence of ply waviness on the stiffness and strength (“first-ply-failure”) reduction of composite laminates under different loads. With this laminated RVE model, the ultimate strength (“last-ply-failure”) of composite laminates with ply waviness is also predicted by employing progressive failure analysis. Progressive failure analysis within individual composite layers was performed using the Puck failure criterion, which can predict the failure mode of fiber composites and includes the formation of delamination at the layer interfaces, and subsequent reduction of appropriate stiffness properties of the failed elements.

Stiffness and strength predictions with the developed laminated RVE model were compared to analytical calculated results and mechanical test results obtained for a variety of layer wave formations intentionally fabricated into otherwise wave-free cross-ply laminates. Results suggest that the computational approach used for the analysis is well suited for predicting stiffness and strength reduction due to realistic formations of ply waviness in composite laminates. Parametric studies are conducted for cross-ply composite laminates with varying degrees of ply waviness as well. Waviness is assumed to be in the direction of the undulating 0° ply. Results show that stiffness and strength reduction are significant in the 0° ply direction only. Mechanisms of stiffness reduction are attributed to the out-of-plane rotation of the wavy plies. The magnitude of the property reduction increases as the amplitude of the undulation increases and the wavelength of the undulation decreases. The analysis presented in this work can be used to establish quality control standards with respect to ply waviness that do not reduce laminate performance below design levels.

7959 | A C^0-continuous RZT beam element for the damped response of laminated structures (23. Finite elements)

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Composite and sandwich structures are appealing to many engineering fields. Despite the increased rate of application, their cost remains higher compared to traditional engineering materials. One of the reasons is the necessary use of experimental characterization and validation of materials and structures respectively. One way to reduce costs is to increase the simulation capabilities. With this respect, finite element analysis is a powerful tool. However, the finite element modelling of composites and sandwich structures requires dedicated strategies in order to account for their non-homogeneity and anisotropy. The variation of stiffness in the thickness direction causes the rise of transverse shear stresses at plies’ interface, necessary to ensure the equilibrium of the structure. In thin laminates, the effect of such stress components is negligible and models based on the Classical Lamination Theory (CLT) can be used with sufficient accuracy. In thick laminates transverse stresses are no longer negligible and need to be accounted for to provide realistic estimates of laminates and sandwich behaviour.

A detailed description is possible through explicit 3D modelling but at the expense of the computational cost. Equivalent Single Layer Theories including shear effects are available, such as the First-order Shear Deformation Theory based on Timoshenko hypotheses, or the Higher-order Shear Deformation Theories which consider higher-order expansions of the axial displacement in the thickness direction. Their computational cost is lower than explicit 3D models but they are based on the assumption of continuous axial displacement along z. However, the elasticity solution provided by Pagano is piecewise. A good compromise between accuracy and computational cost is represented by zigzag functions. Among the others, the Refined Zigzag Theory (RZT) is able to account for both layers geometry and mechanical properties thus providing a physical-based, accurate solution.
While extensively used under static loading, the RZT and its performance under dynamic loading are not yet fully analysed, being only few example available in the literature.
This paper presents a C^0-continuous beam element based on the RZT which is employed to predict the dynamic response of composite and sandwich structures materials. In particular, structures with viscoelastic layers for vibrations reduction will be considered. The damping modelling of the structures will also be addressed.
The main objective is to assess the capabilities of the RZT for both dynamic response and damping predictions of laminates and sandwiches.

8015 | Numerical Analysis of Headed Stud Shear Connectors for Composite Steel–Concrete Beams Utilising Carbon Nanotube under Elevated Temperatures (23. Finite elements)

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This research presents the behaviour of headed stud shear connectors for composite steel-concrete structure under elevated temperatures. This research will analysed the effect of carbon nanotube by using numerical method analysis. The focus of this research is to compare the numerical analysis with the existing experimental results. A three dimensional finite element model (FEM) was developed using the commercial finite element software known as ABAQUS. The FEM results were proved to be reasonably accurate and parametric studies were conducted using different headed stud shear connector diameters and elevated temperatures. Parametric studies were also conducted. These parametric studies will propose design graphs for practising design engineers. The results shows that the failure mode predicted from numerical analysis were found around the base of the headed stud shear connectors at the steel-concrete interface caused by the maximum compressive stress of the concrete and stud shearing. This failure mode was also observed in the experiments conducted. Comparing between normal and nanotube concrete, nanotube behaves better under elevated temperature in term of ultimate capacities, ductility and stiffness. From parametric study, the ultimate load, stiffness ductility and failure mode are significantly influenced by the change of headed stud shear connector diameter. Finally, additional of carbon nanotubes in the concrete resulted less cracking to the composite system under elevated temperatures.

8124 | Modelling elastic properties of 3D woven composite structures (23. Finite elements)

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Finite element models were developed to predict the elastic stiffness performance of 3D orthogonal non-crimp woven composites. A homogenised representative volume element (RVE) of the composite was created in Texgen, a geometric modeller of textile materials. The RVE was derived from the actual woven architecture of the composite and implemented into the commercial finite element analysis software Abaqus, where relevant periodic boundary conditions and displacements were applied to obtain the elastic constants of the composites. The in-plane stiffness predictions were in good agreement with experimental data of samples manufactured and tested as part of this research. This provides the potential to significantly reduce the design time by removing the requirement of manufacturing and testing of the woven architectures.

8183 | Numerical Modelling of Bond Stress-Slip between Steel and Concrete and Parametric Study on the Effect of Bar Size (23. Finite elements)

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The applied load on a reinforced concrete structure is originally received by the concrete part and is then transferred to the reinforcement through their bond with the surrounding concrete. Hence the behaviour and strength of the structure not only depend on the original components but are also influenced heavily by the bond mechanism. As a result, a practical straight forward model for the bond behaviour between reinforcement bar and concrete is vital in FE modelling of reinforced concrete structures. In this paper a total of 15 concrete pull out specimens with 3 different bar sizes are tested in order to study the effect of bar size on the bond behaviour. A finite element model for simulating the concrete-reinforcement bond behaviour using ABAQUS software is presented. Both concrete and steel reinforcement are modelled as 3D solid elements and connector elements are used to define the interfacial bond behaviour. Several bond behaviours suggested in the literature are discussed and a new combined model is proposed which provides a more accurate prediction for stress-slip behaviour. The proposed model is validated by comparing the experimental and numerical results. The study on the bar size effect also agrees well with the suggested model.

8222 | Simplified Seismic Evaluation Method for Steel Members with Thin-walled Stiffened Box Sections (23. Finite elements)

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This study is aimed at developing a simplified seismic evaluation method for steel members with thin-walled stiffened box sections. To determine ultimate strength and ductility of such members, shell element-based FEM analysis is carried out. Then pushover analysis using Fiber model is performed in which the effect of local buckling is taken into account in the assumed stress-strain relation. Predicted strengths and ductility are compared with those of the

shell model analysis, and the accuracy of the proposed method is discussed.

8263 | MPFEM simulation on the 2D compaction of binary Al/SiC particulate composites (23. Finite elements)

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In this study, a multi-particle FEM (MPFEM, with discretized mesh division for individual particle) which incorporates the characteristics of DEM and traditional FEM, was utilized to study the packing densification of mono-sized Al/SiC particulate composites in 2D subjected to single action die compaction. Different initial packing structures, i.e. ordered packings of simple cubic (SC), body centered cubic (BCC), face centered cubic (FCC), and hexagonal close packed (HCP), with layered packing of Al and SiC particles alternatively, and amorphous packings (disordered packing) with SiC particles of different content dispersed in the random packing of Al particles, were all generated by DEM modeling. During compaction, the morphology evolution of the compacts with the compaction pressure was monitored and the relationship between packing density of the composites and the pressure was identified. Meanwhile, the dynamics based on the interactive forces between particles was analyzed and the densification mechanism such as the evolution of pore size and structure, pore filling mode was studied as well. The results show that different initial packing structure of the particulate composites corresponds to different densification behavior. For the ordered initial packings, the force chains in the compacts are ordered with uniform distributions at each height and the deformation of Al particles is regular. While for the amorphous initial packing, the force chains in the compacts are disordered which are mainly determined by the contacts between particles and the deformation of Al particles is irregular. The initial packing structure of SiC particles in the composite can to a large extent influence the densification of the composite compact and its subsequent properties. Therefore, for mono-sized Al/SiC packing mixture, to properly control the distribution of SiC particles is the prerequisite to obtain the high performance composite compacts.

8514 | Finite element modeling of sound transmission between two acoustic cavities separated by a double-wall (23. Finite elements)

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Double walls are a common type of structure, widely used in practice. They are found in all types of constructions: building walls, windows, cars, airplanes….Two plates with a cavity between them give better sound reduction compared to a single wall with the same mass. The space in-between can also be filled with absorbents to increase the sound reduction. The mass-air-mass resonance is a well-known undesirable phenomenon in this kind of structure. At this resonance frequency, the sound reduction decreases to a level that can be lower than the one of a single wall with the same mass. The behavior of the wall is easier to predict at frequencies above and below this resonance frequency than close to it. It can therefore be difficult to make accurate predictions of the total sound reduction of double walls.

In the present work, the transmission of sound between two acoustic cavities (a sending room and a receiving room) separated by a double-wall is investigated using the finite element method. A sound source is placed in the sending room and acoustic absorbing materials are employed in the receiving room. The proposed finite element model is derived from a variational principle involving structural displacement and acoustic pressure in the fluid cavities. To solve the structural-acoustic problem, the direct solution can be considered only for small size models. Some important limitations appear for attaining accurate results over a wide frequency range of interest. Thus, a reduced order-model is proposed to solve the problem at a lower cost. The presented methodology, based on a normal mode expansion, requires the computation of the uncoupled structural and acoustic modes. The uncoupled structural modes are the real and undamped modes of the panels without fluid pressure loading at fluid-structure interface, whereas the uncoupled acoustic modes are the cavity modes with rigid wall boundary conditions at the fluid-structure interface. Moreover, the effects of the higher modes of each subsystem are taken into account through an appropriate static correction. Examples of the sound level difference between two rooms is shown in order to illustrate the accuracy of the proposed finite element reduced order model in terms of noise attenuation compared to direct methods. The influence of some key parameters such as the absorbing material in the receiving room, the damping in the structure, and the characteristics of the double-wall between the domains are also analyzed.

8703 | Advanced Nonlinear Inelastic Analysis of Three Dimensional Composite Steel-Concrete Frameworks (23. Finite elements)

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The present work attempts to develop accurate yet computational efficient tools for the nonlinear inelastic analysis of real large-scale 3D composite steel-concrete frameworks fulfilling the practical and advanced analysis requirements. Essentially, nonlinear inelastic analysis employed herein uses the accuracy of the fiber elements approach for inelastic frame analysis and address its efficiency and modelling shortcomings both to element level, through the use of only one element to model each physical member of the frame, and to cross sectional level through the use of path integral approach to numerical integration of the cross-sectional nonlinear characteristics.

An analytical model for the analysis of steel-concrete composite beams with partial shear interaction including the shear deformability of steel component is presented. Using the concept of the degree of shear connection tangent flexural rigidity of the cross-section is derived and then using the flexibility approach the elasto-plastic tangent stiffness matrix and equivalent nodal load vector of the three-dimensional beam-column element including the shear deformability of the steel component is developed. This model is obtained by coupling an Euler–Bernoulli beam for the reinforced concrete slab to a Timoshenko beam for the steel beam.

The behaviour model accounts for material inelasticity resulting from combined bi-axial bending and axial force. The penalty element method is applied in the present formulation to include the effect of the finite joint size on the element stiffness matrix of the beam-column element. The proposed nonlinear analysis formulation has been implemented in a general nonlinear static purpose computer program, NEFCAD. Advanced finite element simulations have been conducted by using the specialized software for nonlinear analysis of structures, ABAQUS. A numerical model considering a combination of three-

dimensional solid elements (for concrete volumes) and shell elements for steel elements has been developed. It is assumed that slip occurs at the steel-concrete interface.

Several computational examples are given to validate the effectiveness of the proposed method and the reliability of the code by comparing the results predicted by NEFCAD with those given by the ABAQUS software and other results retrieved from the open literature. The comparative results show that the effect of the shear deformability of the steel beam cannot be ignored in the evaluation of the overall structural stiffness. The studies show that the proposed analysis compares very well to finite fibre element solution (Abaqus) with much less computational effort.

8709 | Design of a composite bucket seat used in automobiles (23. Finite elements)

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Bucket seats which account for 3~5% of the total vehicle cost and weight play an important role in determining ride comfort and safety of the high performance automobiles. Therefore, automobile manufacturers are continuously seeking various methods to improve the areas of comfort, safety, reliability, cost and weight within the seat system. In this work, lightweight composite bucket seat structure which has high dynamic stiffness and flexural strength was designed. Finite element analysis (FEA) was performed with respect to the stacking sequence to obtain an optimum design based on impact resistance and the natural frequency. And the CFRP bucket seat was fabricated by a vacuum assisted resin infusion molding (VARIM). To verify FEA results, the dynamic properties including the impact resistance and natural frequency were measured by impact test and modal test.

8734 | Cohesive zone modelling of interfacial and cohesive failure in CFRP/steel joints bonded by thick adhesive layers (23. Finite elements)

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Design of steel-FRP adhesive joints is one of the areas that has been less researched when it comes to strengthening and repair of steel structures using bonded FRP composites. Unlike concrete-FRP joints in which the failure is mostly governed by failure in the concrete substrate, different failure modes are likely to happen in steel-FRP joints which add to complexity associated with the design. Using energy based methods is a solution to get around problems such as complicated calculations and singularity in stress or strain based methods. There has been a lot of research on using damage mechanics and cohesive zone modeling, CZM, for strength prediction of adhesive joints which offers a number of advantages compared to traditional fracture mechanics calculations.
This paper investigates a number of issues such as the influence of the location of the crack path on behavior of the joint, the effect of the adhesive layer thickness on the fracture energy properties and validity of the current equations to derive fracture energy properties of the adhesive for thick adhesive layers and calculation of the interface fracture properties if the failure mode should be governed by debonding at the interface in the joint. Results indicate that the crack path location has an influence on the behavior of the joint in terms of maximum deformation. It is also shown that the current formulae to derive the fracture energy properties from standard DCB and ENF tests are valid for thin adhesive layers and they should be corrected if thick adhesive layers, such as those used in civil engineering applications are used. A new test configuration is also presented in this paper to derive the interface fracture properties. The results are discussed and conclusions are drawn.

8738 | eXtended Finite Element Modeling of Crack Kinking in Composite Laminates under Mixed Mode Loading (23. Finite elements)

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This paper presents a new and consistent scheme of crack propagation in orthotropic composite materials based on eXtended Finite Element Method (XFEM). Stresses and displacement fields for orthotropic material are obtained using complex variable approach. The Stress Intensity Factor (SIF) is obtained using an Interaction Integral. The effect of ratio of stiffnesses in both orthotropic directions on the stress intensity factor (SIF) are analyzed for center crack due to fiber separation in the laminate and through thickness edge crack problems. These effects are found to be accurate in comparison with the available results based on Boundary Element Method (BEM). The formulation is further implemented in an XFEM scheme to model crack kinking under mixed mode loading in orthotropic laminated composite plane problem where transverse cracking and delamination are strongly coupled. Circumferential stress criterion has been used earlier for crack propagation and here we review this aspect considering detailed micro-mechanism of failure. The effect of ply angular orientation dependence of fracture toughness in the orthotropic material is also included in the model. In order to show the importance of this problem, the effect of ply orientation on crack propagation path for initially straight and inclined edge crack problems are analyzed and are compared with results from published literature, which does not consider the effect of angular variation of crack orientation on the fracture toughness. Using these examples the usefulness of the developed XFEM scheme to model various types of problems in realistic composite structures are highlighted.

Keywords:- Extended Finite Element Method, Crack, Crack Propagation, J-Integral, Stress Intensity Factor, Orthotropic Material, Maximum Circumferential Stress.

8765 | Stress Analysis and Delamination Prediction on Overlapped-Grouped (O-G) and Overlapped -Dispersed (O-D) Tapered Composite Laminate using Finite Element Method (23. Finite elements)

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Morden aeronautical structure is being made of laminated composite in which plies are terminated at discrete position to provide taperness. Thickness variation in laminates composites are achieved by changing the number of plies in proportion to the thickness change. It's requires the termination of plies, within the laminate. Ply termination is called ply-drop. In present study two different ply-drop configurations have been taken for analysis purpose under tensile loading, these are overlapped-grouped and overlapped-dispersed. Commercial finite element software ANSYS 14.0 is used for analyses. To construct the model geometry layered 3-D finite element (SOLID 20 node 186) is considered which consist six degree of freedom at each node. Tsai-Wu criterion is used to obtain the value of failure factor for separate plies. Interlaminar stresses variations along the interface of plies are determined to initialize possible delamination sites. For both configurations the value of failure factor is found maximum at position of first resin pocket tip. In case of overlapped-grouped delamination growth occur at position near the thin section but in case of overlapped-dispersed it is spread at discrete positions over the laminate.

8770 | INFLUENCE OF BINDER CONFIGERATION ON 3D WOVEN COMPOSITES (23. Finite elements)

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3D woven composites have the potential to revolutionise the structural composites, provided the knock-down in in-plane properties can be minimised through weave optimisation. Since binders tows interactions produce waviness in warp and weft tows, 3D weaving process needs optimisation. This paper presents a predictive modelling tool based on Representative Volume Element (RVE) of a 3D weave capturing the binder configuration as a function of the weaving process. Implemented in ABAQUS, this predictive tool is able to predict all the elastic constants with a reasonable accuracy. This paper will also present the initial work on strength predictions and the selection of appropriate failure criteria for 3D woven composites.

8916 | A strain gradient notation serendipity plate element free of modeling deficiencies for the analysis of laminated composites (23. Finite elements)

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An eight node serendipity element free of locking and spurious zero energy modes is formulated to model laminated composite plate problems. The element is based on a first-order shear deformation theory and on the equivalent lamina assumption. Stresses are calculated at different points through the thickness of the plate. They are averaged values due to the equivalent lamina assumption. The model represents transverse shear strains and stresses as constants while their actual variations are parabolic. Thus, a shear correction factor is used.
The element is formulated using strain gradient notation. Strain gradient notation is physically interpretable and allows for a detailed a-priori analysis of the finite element model. Its polynomial expansions are inspected and spurious terms which are responsible for shear locking are identified. The element is corrected by simply removing the spurious terms from those expansions. The compatibility modes are also clearly identified and maintained in the strains expansions. This prevents the introduction of spurious zero energy modes into the model. Numerical results show the locking effects caused by the spurious terms on displacement and transverse stresses solutions. They also show that properly refined meshes composed of corrected elements provide solutions which converge rather well to analytical solutions.

8917 | Geometrically non-linear analysis using a 3-node facet shell element for laminated composite structures (23. Finite elements)

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The corotational (CR) kinematic description is used as the kinematic description to evaluate the geometrically non-linear behavior of different types of structures on a static analysis. The CR formulation is the most recent of the formulations proposed for geometrically nonlinear structural analysis. Because of this novelty, it has not reached the same level of maturity of the older Lagrangian formulations (Total and Updated). Along the current research, it was aimed to demonstrate the basic concepts of the corotational approach that is based on the separation of the total motion into rigid body and deformational motion. The aim of this paper is to develop an efficient element for the solution of bending, critical buckling and postbuckling analysis of composite plates and shells. The analysis is based in four important assumptions: (i) strains from a corotated configuration are small while (ii) the magnitude of rotations from a base configuration is not restricted (iii) analysis of the laminated composite plates and shells in the framework of the First-Order Shear Deformation (FOSD) theory and (iv) the Riks-Wempner arc-length control method and Newton-Raphson strategy are used to trace equilibrium paths in the pre and postbuckling range of deformation. The assumed natural deviatoric strain (ANDES) three nodes triangular shell element is implemented for laminated composite material models and its application to different constitutive models is discussed. Based on the numerical examples, it could be concluded that the CR approach and its numerical implementation showed excellent agreement with benchmark results found by other researchers in order to show the adequacy of the presented theory and the effectiveness of the numerical procedure and shell element employed in this work.

8924 | Finite element analysis and study for the mechanical property predictions of Fiber Metal Laminates (23. Finite elements)

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Fiber metal laminates (FMLs) are engineered materials composed of thin structural sheet metal plies alternately bonded to plies of fiber-reinforced polymer. FMLs have received an increasing amount of attention in the aircraft industry due to their light weight, outstanding fatigue resistance, high specific static properties, excellent impact resistance, good residual and blunt notch strength, flame resistance and ease of manufacture and repair. In this work, the FMLs with glass fibers (trade name GLARE) and woven glass fibers are used respectively and effect of fiber orientation on tensile properties of FMLs are investigated. A numerical simulation method based on finite element modeling (FEM) has been developed to predict the stress-strain response of FMLs. Finite element simulation results show that the fiber orientation is the most important parameter on tensile properties of FMLs. Furthermore, the FMLs with woven fibers can decrease the number of layer and the weight of FMLs, when the tensile properties of FMLs are not change obviously. FEM simulations show a good agreement with experimental results, which can be used for the design of novel FMLs.

8985 | STEEL WIRE MESH APPLIED FOR STRENGTHEN SHEAR MASONRY WALLS - STUDY CASE (23. Finite elements)

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Many masonry building located in prone seismic areas need structural interventions; therefore solutions which will increase the wall capacity and ductility, without a major influence on its stiffness is valuable. This article will present the description of such a technique, together with the application addressed to masonry buildings. The technique is derived from the FRP techniques but intending to obtain a higher enhance of the energy dissipation This technique applies a stainless or zinc coated steel wire mesh (SWM) bonded with epoxy resin to the masonry walls, on one or both sides.
Steel wire mesh reinforced masonry have a complex behavior and no analytic procedures to design of are available; therefore, advanced numerical models confirmed by extended experimental tests are need. Summarily is presented the experimental measurements and the finite element and material models adopted for retrofitted masonry specimens. The numerical model is calibrated according to the contactless and fullfield measurements obtained using Limess Vic 3D system.
The extensive experimental tests, carried-out within the framework of PROHTECH research project, have included tests on steel wires, on steel meshes, on 500 by 500 mm retrofitted masonry elements (split tests) and 1500 by 1500 mm masonry walls. The numerical calibration have been made using ABAQUS finite element software.
A typical building for the beginning of the XX century designed without any consideration of the seismic action has been evaluated and consolidated. In conclusion are presented the advantages and disadvantages of the studied retrofitting technique in comparison with other techniques.

8999 | A multi-linear material based FEM for nonlinear analysis of steel-reinforced glulam timber (23. Finite elements)

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The present paper deals with the development and application of an implicit nonlinear finite element model for analyzing glulam-laminated (glulam) timber beams, reinforced with steel bars. A generalized material model is built in a FEM code that can simulate the mechanical behavior of a solid under various type of loading and thermal history. The ability of the model is to schematize the nonlinear behavior, of the interacting materials: glulam timber, adhesive and steel bar, with a multi-linear, piecewise, stress-strain curve for each three-dimensional components of the stiffness tensor, without the need of plasticity theoretical function. This feature habilitate us to properly use this procedure for wood which shows an high anisotropy, affected by a complicate nonlinear behavior, difficult to introduce in a numerical simulation model. Thus, this more adequate representation of the material mechanical characteristics can improve the numerical simulation of material responses. A similar concept was used by other authors representing the stress-strain law, with power functions that fits the measured values from material tests. In the present study wood is schematized as orthotropic material, then the representation of the stress-strain curves is obtained by fitting the raw data measured from experimental tests. The numerical procedure has been applied to analyze a beam made of a wooden glulam, reinforced with steel bar, that is statically loaded in a four-point experimental set-up. The solution of the problem is obtained by an approximate Newton-Raphson iterative procedure, due to the nonlinear nature of the equations, in which load has been discretized into a finite number of steps. A software routine is developed for the material representation and implemented in a general FEM, which is capable to simulate the mechanical behavior of a solid undergoing large displacements and deformations. The numerical results have been compared with those of some experimental tests obtained in a previous work. The proposed methodology has demonstrated its adequateness to describe the mechanical behavior of steel reinforced glulam timber, under bending loads. This encourages us to extend the present approach to other more complex cases, in a future work. Furthermore, this model can contribute, when it is supported by experimental data, to improve current available techniques of timber reinforcement.

9043 | Cold swaging of Al-Cu clad composites, Finite Element and Experimental analysis of deformation (23. Finite elements)

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Cold swaging technology can effectively be applied to fabricate clad composites. The influence of deformation imposed during swaging of a multilayered Al-Cu clad composite was analyzed by finite element method (FEM) simulations and microscopy. The FEM analyses quantified gradients in deformation and the effects of varying the geometry and parameters of the swaging process. The predicted deformation response was correlated with measurements of changes in grain structure, development of preferred orientations, and mechanical anisotropy. The correlations between the predicted and measured results established the utility of numerical analysis for designing axisymmetric clad composites and explaining the complex gradients and patterns in the microstructures produced by cold swaging.

9045 | FEM modeling cermet coatings post-treatment by pulsed high-concentrated energy fluxes (23. Finite elements)

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Thermal spraying of nano- or submicrometer structured cermet coatings from composite powders with particles containing inclusions of a very hard chemical compound dispersed in a metal alloy matrix (TiC-NiCr, WC-Co, Cr2C3-(Co-Cr), etc.) opens up vast possibilities in the formation of wear- and corrosion resistant surface layers intended for use under severe environmental conditions.
But, the high carbide phase content in ceramic-metal powder particles (50-70%vol. and higher) makes the melted metal binder, containing hard, finely dispersed suspended inclusions, highly viscous. Among other things, the high viscosity of sprayed particles leads to a low degree of their deformation during impingement onto substrate or previously sprayed coating layer. That is why the plasma sprayed ceramic-metal coatings normally have rather high surface roughness and comparatively high open porosity.
Decrease in porosity of cermet coating at simultaneous increase of its bonding strength with substrate is possible by means of subsequent heat treatment. The problem consists in binder melting at minimum impact on carbide inclusions and substrate. It is possible to realize in practice high-temperature post-treatment of coatings, practically without volume heating of the base, at their pulsed high-energy impact. Because the experimental development this technology is rather labor- and power-consuming procedure, computer optimization is very perspective. With use of the developed physical model of porosity evolution at pulsed high-energy treatment of coating, the computing experiments based on FEM modeling were carried out, which allowed to optimize power density in a single pulse and its duration depending on thickness and porosity of cermet coatings, as well as volume ratio of carbide inclusions.

9058 | Research on Creep Behavior of Prestressed Composite Box-girders with Corrugated Steel Webs (23. Finite elements)

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Prestressed concrete box-girder bridges with corrugated steel webs have found increased applications in bridge construction in China in recent years. This is predominantly due to the advantageous properties of the structures, such as low self-weight, high sheer strength, easy maintenance, and substantial resistance to earthquake. These new structures still have to be considered as demonstration projects, which, however, show potential advantages over traditional structures. The three-span prestressed composite continuous box-girder with corrugated steel webs of the Taohuayu Yellow River Bridge with the span arrangement of 75m+135m+75m was completed in Henan Province in 2013, and the three-span prestressed composite continuous box-girder with corrugated steel webs of the Qianshan River Bridge in Zhuhai with the largest main span of 160m in China is under construction. More than 40 bridges of these kinds have been built in China, and China has become the second country where these composite structures have been widely used.
Creep behavior of concrete has very important influence on the calculation of construction camber of large span continuous box-girder bridges. The objective of this study is to investigate the difference of creep behavior between the prestressed composite box-girder with corrugated steel webs and the traditional prestressed concrete box-girder. The two kinds of simple supported box-girders with the same span of 40m were modeled with the commercial finite element software ANSYS-Civilfem. Then the creep effects including long-term deformation and internal & external pretress loss in both models were simulated and compared under the two kinds of conditions of the same top & bottom plate initial stress and the same prestress configuration. The numerical results show that the deflection increment and the prestress loss rate of prestressed composite box-girder with corrugated steel webs is larger than that of traditional PC box-girder resulted from the concrete creep. Nevertheless, the prestress loss rate of PC composite box-girder with corrugated steel webs is smaller than that of traditional PC box-girder.

9076 | Fluid-Structure Interaction Analysis of Composite Shell Structures (23. Finite elements)

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The design of missiles and launch vehicles, shipbuilding and aerospace structures makes an extensive use of composite shell structures. Therefore, the dynamic behavior of composite made structures is of keen interest in the design of structural elements in the space and aeronautical, petroleum and nuclear industries. These structures often experience different mechanical, fluid and thermal loadings during their operation. This problem has given rise to a number of studies of the linear and non-linear vibrations of composite shell structures subjected to different loads e.g. the flowing flow loading that may cause excessive structural vibrations and consequently a considerable change in the dynamic response of the structures. This paper focuses mainly on development and application of a hybrid finite element approach used for linear and geometrically nonlinear vibration analysis of composite plate and shell structures, with and without fluid-structure interaction. The hybrid finite element approach, shearable shell theory and velocity potential flow theory have been combined to establish the dynamic equations of the coupled fluid-structure systems. Development of a hybrid element for different geometries of plates and shells is briefly discussed. The set of matrices describing their relative contributions to equilibrium is determined by exact analytical integration of the equilibrium equations. In addition, studies dealing with particular dynamic problems such as dynamic stability and flutter of plates and shells coupled to flowing fluids are discussed. This paper is structured as follows: after a short introduction on some of the fundamentals of the developed model applied to vibrations analysis of shells and plates in vacuo and in fluid, the dynamic analysis of anisotropic structural elements is discussed. Studies on dynamic response of plates in contact with dense fluid (submerged and/or subjected to liquid) follow. Dynamic response of shell type structures subjected to random vibration due to a turbulent boundary layer of flowing fluid is also discussed. Furthermore, aeroelasticity analysis of shells and plates (including the problem of stability; divergence and flutter) in contact with light fluids (gases) are discussed. These studies present very interesting results that are suitable for various applications. The proposed method has been developed and implemented for the design and analysis of shells of revolution (e.g. cylindrical, conical, spherical),cylindrical panels, circular and rectangular plates subjected to different mechanical and thermal loadings, internal and external potential flow, supersonic airflow, structures made from traditional, composite and advanced composite materials. Reasonable agreement is found with other theories and experiments.

9086 | MODELING AND STRUCTURAL ANALYSIS OF LADDER CHASSIS MADE OF COMPOSITES WITH DIFFERENT LAY-UP SEQUENCE (23. Finite elements)

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The chassis of a heavy vehicle serves as a backbone for supporting the body and its different parts. It deals with the static and dynamic loads, without undue deflection or distortion. Weight reduction is now the main issue in automobile industries with development of new composite materials and various reinforcement structures. In the present work,the chassis frame is initially modeled by considering 'C' cross section in Pro-E 5.0 and then analyzed using Ansys 13.0. The static analysis is done with three different composite materials subjected to the same load as that of a steel chassis. The best among the four frames is chosen from the static analysis.
The dynamic behavior is obtained for the best material that was chosen from static analysis. The various mode shapes and their respective natural frequencies are obtained by modal analysis. Through harmonic analysis of different lay-ups such as, [0/90/45/-45], [90/0/0/90], [0/45/-45/90] and [90/0/45/45] the frequency and amplitude of vibration are determined. Then the results are compared to finalize the best lay-up sequence among them.

9119 | Aero-elastic analysis of composite plate swept wings using the finite element method (23. Finite elements)

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A Finite Element Model (FEM) is developed for examining the aero-elastic stability of composite plate wings. The FE method coupled with the vortex lattice method has been applied to calculate the wing divergence speed, and coupled with the doublet lattice method to predict wing flutter. The effect of the composite layup is integrated into the FEM. The coupling between the aerodynamic and structural analyses has been expressed in terms of the shape functions of the FEM. The plate wing structure has been divided into linear triangular elements, each of which has five degrees of freedom at each node, and taking into consideration the fiber orientation angles of the composite laminate. A MATLAB code has been developed and validated by comparing the results with those of other publications. The effect of different laminate configuration on the aero-elastic characteristics (divergence and flutter) of both the straight and swept-back wings is investigated.

9121 | Finite element formulation for stiffened structures (23. Finite elements)

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In the present paper a finite element formulation to predict the behavior of stiffened plates such as ship decks will be developed. For this accomplishment, a linear but robust finite element formulation base on recently developed generalized higher order shear deformation theories (HSDTs) will be implemented for further calculations. The equilibrium equations will be derived using the principle of virtual work. Then, several types of ship structures will be calculated, and comparison with commercial software results such as ANSYS, will carried out in order to stress out the importance of using HSDT over the first shear deformation theory (FSDT).

Keywords: Static analysis, stiffened plates, finite element formulation, Ansys.

9177 | MODELLING SPECIAL DRILL BIT GEOMETRY FOR CFRP COMPOSITES (23. Finite elements)

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Carbon Fiber Reinforced Polymer (CFRP) composites are widely used in high responsibility applications in different strategic sectors. Usually the composite components are manufactured close to the final shape. However some machining operations are needed to achieve work-piece requirements. Due to the properties of this kind of materials because of the hard and abrasive reinforcement, LFRP are “difficult to cut” materials. Between all the manufacturing operations, drilling is very common to machine holes previously to mechanic joining of composite pieces.

The most common damage found during drilling is delamination. Delamination not only reduces drastically assembly tolerance and bearing strength, but also has the potential for long term performance deterioration under fatigue loads. This inter-ply failure phenomenon is highly influenced by the drill geometry and the cutting parameters to mitigate damage in CFRPs [1,2].

The interest on 3D models is interesting in the way that it can be used as a good prediction tool and to predict optimal drilling parameters. Only few works in technical literature deal with finite element analysis of these processes [3,4]. The authors have developed 3D models for orthogonal cutting of LFRP including chip removal and material erosion and allowing multidirectional laminate and delamination modeling [5,6]. Then also complete and simplified models of drillings for conventional twisted drills [7].

In this work, three-dimensional (3D) finite element models of drilling for both types of composite laminate (UD-ply and woven) have been developed, accounting for complex kinematics and interactions at the drill-workpiece interface. In this case a special step drill bit has been used and validated with experimental results carried out by the authors in terms of cutting forces and delamination.

These 3D damage models were developed and implemented into the finite element code Abaqus/explicit through a user-defined subroutine (VUMAT) in order to predict damage at each ply. Interface cohesive elements were inserted between the plies of the modelled laminate to simulate out-of-plane failure. The general contact algorithm in Abaqus/explicit was used to simulate contact conditions between the step drill and the composite laminate, and between the layers by defining appropriate contact-pair properties. Element deletion was used to erode damaged elements during the hole-making process based on initiation and evolution of damage in the meshed CFRP elements [8].

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9187 | Development of DKMQ Element for Error Estimation in Composite Plate Structures (23. Finite elements)

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The rapid advancement of technology in computation and material for civil engineering has encouraged construction designers to create sophisticated and futuristic building design as can be seen nowadays. When we deal with complex structures, there is no exact solution so the deformation occurred will be difficult to know. The complexity of a structure involves complexity in shape, which is usually non-symmetry, characteristics of nonlinear material, and complicated loading condition. To understand such structure, modeling of the structure using analysis or numerical simulation is required. Finite Element Methods (FEM) is a method used to calculate structures using numerical analysis to solve various problems in structures, soil mechanics, fluids, etc. FEM modeling begins with discretisation process of continuum structure into small elements with simpler geometry shape called finite element.
Since FEM is an approximation method where exact solution is estimated using repetition in discretisation process by increasing the number of element or refining the element size, a discretisation strategy must be taken in each mesh refinement process. The scale of error at each mesh size can only be estimated since no exact solution exists. Hence, what becomes important is how to estimate the scale of error, how much the acceptable error limit is, and what discretisation strategy should be taken.
Error in solution is unavoidable in finite element method application, either caused by inappropriate model, numerical integration usage, inaccuracy of numerical solution, or rounding error accumulation in numerical process. A complex problem usually has no exact solution; therefore, the error happened is also difficult to determine. Error estimator is developed to gain solution as close as possible compared to exact solution.
The development of modern technology has been used composite as the main materials. It is very light but it would be very strong when we compare to non-composite materials. Now, it has been developed composite agro-material made from renewable materials that can be used in large number of constructions. Sustainable future will be achieved by using composite as the main materials in engineering constructions. For this reason, it is required a computational method to support the analysis of composite structures. Moreover, a good precision of computational method in composite structures application is very crucial. This paper “Development of DKMQ Element for Error Estimation in Composite Plate Structures” will introduce a new computational method and error estimation in composite plate structures using DKMQ element.
DKMQ (Discrete Kirchhoff-Mindlin Quadrilateral) element was developed by Katili in 1993. DKMQ element is a very good Quadrilateral element which can take into account the transverse shear strain and it gives a good result in isotropic analysis for thin to thick plate problems. Moreover, DKMQ element is used in commercial software MIDAS-GEN and ROBOT. The proposed papers will focus on the development of DKMQ element for error estimation in composite plate structures. We will validate the results of DKMQ in composite plate structures with some standard problem tests, including one or several orthotropic layers and compare with the Pagano and Srinivas benchmark tests. Then, we will focus in the development of DKMQ element in error estimation for composite plate structures using various types of recovery method (Averaging, Projection, Superconvergent Patch Recovery and Recovery by Equilibrium in Patches methods) to get the solution close to the exact one.

Keywords: DKMQ element, composite plate structures, Pagano, Srinivas, error estimation, Averaging, Projection, Superconvergent Patch Recovery, Recovery by Equilibrium in Patches

9215 | FE formulation for a generalized quasi-3D layerwise HSDT for beams (23. Finite elements)

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Abstract:

This paper presents a finite element formulation for a generalized quasi-3D layerwise HSDT for the bending analysis of advanced composite beams. The present theory accounts the thickness stretching effects, therefore no shear correction factor is used. Lagrangian and Hermitian interpolation functions are used to describe the primary variables corresponding to the in-plane displacements and transverse displacement, respectively. In addition, the generalized governing equations of a layerwise HSDT beam and boundary conditions are derived by employing the principle of virtual work. Navier-type analytical solution is obtained for FGP subjected to transverse load for simply supported boundary conditions. Analytical and numerical examples of the quasi-3D HSDTs (non-polynomial, polynomial and hybrid) derived by using the present generalized formulation are compared with 3D exact solutions and with other HSDTs.

Keywords: Shear deformation, Static analysis, stiffened plates, finite element formulation.

9308 | Simulation of Stress Concentration Problems in Laminated Plates by Quasi-Trefftz Finite Element Models (23. Finite elements)

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Hybrid quasi-Trefftz finite elements have been applied with success to the analysis of laminated plates. Two independent fields are approximated by linearly independent, hierarchical polynomials: the stress basis in the domain, adapted from Papkovitch-Neuber solution of Navier equations, and the displacement basis, defined on element surface. The stress field that satisfies the Trefftz constraint a priori for isotropic material is adapted for orthotropic materials, which leads to the term “quasi”. In this work, the hexahedral hybrid quasi-Trefftz stress element is applied to the modeling of non-symmetrical laminates and laminated composite plates with geometric discontinuities. The hierarchical p-refinement is exploited.

9354 | COMPUTER AIDED FINITE ELEMENT ANALYSIS OF FRC BEAMS CONTAINING PVA AND BASALT FIBRES (23. Finite elements)

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This paper investigates the computational performance of the proposed analytical models for the compressive and tensile stress-strain curves to predict the flexural behavior of fiber reinforced concrete (FRC) using finite element analysis (FEA) approach. The analytical models were proposed by the authors for the prediction of the tensile and compressive stress-strain behavior of high performance fiber reinforced concrete (HPFRC) containing up to 3% volume fraction of the PVA and Basalt fibers. For the similar mixes of FRC, 21 beams subjected to three-point bending load were analyzed by modeling in finite element analysis (FEA) program ATENA 3D and the proposed analytical stress-strain models were incorporated into the program. The computer generated load-deflection responses of FRC beams containing up to 3% volume fraction of the PVA and Basalt fibers are compared with the experimental results. The results of FEA of all beams showed a good correlation with the experimental results in terms of the maximum load, load vs. mid-span deflection patterns and the maximum tensile strains.

9374 | Constituent materials micro-damage modeling in predicting progressive failure of braided fibre composites (23. Finite elements)

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Braided textile composite exhibits a mechanism to efficiently distribute the load throughout the structure as the continuous fibres in the braided textile reinforcement are mechanically interlocked with each other, which makes braided structures impact resistant. However, the successful prediction of the strength of braided textile composites still remains as a challenge.
In this paper, a numerical simulation model based on a meso-scale approach is presented for the prediction of the tensile strength and progressive damage behaviour of braided textile composites, in which the yarns are treated as a homogenized entity and the main focus is on the failure modes of the fibre yarn and matrix. A homogenized representative unit cell was built for finite element analysis. The matrix and fibre yarn in the unit cell were explicitly modelled by finite elements and their material properties were directly assigned to the elements. The 3D Hashin and Stassi failure criteria were respectively selected for the yarn and the pure matrix. The selected damage models were then included in the USDFLD subroutine via FORTRAN 77 in Abaqus to account for the damages in individual constituents.
It was found that the ultimate strength of the braided composites decreased with the braiding angle of the unit cell. Failure mechanisms were also observed to change with the braiding angle. To validate the developed damage model, the simulated results were then compared with a recent experimental and micromechanics-based numerical study by Xu [1]. The tensile stress-strain curves of composites with different braiding angles agreed closely with the experimental and simulated results reported by Xu [1].

Keywords: strength, tensile, prediction, finite element, braided, composite

[1] Xu, L., Jin, C.Z. and Ha, S.K. Ultimate strength prediction of braided textile composites using a multi-scale approach. Journal of Composite Materials 2014; doi:10.1177/0021998314521062

9396 | MECHANICAL CHARACTERIZATION OF A CARBON FIBRE COMPOSITE THROUGH A COMBINED EXPERIMENTAL AND NUMERICAL APPROACH (23. Finite elements)

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The numerical simulation of composite components under extreme loading conditions is not straightforward as it requires an extensive experimental program in order to provide a thorough material mechanical characterisation. The reliability of these numerical models is strictly related to the accuracy of the material mechanical characterization starting from simple coupon specimens.
In this context, the present paper is part of a wide research activity focused on the investigation of the mechanical behaviour of a MTM45-1/IM7 composite (carbon fibre in an epoxy matrix) through a series of different standard tests. An experimental preliminary program has been planned, including tensile tests (considering both 0° and 45° fibre direction specimen) and tensile tests on specimens with an open hole. All the experiments are reproduced numerically in order to estimate reliable material parameters that can be used as input for more complex simulations characterized by different and also extreme loads.
Particular attention has been devoted in this study to the experimental evaluation of the damage mechanisms taking place in the tested specimens. Finally, the possibility to numerically simulate such kind of damages has been investigated and all the experimental tests have been reproduced by means of a virtual testing approach.

9414 | Coupled dynamic responses of moored Spar in deep water hydrodynamic environment (23. Finite elements)

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A few propelled floating structures were proposed and created till date because of their expense viability and productiveness in deep water investigation. Spar platform has been behaved as a productive alternative amongst them. In any case, the exact conduct of completely coupled activity in deeper water is still an extraordinary issue to be forecasted in real ocean environment. Nonlinear finite element examination for completely coupled 3D model of floating spar platform structure can be an affluent appliance to conjecture the responses, where primary assemblage of Spar platform and mooring lines are considered in a joined compact coupled system. The forecast of platform movements depends on the immediate mass, stiffness and damping of mooring lines in the coupled system. To characterize precisely the interaction between the platform and mooring lines, coupled dynamic investigations are proper for getting responses in deep-ocean. Thusly, the main objective of this paper is to examine the hydrodynamics of completely moored Spar platform under actual sea environment. The present moored Spar model is more precise to hold continuity of the structure and boundary conditions, loadings taking all the nonlinearities. Considering the coupling impacts of the platform and its mooring system, hydrodynamic examinations of a moored Spar has been done in time domain. In light of the boundary component method, the 3-D model of the moored Spar and the related free water surface model are simulated. The wave excitation forces, included mass, and other hydrodynamic properties are legitimately characterized. Numerical simulation and motion investigations are completed with the commercial finite element (FE) program ABAQUS. Tension to the deformable mooring lines is similarly disseminated. Wave loading acts at the same time on the rigid Spar structure and deformable mooring line. The completely coupled responses of inflexible rigid Spar structure and mooring line have been assessed. The improved coupled investigation approach for Spar platform subjected to hydrodynamic forces joins computational savings keeping up adequate exactness. Unbending rigid body movements impact the element movement responses of Spar. The tension in catenary mooring line (CML) diminishes after certain wave term fundamentally because of the CML damping in the combined coupled Spar-mooring system.

9465 | A finite element formulation for viscoplasticity (23. Finite elements)

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A finite element formulation for viscoplasticity

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Many composite materials may exhibit a viscoplastic material behavior when subject to external loadings or thermal conditions. In this case it is necessary to consider a time dependent constitutive material model to properly reproduce the experimental evidences shown in laboratory tests, see among others Perzyna [1] and Skrzypek and Hetnarski [2].
In the present paper a finite element formulation for viscoplasticity problems is considered and applied to composite structures. A strategy is illustrated for the derivation of the proper variational principles by casting the non-linear field equations and the constitutive multivalued equations into a viscoplastic operator governing the structural problem, see e.g. Oden and Reddy [3], Reddy [4] and Koiter [5].
In the paper a consistent procedure is illustrated for deriving a multifield potential in all the unknown variables of the viscoplastic structural problem and accordingly the relevant multifield variational principle is presented. The proposed procedure shows to be suitable for the consistent derivation of other variational principles in viscoplasticity with different combinations of the unknown fields, see Reddy [4], Koiter [5], Washizu [6]. The property of the procedure of generating other variational principles is illustrated by deriving the extensions to viscoplasticity of the Hu-Washizu and Hellinger-Reissner principles, see De Angelis [7].
The presented treatment provides the support for a variationally consistent development of numerical algorithms for finite element applications on composite structures. Accordingly, a numerical integration scheme for viscoplasticity is discussed and a computational procedure is illustrated for the numerical solution of structural problems in viscoplasticity.
Computational results are finally reported in order to show the efficacy of the algorithmic scheme and the effect of the loading rates on the viscoplastic behavior of composite materials.

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6859 | Mechanical Stability of Cylindrical Shells Reinforced by Single-walled Carbon Nanotubes Based on T.S.D.T. (24. Buckling problems)

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This paper presents the buckling analysis of cylindrical shells reinforced by single-walled carbon nanotubes (SWCNTs) under mechanical loads. The material properties from molecular dynamics simulations, based on the multi-scale approach, numerical illustrations are carried out for perfect geometrically shells uniformly distributed carbon nanotube-reinforced composite (UD-CNTRC) shells under different values of the nanotube volume fractions. The equilibrium and stability equations are derived using the total potential energy equations, Euler equations and third order shear deformation theory assumptions. The resulting equations are solved for simply supported boundary conditions. The critical pressure loads are calculated for CNTRC cylindrical shells. It is found that in the CNTRC cylindrical shells, increasing of values of the nanotube volume fractions causes to increase of the critical pressure loads.

6885 | The effect of geometric nonlinearity on dynamic stability of composite laminates (24. Buckling problems)

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A higher order shear deformation theory is used to investigate the effect of geometric nonlinearity on instability regions associated with composite plates undergoing dynamic buckling. Both transverse shear and rotary inertia effects are taken into account. The procedure is implemented using an iterative finite element procedure. The natural frequencies are computed and compared with available results based on the classical plate theory and the first-order shear deformation theory for both isotropic and composite plates. The first order approximation of the first instability region is determined and the influence of geometric nonlinearity is estimated. The instability region is found to be shifted to higher parametric resonance frequency and its width decreases by taking into account geometric nonlinear effects.

7058 | Numerical and experimental investigation of post-buckling behavior of square cross-section composite tubes. (24. Buckling problems)

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This paper deals with the buckling and post-buckling behavior of thin-walled square cross-section tubes subjected to static compression. The columns under consideration were made with the autoclaving technique from eight layers of a glass fibre reinforcement polymer unidirectional prepreg tape. Six different layers' arrangement has been taken into account. The following experimental data have been collected: force-displacement relations obtained from an employed Zwick/Roel universal testing machine; strains at choosen points of the tube using strain-gauges technique; map of deflections obtained from non-contact 3D optical method (System Aramis made by GOM company). All obtained results were used to determine buckling load and equilibrium paths in pre- and post-buckling range. The numerical model of analysed tube has been prepared in ANSYS software. The linear and nonlinear buckling analysis has been performed. The experimentally obtained results have been used to validate proposed FEM model. The influence of layer arrangement on buckling and postbuckling behavior, differences between numerical and experimental results and methods employed for buckling load determinations have been discussed.

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7096 | Influence of boundary conditions on the behavior of composite channel-section columns under compression (24. Buckling problems)

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The paper deals with experimental investigation and numerical analysis of influence of boundary conditions on critical load and post-buckling behavior of compressed composite channel-section columns. The columns were made of 8-ply glass-epoxy laminate. The six different layers arrangement were considered. Tests were conducted using two test stands. In the first of them, special self-aligning grips with spherical bearings were used. In the second stand the stiff plate was mounted to the upper jaw and has one degree of freedom (vertical movement). The table with spherical bearing mounted in the bottom jaw has 3 DOF (rotations about three perpendicular axes). The strain-gauges technique has been used for all tested specimens. Additionally the second stand has been equipped with the ARAMIS system for non-contact 3D displacement measurements. Numerical analysis were conducted using ANSYS software. Two models were prepared with boundary conditions corresponding to test stands. The critical load values were determined from experimental studies and nonlinear numerical analysis using several well-known methods. To estimate the failure load based on stress state obtained from numerical calculations the Tsai-Wu criterion and maximum stress criterion have been applied. The obtained results were compared with experimental measurements. Acknowledgment. The investigations has been performed under the research project financed by the National Centre for Science - DEC-2011/03/B/ST8/06447.

7601 | Design formulae for buckling of Built-in-Free and Rotationally Restrained-Free Orthotropic plates. (24. Buckling problems)

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In this paper simple closed form equations to predict the buckling load of uniaxially loaded orthotropic plates with one unloaded edge rotationally restrained (RR) and the other unloaded one free are presented.

The formulations available in the literature to predict the instability of RR-free orthotropic plates with a high level of accuracy in the whole range of rotational restraint are difficult to implement in the standards and design guides because of their complexity. Simpler available formulations have a high level of accuracy only for low levels of rotational restraint, tending to errors of about 10% as rotational restraint increases. The formulations presented in this paper show better levels of accuracy than the aforementioned available formulations and also have a simple form. These equations, for long and short plates, were obtained by the Ritz method, using a simple harmonic displacement function and considering the superposition principle to meet the boundary conditions at the free edge.

The accuracy of the presented equations has been contrasted with the exact solutions and experimental results available in the literature.

7681 | Effect of edge reinforcement and low-speed impact damage on the buckling stability of composite I-section beam loaded in shear (24. Buckling problems)

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This paper addresses the effects of reinforcements around cutouts and low-speed impact damage on the buckling stability of composite I-section beams made of Carbon Fiber/Epoxy composites. The I-section having two diamond-shaped cutouts in the web and three reinforcement rings bonded to one side is clamped at one end and subjected to a shear load at the other free end. An experimental and numerical investigation was performed into study the effects of edge reinforcement and impact damage on the bucking load factor, post-buckling response, and first-ply failure load. A numerical model was developed for simulating the buckling and post-buckling response in finite element method, and buckling load was predicted by using both linear and nonlinear FE analysis. Tsai-Wu failure criterion was employed to detect the first-play-failure load in nonlinear analysis by predicting the load-deflection response of the I-section beam. In order to account for the influence of impact damage, the results of drop-weight impact tests on the I-section beam were presented. The experiments loaded in shear were carried out on three different specimen configurations (cutout, edge reinforcement, impact damage) to validate the numerical model and results. Good agreements were obtained between the numerical simulations and test results. The results reveal that the edge reinforcement can improve the critical buckling load by 28.78% as well as the ultimate failure load by 23.24%. However, impact-induced damage had little effect on the buckling behaviour and strength, and the damage was able to change the failure mode and to lower the critical failure load by 5.45%.

7732 | Buckling performance of composite cylindrical shells subjected to axial compression loads (24. Buckling problems)

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An experimental study had been carried out to evaluate the buckling performance of composite cylindrical shells. Four test samples made of warp knitting fabric were adopted in the experiment: an intact cylindrical shell, one with an opening, one with an axial gap and one with low energy impact damage. The progression of buckling from initiation, growth and fracture with material failure was recorded in the compression experiments. The strain of several strategic points of the cylindrical shells was recorded by strain gauges with the applied compression loads increasing to illustrate the distribution of buckling field. Results showed that fluctuation of load-strain diagram is a significant sign of buckling occurrence of composite cylindrical shells under compression. Moreover, openings, gaps and damages could reduce bearing capacity on different levels according to the area reduction in the bearing sections of cylindrical shells.

7741 | A Laminated Shell Model for Buckling Analysis of Laminated Glass Structures (24. Buckling problems)

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This paper presents an efficient laminated shell model for the analysis of plates and shells with alternate stiff/soft material layer-up schemes through the thickness, which is applicable to the modelling of laminated glass structures. Restricting the focus on such sandwich structures where layers of stiff materials are separated by soft cores in between, in the proposed shell model a set of layer-wise piecewise linear modes are added to the Reissner-Mindlin type formulation, the number of which is dependent on the number of core sheets. The efficiency of the shell model is addressed through comparison against a group of zigzag theories in terms of both accuracy and the number of degrees of freedom. A 9-noded shell element based on the laminated shell model is formulated in a co-rotational framework to allow large displacement analysis. Further enhancement of computational efficiency is achieved by defining the additional freedoms in a so-called shell coordinate system to eliminate the co-rotational transformations of nodal forces and stiffness associated with these freedoms. The proposed shell element is used for nonlinear buckling analysis of laminated glass structures with its applicability verified through comparisons against the results of detailed 3D solid model. It is also used to assess the adequacy of an effective thickness method, which is widely adopted in the design and assessment of glass structures. Further investigation is made on the influence of such characteristics of laminated glass as the number of glass plies and the relative thickness of PVB on the behaviour of laminated glass structures.

7783 | A beam formulation for nonlinear stability analysis of semi-rigid composite frames (24. Buckling problems)

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Stability limit state evaluations of frame-type structures are usually carried out under the assumption that structural connections are either perfectly rigid or perfectly hinged. Such an approach simplifies the stability analyses significantly, but often fails to represent the real structural behavior, because the connections of actual structures exhibit a flexible behavior falling in between the two idealized cases, filling the entire flexibility spectrum from hinge-like connections, over semi-rigid connections, to rigid connections. The flexible behavior is the result of the complex interaction among the various components of the connection construction itself. Therefore, numerical analysis procedures must be broadened by incorporating the real connection characteristics as an alternative of the idealized connection approach, so as to improve the accuracy of stability analysis.
To perform the nonlinear stability analysis for a frame-type structure, a nonlinear beam model should be made available, with which the load-displacement behavior of a structure can be obtained by one of the incremental descriptions. Each description utilises a diferent structural configuration for describing the system quantities, based on which a set of nonlinear equilibrium equations can be derived for the structure. This set can be further linearized and solved using some incremental-iterative schemes, consisting of the predictor, corrector, and checking phases.
This paper presents a nonlinear beam element for the nonlinear stability analysis of semi-rigid frames, composed of the straight and prismatic thin-walled composite beam members. The equations of equilibrium are derived using the updated Lagrangian incremental description and the nonlinear displacement field of cross sections, which accounts for the second-order displacement terms due to large rotations. In this study, it is assumed that the cross section is not deformed in its own plane, but can be subjected to warp in the longitudinal direction. Although displacements are allowed to be large, strains are assumed to stay small. External loads are static and conservative. Internal moments are represented as the stress resultants calculated by the

Euler-Bernoulli theory for bending and the Vlasov theory for torsion. The laminates are modeled on the basis of classical lamination theory.
Semi-rigid connections are allowed to occur at finite element nodes by modifying the stiffness matrices and nodal vectors of a nonlinear beam element for which rigid connections at the end nodes are assumed. A special transformation matrix is derived for that purpose. The numerical algorithm is implemented in a computer programme and its effectiveness is validated through the test problems.

7860 | Nonlinear buckling analysis of thin-walled laminated composite beams with monosymmetric sections (24. Buckling problems)

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This paper presents numerical results of nonlinear buckling analysis of thin-walled composite beams of monosymmetric sections with arbitrary lay-ups. This model is based on updated Lagrangian incremental description and non-linear displacement field which accounts for the second order terms due to large rotations. It is assumed that the thin-walled cross section does not deform in its own plane, thus the local buckling effects in this study are neglected. The contour warping in the longitudinal direction are taken into account. Displacements are allowed to be large, strains are assumed to stay small. External loads are static and conservative. The Euler-Bernoulli theory for bending and the Vlasov theory for torsion are assumed. The laminates are modeled on the basis of classical lamination theory. The fiber orientation and laminate stacking sequence effects, longitudinal to transverse modulus ratio, location of applied load and high to span ratio are investigated. Several numerical examples are presented.

7991 | Imperfection sensitivity analysis of laminated folded plates using Koiter’s asymptotic approach (24. Buckling problems)

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The design of composite structures is most often dominated by buckling [1], complex-post buckling behaviour and sensitivity to imperfections.
Imperfection sensitivity analysis requires the identification of a large number of buckling modes and their interaction. Because of the large number of possible modes and our a priori ignorance about which ones would interact with each other, such analysis is prohibitively time consuming.
The aim of this work is to propose a robust and efficient methodology to calculate the imperfection sensitivity of laminated composite folded plates.
The proposed methodology does not require a priori knowledge of the shape and magnitude of imperfections and does not rely on lengthy continuation analysis. Instead, it uses Koiter's perturbation approach [2] to calculate the bifurcation load, post-buckling path, and interaction between modes to detect bifurcations on the post-buckling path of individual modes, as well as the paths emanating from those bifurcations.
The Monte Carlo method is proposed herein to find the modes that yield the most unfavorable, imperfection sensitive path. Although Monte Carlo is an expensive method, the computational cost is keep low thanks to the efficiency of both the element used and Koiter's approach[3]. Also, Koiter's approach is quite demanding about the quality of higher order (up to 4th order) derivatives of the energy. The element formulation used is uniquely suited to satisfy those demands for accuracy at a low computational cost [4,5]. The proposed methodology allows us to run thousand of analysis in a few seconds.

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8041 | FRP Shear Strengthening for the Web Panels of Steel Plate Girders (24. Buckling problems)

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This paper examines different forms of bonded FRP strengthening used to improve the shear capacity of thin web plate girders. Slender plates such as the webs in plate girders are used in a variety of structural engineering applications because this results in an efficient use of material, and their postbuckling reserve of stiffness and strength. In-plane loading of these thin plates close to (or even exceeding) the buckling load results in relatively large out-of-plane displacement, which in turn induces high secondary bending stresses at the welded plate boundaries. The fatigue performance due to these bending stresses is of particular concern.
This paper presents the result of tests performance on thirteen steel plates subjected to in-plane shear. The plates were tested for in-plane shear using a specially manufactured “picture frame” arrangement that has been designed to induce the proper boundary conditions and stress distributions to simulate

the web plates in realistic plate girders.
The aim of this initial series of tests is to investigate the performance of different forms of strengthening under static load, in preparation for a series of cyclic tests that will investigate the fatigue performance of the strengthened system. So far, only the static tests have been started, involving different FRP materials (CFRP and GFRP), different forms of FRP (flat or corrugated sections), and different orientations (e.g. aligned with the tensile or compressive diagonals), applied to the steel plates. Each of the test configurations have also been analysed numerically, and then combination of experimental and numerical work is used to suggest the most appropriate strengthening method for fatigue performance.

8054 | Semi-analytical panel buckling of cylindrical composite grid-stiffened structures comprising discrete stiffener formulations (24. Buckling problems)

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The ultimate load-carrying capability of grid-stiffened structures like isogrid or orthogrid under in-plane compression or shear is typically determined through equivalent stiffness methods, more colloquially known as smearing techniques. These smeared stiffnesses are then applied to buckling criteria of an unstiffened shell to predict general instability, respectively global buckling. However, these predictions frequently show substantial non-conservative deviations when comparing e.g. against FEA or test data. One of the reasons may be found in the neglected discrete nature of the grid-stiffened shell, which effectively does not comply with the assumptions implied in smeared stiffnesses. In particular for the case of a wide-spaced arrangement of stiffeners, the resulting buckling patterns obey the cell-like structure and develop localised instability, spanning several adjacent skin fields, but leaving some stiffeners unaffected, respectively undeflected. This mode of instability is denoted panel buckling.
For the purpose of improved accuracy, a semi-analytical approach is formulated based on the Ritz energy method encompassing a composite cylindrical panel subject to in-plane compression and shear forces, stiffened by a selection of axial, circumferential and diagonal eccentric stiffeners, and making use of periodic boundary conditions. The explicit prediction of panel buckling modes is achieved by the definition of a multitude of specific admissible displacement fields which circumvent possible anterior skin buckling.
Results are derived for isogrid, diamond grid and orthogrid panel configurations and compared against global buckling using smeared stiffnesses, underlining the importance of the discrete treatment of the stiffening structure. Parametric studies lead to the observation of differing design optima with respect to global and panel buckling and guide the definition of beneficiary stiffener arrangements and cross-sections in preliminary design tasks.

8619 | THE SINGLE PERTURBATION LOAD APPROACH APPLIED TO COMPOSITE CONICAL COMPOSITE STRUCTURES: SIMULATION AND VALIDATION (24. Buckling problems)

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Thin walled conical structures are widely used in aerospace, offshore, civil and other engineering fields and industries. One example for conical shells is for instance parts of launcher transport systems. The running EU project DESICOS (New Robust DESIgn Guideline for Imperfection Sensitive COmposite Launcher Structures, contributes to lighter and cheaper structures by a new design procedure for imperfection sensitive composite launcher structures, exploiting the worst imperfection approach efficiently. For most relevant architectures of cylindrical and conical launcher structures (monolithic, sandwich - without and with holes) 12 partners develop new design methods which will be validated by tests of structures designed and manufactured within the project. Hühne developed the Single Perturbation Load Approach (SPLA), a robust design method that stimulates a single buckle, which is assumed as a “worst-case” geometrical imperfection. The method accounts for imperfections of geometry only. There have been carried out considerably more numerical, analytical and experimental studies on cylindrical shells than on conical shells. This study focuses on validation of the SPLA for the composite conical structures. The finite element analysis results have to be correlated with the buckling tests (axial compression).
From the numerical simulations in the previous studies it was concluded that the KDF values obtained using the SPLA could be almost twice as big as the NASA KDF. The SPLA applied to the structure with the thickness and/or mid-surface imperfection gives 1.8 % deviation between minimum and maximum value of KDF. Therefore, the SPLA applied to the perfect structure could be used in the early stage design to represent with reasonable accuracy the behaviour of a structure with geometric imperfections. However, this preliminary conclusion has to be corroborated by tests.

8697 | Analytical formulation for the postbuckling analysis of unsymmetrically laminated composite plates under combined inplane compression and shear loading (24. Buckling problems)

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The paper present a closed-solution for the postbuckling behavior of long unsymmetrically rotationally-restrained laminated composite plates subjected to compression and shear load combinations. In analysis, the plates under consideration are assumed to be infinitely long and elastically restrained in the longitudinal edges. Nondimensional parameters are introduced in order to cover a wide class of material properties and laminate configurations. The solution is derived by proposing shape function in conjunction with Galerkin method. Then the terms of displacements, strain and stress components can be obtained analytically. Finally, the closed-form solution is validated by finite element simulation for finite length long plates under different ratio of compression and shear loading and the comparison results show that the closed-form solution can predict the postbuckling behavior well in the initial postbuckling phase.
Keywords: Closed-form; Laminated composite plates; unsymmetrically; Postbuckling;

8769 | Buckling analysis of stiffened composite pressure vessel under hydrostatic pressure using finite element method (24. Buckling problems)

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The most important property required in any structural material is high strength to weight ratio and corrosion resistance, hence composite materials gained grater interest in this field. The body of Unmanned Underwater Vehicle (UUV) is made up of composite cylindrical vessel which is subjected to different kind of loads when they are travelling in their respective environment. Buckling and post-buckling are the most dominant failure mechanism when the compressive stress generated by the external hydrostatic pressure reaches at elevated level in case of composite UUV. The present research was aimed for comparing the performance of stiffened and un-stiffened filament wound composite pressure vessel used for under water vehicle applications. Three different configurations of stiffener with three different fiber orientations ([±30/90] FW, [±45/90] FW & [±60/90] FW) have been considered for the buckling analysis of filament wound carbon/epoxy composite pressure vessels. The analysis is performed by using commercial finite element software ANSYS 14.0 APDL. 10 MPa external hydrostatic is applied which is equal to the pressure at a depth of 1000 m in water. The analysis results showed that the stiffened composite shell gives the higher value of critical buckling pressure compared to the un-stiffened ones. The finite element results also shows that the grid stiffened composite pressure vessel with ply orientation [±60/90] FW can sustain maximum limit of applied hydrostatic pressure while compared with the results for hoop oriented and vertically orientated stiffened composite pressure vessels.

8949 | NUMERICAL EVALUATION OF THE LOCAL BUCKLING MOMENT FOR PULTRUDED FRP BEAMS (24. Buckling problems)

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The interest of the scientific community in obtaining the local buckling stresses for pultruded FRP (PFRP) shapes is shown by the huge number of published studies on this subject. The main objective of the present paper is to provide accurate estimates of the local buckling moment for PFRP beams. These estimates are fundamental for defining the nondimensional slenderness parameter introduced by the Italian Design Guide CNR DT 205/2007 [1] for beams in pure bending. One of the most technically sound formulations is that proposed by Kollár [2], who derived explicit expressions for the critical normal stresses of flange and web panels of PFRP beams that depend on the rotational stiffness of the web-flange junction in compression. This formulation is based on a consolidated approach for estimating the flange buckling strength of typical steel profiles [3].
In the present paper, a literature review is initially reported. In particular, it is shown that the approximate expression for the critical stress provided in [3] for steel members tends to underestimate the local buckling strength, especially in the case of wide-flange cross-section profiles. This underestimation becomes particularly evident for PFRP beams. For example, in [4], on the basis of the results of 10 bending tests, an average ratio of 1.2 between experimental and predicted local buckling moments was obtained. Anyway, it has clearly been shown that the web-flange junctions play a crucial role in determining the buckling and ultimate strengths of PFRP beams [5]. Therefore, the experimental and numerical characterization of the junction behaviour is necessary [6]-[7]. The rotational spring stiffness used in Kollár's model to reproduce the behaviour of the web-flange junction seems sensitive to the shear modulus of the flanges [4] and to the ratio Io,f/Io,w [8], with Io,f and Io,w being the ratios between transverse and longitudinal Young's moduli for the web and flanges, respectively. Hence, in the present paper estimates of this stiffness based on a series of finite element buckling analysis results are finally reported. The influence of possible differences in the mechanical properties between flange and web panels is suitably taken into account.

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9049 | A NEW FOURIER–RELATED DOUBLE SCALE ANALYSIS FOR WRINKLING ANALYSIS OF THIN FILMS ON COMPLIANT SUBSTRATES (24. Buckling problems)

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In this paper, a new Fourier-related double scale approach is presented to study the wrin- kling of thin films on compliant substrates. By using the method of Fourier series with slowly variable coefficients, 1D microscopic model proposed by [1] is transformed into a 1D macroscopic film/substrate model whose meshes are not related with the wrinkling wavelength. Numerical tests prove that the new model significantly improves compu- tational efficiency with

accurate results, especially when dealing with high wavenumber wrinkling phenomena. Besides, the lowest wrinkling pattern is automatically predicted by accounting for several harmonics in Fourier series with a given random wavenumber. The established nonlinear system is solved by Asymptotic Numerical Method (ANM), which has advantages of efficiency and reliability for stability analyses.

Key words: Fourier series, Film/substrate, Wrinkling, Asymptotic Numerical Method

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9166 | Refined Buckling Analysis of Composite Plates Under Various Boundary Conditions (24. Buckling problems)

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Composite structures are increasingly used in modern engineering applications. Among the different geometries, quadrilateral plates are commonly found in various constructions, such as aircraft wing or tail panels. Many efforts in the literature have been devoted to the study of thin and thick composite plates by means of analytical and semi-analytical methods. In the past, solutions have been derived in the context of first- and higher-order shear deformation theories. Depending on the loading and the boundary conditions, these solutions can be found in exact or approximate manner [1].
In this paper, the buckling of laminated plates under in-plane loadings is assessed by applying the Ritz method. The formulation is developed within the framework of a variable-kinematic theory, offering the advantage of automatically handling theories of various order in the context of the same, unified, approach. Both layerwise and equivalent single layer theories are considered.
As compared to other works in the literature, where restrictions exist with regard to the lay-ups - often limited to cross-ply - and the boundary conditions - in most cases of simple-support at two parallel edges or at the four edges -, the present approach makes possible the analysis of a wider range of configurations. Any combination of simply-supported, clamped and free edges can be handled, and lay-ups are not limited to the cross-ply sequences. Furthermore, multi-axial loading conditions of bi-axial compression/tension and shear are accounted for.
The problem is formulated referring to the Principle of Virtual Displacements (PVD). Following a previous study on the free vibrations of skewed composite plates [2], the three components of the displacement are expanded as the product of Chebyshev polynomials and boundary characteristic functions. The Ritz fundamental nuclei of the variable-kinematic approach, whose expression is independent on the order of theory, are derived and successively expanded at ply and laminate level. The buckling problem is reduced to a standard eigenvalue problem and is characterized by a relatively small number of degrees of freedom. Therefore, it is suitable to perform parametric studies and trace design charts with a reduced computational effort.
The potentialities of the method are assessed by presenting the results for a wide range of configurations, including different material anisotropy ratios, lay-ups and width-to-thickness ratios. Results are provided also in the form of interaction curves for various loading and boundary conditions. The quality of the predictions is validated by comparison with three dimensional solutions available in the literature, and with the exact solutions obtained referring to the Lévy-type solution of the same problem. Thanks to their accuracy, the results here presented can be a useful reference to be used in the future by other researchers for benchmarking purposes.

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9193 | Unilateral contact buckling of stiffened rectangular plate under non-uniform compression (24. Buckling problems)

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Local buckling of rectangular concrete-filled steel tube (CFT) member can be categorized as the stability issue of unilaterally constrained plate under in-plane load. This study presented a solution method for unilateral buckling behavior of longitudinal stiffened plate subjected to combined bending and compression. The concrete infill is considered as tensionless elastic foundation, allowing the local buckling mode to be simulated by a series of eigen functions. Using the principle of minimum total potential energy, the plate buckling equations were derived. After that, the Galerkin's method was employed to convert the governing partial differential equations into a set of nonlinear algebraic equations. The buckling coefficient was obtained through an iteration method, and a new modified path-following constraint was founded to accelerate convergence velocity. In addition, the variations of critical buckling coefficient k and breadth to thickness ratio (b/t) limition with longitudinal stiffener were discussed. It shows that the local buckling load can be enhanced by optimizing the stiffener's position and cross section. The buckling modes changed by the stiffener, including wavelength and distribution, were also showed. Comparisons were made with results available in the related researches to prove the validity of this approach. The proposed method can be adopted in the local buckling analysis for thin-walled steel plate of CFT.

9232 | Thermal Buckling of Empty Closed Cylindrical Nano-Tube Viruses under External Pressure (24. Buckling problems)

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Viruses are nanometer-sized living objects which carry the genetic codes (DNA or RNA) of the body and they are coated by a protein shell known as capsid. In this study, an analysis for the thermal buckling of empty (without genetic materials) closed cylindrical capsid shells subjected to external pressure varying as a power function of time is presented.
The stability and compatibility equations are obtained by using the classical shell theory. Analytical solution is assumed to satisfy the simply supported boundary conditions and Navier method is applied to obtain the closed-form relations of buckling loads. Critical buckling loads are obtained by considering the different values of the loading parameters. The results show that the critical parameters are affected by the variations of loading parameters and by the temperatures.

6351 | Interlaminar interface Modeling for delamination predicting in a new woven composite for orthopedic use (25. Failure and Damage)

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In this study, delamination initiation and propagation are numerically predicted of a new laminated composite reinforced with natural organic load. This hybrid composite is used for the manufacture of composite for orthopedic use and also for other applications in the future. In order to describe the interface damage, an approach based on the indirect use of fracture mechanics considering a softening stress-relative displacement law is presented. Numerical simulations are compared with experimental results carried out in 3ENF deflection in order to detect the initiation and damage growth of new composite.

6360 | An energetic approach to the low cycle fatigue damage of sandwich structures with Separation of core shear energy in flexural loading (25. Failure and Damage)

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Paper aims to characterize the damage due to shear buckling of the core in sandwich composite structures. Composites of CFRP face-sheets of different thicknesses (1 and 3 layers) with an 8mm core of Nomex honeycomb are tested. A method is developed to perform DIC on sandwich composite structures in order to measure the shear strain. The evolution of shear strain is plotted along the length of the specimen. The effect of low cycle fatigue loading on the shear strain evolution is investigated. Hysteresis curves of load vs. shear strain are plotted. Shear energy absorption by the composite structure is calculated. The evolution of the shear energy absorption under LCF conditions and the effect of face-sheet thickness on the shear energy absorption are also studied. An energy absorption criterion for sandwich structures is developed. It compares the evolution of absorption of energy due to shear during cycling for materials with different face-sheet thicknesses. This criterion can be used to remove the effect of face sheet stiffness on the total energy absorption, thus only shear absorption by the core can be measured under LCF conditions.

6704 | Fracture analysis for the attachment of fiber reinforced plastic composite on a V-notch wedge structure (25. Failure and Damage)

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Many engineering components and structures contain sharp V-notches with various angles, and it is widely recognized that sharp V-notches are regarded as wedge structures. When the structure is subjected to mechanical loads, the apex develops intense stress and is vulnerable sites to initiate failure on brittle materials.
In the present work sharp V-notched specimens can be reinforced by CFRP composites surface attachment and corresponding fracture behaviors are investigated experimentally. The results obtained from the cross section of fracture show that the fracture is absolutely delayed for the two-sided reinforced specimen. In addition, the finite element software is used to study the localized stress at the notch tip. Based on critical forces, the critical value of stress intensity factors are obtained through finite element analysis. The objective of this paper is to show the advantages of the CFRP attachment for reducing fracture of V-notched components.

6837 | Dynamic prediction fatigue life of composite wind turbine blade (25. Failure and Damage)

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In this paper we are particularly focusing on the dynamic crack fatigue life of a 25 m length wind turbine blade. The blade consists of composite materiel (glass/epoxy). This work consisted initially to make a theoretical study, the turbine blade is modelled as a Timoshenko rotating beam and the analytical formulation is obtained. After applying boundary condition and loads, we have studied the stress, strain and displacement in order to determine the critical zone, also show the six first modes shape to the wind turbine blade. Secondly was addressed to study the crack initiation in critical zone which based to finite element to give the results, then follow the evolution of the displacement, strain, stress and first six naturals frequencies as a function of crack growth. In the experimental part the laminate plate specimen with two layers is tested under cyclic load in fully reversible tensile at ratio test (R=0), the fast fracture occur phenomenon and the fatigue life are presented , the fatigue testing exerted in INSTRON 8801 machine. Finally which allows the knowledge their effect on the fatigue life, this residual change of dynamic behavior parameters can be used to predicted a crack size and diagnostic of blade.

6879 | Intralaminar and Interlaminar Failures of Laminated Composite Structures Due to Low Velocity Impact (25. Failure and Damage)

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In this paper the capability of a finite element model based on shell element approach and a cohesive zone modelling for laminated composite structures

subjected to low velocity impact was investigated. Various procedures are available to modelling impact phenomena by commercial finite element codes. Accurate modelling of contact phenomena is based on appropriate selection of element type, solution method, failures criteria and contact modelling. Most important mechanisms of energy absorption in a laminated structures composed of composite materials due to low velocity impact are intralaminar and interlaminar failures. These failures modelled with a failure criterion and cohesive zone modelling. The impact response and failures of a laminated composite plate was simulated using explicit nonlinear finite element code LS-DYNA. Focus of this study is to develop an efficient modelling with good accuracy to predict impact response and damage developed due to low velocity impact and compares with experimental results from literature.

Keywords: Low velocity impact; Intralaminar failure; Laminated structure; Delamination

7105 | Comparisons of performances of several new designs of shockAbsorbers (25. Failure and Damage)

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In the field of shock absorption, composite materials coupled with emerging reinforcement techniques opens a wide range for new designs. In this contribution several foam/woven composite structures are challenged by dynamic impact loadings such as dynamic crushing tests and canon ball impact tests. Starting from a foam part simply braided with a Kevlar fiber woven composite as a reference, several configurations are tested that involve inner reinforcement walls made of carbon and/or kevlar woven composites and discrete reinforcement techniques such as stitching and sewing.
A numerical study and an analytical study are also performed. For the numerical study, the FEM strategy to model the braided woven fabrics is used in order to have a better understanding of the influence of the different rupture mechanisms on the impact response.
Exploitation of the tests results allows to get some clues about the damage mechanisms involved and to draw some conclusions about the performances of the structures tested. The numerical results are compared to those obtained experimentally.

7468 | Evaluation of compressive test methods for braided composites using coupon and tube specimens (25. Failure and Damage)

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Near net-shaped braided composites have the property to be always geometry-bound, meaning that the semi-finished product and the geometry of the structure are manufactured simultaneously. This is unlike weaves and non-crimp fabrics, which are produced independently of the final structure.

Hollow, tube-like structures with a large length-to-width-ratio are the principal application of braided composites. Thus, it makes sense to use realistic test specimens, which represent simplified structures. Ideally, tubes with a constant circular cross-section are used for testing. This way, the local effects of e.g. edges on the usually used coupon specimens are eliminated.

Here, a quantitative comparison of two compressive test methods for braided carbon-epoxy composites with different braiding angles is presented. Using adequate test setups, standard coupon specimens and tube specimens are tested up until failure. The differences in stiffness, strength and ultimate strain between the two test series are analysed and interpreted. For biaxial braids, the test results show that the qualitative behaviour of the two test types is similar. However, both the strength and the ultimate strain of the tested tubes are lower than the values of the coupons. Analytical and numerical calculations indicate that buckling can be excluded.

Based on these findings, a recommendation for future testing of braided composites is given.

7494 | 3D CRACK ANALYSIS OF A CHOPPED GLASS-REINFORCED POLYESTER CRUCIFORM SPECIMEN UNDER BIAXIAL LOADING USING TWO DIFFERENT NUMERICAL TECHNIQUES FOR MODELLING CRACKS: XFEM AND A PROGRESSIVE DAMAGE MODEL (25. Failure and Damage)

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In this article, in order to computationally simulate the crack behaviour of a 3D chopped glass-reinforced polyester (CGRP) structure subjected to a biaxial in-plane loading, two different numerical techniques were considered. Firstly, the crack initiation and propagation of the CGRP structure was modelled by means of eXtended Finite Element Method (XFEM). This discontinuous approach allowed the crack propagation to be mesh-independent so no-conforming mesh was necessary contrary to the traditional Finite Element Method (FEM). In this case, crack initiation using XFEM was solution-dependent, thus, as a natural output the crack initiates without any a priori crack definition. Secondly, a novel progressive damage model (PDM) for prediction of damage in fibre-reinforced composites was implemented into the CGRP specimen. For computing the dominant damage mode into the PDM a new characterization of unitary damage directors was given. Finally, computational and experimental results were compared showing a reasonable agreement for the two numerical approaches.

7532 | MODELLING ADHESIVELY-BONDED JOINTS IN COMPOSITE STRUCTURES BY COHESIVE ZONE MODELS (25. Failure and Damage)

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Bonded joints are widely used in several fields of engineering, as an easy and efficient method to join components. Cohesive Zone Models (CZM) have

been used in the last decade for their strength prediction, allowing simulation of damage growth within bulk regions of continuous materials or interfaces. Compared to conventional FE, a much more accurate prediction is achieved, as this technique provides an accurate representation of the entire failure process. A useful feature of CZM is that different shapes can be developed for the cohesive laws, depending on the material or interface to be simulated, allowing a faithful representation of the fracture processes. The triangular and trapezoidal CZM shapes are most commonly used for strength prediction of typical structural materials.

This work studies the influence of the CZM shape used to model a thin adhesive layer in single-lap carbon-epoxy composite adhesive joints, for an estimation of its influence on the strength prediction under different material conditions. As a result of this study, some conclusions were established to assess the importance of using a CZM shape for a given adhesive that faithfully represents its behaviour, under different material behaviours (a brittle and a ductile adhesive were tested). The viability of using a triangular CZM that is easier to use, without compromising the accuracy of the results, was also assessed.

7616 | Experimental Verification of a Matrix Failure Criterion for a Laminated Composite Material under Biaxial Loading (25. Failure and Damage)

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Advanced composites have increasingly gained popularity since the 1970s, yet the failure theories used to predict their material behaviour is a field of research that is still being explored. It is due to reasons such as these that different modes of failure for a composite need to be looked at.
In this paper the authors look at matrix dominant failure under biaxial loading. There have been little experimental results published in literature to examine this mode. A biaxial composite specimen designed to carry out such tests is presented alongside experimental results.
A micromechanical approach based on finite element analyses is used to obtain the failure stress within the matrix phase of a representative volume element. The failure of the composite specimen was captured through the use of a thermal camera where the corresponding biaxial failure loads were recorded. The experimental failure loads were applied in a finite element macromechanical analysis of the laminate to obtain the macroscopic failure strain components at the failure area. In the micromechanical analysis, the failure strains obtained from the macroscopic FEA were applied as the loading condition on the representative volume element. These failure stress results in the matrix are compared to experiments performed on a carbon fibre/epoxy resin lamina specimen and a pure resin specimen. The resins in both specimens were identical. A failure criterion for matrix dominant failure within the tension-tension quadrant of the biaxial failure envelope is then presented. It is shown that biaxial tests performed on the specimen made purely of the isotropic resin matrix material gives a close predication of initial matrix failure within the composite lamina.

7626 | Numerical procedure for mesoscopic scale damage modeling of woven polymer matrix composites (25. Failure and Damage)

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Woven composites are of great interest for industrial applications as they are increasingly used for lightweight applications in aeronautics as well as in the automotive industry. The reinforcement can be draped or directly woven into complex shapes, which reduces the number of assembly operations needed, and hence the number of weak points in the structures as well as production costs. The multi scale nature of woven composites poses a challenge to the development of reliable finite element (FE) models able to predict the macroscopic structural response of a mechanical part. In order to take into account the influence of the fiber reinforcement architecture on the mechanical behaviour of a part, such modeling is carried out at the mesoscopic level, which is the scale of the yarns. In particular, the modeling of damage at the mesoscopic scale requires a precise description of the interlaced warp and weft yarns to identify damage mechanisms such as (i) intra yarn transverse cracks, (ii) decohesion between yarns or between yarns and matrix and (iii) inter yarn matrix cracks. Therefore, the composite is represented in the numerical model by the smallest pattern representative of the whole reinforcement architecture: the Representative Unit Cell (RUC).
A FE strategy is presented in order to identify and model the characteristic mesoscopic damage mechanisms of textile reinforcements embedded in a solid polymer matrix. A consistent mesh of the RUC of a multi-layered plain weave fabric composite taking into account the influence of the dry fabric preforming before resin injection, the relative shift and nesting between fabric layers is used. An appropriate mesh quality is ensured using both geometry- and energy-based error indicators. The effects of mesoscopic damage on the macroscopic mechanical properties, obtained performing periodic homogenization, are evaluated by inserting discrete cracks in the FE meshes. A failure criteria for fiber reinforced polymer composites is used to determine intra yarn damage onset. The numerical results show the same trends as the experimental observations. However, this method is only suitable for loading conditions under which the damage mechanisms are a priori known (such as uni-axial tension along the warp or weft direction). For more complex loading conditions, fracture mechanics-based tools developed at ONERA are used to simulate damage propagation in the RUC.

7632 | Study of the interlanminar fracture of composite materials in mode III (25. Failure and Damage)

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The purpose of this study was to identify the behavior of composite materials in mode III interlaminar fracture using the Split Cantilever Beam (SCB) test. A delamination was introduced at the mid-plane of the tested specimens. A SCB fixture was designed to provide the corresponding load configuration and to get a pure mode III effect on the crack tip. Load versus displacement curves were given by the UTM (Universal Test Machine) and were used in the calculation of the mode III critical energy release rate (GIIIc). A finite element model using MSC SimXpert was used to verify the experimental results and investigate the crack propagation using the VCCT (Virtual Crack Closure Technique) method. Studies were performed for different initial crack lengths and

with respect to the specifications provided by the ASTM (American Society for Testing and Materials). The effects of both modes I and II were studied and analyzed in order to confirm the accuracy and relevance of the SCB method for the calculation of the mode III critical energy release rate.

Keywords: composite materials, mode III, energy release rate, delamination, crack propagation.

7676 | Brittle interface crack between two elastic layers **(25. Failure and Damage)**

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The 2D elasticity mixed-mode partition problem is revisited for rigid interface cracks between two elastic layers. Because of material mismatch, the stress field near the crack tip has strong oscillations. This results in the non-convergence behavior of individual energy release rate (ERR) partitions with reducing crack extension size although the total ERR and individual stress intensity factors (SIFs) stress still have definite values. Hence, individual SIFs are often used to study the fracture behavior near the crack tip. By extension of the authors' recent works and the works of previous researchers, completely analytical expressions are derived for the SIFs. Excellent agreement is observed between the present completely analytical results and the previous semi-analytical results.

7677 | Experimental assessment of mixed-mode partition theories for fracture toughness in laminated composite beams **(25. Failure and Damage)**

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Three mixed-mode partition approaches are assessed for delamination in generally laminated composite beams by using extensive experimental data. The approaches are the 2D finite element method (FEM), the crack tip element non-singular field (CTE/NSF) partition theory developed by Davidson with the aid of experimental results, and the completely analytical Euler beam partition theory developed by Wang and Harvey. Two different fibrous laminated materials are considered, namely low-toughness C12K/R6376 and high toughness T800H/3900-2. The laminates considered include both unidirectional and multi-directional layups with delamination occurring on 0/0, 0/45, 45/0, 45/45 and -45/+45 interfaces. The assessment shows that the 2D FEM approach has poor agreement with Davidson's fracture toughness data obtained from experimental testing, but that the CTE/NSF and the Euler approaches produce very good agreement.

7678 | Effect of through the Thickness Selective Stitching on Inter-laminar Strength in Bonded Lap Joints of Composite Laminates **(25. Failure and Damage)**

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In a typical bonded lap joints of composite laminates, the inter-laminar/interface strength is weak compared to the in-plane strength. This strength can be improved by through the thickness selective stitching. In current paper, using the stress based material failure model, studies are made on the various influencing factors of stitching on the strength of a typical lap joint. Present study is performed using ABAQUS due to its strong nonlinear analysis capabilities and provisions for performing progressive failure studies. Typical bonded lap joints (single and double) with unstitched and stitched configurations are analyzed. The effect of through the thickness stitching (TTTS) is assessed for factors like selective stitching, stitch density and stitch material.

It is observed that in unstitched model the failure initiation is primarily caused by stresses in the thickness direction at the edges of the lap. The same stresses are found to reduce because of the effect of TTTS. Thus inter-laminar failure is delayed by the TTTS thereby increasing the capacity of the lap joint. Increase in failure strengths is highly sensitive to the stitching density especially in case of single lap joints. The same is found to be significant only for stitch spacing less than 4mm. Carbon and Kevlar fibers used as stitching materials did not make significant difference to the ultimate failure loads. However, Carbon fiber is able to give better failure initiation strength compared to the Kevlar fiber in denser stitched models. The joints are further analyzed for "Selective stitching" where in the stitching is restricted to the regions close to lap edges. The results show that selective stitching is able to provide failure strengths close to that of overall stitched model.

Key Words – Through Thickness Stitching in Composites, Inter-laminar Strength, Finite Element, ABAQUS, USDFLD Subroutine

7704 | The Barenblatt analogue of dipolar gradient elasticity **(25. Failure and Damage)**

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The cohesive zone theory is a popular one in the field of Fracture Mechanics. It originated in the 1960's by G.I. Barenblatt. In this renowned work, the fundamentals of the theory are presented. In brief, the fracture process is explained, as well as the development of a zone where the material inherently exhibits cohesive forces that prevent further crack propagation. This specific consideration of the fracture process has attracted a lot of attention from researchers over the time and led to its applicability in various fields (e.g. metals, biomaterials, composites, textiles, ceramics etc.).

In the present study, this technique is examined within the context of dipolar gradient elasticity. The standard central crack problem is investigated and, utilizing analytical solutions and numerical results, a linkage among cohesive zone metrics and dipolar gradient elastic constants is achieved.

The combination of these two theories and the emanating results seem to be satisfactorily describing the toughening mechanism of composites, as relevant experiments on textile materials suggest.

7727 | Mechanical properties of a high strength Aluminium Alloy developed for ballistic protection application (25. Failure and Damage)

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Lightweight materials are very attractive in the global industry, and more specifically in the automotive and aeronautics fields. For army vehicles the reduction of the weight has increased the need for lightweight metal and ceramic armor systems.
Metal Matrix Composites-MMCs are thriving due to their superior mechanical performances over the conventional metal counterparts, for an equivalent weight. In this group of materials, Aluminium alloy based MMCs stand out of the rest due to the advantage of lightweight. Furthermore, B4C, ranking third regarding hardness and second regarding wear resistance, is also lighter than conventional other ballistic ceramics like Al2O3 or SiC, and has a good chemical stability. All these characteristics make Al/B4C combination a very encouraging solution for armour systems.
The powder metallurgy route was chosen as it allows simultaneously a very fine control of the microstructure and a homogeneous distribution of reinforcements. The powder is synthesized through high energy ball milling, and then consolidated through the spark plasma sintering technique, whose parameters were optimized. The developed composites were mechanically tested in quasi-static and dynamic conditions.
Then, ballistic evaluation was performed on the composite against a 7.62 ammunition through the measurement of the residual velocity of the projectile. Results were compared to the one observed for commercial aluminium alloy plates used in armour system.

7745 | Analysis of the crack propagation in composites with irregular microstructure (25. Failure and Damage)

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1. Introduction
Presented paper contains results of fracture analysis of brittle composite materials with a random distribution of grains like concrete and other geo-materials. The composite structure has been modelled as an isotropic matrix that surrounds circular grains with random diameters and space position. Analyses were preformed for the rectangular “numerical sample” by finite element method. These models were generated using the author’s computer program RandomGrain. Fracture analyses were accomplished with the author’s computer program CrackPath3 executing the "fine mesh window" technique. Calculations were preformed in 2D space assuming the plane stress state.
2. Analysis of cracking
The CrackPath3 computer code is using the new criterion for prediction of the crack propagation direction which is simpler than suggested for polycrystalline materials by Sukumar and Srolovitz [7]. The new strategy consists in exploiting the condition of the minimum energy of cracking material calculated on the basis of the author's failure criterion (PJ criterion) for brittle materials [4,5]. The program calculates the stress field using finite elements methods and then it seeks the point of the crack initiation on the basis of the JP criterion. This is the point of the highest value of the material effort ratio.The the crack is assumed to continue in direction of highest value of the effort ratio gradient [6]. The value of the material effort ratio is calculated based on the formula containing stress tensor components and material constants according to the PJ failure criterion.
After finding the direction of the crack propagation, a FE mesh is modified in surroundings of the crack tip in order to add the next crack segment with the length equal to the size of the incised element. The procedure is carried on until the demanded number of steps is achieved or the crack stops propagating.
Other methods of analysis of crack propagation in the heterogeneous materials were described e.g. in papers: Bažant [1], Carpinteri and others.[2], Mishnaevsky [3].
3. Conclusions
Very dense FE mesh in surroundings of the crack tip is necessary for receiving the satisfying accuracy of the results of cracking analysis based on finite elements and re-meshing technique. It is particularly noticeable in case of materials with the complicated structure. Restrictions associated with the computation time and possibilities of computer systems do not allow the unlimited increasing of the mesh density of the computational models. The method presented in this paper allows overcoming some of these obstacles. It can be used to the purpose of shortening the computation time at the fixed precision or increasing the precision at the settled computation time.
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7766 | A fatigue failure theory for fibre-reinforced composite laminates based on the improved Puck’s failure theory (25. Failure and Damage)

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Fatigue is one of the most important failure modes of fibre-reinforced composites. In this paper, a new fatigue failure theory for multidirectional fibre-reinforced composite laminates is developed, by combining the interaction residual strength and interaction residual stiffness models with the recently improved Puck's failure theory [Dong, Wang and Karihaloo, 2014, Composites Science and Technology] which includes the in situ strength effect. This fatigue theory can predict both the fatigue life and residual strength of fibre-reinforced composite laminates under multidirectional loadings, with consideration of the gradual degradation of strength and stiffness of the laminate. The theoretical results are in good agreement with available experimental results [Kawai and Honda, 2008, International Journal of Fatigue].

7801 | INTER-LAMINAR AND INTRA-LAMINAR DAMAGE GROWTH IN STIFFENED COMPOSITE PANEL WITH SKIN-STRINGER DEBONDING (25. Failure and Damage)

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In this paper, a numerical study on inter-laminar and intra-laminar damage growth in a stiffened composite panel with a skin-stringer debonding is presented. A novel numerical methodology, based on the Virtual Crack Closure Technique (VCCT) and fail release approach, developed and validated for circular skin delamination in [1] has been improved here to predict the compressive behavior of stiffened panels with a partial separation between skin and stringer. The methodology is able to predict the evolution of inter-laminar damages without the issue of the standard approach in terms of mesh size and time increment dependency. A user material subroutine (USERMAT), which allows to define a custom material constitutive model, has been introduced to predict the onset and evolution of intra-laminar damage. With the simultaneous use of both the procedures is possible to follow the damage evolution in the stiffened panel up to the ultimate failure load. The effectiveness of the proposed methodology has been proved by comparison with literature experimental data on a single-stringer composite panel and numerical results obtained with the standard VCCT approach implemented in a commercial FEM software. The analysis of the load versus applied displacement curve and the assessment of the extension of the debonding at failure has been used as criteria to evaluate the effectiveness and the accuracy of the proposed numerical tool.

7828 | A Stress-based Failure Criterion for Steel-Concrete Composite Wall Elements (25. Failure and Damage)

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A failure criterion model is presented for predicting the ultimate strength of steel-concrete sandwich composite (SC) wall elements subjected to in-plane shear and normal stresses. In the new model, the SC wall is treated as a composite material and the concept of equivalent stress is introduced. A failure envelope and failure surface demonstrated in principal stress space and σx-σy-τxy space respectively are proposed for convenient application. Comparison of theoretical analysis with existing experimental results and detailed nonlinear finite element numerical simulation showed that the method possesses the advantages of easy computation and high accuracy. In addition, the verified model is further modified to account for the effects of out of plane shear stresses. The modified failure criterion, not only generates the principle of strength check and safety evaluation of SC wall elements under complicated stress state, but also lays a foundation for force-based failure criterion of SC wall on the member level.

7835 | Stress concentration of composite laminates with large cutouts (25. Failure and Damage)

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The composite laminate with a big hole may induce serious stress concentration to threaten its integrity and strength, so it is an essential problem to study in practical composite applications. However, the orthotropic and heterogeneous characters make the theoretical work difficult to carry on. In this paper, the stress concentration of composite laminates with big holes is studied by numerical and experimental methods. Here, we consider two kinds of hole (circular or rectangular) in composite laminates under two typical stress states, separately. One state is the simple unidirectional tension, the other one is the pure shear in plane. After the numerical analysis by finite element method, the experiments are performed by strain gauges and digital image correlation (DIC) method simultaneously during the loading process. Results reveal that the stress concentration factors with a big hole are higher than the small hole situation, and the stress concentration locations are quite different from the isotropic homogeneous plate. Therefore, it should combine the composite failure modes to study. In addition, the local buckling around the big hole can cause non-ignorable influence, especially under shear load.

7849 | Investigation of the interaction of damage mechanisms in composite materials (25. Failure and Damage)

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In the past decades, many stiffness reduction progressive damage models have been developed in order to capture the nonlinear anisotropic degradation of composite materials. However, the interaction of the damage mechanisms apparent in heterogeneous media, and their effect on the effective, homogenized material behavior is still part of the research. An experimental attempt to properly measure the damage evolution (or stiffness reduction) of a composite in all directions is demanding even for all necessary loading scenarios. Thus, numerical investigations of representative volume elements (RVEs) of the micro structure under periodic boundary conditions can be used to replace these experiments. Nonetheless, these micromechanical investigations must be validated with experimental data.

In this work, the microstructure of a carbon fiber reinforced plastic with random fiber locations are generated assuming straight, aligned, cylindrical fibers. An anisotropic material model, taking the damage interaction into account, will be presented. In a first step, this material model is adapted to the initially homogeneous pure epoxy matrix phase at the micro scale. The carbon fibers are modeled as a transversely isotropic material. The homogenized stress-strain response for RVEs of different sizes is compared to experimental results, and the effect of the damage interaction is shown. In a second step, the anisotropic damage material model is fitted to the predicted numerical investigations of the micro scale, simulating the composite level effective material behavior of unidirectional plies. This can be used in a meso scale model of a woven composite, which consists of the tows and the pure matrix phase. At that scale, the tows can be modeled as unidirectional material – the neat matrix phase is modeled the same way as in the micro scale. Again, an RVE of the internal structure is generated and investigated under periodicity conditions, and the damage evolution driven by the internal structure at that scale is presented.

7893 | Research of static and dynamic properties of composite structures manufactured with polyurethane resins (25. Failure and Damage)

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The paper presents the results of the influence of fillings, reinforcements and of metallic particles on the static and dynamic properties of composite with polyurethane resins. Tensile strength, compression strength and Charpy impact test were specified for the different ingredients composition. Reinforcements were glass fibers and rovings cut, fillings were aluminum hydroxide and aluminum powders with different grain size and varying percentage share. The research was targeted on the selection of optimal components for the production of tools used for stamping processes of large shell elements with aluminum alloy sheets.

7908 | Numerical and experimental investigation of composite tubes under hydrostatic pressure (25. Failure and Damage)

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Oil and gas play a vital role in the global economy as one of the most important and complex industries in the world. Metallic tubes have been traditionally used in many offshore oil and gas applications where the hostile environmental conditions and high hydrostatic pressures are the main challenges. As the demand for higher subsea depths and more advanced applications are growing, the need for the replacement of the conventional metallic tubes with composites is becoming important.

Composite tubes under internal pressures have been thoroughly investigated in previous work. However the investigation of composite tubes for applications where external hydrostatic pressures are present is rather limited. Conventional forms of fibre reinforcement such as tape lay-up and pultrusion have been extensively explored through optimisation of lay-ups and materials. However as the demands for high production rate of advanced composite materials increase, attention has focused on the new fibres architecture as means of reinforcement that were originally used to produce textile fabrics such as braiding and pullwinding [1,2].

This work aims to demonstrate the performance of a number of manufacturing techniques for composite tubes under hydrostatic pressures (e.g. traditional woven tape lay up to more advanced braiding, filament winding and pullwinding technology). The behaviour of the tubes under external hydrostatic pressured is optimised through the investigation of different fibres, resins, layups, fibre architecture and tube configurations. Finite element analysis models have also been developed in order to provide a supplementary way of understanding the failure mechanisms and optimise the tubes design specifications.

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7922 | Continuum damage model for inter-fibre failure of unidirectional laminates (25. Failure and Damage)

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The Puck failure criterion has been increasingly used in determining the critical stresses that trigger the inter-fibre failure (IFF) of unidirectional composites. However, the damage evolution and crack growth after damage initiation has not been well addressed. In this paper, a continuum damage model is presented to predict the complete failure process of UD laminates. The cohesive zone method is employed in combination with IFF failure criterion to govern the degradation of damaged element. A virtual crack plane is assumed to develop along the critical failure angle of Puck theory. The opening and shear displacement with respect to the crack plane is calculated by rotation of strain tensors. Characteristic length of bulk elements is introduced to avoid the mesh dependency. Mixed mode bilinear damage evolution law is used here, in which the fracture toughness change as the ratio of shear stress component. Single element simulation is carried out to verify the model. The presented model is demonstrated by simulating uniaxial compression tests of IM7/8552 laminates, and its accuracy is shown by good agreement with experiments.

7940 | Fatige damage identification of fibre reinforced composites (25. Failure and Damage)

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The growth in the use of composites urges the need to deepen the knowledge about the fatigue behavior of fibre reinforced composite materials. Damage identification based upon the changes in the natural vibration properties is a widely used method [1]. A modification of structural mass, damping and stiffness stems from the induced damage and these changes in the physical properties will cause detectable changes in the modal response in composite structures. Fatigue-induced microscopic damage accumulation in structures results in localized stiffness reduction. Local stiffness degradation is thus a good quantity to monitor fatigue [2].
Shearography, an interferometric optical method that produces full-field displacement gradients of the inspected surface, can be used to measure the modal shape slope. Previous studies [3] showed that the slope information obtained using out-of-plane shearography can then be used to identify the local stiffness. The stiffness-identification method has previously been validated on aluminum beams with a known stiffness distribution.
A 1D local stiffness identification for Euler-Bernoulli beams was already successfully implemented for CFRP specimens using two approaches: by dividing the bending moment of a deformed beam by the local curvature and by using a scanning element method [3, 4].
The promising features of shearography, amongst others the ability to quickly produce full field results though a rather low equipment cost, are further exploited in the 2D stiffness identification of CFRP and GFRP plates, which is currently being developed. The two out-of-plane gradients (slopes) of the modal shape of a plate vibrating at its resonant frequency with free-free boundary conditions are captured and used in the local stiffness identification method. The current approach uses Fourier series as the shape function in the fitting of the modal slopes.
This article presents a scaled-down, one-dimensional local stiffness identification method for thin beams. The slope of the first mode shape under acoustic excitation of uni-directional CFRP [+45/-45]_2s beam specimens and GFRP in different lay-ups for the undamaged and for different damage states till failure is measured using quantitative shearography [5]. The scaled-down 1D local stiffness identification method for thin beams is a step towards 2D thin plate local stiffness identification. The technique using a Fourier series-fitted slope of the experimental modal shape measured using quantitative out-of-plane shearography is introduced as a promising means for local stiffness identification. Results will be presented for CFRP and GFRP and a variety of lay-ups, including the quantification of the beam's local stiffness reduction at different levels of fatigue damage.
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7958 | An evaluation of micro-scale based continuum damage mechanics models applied to low energy impact loads in composite materials (25. Failure and Damage)

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The study of damage mechanics in composites has been undergoing a change in the last one to two decades due to the conceptual change of going from phenomenological to physical based models. Several studies on the use of continuum mechanics coupled with micro-scale or multi-scale approaches have been discussed. However, due to the large computational requirements of such methods, in general, only static, quasi-static, and fatigue analysis are made; mostly due to the similarity of fatigue and quasi-static behavior in composites materials. Moreover, in general, studies treat only monotonic loads due to easier experimental evaluation. In this scenario, however, due to the complexity of the problem, the impact load is usually treated with phenomenological models. As such, studies on the evaluation of such models and approaches are still needed for impact loads. In particular, in this work, there is a evaluation of potentialities and limitations of intralaminar damage evolution prediction approaches founded at literature, considering quasi-static monotonic axial stress, indentation and/or low energy impact loads in composite materials. Those approaches use meso-scaled Representative Volume Elements (RVEs) numerical analysis of the laminate with homogenized layers to calculate damage evolution due to intralaminar cracking. The present work follows that strategy by using a stiffness degradation analysis calculated via finite element analysis for glass fiber-epoxy and/or carbon fiber-epoxy [0°/90°3]S composite coupons and plates. In particular, the parameters for the calculations of crack nucleation, crack density and RVE size are analyzed for numerical stability and convergence. In addition, the influence of the material constitutive model used for the stiffness degradation analysis is studied by considering the laminate to be under plane stress behavior, orthotropic behavior or full anisotropic behavior.

7975 | Non linear elastic behaviour of glass fibre reinforced composites with delamination (25. Failure and Damage)

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Vibration measurements are sufficiently sensitive to detect damage and health monitoring of the structure even with cracks situated in hidden or internal zone. However, vibration linear technique is the most currently used based on the stiffness reduction and the decrease of natural frequency. Those methods are not sensitive to damage as the new method of non-linear vibration. This tool is used to reveal the complex of the elastic behaviour of composites. In fact, delaminated composites have shown extreme non linearity. The aim of this work is to use the non linear vibration method to evaluate the behaviour of a glass fibre reinforced composites with double delaminations. To this end, experimental studies were carried out based on vibration method.
The composite materials used in the present work is the glass fibre laminates constituted by unidirectional layers of E-glass fibres and epoxy resin, with the stacking sequence [02/902]s. Laminates were prepared by hand lay-up process. Double superposed deliminations are artificially made using Teflon

tape during the lay-up at the interfaces between plies having different stacking directions. Specimens with two symmetric delaminations over the entire width are manufactured.
The non linear resonance method consists on inducing and attending specimen on its resonance flexural modes with different excitation level (amplitude). In this experience the beam is excited with ten successive amplitudes for the first six bending modes. Three beams were tested for each delamination length. Chosen amplitudes excitations are in the non linear elastic behaviour of the composite for all specimens having different delamination size. Experiences were carried out under the instruction of the ASTM (E 756_98). Measurements data lead to obtain the resonance frequency for every fundamental amplitude level. The quality factor of the equivalent mode for fundamental resonance amplitude is determined experimentally by picking the maximum amplitude -3 dB from the resonance curve.

The classical theory of linear elasticity can describe the behaviour of composite materials. For composite with delamination, the behaviour is not lounger classical. Hysteretic nonlinearity becomes the sensitive method to give details the behaviour of dynamic delaminated composites. Consequently, two parameters will be determined which are the non linear hysteretic elastic parameter □f and non linear hysteretic dissipative parameter □□□ □f is related to the modal frequency and□□□is related to the modal damping. The parameters □□ and □f measure the importance of hysteretic effects (respectively, elastic and dissipative) in the context of the nonlinear resonance method. The variation of those parameters for progressively delamination length will be presented and discussed for the first six bending modes. Then sensitive modes will be chosen.

8062 | Initiation of failure in a unidirectional fiber composite in a four point bend setup (25. Failure and Damage)

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A four point bend setup is used in observing compressive damage initiation in a unidirectional single edge notch beam. Post observation of the polished specimens showed indication of a micro buckling instability at the notch tip. The damage initiation is modeled as an individually fiber and matrix discretized 2D plane strain finite element model. To reduce calculation time the superelement approach is used to model the whole beam except a small local area at the notch tip. A good agreement of the critical force is found between the analysis and the experiments. A comparison is made with the compressive crack approach.

8077 | Failure modes of unidirectional fiber reinforced materials under off-axis loading (25. Failure and Damage)

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Composites are very sensible against the angle of loading because of their highly anisotropic mechanical properties. Especially the resistance against failure strongly depends on the angle between the loading axis and the fiber direction since the fracture resistance in fiber direction is several times higher than transverse to the fibers. In unidirectional plies even small angles lead to a significant reduction of the strength. The failure processes taking place in unidirec-tional plies under off-axis loading are the key factors dominating the failure of laminates.

Off-axis tests offer the chance to observe the failure processes taking place in unidirectional plies. Two highly different principal failure modes occur in unidirectional plies exposed to off-axis loading depending on the length to width ratio of the specimens as well as on the off-axis angle, this is, inter fiber failure and fiber breakage. Inter fiber failure with almost no fiber breakage occurs if a fracture surface can develop from one longitudinal edge of the specimen to the other, that is, without touching the clamped regions on either side. If, however, a suf-ficient number of fibers are clamped on both ends fiber breakage necessarily has to occur, accompanied by a more or less intensive inter fiber failure. With growing fraction of fibers matching the clamped zones the damage of the specimen increases. Since the question of inter fiber failure or fiber fracture is no intrinsic material property but depends on the specimen geometry the data of different failure modes must not put together which is commonly done.

A number of off-axis tests was performed under quasistatic loading for a carbon fiber rein-forced epoxy resin with a fiber volume fraction of 55%. The two different failure modes are discriminated. It is shown that a strong decrease of the failure load occurs even for small of axis angles in the fiber fracture mode. For the 0° specimens only minor load drops are observ-able before final failure. The splitting of the specimens occurs during final failure. For small off axis angles several load drops occur before ultimate failure. It is shown that these are re-lated to initial inter fiber failure in the vicinity of the sides of the specimens.

In addition to the monitoring of the mechanical data, acoustic emission testing was performed for 0° and 3° off-axis specimens. The 0° specimens show a notable acoustic activity after reaching 30% of the failure load. The activity increases exponentially approaching the ulti-mate failure. These signals are related to breakage of fiber bundles as well as a number of short inter fiber cracks. The load drops result only few isolated signals with higher amplitudes. At final failure a large number of events with very high amplitudes occurs.

The 3° specimens exhibit a lower acoustic activity at low load levels. The load drops cause a large number of signals with high amplitudes. These are mainly related to inter fiber failure. After the load drops the acoustic emission activity goes down again. This happens several times until the final failure occurs, where massive fiber breakage and inter fiber failure occurs, giving rise to a high density of events with very high amplitudes.

Parallel to the experimental studies the stress field arising in the test specimens was analysed by finite element simulations. It is shown how the clamping influences the stress distribution by reducing the lateral contraction as well as by preventing the rotation of the specimen. Both effects lead to significant shear stresses in the vicinity of the clamping. The influence of shear stresses is visualised by SEM pictures showing significant shear cusps developing in the frac-ture surface near the clamped zones.

8101 | Damage evaluation of hybrid sandwich panels after impacts (25. Failure and Damage)

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Sandwich technology is a well-established method to offer an optimized design, which is a trade-off between the environmentally-driven demand to reduce fuel consumption and material usage, and the need for performing and safe structures. Sandwich materials, made of stiff external layers and an inner more compliant core, find in the literature many applications in panels, saving weight without losing structural integrity. For instance, in the automotive field, sandwich panels are suitable and deeply used for structural requirements as impacts, for passenger protection and comfort as acoustic or thermal insulation, etc.
Object of this work is a hybrid flat panel, made of two thin external stainless steel (AISI 316L) facings, bonded to an inner core of polyolefin. This kind of metal-polymer panel is designed for the automotive field, since its applications can be side and roof panels of cars, vans or coaches.
These panels are characterized by several parameters, as materials, thickness and surfaces of the layers. Aim of this work is to study the effect of these different parameters on the behavior of the hybrid sandwich material after impact.
Low speed impacts, as the case of stones or small objects against vehicle panels, generate a well visible damaged region. A plastic damaged region is, in fact, clearly located at the impact point and residual stresses are generated all around it. It is not easy to evaluate the effect of this damage on the residual mechanical behavior of the panels and to verify if the panel has to be removed or not.
In order to monitor the mechanical post-impact behavior of the panel, different configurations are prepared: 1) a single metal sheet (0.5 mm thick); 2) half a sandwich, with just two layers: the core and just one skin; 3) full hybrid panels with different thicknesses of facings (from 0.13 to 0.5 mm) and polymeric core (from 0.3 to 0.6 mm). These variations in sheet and core thickness are taken into account to evaluate the possibility to design a lightweight structure, able however to sustain loads and keep adequate stiffness.
Impacts are performed considering the same energy level, by a drop weight. To evaluate the impact damage (dimension and deformation) and its effect on the residual stiffness and strength of the panel, rectangular specimens are cut out, centering the damaged and plastically deformed region. Static tensile tests are then performed on these specimens, by monitoring surface temperature by a thermal camera.
During a static test, the thermal response of undamaged homogeneous materials can be divided into three regions: an initial linear decrease of the surface temperature corresponding to a macroscopic linear elastic response; a second part with a non-linear temperature trend, reaching a minimum value; a third portion where temperature increases till failure. Combining stress and temperature curves, a stress corresponding to the beginning of an irreversible damage can be evaluated, which is the end of the first linear region.
Thermography is particularly useful in case of complex materials, where many failure mechanisms are acting. Indeed, the trend of surface temperature is an energetic parameter, able to provide accurate information for the material characterization.
In this work, the thermographic technique is extended to impacted hybrid samples. From the obtained results on damaged and undamaged materials, quantitative considerations are proposed to relate the variation of the surface temperature to the damage introduced in the panels. Following this procedure, the thermographic technique resulted a valid tool to detect induced damage and quantify the residual stresses present in the panel after the impact.

8107 | INFLUENCE OF PLY THICKNESS ON THE DAMAGE EVOLUTION IN OPEN-HOLE LAMINATE PLATES (25. Failure and Damage)

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The design of structural elements made of laminates requires a better understanding, especially under the presence of open holes and defects. Several composite structures, such as aircraft frames, include large numbers of holes for joining purpose and cut-outs for access. The effect of open-holes on the mechanical behavior of composite structures, during a loading stage, produces stress concentrations in its proximity and a remarkable decrease of the strength compared with unnotched laminates. The stress concentration factor of a laminate depends on the material properties and the laminate lay-up.

The influence of ply thickness on laminate strength has been previously analyzed in the literature; however, less information can be found about its influence in the damage evolution. In this work, the discrete damage mechanics model of Barbero-Cortes, augmented by a fiber damage model, is employed to study the damage evolution in open-hole composite laminates subjected to in-plane tensile loads. This model was previously validated with several laminates. The influence of the ply thickness on the crack density evolution, stress-displacement curves and notched strength for different laminates is analyzed qualitatively and quantitatively.

8108 | Validation of the SAMCEF material models for inter and intra-laminar damages in laminated composites made of NCF plies (25. Failure and Damage)

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In order to propose predictive simulation tools, it is important to use material models able to represent the different modes of degradation of the plies forming the laminated composite structure. Damage at the interface between the plies, that is delamination, must also be taken into account in the model. Inter and intra-laminar damages in laminated composites made of bi-axial NCF plies are considered here. The numerical experiences are conducted with the SAMCEF finite element code. Simulation is compared to experimental results, and validations are done at the coupon level and at upper stages of the pyramid of tests.

The material model for the intra-laminar damage is based on the continuum damage mechanics approach initially developed by the Ladevèze's team in Cachan. The laminate is made of homogenous plies. Damage variables impacting the stiffness of each ply are associated to the different failure modes, representing the fiber breaking, matrix cracking and decohesion between fibers and matrix. The specific damage model is first presented. Then, the basics of the parameter identification procedure of such a material model are briefly explained. This procedure is based on test results at the coupon level, and allows determining not only the elastic properties but also the value of the parameters describing the non-linear behavior of the material. The obtained values are then validated on a comparison between test and simulation on a coupon with a stacking sequence not used for the identification.

The cohesive elements approach is used for modeling the inter-laminar damage. The approach is also based on the continuum damage mechanics in a formulation initially developed by the Ladevèze's team in Cachan. A damage model is assigned to some interface elements inserted between plies to represent their possible de-cohesion and a fracture criterion is used to decide on the inter-laminar crack propagation. Using such cohesive elements in the analysis allows estimating not only the propagation load but also predicting the crack propagation and the residual stiffness and strength during the fracture. The inter-laminar damage model is presented together with the basics of the parameter identification procedure relying on DCB and ENF tests.

In this paper, it is also demonstrated that, in general applications, modeling delamination alone is not enough, which means that it is essential to model the damage inside the plies besides the damage at the interfaces. This is illustrated for the ENF test case in which simulation is compared to analytical solutions and test results. It is seen that when only 0° plies are considered, the behavior is quasi-linear up to the crack propagation load, which is the first maximum point of the displacement/reaction curve. However, when 45°/-45° plies are considered, the non-linear behavior observed in the tests can only be reproduced if the damage inside the plies is modeled besides delamination. We note in that case a very good agreement between tests and simulation.

The linear and non-linear material properties identified at the coupon level are then used at the upper stage of the pyramid, on e.g. a L-shaped beam and/or a CAI test case. Comparison between tests and simulation demonstrate that the modeling and analysis approach is predictive.

8159 | FREE-VIBRATION ANALYSIS OF DELAMINATED SHELLS VIA UNIFIED FORMULATION (25. Failure and Damage)

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The present work deals with the free-vibration analysis of multilayered composite shells affected by localised delamintions. The delamination in composite structures may occur either during the manufacturing process or during service period of the structure. Delaminations can be distinguished into two types, one delamination at the free edges caused by high free edge stresses, and the other embedded within the body of the structure which may be due to manufacturing defects or voids, or due to impact loads. To facilitate the understanding of the effect of the delamination on the structures, and to analyze possible algorithms for structural health monitoring of delaminated structures, delamination models are required. Several authors have studied delaminated shells, like Nanda and Sahu have carried out free vibration analysis of delaminated composite shells [1] using different shell theories. Dynamic instability of delaminated skew plates subjected to static and dynamic loads based on higher order shear deformation theory was studied out by Noh and Lee [2]. These works used a single theory or couple of theories to carry out their studies. The proposed investigation tries to comprehensively carry out free vibration analysis of delaminated composite shells using refined and advanced shell models, contained in the Carrera s Unified Formulation (CUF). One of the most interesting features of the CUF consists in the possibility to keep the order of the expansion of the state variables along the thickness of the plate as a parameter of the model. Finite elements with layer-wise capabilities are employed to ensure an accurate description of the mechanical fields in the layers. It is essential to take into account the discontinuity of the mechanical properties at the layer interfaces. For these reasons, the use of classical plate theories based on Kirchhoff and Reissner-Mindlin hypotheses can lead to inaccurate results. The Mixed Interpolated Tensorial Components (MITC) method is employed to contrast the membrane-shear locking phenomenon that usually affects shell finite elements. This formulation has already shown all its potentiality as a base for finite elements in the mechanical analysis of multilayered shells [3]. Some results from the free-vibration analysis of shells will be provided, in order to show the efficiency of models presented.

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8211 | VARIABLE-STIFFNESS COMPOSITE PANELS: Effects of manufacturing on laminate properties (25. Failure and Damage)

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Variable-Stiffness Panels stand out thanks to their improved structural efficiency and their ability to obtain variable stiffness and load redistribution. However, despite these advantages, conventional laminates with straight fibre architectures are still preferred by designers. One of the main reasons that limit their use is the incomplete knowledge of the effect of all manufacturing details and the response to damage mechanisms. For the effective application of Variable Stiffness Laminates, mainly in the aerospace sector, three major issues are identified.

The first issue is the advanced level of manufacturing technology, with the use of Automated Fiber Placement (AFP) systems. This technology represents an advance in the state-of-the-art of automated processes for the production of fibre-reinforced composites with high accuracy and repeatability for complex design. The secondly is the understanding of the effect of the process-induced defects on the mechanical response and structural failure mechanisms of the laminates. Thirdly, the development of reliable design methodologies able to predict the mechanical response by means progressive damage simulations. The development of computational tools to simulate the mechanical response of Conventional and Non-Conventional composite structures through nonlinear finite element analyses can give beneficial insight that will lead to an effective reduction of testing campaign.

The present work is focused on the analysis of the influence of the process-induced defects on the structural performance of Variable Stiffness Laminates. To fulfil this objective, progressive damage simulations (from inception to final collapse), which take into account the manufacturing constraints, have been developed. Both the ultimate failure load and the progressive failure mechanisms have been predicted with high accuracy in comparison with the results obtained in the experimentalcampaigns.In general, the experimental and numerical results show that the influence of manufactured-induced defects is more significant in samples without holes, where the defects themselves are acting as the initiators of the damage, while in the notched specimens failure mechanisms are primarily driven by the stress concentrations around the holes. Therefore, the detrimental effect of the manufacturing defects is limited.

8229 | Fibre reinforced concrete with a combination of polyolefin and steel-hooked fibers (25. Failure and Damage)

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Self-compacting polyolefin fibre reinforced concrete has shown high performance in both fresh and hardened state. Post-cracking behaviour provides notable residual strengths especially for significant deformations. For small deformations, flexural residual strength could be enhanced with a small amount of steel-hooked fibers, obtaining a hybrid fibre-reinforced concrete well suited for structural use. Four types of conventional fibre-reinforced concrete with steel and polyolefin fibers were produced on the basis of the same self-compacting concrete also manufactured as reference. These concrete mixtures were manufactured separately with the same fibre contents being subsequently used for two more hybrid mixtures. Fracture properties, in addition to fresh and mechanical properties, were assessed. The research showed both synergies (with the two types of fibers working together in the fracture processes) and an improvement of the orientation and distribution of the fibers on the fracture surface.

Keywords: hybrid fiber-reinforced concrete, polyolefin fiber-reinforced concrete, steel fiber-reinforced concrete, self-compacting concrete, macro-synthetic fibre reinforced concrete

8576 | Simulation of Lightning Strike Damage in Carbon Nanotube Doped CFRP Composites (25. Failure and Damage)

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This study focuses on understanding the damage behaviour caused by the lightning strike of carbon nanotube doped carbon fibre reinforced plastic (CFRP) composites. Lightning strike damage of CFRP depends on the electrical and thermal anisotropic properties of the material. Material damage is likely to occur after lightning strike due to low electrical conductivity of CFRP composites through the thickness. Extremely high temperatures may result delamination of the composite plate due to decomposition of the matrix resin, and fibre breakage due to sublimation of the carbon fibre. The main factor of the damage in the composite structures due to lightning strike is the low electrical conductivity of the resin. Therefore, recent studies focus on how to increase the conductivity of epoxy in laminated composites to reduce the damage. Carbon nanotube (CNT) reinforcement has been considered to use for this purpose because they have high electrical and thermal conductivities along with the excellent mechanical properties.

The aim of this study is to understand the damage behaviour of CFRP used in aerospace structures subject to lightning strike. The simulation of lightning strike damage is a complicated problem because it requires coupled thermal-electrical analysis. Quasi isotropic CFRP rectangular plate with CNT doped or undoped resin is modelled in Abaqus finite element program to investigate behaviour of lightning strike damage. The plate is subject to concentrated electrical current attributable to lightning strike under an electrical and thermal boundary condition. The temperature dependency of electrical conductivity is also considered in the model. Steady-state electrical analysis and transient heat transfer analysis are coupled and conducted at each time increment by application of Joule heat generation to each finite element. Electric breakdown after decomposition of matrix is considered by changing the electrical conductivity through the thickness direction. The electrical potential, electrical current, Joule heat generation, temperature of the elements are obtained. The effect of different lightning current waveforms, peak currents, and the weight percentage of CNT doped resin are investigated. Coupled electrical and thermal analysis is carried out using multi-physics, the results of which are verified with the experimental data obtained in open literature. Damage region is estimated by considering the decomposition temperature of the resin. It is assumed that CNTs in different weight percentage are added to resin and the enhanced electrical properties of the plate through the thickness are updated to run coupled thermal electrical analysis.

The results show that the damage area in each ply and the depth of the damage are nonlinear under the effect of either different waveforms or peak lightning strike currents. The fibre orientation of the plies affects the size and shape of the damage area due to higher electrical conductivity of carbon fibres. As a result, the damage area in each ply and the depth of the damage are not linear under the effect of either different waveforms or maximum strike currents. As the peak strike current or current waveform changes, the energy input to the system also changes and the damaged area varies accordingly. When the weight percentage of CNT doped into the resin increases, the damage region substantially decreases because the electrical conductivity through the thickness of the plate plays significant role for the lightning strike damage. Therefore, increasing the conductivity through the thickness of CFRP reduces the damage region as much as by 63% when the CNT doped resin is used.

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8627 | Influence of water absorption on the damage response of UD carbon fabric/epoxy composite laminate due to simulated lightning strike (25. Failure and Damage)

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Water immersed unidirectional carbon fabric/epoxy composite laminates are subjected to simulated lightning strike to investigate the influence of water absorption on the damage response of the specimen. The strike up to 30 kV (25kA) is inflicted on both dry conditioned and water saturated specimens with two stacking sequence ([452/02/-452/902]s, [302/02/-302/902]s). Damage responses are assessed by visual inspection, image processing, ultrasonic scanning and field emission scanning electron microscope. The results showed that the damage area for the water absorbed specimen is larger than the dry conditioned counterpart. Unlike a center-damaged hole on the surface of the dry conditioned sample, dramatic fiber break up and resin damage can be observed for the water immersed specimens of the two stacking sequence. Ultrasonic scanning showed that, compared to the pristine ones, the penetrated damage depth for the water absorbed specimen is doubled with internal delamination more intense and longer extended, indicating noticeable decrease of the impact resistance and damage tolerance of the specimen after exposing to water. SEM images revealed that water absorption intensified the lightning strike damage by deteriorating the fiber strength and the bonding at fiber-matrix interfaces of the specimens.

8632 | Semi-analytical method for calculating the fracture parameters of repaired aluminum panels with composite patches **(25. Failure and Damage)**

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Crack propagation analysis in repaired structures is an important issue in the fracture mechanics. Semi-analytical methods in calculation of stress intensity factors are interesting for the researches and designers due to their simplicity and low computational cost. In this paper, a semi-analytical method is developed to calculate the fracture parameters such as the stress intensity factors for centrally cracked aluminum panel; in mode-I condition, which have been repaired and stiffened with single-side composite patch and stringers, under fatigue loading. The presented formulation is investigated with various patches thicknesses and layers angles of the repaired panels. The obtained results are verified with finite element analysis. In this regard, we reach the conclusion that the proposed formulation is acceptable.

Keywords: Crack propagation, Repair, Composite patches.

8657 | Analysis for delamination failure at the root end of the composite wind turbine blade **(25. Failure and Damage)**

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The structural safety of a composite wind turbine blade, the largest composite structure in the world, has become more crucial as it has been larger. Nowadays a wind turbine blade is developed up to 80 m in length. However, also the number of reporting on failure of wind turbine blades in wind farms increases. One of the representative failure modes of a wind turbine blade is failure at the blade root, which is mounted on a pitch bearing by T-bolt assembly. In this study, we also experienced delamination failure at the root during fatigue testing of a 3MW full-scale wind turbine blade according to international standard IEC 61400-23: Full-scale structural testing of rotor blades. Comparing the measured strain data of a T-bolt at the root and the result of detailed FE analysis on the composite root structure including T-bolt assembly, we found what kind of phenomenon occurred at the root and how it caused the delamination failure. Our result on the failure phenomenon would lead to enhance the structural safety of a huge composite wind turbine blade.

8675 | Experimental inverstigation of the interlanminar fracture of composite materials in mode III **(25. Failure and Damage)**

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The purpose of this study was to identify the behavior of composite materials in mode III interlaminar fracture using the Split Cantilever Beam (SCB) test. A delamination was introduced at the mid-plane of the tested specimens. A SCB fixture was designed to provide the corresponding load configuration and to get a pure mode III effect on the crack tip. Load versus displacement curves were given by the UTM (Universal Test Machine) and were used in the calculation of the mode III critical energy release rate (GIIIc). Studies were performed for different composite materials and layups, initial crack lengths, specimen dimensions and stacking sequences. All the tests were performed with respect to the specifications provided by the ASTM (American Society for Testing and Materials).

Keywords: composite materials, mode III, energy release rate, delamination, crack propagation, experiments.

8681 | STUDY ON BEHAVIOUR OF GRE TUBES SUBJECTED TO REPEATED INDENATION LOAD AT DIFFERENT LOCATIONS **(25. Failure and Damage)**

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1 Introduction

Behavior and strength of composite tubes under different loading conditions, for example impact or indentation, is widely studied however little attention has been given to behavior under repeated impact or indentation loading incidents[1]. The research conducted so far to understand behavior under repeated load has studies plates or beams generally; however no such work is available in literature on cylindrical or curved geometries. In a recent work [2], authors studied behavior of GRE tubes under indentation and damage occurred due to such loading. It is not known how this already damaged structural component will behave under similar loading at a different location. It is a practical scenario, from the service life of tubes or pipes, where these might experience repeated loading and most likely at a different location or at a distance from the previous loading incidence.

The purpose of this experimental work is to observe behavior of GRE tubes subjected to repeated indentation load at two different locations. The second loading point is chosen at 180º to the first point. It is exactly on the opposite side of the tube such that the centers of loading points are on same line but 180º degree apart.

2 Background

Authors have recently carried out study on scaling effects by using four different scales [2] Same scales will be used to observe behavior under repeated loading. This will provide direct comparison of any change in behavior of GRE tubes subjected to repeated indentation load across four different scales. [±55º] cylindrical GRE Specimen for four different scales (n=1/4, ½, ¾, and 1) are subjected to indentation. Force displacement data is obtained from MTS tensile test machine. Energy is calculated by estimating area under the curve by Trapezoid method.

3 Experimental Setup

In this current work these specimens will be subjected to indentation such that the center point of indentation load would be on same line on exactly opposite side 180º apart. Force displacement and energy displacement relation will be compared for repeated loading at different indentation points. Damage and delamination growth as a result of indentation at a distance from each other will also be estimated. This should also provide an insight into change in damage behavior due to repeated indentation.

Indentation tests will be carried out on MTS tensile test machine. Required parameters including force, displacement, time and energy will be recorded with the help of integrated MTS data acquisition system and software. Damage initiation and growth due to indentation will be monitored with the help of an upward facing mirror placed inside the tube during the experiment and aligned with the indenter location. Videos for all scales will be captured for post experiment analysis and for the measurement of the damage growth reflected by the mirror.

4 Expected results

This work will present experimental results including slope of force displacement relation, Energy absorbed by the specimen and permanent deformation experienced by each specimen subjected to indentation load at 180º to the first point of loading. Damage initiation and growth with respect to displacement, force, energy and time will be plotted and compared to understand behavior under repeated indentation at distance.
5 References
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8692 | The properties of Composite Coatings under Lubrication Conditions with ZDDP and Ionic Liquid as a Lubricant **(25. Failure and Damage)**

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The purpose of the study was to determine the wear resistance of Ni and Ni-Co-WC coatings sprayed by High Pressure/High Velocity Oxy Fuel (HP/HVOF) technique. HVOF coatings are widely used in various industrial applications because of their resistance to high-temperature chemical corrosion and frictional, erosive or cavitation-wear, etc. The main advantage of this technology is that the coatings are easy to produce and their properties can be modelled by appropriately changing the ingredients. The analysis involved assessing the wear resistance of HVOF coatings under dry friction and boundary lubrication conditions, with the latter related to the tribochemical interactions between the coatings and the lubricant additives. It was important to establish the character of the tribological effects of the anti-wear lubricants. The lubricants used in the tests were: zinc-dialkyldithiophosphate (ZDDP) and ionic liquid (IL). The coatings were examined before and after friction tests using a scanning electron microscope (SEM) and an optical profilometer. The texture analysis showed that the final roughness was dependent on the coating material. The hardness of the coated and uncoated elements was measured by means of a Matsuzawa microhardness tester. Electrochemical corrosion analysis involved polarization measurement and impedance measurement. The tribological examinations were performed under dry friction and boundary lubrication conditions using a ball-on-disc tribometer. The lubricants tested were mineral oil, mineral oil with 1% ZDTP and an ionic liquid (1-butyl-3-methylimidazolium tetrafluoroborate, BMIBF4). The comparative analysis of the tribological and corrosion properties of the composite coatings confirms that the tribochemical activity depends on the lubricating substance applied. Under friction conditions the tribological efficiency of the anti-wear coatings was different for different lubricants.

8694 | Damage development ahead of growing cracks in unidirectional fibre reinforced plastic composites **(25. Failure and Damage)**

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This paper presents recent findings from a study of the early stages of damage development ahead of a growing crack in 90˚ unidirectional carbon fibre epoxy composites. A specially designed specimen, which allowed cracks to be arrested before causing two piece failure, was used for the study. The development of fine scale damage in the process zone ahead of the arrested cracks was examined in 3-D using serial sectioning coupled with high magnification scanning electron microscopy and focussed ion beam milling. The results indicate that cracking is initiated by the formation of micro cavities in the matrix midway between neighbouring fibres. The cavities then link up to form a crack. These findings are considered to be consistent with the postulation of the Onset Theory that failure in 90˚ plies is initiated by cavitation in the matrix resulting from dilatational strain.

8699 | Friction and wear behavior of the hybrid ceramic composites (25. Failure and Damage)

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High requirements, which medicine puts biomaterials, cause that they belong to one of the most expensive fabicated by person. It forces the necessity of application of newest material and technology to obtain the product with fairest characteristics (mainly very high biocompatibility, tribological and corrosion resistances and proper mechanical properties). More generally, in esthetic dentistry, hybrid ceramic composite is applied. It is exposed on different kind of tribological damages, but their constancy depends from employed materials with friction pairs. This work presents analysis of influence of surface's roughness on tribological properties of hybryd ceramic composite. In friction pairs operating under dry friction and lubricated conditions, the elements with hybryd ceramic composite showed good tribological properties (low friction and low wear). The reaearch realize in conditions of libricationby artificial saliva. The presence of artificial saliva as lubricant contributed to an improvement in the tribological properties of the elements of tribological systems.

8718 | Fracture Mechanic Analysis of Bondings for Multi-Material Vehicle Components (25. Failure and Damage)

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Lightweight vehicle design is essential to decrease emissions. Conventional materials and constructions methods are reaching their limits, leading to the consideration of lightweight materials such as fibre reinforced plastics for mass production. The combination of both fibre reinforced plastics and metallic materials is called multi-material, or hybrid design.
Therefore the BMBF Forschungscampus Open Hybrid LabFactory aims to develop new manufacturing technologies for economic and multifunctional lightweight design. The Open Hybrid LabFactory is a public private partnership where both companies and universities collaborate on research. The goal is to develop design and evaluation tools for use case specific ecologically optimised multi-material vehicle components.
Ecology, lightweight design and economy are conflicting development goals, thus compromises are required and an assessment of the ecological, economical, and lightweight properties is necessary.
Bondings are widely used in manufacturing of fibre reinforced structures. The predictability of the crack propagation behaviour is important for safety and reliability aspects. A promising approach can be found with the principles of fracture mechanics, which were originally developed for the damage tolerance analysis of principal fibre reinforced aircraft structures and are here adapted to multi-material combinations.
Within this presentation a method suitable for structural design is presented for the most efficient calculation of mixed mode energy release rates, even in analysis models of complex structures. The evaluation of the fracture mechanical data is performed within a user defined adhesive interface element during the solution of a standard finite element analysis. Even the fatigue behaviour, including crack propagation can be analysed. The capacity of the method is demonstrated with a static analysis of a multi-material CNG pressure vessel.
Measurements of critical energy release rates as design values (Mode I, Mode II) will be shown for a CFRP-X7Ni9 material combination bonded with Scotch-Weld DP 490 (3M), established with standardized test specimen (Double Cantilever Beam, End Notch Flexure Specimen).
In order to compare various component concepts, these properties are among other information used for the development of a software tool. This tool contains empirical and analytical formulae, which estimate the aforementioned properties and various evaluation methods to compare different concepts.

8739 | Influence of fibre aqueous-based sizing treatments and of the matrix intrinsic reinforcement on the damage mechanisms of novel laminated acrylic thermoplastic composites (25. Failure and Damage)

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The current environmental concerns imply the utilization of polymer structural composite that could be recycled into raw materials and reused. To address these issues, a great attention is paid to the development of thermoplastic matrices to replace conventional thermoset matrices, and/or the use of bio-based materials to replace petroleum-based materials. Our work is focused on the development of novel laminated composites with an acrylic thermoplastic resin as matrix, reinforced with layers of glass or hemp fabrics, produced by the infusion technique. However, amorphous thermoplastic matrices were reportedly having a toughness closer to that of thermoset matrices, and the compatibilization between the fabrics layers and the matrix has to be optimized.

The objectives of our works are to i) increase the toughness of the acrylic matrix by dispersing functionalized nanoclay or acrylic tri-bloc copolymers (nanostrength) with different concentrations, and ii) to increase the fiber - matrix adhesion by using aqueous-based formulations of multifunctional prepolymers apply by sizing treatment of the fibers. The initial morphology of the composite were analysed by atomic force microscopy to investigate the dispersion state of the particles within the acrylic matrix, the possible presence of process-induced porosity and the fiber – matrix interface quality. The composites were then analyzed by tensile testing, bending testing and impact testing (drop weight tower), and the post-mortem specimens were analyzed by scanning electron microscopy and x-ray micro-computed tomography to visualize the damage mechanisms and the interface fracture profile.

The main results obtained with glass fabrics indicate that the dispersion state of the reinforcing agent nanostrength was not optimal and that increasing the concentration in reinforcing agent was detrimental to their dispersion state. Nevertheless, it was noted that the addition of nanostrength slightly increased the strength and impact resistance of the materials. We are currently processing the laminated composites with nanoclay and testing some innovative sizing treatments of the reinforcement materials. These treatments include unsizing in the case of glass fiber and application of an aqueous-based sizing with appropriated prepolymers in the case of glass and hemp fabrics. The influence of the dispersion of nanoclay and of the compatibilization

methodology on the mechanical properties of the composite is under investigation.

8755 | Effects of loading span on mode II interlaminar strain energy release rate of unidirectional E-glass/epoxy laminates (25. Failure and Damage)

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The apparent critical energy release rate (ERR) of composite laminates has often been found to vary with specimen geometry. Evaluation of critical ERR is valuable in material development and selection for supporting design and analysis to produce delamination resistant structures. The Four Point Bend end-notched flexure (4ENF) test can be used to determine the mode II interlaminar critical ERR, GIIc, of laminated composites. In this paper, the effects of loading span on mode II critical ERR have been investigated on 4ENF specimen of unidirectional E-glass/epoxy laminates. Experiments have been performed on three different values of loading span. A finite element model has been developed to calculate the mode II energy release rate including cohesive interface elements. Friction of crack faces and the shear nonlinearity at the vicinity of crack tip has been considered in the finite element model. The FE calculations have been validated with the experimental result.

8768 | Mechanical properties of Nickel reinforced AC8A composites fabricated by low pressure infiltration process (25. Failure and Damage)

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Ni reinforced Al alloy composites were fabricated by low pressure infiltration process. Porous Ni was applied as preform. The fabrication was conducted under 0.3 MPa at 600, 700 and 750 degrees centigrade, respectively. Intermetallic compounds Al3Ni generated between Al and Ni were observed in the composites. Microstructure, Vickers' hardness and wear characteristics of the composites were also investigated.

8784 | Thermo-mechanical behavior of aeronautical composite materials exposed to fire (25. Failure and Damage)

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This research has been realized in the framework of the AircraftFire program, funded by the CEE (FP7).
Safety aboard aircraft is always one of the main preoccupations of aircraft manufacturers and airline companies. Therefore, fire safety is one of the major research topics that have been addressed to improve the passenger safety. The aim of AircraftFire program is to contribute to increase survival of the passengers and crew in the new generation of aircraft during fire scenarios in flight or upon impact. Indeed, a wide use of composite materials for the fuselage, wing and structure in the new generation of aircraft (B787 or A350 families) to reduce the weight increases the thermal load and thus the risk of fire. The aim of this study was to characterize the mechanical behavior of different structural composite material submitted simultaneously to a flame attack and a mechanical stress in order to:
- evaluate the coupled effect of the stress and heating source on the material behavior,
- compare the behavior of different materials submitted to such thermal aggression and stress loading,
- describe the failure modes.

For this purpose a mechanical testing machine has been designed and built by P'Institute specifically for the AircraftFire program. The equipment allows 3 or 4 points bending test and is coupled with a burner or a cone calorimeter. During the test, the load or the displacement can be controlled and the temperatures on the back side of the specimen were recorded. Two different fiber stress states in front of the flame could be achieved (tension or compression).
The burner design allows a hot jet gas which is similar to a kerosene fire from a large post-crash. The main features of the burner are a wide range of heat flux up to 200kW/m² over a diameter of 3.5cm, and a maximum temperature gas exhaust of 1200 ° C.
Four structural materials were tested combining different layup and type of matrix (AcF1, 2, 3 and 6) in two different thicknesses (2 and 4mm). During the tests, four heat flux range were chosen in the range 75 to 200kW/m². For the 2mm thickness specimen, two different deflection have been used (15 and 30 mm) while for the 4mm one, only the 15 mm deflection has been applied.
Over 50 experiments have been performed during this program in order to get general outline of the composite materials behavior submitted to flame impact. Additional tests were done on specimen without any stress at different exposure times to the heating source in order to measure the pyrolysis thickness and assess the damage area generated inside. Several major results have been obtained:
- The combination of the load and the thermal aggression leads to a failure of the specimen while the specimen don't break when the load only is applied
- In the case studied, the specimens fail systemically before the ignition time of the composite material
- The fiber stress state (tension vs compression) in the exposed side to the flame leads to two totally different failure modes causing greater failure time in compression than in tension
- The failure time decreases while the heat flux increase
- The failure time decreases while the stress increases
- The matrix type has a strong influence on the failure time
- The failure occurs only with few plies pyrolysed

Thermo mechanical simulation works were performed on AcF2 in order to evaluate the stress field and the effect of the temperature increase taking into account:
- 3D temperature evolution in the specimen
- mechanical properties evolution with the temperature
- pyrolysis zone described by a damage parameter

Currently, part of the load evolution during the test is well described by the effect of the temperature on the mechanical properties. But up to now, models developed do not describe accurately the sudden failure of the specimen. Further investigation of the damage mode should be performed to describe in a better way the sudden drop of the load related to the failure.

8794 | Effect of stacking sequence on the fatigue behaviour of CFRP laminates developed for wind turbine blades (25. Failure and Damage)

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Wind turbine blades are mostly made of glass fibre reinforced polymer (GFRP) or carbon fibre reinforced polymer (CFRP) composites due to their good strength to weight ratio, corrosion resistance, excellent fatigue properties and electrical properties. Although glass fibres are extensively used for wind turbine blades, carbon fibres have recently gained increasing interests as a result of the better properties compared to glass fibres and their decreasing price. Wind blades in service are subjected to highly variable loads such as aerodynamic, gravitational and inertial forces. The aerodynamic and gravitational loads will bring about bending stress in the blade. As the wind is variable and chaotic, the common failure mode of wind blades is mechanical fatigue. Therefore, it is essential to investigate the bending fatigue behaviour of CFRP composites in order to predict the service life of the blades subjected to variable loads.
The fatigue mechanisms of fibre reinforced polymer (FRP) composites are complex and generally in the forms of delamination, matrix/fibre debonding, matrix crack, and fibre failure. Initial defects in FRP may not cause immediate structural failure; however, the accumulated damage leads to the decrease in stiffness, strength and fatigue life. It is very important to observe the damage progression during fatigue test and determine how the accumulated damage leads to the degradation of properties in FRP composites. The stacking sequence also affects the damage evolution and thus service performance of FRP composites.
The present work investigated the tensile and fatigue behaviour of two kinds of CFRP laminates with the stacking sequence of [0/+45/-45]s and [+45/-45/0]s, which have been extensively used by wind blade manufacturers. Both linear and Sigmoidal (Boltzman) models were used to fit the stress-life curves. The stiffness degradation was quantitatively characterised during the fatigue process. In some static tension and fatigue tests, the load was interrupted at different stages; the specimen was then scanned in x-ray microtomography. The following conclusions were drawn:
• Tensile properties of CFRP laminates are affected by the layup sequence, even though the laminates have the same number of plies oriented at 0°, +45° and -45°. The [+45/-45/0]s CFRP laminate has higher ultimate strength and failure strain than the [0/+45/-45]s laminate.
• Sigmoidal model seems to better represent the stress - fatigue life relation than the linear model for both laminates, especially with the [+45/-45/0]s layup. Under fatigue loads, the [+45/-45/0]s laminate has better fatigue resistance with smaller stiffness reduction compared to the [0/+45/-45]s laminate.
• The damage process under tension and fatigue loads is similar in both the [+45/-45/0]s and [0/+45/-45]s laminates. Matrix crack initiated in the 0° plies and propagated to the adjacent 45° plies. Meanwhile, edge delamination occurred at the 0/45 interfaces and expanded through the width of the specimen. At the late stage, delamination at the 0/45 and +45/-45 interfaces grew rapidly associated with fibre failure at the 0° plies, which leaded to the final failure of the CFRP composite.

8801 | Progressive Fatigue Damage Analysis of CFRP under Multiaxial Stress State (25. Failure and Damage)

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Fatigue analysis of CFRP has been carried out in the past several decades. Phenomenological fatigue models are the most common models which are adopted to predict fatigue of CFRP. Although these fatigue modes are successful to predict fatigue life, it is important to study failure mode of CFRP under loading which cannot be observed in phenomenological fatigue model. In this paper, progressive fatigue model is established to model the failure mode of composite laminate. Since composite is anisotropy, composite is under multiaxial stress state even if the composite is under uniaxial stress. It is quite important to select a multiaxial fatigue model to study composite fatigue. In our model 3D Tsai-Hill static failure criterion is used to calculate equivalent stress which is adopted to study influence of multiaxial stress on the fatigue life. Fatigue mode of CFRP is realized by ABAQUS USDFLD subroutine. In this progressive fatigue subroutine, field variable is used to connect fatigue life of element and damage state of element. Once fatigue condition is satisfied, element is failure, and then the engineering constants of CFRP change with stiffness degradation rule. Stress of composite laminate is recalculated. Models with different stress amplitude and ratio loading are investigated by progressive fatigue method, and numerical results show excellent agreement with experimental results.

8821 | Deterioration Mechanism of Pultruded GFRP Profiles in Marine Environment Based on Microstructure Analysis (25. Failure and Damage)

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Pultruded glass fiber reinforced polymer (GFRP) profiles have been applied in dock pontoons, oil platforms, rapid fabricate houses in island, and other marine structures because of their advanced functions and properties, such as reliable performance, low price, and good designability. However, the marine environment has a big effect on the GFRP matrix resin and the interface between matrix and fiber. Physical aging and chemical aging occur for the matrix resin, thus leading to the reduction of the mechanical properties. Most previous durability research have focused on the aging behavior and the law, but the deterioration mechanism and durability reinforcement based on microstructure analysis have become an increasingly prominent issue, and need to be investigated. In this paper, the deterioration law of macroeconomic performance of the pultruded GFRP profiles under the effects of salinity, temperature, moisture, and UV intensity was determined. Furthermore, the chemical structural changes, the movement of the polymer chain segments, and the deterioration situation of the interface before and after the aging testing of GFRP profiles were observed by the microstructure characterization methods, thus, the relationship between macroscopic properties and their microstructure was explored, revealing the deterioration mechanism.

8829 | Influence of residual stresses on crack propagation in ceramic particulate composites (25. Failure and Damage)

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The contribution is focused on the investigation of the role of residual stresses in ceramic particulate composites. Special attention is devoted to the influence of residual stresses on fracture behavior and the crack propagation in this kind of composite.
In some particular cases, the matrix of the composite may be used to tailor the properties of the final composite. One example is that of Low-Temperature Co-fired Ceramics (LTCC), used as substrate material for production of multilayer electronic circuits and sensors for medical, automotive and communication devices. LTCC ceramics consist of ceramic particles (typically alumina) embedded in a glass matrix. LTCC technology was developed around three decades ago as an alternative to overcome conductivity problems with tungsten metallization in alumina substrates used in High Temperature Co-fired Ceramics. The main characteristic of LTCC is their relatively low sintering temperature of the ceramic particles (circa 850°C), which is possible due to the use of the glass matrix with a low melting point. However, important residual stresses developed during cooling down from the sintering temperature in the composite matrix due to differences in coefficients of thermal expansion of particles and matrix.
In the contribution a behavior of the crack propagating in the field of strong residual stresses influenced by particles presence is studied. The crack propagation in this complex stress field is investigated by procedures of linear elastic fracture mechanics. The change of the crack propagation direction due to residual stresses or shielding effect of the particles is considered. The procedure used is able to take into account the crack arrest in the vicinity of particles or to decided, if the crack will propagate through the particle or under which condition this behavior can occur. Procedures based on combination of finite element method (FEM) and (generalized) linear elastic fracture mechanics lead to the determination of the path of crack propagating in the particulate composite and describe (by means of fracture mechanics) the crack propagation (by K-calibration along the crack path). The result is the knowledge of the crack behavior in the particulate ceramic composite influenced by (strong) residual stress field. A suitably chosen material combination can lead to the crack arrest under given loading conditions or to the deceleration of crack growth. This knowledge can be used for better design of such kind of materials with higher resistance to the crack propagation or for the lifetime estimation in the case of subcritical crack growth (SCCG) in ceramic particulate composites.

8858 | Towards damage modelling of composite structures in AIRBUS: State of the Art and Challenges (25. Failure and Damage)

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In the aerospace industry, the use of advanced composite materials in primary structural applications has reached a strong level of maturity. However, a common problem in design is that composite materials exhibit quasi-brittle behaviour with very little plastic stress relief. In addition, material behaviour is orthotropic, thus resulting in the need for extensive mechanical testing. In order to circumvent this problem, and to extend the design space, damage modelling of composite materials is of strong interest to the aerospace industry. The methods are based on detailed failure criteria and continuum damage mechanics and are expected to replicate the behaviour of composite laminates both up to, and including, final failure. The methods were incorporated in both three-dimensional finite element models of standard coupon tests and large-scale structural simulations. This presentation focusses on:

1. Current capabilities in the industry and academia. A benchmark study has been performed on both simplified and detailed approaches
2. Future challenges – exploitation of damage models
3. Gaps to filled in future research

The benchmark represents a significant way forward in the definition of a mature damage mechanics method to support airframe sizing, and also provides the context for future developments in computational damage mechanics.

8928 | Numerical evaluation of residual stresses in composite structures (25. Failure and Damage)

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In fibre/polymer composite materials when they are cooling from the fabrication temperature to the room temperature the residual stresses arise because of mismatch in the thermal expansion coefficients between the polymeric matrix and the fibre. The residual stresses are almost always present in the polymeric composite structures therefore they should be taken into account during design and modelling of composite structures. The most important task in this field is evaluation of the residual stresses and factors that may have the critical influence on their appearance and value. Next, the existence of the residual stresses in the composite structure should be analysed in the case of possible influence on their fatigue damage. Moreover, the conducted studies try to understand how the residual stresses can be stipulated and use to improve the properties.
Fatigue damage of composite materials is a complicated mechanical phenomenon due to a really complex nature of such materials. When the cyclic loading is present, damage accumulates in composite materials and affects the fracture or failure of structures. The most possible damages that can arise include a progressive matrix cracking, brittle fracture of fibres, debonding of fibre–matrix interface and debonding of adjacent layers (delamination). Despite extensive studies in this area, there exists an open question of how to model such a phenomenon taking into account possible factors that may have a critical influence on the final damage.
Usually, the residual stresses influence on the fatigue damage of composite materials are not considered due to complexity in derivation of residual stress values. The present paper is dedicated to the numerical analysis of residual stresses in laminate composite structures to evaluate their influence on the fatigue damage. In order to assess the residual stress influence on final destruction of composite structure firstly the values of the pre-stresses have been prescribed and next the fatigue process progression for up to the final failure was conducted with the help of finite element modelling. The prescribed pre-stresses simulated the existence of non-zero residual stresses arising in manufacturing process which play a crucial role in the evaluation of the fatigue life. For instance, they shift the First-Ply-Failure envelope, buckling loads etc., and depending on the form of residual stress loading can increase or decrease the final values of fatigue life.

8969 | An evaluation of mechanical properties and failure modes of multi-layer glass reinforced polypropylene thermoformed composite material to be used in automotive industry (25. Failure and Damage)

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The work described in the paper was aimed at an evaluation of mechanical properties and failure modes of multi-layer glass reinforced polypropylene thermoformed composite material to be used for manufacture of 3D selected components in automotive industry. The work was performed as a part of the 7th Framework Programme project 3D-LightTrans. The goal of the project is to establish and provide access to groundbreaking, highly flexible and adaptable low-cost production technologies for manufacturing of high performance light weight 3D multifunctional textile reinforced polymer composites for structural components. This approach will move the use and application of 3D multifunctional textile reinforced polymer composites from its current position in cost intensive, small series niche markets, to broadly extended mass product applications in the automotive sector, and also in other key sectors, like consumer goods, medical devices, sport equipment, machine parts and renewable energy systems.
The investigated material was a high-tech polymer composite combining the superior properties of the reinforcement material (glass) with the ultra-light weight and low cost of polymer matrix (polypropylene). The material is characteristic by continuous fibre reinforcement in the form of woven multilayer fabric with Z reinforcement, showing enhanced performance compared to short fibre reinforced composites and allowing for a better control of the distribution of the reinforcement material. The material was developed in a collaboration of the project consortium partners, particularly those with an extensive expertise in the area of materials, production research and technical textiles, like Austrian Institute of Technology, University of Ghent and TU-Dresden, where the material plates were manufactured.
A comprehensive experimental programme was performed with the aim to evaluate strength and E-modulus of the material under different types of loading, static tension, compression and flexure. Tests were performed in three most important directions, warp, weft and +-45 deg. In addition, effects of modified test conditions, like gauge length during compression tests, on final mechanical properties and failure modes were investigated. The experimental programme was completed by evaluation of failure modes at different loading including microscopic and microstructure scale.
The most important results are as follows: (i) Flexural strength in both warp and weft directions was similar, the strength in weft direction is slightly higher. (ii) In warp and weft directions, flexural strength was almost comparable with tensile strength, being mostly between 200 and 300 MPa. On the contrary, in 45 deg direction, flexural strength was quite comparable with flexural strength in warp and weft directions unlike tensile tests, where strength in 45 deg direction was considerably lower in comparison with warp and weft directions, more than twice.
Further details of the experimental programme and results are discussed in the contribution.

8970 | Damage assessment of notched composite structures and adhesively bonded repairs (25. Failure and Damage)

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The use of carbon-fibre reinforced plastic (CFRP) composites in the design of structural parts with high mechanical performance requires a better understanding, especially in the presence of open holes and damage. The effect of the presence of notches on the behaviour of composite materials is an important topic because it causes a large decrease in strength compared with an unnotched laminate and they have an important effect on the growth of damage zones.
Notched strength has been reported in many studies as directly related to the type of damage at the notch tip, such us matrix cracking in the off-axis plies, delamination and axial-splitting in the 0º plies, before failure occurs. Interlaminar damage, such us delamination, typically reduces notch stregth, as individual uncoupled plies are free to fail by the fracture mode of least resistance. Conversely, intralaminar damage at the notch tip provides stress relief as the notch geometry changes, thus increasing notched strength, if plies are still bonded to each other. Regarding laminate lay-up and stacking sequence, it has been shown that laminate notched strength varies substantially with both the specified set of ply fibre orientation as well as the order in which the specific plies are arranged in the laminate. Different type of through-thickness discontinuities have been used in order to evaluate the notched characteristics of CFRP laminates. However, the open hole laminate has been adopted as industry standard for determining the notched strength for CFRP laminates. On the other hand, results can be strongly dependent on testing configuration, as for example, the well known 'notched size effect' or effect of lay-up.
The mechanical behaviour of notched composite structures is complex .It is therefore more desirable when performing experimental investigation on laminated composites to obtain extensive full-field strain data, rather than limited strain or displacement measurements obtained from traditional electrical strain gauges or extensometers. A limited number of studies focus on the assessment of the damage process in notched composite structures using Digital Image Correlation (DIC) techniques has been applied before.
On the other hand, one of the mayor challenges in aerospace industry, due to the extensive use of advance composites in primary and secondary aerospace structural components, is structural repair. Bonded composite repairs provide an alternative to mechanically fastened repairs with significantly higher performance. However, structural bonded repairs, especially with primary structures, pose several scientific challenges with the current existing repair technologies, as for example damage assessment and performance of external bonded patch repairs.
The objetive of this work is the characterization and the assessment of the damage in CFRP laminates with an open-hole and adhesively bonded repairs under uniaxial tensile loading. An experimental test series was carried out to determine unnotched and open hole ultimate strength of laminates made from M21E/IMA, an unidirectional prepreg used in A350 XWB primary structures. Different stacking sequences were examined to gain an insight into the assessment of different type of damage in notched laminates and adhesively bonded repairs under uniaxial tensile loading. In addition, notch sensitivities of the different laminates have been evaluated using the strength of unnotched specimens as benchmarks. Furthermore, the performance and damage assessment of open-hole specimens fabricated from quasi-isotropic laminates were examined. DIC technique was used to used to investigate the tensile strain fields around the holes in the previous specimens. X-radiography was performed to identify the damage localized around the hole. In the second part of the work, external patches were bonded in M21E/IMA laminates with different stacking sequences. Tensile tests were carried out observing damage and performance.

8994 | Effect of Initial damage on CFRP retrofitted centre-notched steel plates (25. Failure and Damage)

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Carbon fibre reinforced polymers (CFRPs) are now widely used in design and construction of aerospace, mechanical and civil engineering applications. In the field of civil engineering, these materials gained most of their popularity in strengthening applications. Although several successful applications of strengthening steel structures exist worldwide, up to now there is no specific standard or guideline in use by engineers and researchers in this field. This can mean that sufficient data is not yet available and more experiments, lab work and numerical analysis for obtaining valid mathematical models is required. In this research the effect of fatigue is seen on strengthened steel plates with CFRP patches. Two sets of steel plates are tested with different

initial damage levels (initial crack length) and the effect of prestressed CFRP on the fatigue life of both types of specimens is studied. The results show how the effect of prestressing can be used to improve the remaining fatigue life of the centre-notched steel plates. On the other hand, the effect of initial damage is also found to be significant as it directly affects the stress intensity factors at the crack tip, speeding up the crack propagation rate.

9061 | Determination of Characteristic Lengths for open-hole and pin-loaded Composite Joints by Means of 3D Progressive Damage Analysis (25. Failure and Damage)

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Abstract
The current study deals with the progressive damage analysis to obtain characteristic lengths of open- hole and pin- loaded composite joints. For a 3D progressive damage analysis, a user define material code (UMAT) concerning diverse models, in the finite element analysis package ABAQUS, was developed to predict the failure load and characteristic lengths of the composite pinned joints. Investigation of failure criterions and property degradation rules effects on the failure behavior of the joints to obtain a numerical method for determination of characteristic lengths properly, are the objectives of study. A series of tests also were carried out to compare with numerical results representing good agreement between experimental results and numerical prediction.

Keywords: Composite pinned-joints, Characteristic length, Progressive damage analysis, Failure criterion.

9062 | Load-displacement behavior simulation of shape memory alloy hybrid composites (25. Failure and Damage)

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Abstract
Shape Memory Alloys (SMAs) are a type of Shape Memory Materials (SMMs) that they can recovery large deformation and return to their primary shape by remove of stresses along with rising temperature. In this paper overall behavior of a shape memory alloys hybrid composite (SMAHC) plate subject to uniaxial static loading were discussed. SMAs wires used for improve material properties in Glass-Epoxy composite subject uniaxial loading at ambient and high temperatures. In this study the influence of various parameters that include: the SMA fiber volume fraction, the temperature loading have been investigated. In order to simulation SMAHC of ANSYS 14.0 Finite Element Analysis (FEA) software is used. This model is capable to modeling properties of SMAs which include: the shape memory effect (SME) and Superelasticity (SUPE). The material option for superelasticity is based on model Auricchio and The material option for the shape memory effect is based on the 3-D thermomechanical model Souza and Auricchio .Since the temperature remain constant during loading in the experiment, solids 185 or 186 element are used. Numerical simulation of typical tests performed on shape memory alloy hybrid composites are presented and compared with available experimental data.
Keyword: Shape memory alloy hybrid composite, SME, Nitinol wire

9098 | Influence of Nd3+:YAG laser irradiation on the structure of composites with carbon fibers (25. Failure and Damage)

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The carbon-based composites: carbon fiber reinforced plastic (CFRP) and 3D C/C composite samples were exposed to the Nd3+:YAG laser beams (1.064 mm; i.e. near infrared, NIR range). Experimental parameters for the interaction of the laser beam with 1.5 Hz pulse frequency , and pulse duration = 0.7 ms, were: energy density was between 128 and 1468 J cm-2, pulse energy was from 1 to 3J and mean power was in range: 0.4 to 5.5 kW. The exposition by laser beam was normally to the sample surface. The laser beam was focused by appropriate lens. In all experiments, provided in applied working regimes, the surface damages have occurred. The results of laser damages are analyzed by light and electron scanning (SEM) microscopes. Program Image J is executed for quantitative analysis of generated damages of based on micrographs obtained by light microscopes.

9147 | Numerical evaluation method for crack initiation and growth phenomena of polyurethane foam-based insulation structures under dynamic cyclic pressures using damage-coupled finite element analysis (25. Failure and Damage)

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The polyurethane foam-based LNG insulation systems such as GTT Mark-III are always operated under repeated severe surroundings, namely, sloshing and ambient-cryogenic thermal gradients. Accordingly, the LNG insulation systems can be failed/fractured abruptly during their operation, and this phenomenon leads to not only leakage of LNG but also tremendous loss of human and financial resource. In order to evade the aforementioned disaster, the precise material nonlinear behaviors and failure features should be identified, and a suitable computational analysis code should be prepared prior to the design and fabrication of LNG insulation systems. Therefore, in the present study, the failure characteristics such as stiffness degradation, and crack initiation and propagation phenomena for glass fiber-reinforced polyurethane foam (RPUF) of GTT Mark-III type LNG insulation systems will be evaluated computationally. In particular, in order to describe the damage nucleation and growth as well as the elasto-viscoplastic behavior specifically, a temperature- and strain rate-dependent damage-coupled constitutive model will be proposed. Furthermore, the implicit formulation and computerization procedure of the proposed mechanical model will be introduced. As a result of the present study, a material card for well-known commercial FEA code, ABAQUS UMAT will be developed, and a series of damage simulations for LNG insulation systems under various dynamic cyclic pressures will be demonstrated. Finally, in order to validate the proposed mechanical model and the material card, the simulation results will be compared to the dynamic

cyclic test results of LNG insulation systems.

9149 | Post-buckling-driven surface delamination (25. Failure and Damage)

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Delamination propagation in layered isotropic or laminated composite materials is often driven by post-buckling, which typically produces mixed-mode fractures. The total fracture toughness depends on the amount of fracture energy contributed by the action of each pure fracture mode (mode I opening, mode II shearing and mode III tearing). Therefore, in order to study post-buckling-driven delamination behaviour, it is an essential task to partition the total energy release rate of a mixed-mode delamination into contributions from the action of each pure fracture mode. The present work considers through-width delamination propagation in beams made of layered isotropic or laminated composite materials under in-plane compression. Analytical theories to partition the total energy release rate are developed based on authors' previous work. In addition, analytical theories are also developed for the study of propagation behaviour. The work is validated against numerical simulations and experimental results.

9162 | Plastic damage model for fatigue in composites (25. Failure and Damage)

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This work proposes a plastic damage constitutive model at composite constituent level that accounts for fatigue effects by affecting both the strength and the stiffness of the composite component. The behavior of the composite material will be obtained by means of the rules of mixtures (ROM) theory [1]. The constitutive model is based on the "Barcelona Plastic Damage Model" [2] and makes use of the integration scheme proposed by Luccioni et al. [3] for the simultaneous integration of damage and plasticity constitutive equations. Its capabilities of dealing with "Ultra-Low-Cycle Fatigue" in steel have been studied by Martinez et al. [4] and offered good results in terms of life prediction and hysteresis loop, both for constant amplitude cyclic loading and for random cyclic loading. The application of the model for "Low-Cycle Fatigue" has been shown in Barbu et al. [5] also for metallic materials.
The present work explores the use of the coupled plastic damage model and ROM theory for composite materials where the failure occurs in the "Low-Cycle Fatigue" regime and is due to either component failure or to delamination between matrix and fiber. At component level, the model is valid for materials with a softening behavior and materials that exhibit first hardening and then softening. Numerical examples will be shown in order to better illustrate the model behavior for carbon fiber/ epoxy matrix composites.

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9170 | ACOUSTIC EMISSIONS AS AN INDEX OF DISSIPATIVE CAPACITY IN FRP MATERIALS UNDER COMPRESSION (25. Failure and Damage)

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Typically pultruded FRP materials are elastic in their mobility but with potential frangible tendency. FRP materials are characterised both in compression and under tension - by a material phase of collapse and softening as a crisis mechanism that is a result of the sum of several local collapse mechanisms that interact with each other. These, in turn, are inevitably influenced by the mechanical characteristics of the fibre and matrix components and their mechanical interaction. The collapse phase is also characterized by acoustic emissions that can then be assessed to assist in profiling the damage made to the material. This research analyses the acoustic emissions resulting from the experimental assessment of pultruded FRP samples under compression. For each compression test, the acoustic emissions generated during collapse are measured with dedicated instrumentation. The research also aims to evaluate the acoustic emissions as an index of the dissipative capacity of the pultruded FRP undergoing collapse. The acoustic emissions are measured in samples that had been previously subjected to a variety of different temperature cycles.

9172 | A generalized growth model for damage in unidirectional composites (25. Failure and Damage)

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Damages at different levels, either manufacturing induced or due to thermo-hygro-mechanical loads, are quite conventional in laminated composite structures. Pertaining to the fact that interface between the constituents is more susceptible to damage, mostly initiated as a diffuse damage, its evolution and interaction leading to the formation of other mechanisms need clarity. Diffuse damage and matrix crack are two mutually existing identifiable modes often noticed prior to laminate level mechanisms. By providing a platform for the assessment of damage development at a conceivable length scale,

computational models aid in unravelling the mechanics behind such experimental observations. In the present work, a micromechanics based continuum damage model is proposed to scrutinize the formation of a transverse matrix crack from diffuse damage. The potential of mathematical theory of homogenization is explored to conduct the micromechanical analysis of damaged representative volume elements (RVE). The varied sensitivity of diffuse damage growth under inplane shear and transverse load is analyzed by means of evaluating stress concentration factors at critical regions in an RVE. Further, the coalescence of circumferentially evolved diffuse damages resulting in a through the thickness matrix crack is discussed. It is seen that at small angles diffuse damage growth is shear dominant, however, the growth becomes equally favoured under normal and shear stress at higher angles. The study came up with the conclusion that, critical length of diffuse damage along the fibre direction appears as a prerequisite for the matrix crack to initiate. Microlevel analysis yields a unified explanation for the coupling between the two mechanisms. The effect of fibre volume fraction and matrix plasticity in damage growth mechanisms are taken into account.

9176 | Numerical Simulation of Progressive Fatigue Damage in Laminated Composites (25. Failure and Damage)

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Numerical Simulation of Progressive Fatigue Damage in Laminated Composites
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Abstract:
Polymeric composite due to their high specific strength and stiffness and their inherent potential for weight reduction in comparison to traditional metals have got large attention in aerospace structures. However their applications under cyclic loading conditions necessitate to simulate their fatigue behavior under various loading conditions. The main objective of this research is to develop a FE model to predict fatigue life of laminated composites under uniaxial loading. In progressive fatigue damage modeling methods, utilizing FE method is a necessary step to calculate stresses redistribution inside the structures due to the damage propagation and subsequently material properties degradation. It was assumed that fatigue damage propagation is related to the stiffness degradation of each ply in the laminate. Progressive damage model proposed by Shokrieh-Lessard was employed to account for stiffness degradation and damage propagation cycle by cycle. Failure prediction was carried out using stress-based failure criteria. A user defined subroutine (UMAT) in Abaqus software was developed to simulate fatigue damage propagation cycle by cycle. The developed fatigue life model predictions showed a good correlation with available experimental data.

Key words: Progressive Damage Modeling, Fatigue, Composite, Finite Element

9198 | Fatigue failure and optimization of composite plates and shells with holes (25. Failure and Damage)

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Fatigue failure and optimization of composite plates and shells with holes.

9200 | Prediction of Long Term Performance of GRP Pipes Subjected to Sustained External Pressure Based on Linear Regression Analysis (25. Failure and Damage)

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Long term ring stiffness test and long term sustained external pressure test were performed to predict the long term performance of GRP pipes. GRP pipes were constructed by continuous filament winding technique which sequentially and continuously distributes glass fiber, polyester resin, and sand into a cylindrical mandrel. This method provides different length of GRP pipes and GRP pipes for this study were cut into 300 mm. GRP pipes had nominal diameter of 400 mm, nominal thickness of 10 mm, nominal pressure of 16 bar, and nominal stiffness of 10,000 N/m2. Two GRP pipes were used for long term ring stiffness test and 21 GRP pipes were used for long term sustained external pressure test. The vertical deflection of GRP pipes was obtained through long term ring stiffness test. The failure pressure and failure time of GRP pipes were measured from long term sustained external pressure test. All the tests were conducted up to 10,000 hours under wet condition.The linear regression analysis was performed to predict long term performance of GRP pipes and its validity was verified through correlation coefficient. According to the results, the creep coefficient after 50 years and regression ratio of GRP pipes were found to be 0.66 and 0.59, respectively, from long term ring stiffness test. The ring stiffness of GRP pipes after 50 years was degraded up to 41 % of the initial ring stiffness. The regression ratio of GRP pipes was found to be 0.44 from long term sustained external pressure test and the long term performance of GRP pipes after 50 years was degraded up to 56 % of the initial performance. Based on the regression ratio, circumferential failure strains for first 6 minutes and 50 years were revealed as 1.82 % and 1.23 %, respectively.

9202 | Crack propagation in anisotropic materials under thermomechanical loading using XFEM (25. Failure and Damage)

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The extended finite element method (XFEM) is introduced to solve the problem of cracked media in thermo-anisotropic elasticity. The concept of level set is used to locate the discontinuity and the singularity, to enrich the jump in fields and to track crack propagation. The crack tip enrichment is derived from the asymptotic analysis in anisotropic media and used to enhance the crack tip region behavior modelling accuracy. The problem solving methodology consists to solve the heat transfer equation and then to couple the temperature as body forces into the thermomechanical problem. The crack growth is driven by the maximum hoop stress to strength ratio criterion, once it is satisfied, the orientation angle is calculated, the crack is incrementally advanced and the level set functions are updated. The method is validated by comparing the stress intensity factors (SIFs) with the existing ones for static cracks.

The implemented method seems to be efficient and the obtained results are in good agreement. The study is then extended to some parametric studies of crack propagation.

9212 | Instability analysis of Shear Bands using the instantaneous growth-rate of a perturbation (25. Failure and Damage)

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Shear banding, as an unstable process of localization, is a common precursor to fracture in materials under high strain rate loadings. Therefore, the detection of the instability point after which localization will occur is of significant importance. Due to the very complex nature of the physical phenomena occurring during the shear banding process, the study of this instability point has been the subject of substantial research.

In this work we propose a different alternative for defining this point based on the notion of generalized stability analysis. We study the behavior of the instantaneous growth rate of a perturbation tangent to the trajectory of the solution and compare it with a local criterion for instability. We then propose an approximation of this quantity that is cheaper to compute and imposes less restrictions on the problem.

We show that for a particular class of problems, in 1D and 2D examples, both quantities successfully find the instability point predicted analytically and verified experimentally in the literature. This methodology is general and can be applied to many different problems for which instability that leads to localization and fracture is important. An example with titanium matrix composites reinforced with titanium carbide particles is presented.

9223 | Experimental Hysteretic Behavior of High Strength Concrete Columns Confined by Butt-welded Closed Composite Stirrups (25. Failure and Damage)

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Abstract: This study was carried out on the six tested specimens of high strength concrete columns with butt-welded closed composite stirrups under varying axial force and cyclic lateral loads. The tests focused on the structural performance (deformation) and hysteretic characteristics of the columns considering the influence of the axial compression ratio and the volume-stirrup ratio. Based on the experimental results, the characteristics of hysteretic curves were analyzed, and the hysteretic rule of restoring force model was verified. According to the regression analysis of the test results, it was determined that the unloading rigidity and strength degradation rate under repeated loading conditions are mainly due to the two parameters of the "displacement ductility factor" and "axial compression ratio". The tri-line skeleton curves of the restoring force model consist of three phases. The first phase is the elastic phase, and the second phase is the strengthening phase and finally the strength degradation phase. According to the test results, the skeleton curves were determined by the section layer and the statistical regression analysis methods. The influence of the axial compression ratio and the volume-stirrup ratio were considered in its strengthening and strength degradation phases. By considering the influence of axial compression ratio and the volume-stirrup ratio to the hysteretic characteristics of high strength concrete columns confined by butt-welded closed composite stirrups, the shear force-lateral displacement restoring force model was established.

9229 | Dynamic behavior of ocean current turbine blade with damage (25. Failure and Damage)

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This study is concerned the behavior of the marine current turbine blade. This work devoted initially to make a analytical part, the turbine blade is modelled as a Timoshenko rotating beam and the mathematical formulation is obtained. After applying boundary condition and loads, we have studied the stress, strain and displacement in order to determine the singularity zone, also show the six first modes shape of blade. Secondly was consisted to study the crack initiation in singularity zone which based to FEA to give the results, then follow the change in displacement, strain, stress and first six naturals frequencies as a function of crack propagation. In the experimental study the laminate plate specimen with two layers is tested under cyclic load in fully reversible tensile at ratio test (R=0), the damage phenomenon occur and the lifetime are presented , the fatigue testing exerted in INSTRON 8801 machine. Finally we provide the knowledge of their effect on the lifetime, this residual change of naturals frequencies parameters can be used to predicted a crack length.

9283 | CHARACTERIZATION OF FIBER REINFORCED POLYUREA COATING SYSTEM UNDER CYCLIC LOADING (25. Failure and Damage)

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This paper has been conducted to evaluate fatigue damage in polyurea as the external coating system for the reinforced concrete beams. Ease of application and multi-hazard benefits of polyurea has made it useful in retrofit-repair situations. Rather than blast and impact mitigation, polyurea has the capability of flexural and shear reinforcement for structural members. In this phase of research, large size reinforced concrete beams were fabricated and strengthen in two levels of polyurea thickness. Specimens were subjected to four-point bending testa under cyclic loading with controlled-stress mode. Based on pseudo strain concept, Schapert's nonlinear elastic-viscoelastic correspondence principle was used to evaluate mechanism of damage in polyurea coating system under repetitive loading. Two analytical predictions of relaxation modulus were represented to calculate pseudo strain in polyurea coating by using available creep compliance test data. Results presented in this paper indicated that when cyclic load amplitude is low, pseudo strain concept remove hysteretic behavior and provides linear relationship between pseudo strain and tensile stress in polyurea. It is concluded that correspondence principle represent an accurate model for damage growth and fracture healing of external polyurea coating under fatigue loading.

9284 | Damage tolerance in aluminum plates repaired with composite patch: A numerical study (25. Failure and Damage)

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The traditional repair method for cracked aircraft structure is fastening metal reinforcement using bolts and rivets. This method makes worse the stress concentration problem due to drilling of additional fastener hole. In addition, the application of metal reinforcement changes the stress distribution of repair area and causes the stress concentration along the neighborhood of repair. However, externally bonded composites patches have proved to be an effective method of repairing cracks or defects in aircraft structures. [1–6]. The adhesively bonded composite repairs cause minimum stress concentration and alter the load path that induce efficient load transfer from cracked structure to reinforcement [7]. Thus, the reduction of stress intensity factor caused by bonded patch repair prevents or retard crack re-initiation or further growth. Improvements in durability and damage tolerance have been also demonstrated through this technology. Adhesively bonded composite patch repair technique has been expanded its application to the repair of load bearing primary structure from secondary structure repair. Therefore, a through understanding of crack growth behavior of thick panel repaired with bonded composite patch is needed. In this study, the fatigue crack growth behaviour of cracked aluminum plate repaired with bonded composite patch in plates with different thickness was investigated. Adhesively bonded composite patch repairs have been successfully applied to military aircraft and to commercial aircraft industry recently. Also this technique has been expanded its application to the repair of load bearing primary structure from secondary structure repair. For that reason, a through understanding of crack growth behaviour of thick panel repaired with bonded composite patch is needed. The fatigue crack growth behaviour of aluminium panels repaired with bonded composite patch were investigated by using the codes Zencrack in combination with Abaqus which enable the user to determine the crucial fracture mechanics parameters such as: stress intensity factors. Furthermore, a damage model has been implemented for the adhesive in order to understand the consequence of the adhesive failure on crack propagation in the aluminium plate by means of coupled fracture-damage mechanics simulations. Effect of the thermal residual stresses induced during the curing processes was also considered. The aim of this investigation is to provide a reliable numerical tool to achieve the most favorable design. In fact, a new subroutine has been introduced in order to allow the users to add the patch during the analysis at, well defined (or even random) lengths of the crack. Two types of crack shapes (namely: wall-through and corner crack) and several loading conditions have been analyzed to assess the reliability of the patch repair. The results obtained from the computational analyses have been compared with experimental results available in the literature.

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9385 | Modeling of Delamination in Composites Curved Parts (25. Failure and Damage)

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Composite materials are incorporated into complex geometries and curved parts instead of metallic materials with the recent advanced manufacturing technologies. Rib and spar flanges of wing and spar sections of wind turbine blades are among the applications of load carrying metallic structures replaced with curved composite parts.

Angle brackets, such as the types explored within this paper, exhibit weakness around the radius due to excessive through-the-thickness tensile stresses which can lead to delamination. While most layered composites are designed to have superior in-plane stiffness and strength, they are often not as strong when they are subjected to interlaminar stresses. This paper will analyze the threshold of delamination of unsymmetric cross ply [0n/90n] angle brackets, which will be subjected to 4-point bend loading, in order to evaluate the through-the-thickness tensile stresses around the radius. The use of unsymmetric cross ply laminates will increase the magnitude of the interlaminar stresses around the radius, generating a quite interesting case study for delamination. Different beam thicknesses and widths will be analyzed. Finally, model results will be correlated with test data and various delamination criteria will be analyzed.

6344 | Thermally Conductive Polymer Composites with Continuous Cu Thermal Dissipation Pathway (26. Thermal problems on Composite structures)

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Thermal management of polymeric composites is a crucial issue to determine the performance and reliability of the devices. We demonstrate two facile and straightforward approaches to produce thermally conductive polymer composites with continuous heat dissipation pathway of Cu. In the 1st particulate approach, the polymeric composites were created by the Cu metallization of PS bead and the hot press molding of Cu-plated PS beads. The unique three-dimensional Cu shell-networks in the PS matrix demonstrated isotropic and ideal conductive performance at even extremely low Cu contents. In contrast to the conventional Cu beads/PS composites at 23 vol %, the PS composites with Cu shell networks revealed 60 times larger thermal conductivity. In the 2nd fiber approach, copper shells on carbon fibers were coated through electroplating method and post-treated via RTA technique to reduce the degree of imperfection in the Cu crystal. A PAN-based carbon fiber fabric was used as a template to form continuous Cu heat conduction pathway in the composites even at very low Cu content. The epoxy/Cu-plated carbon fiber composites with Cu shell of 12.0 vol% revealed 18 times larger thermal conductivity than epoxy/carbon fiber composite. Our facile route offers a straightforward strategy for achieving the efficient thermal conductive polymeric composites by the introduction of continuous, percolated metal thin layers as an efficient conduction pathway.

7569 | Thermomechanical behavior of aeronautical structural carbon epoxy composite submitted to a laser irradiation (26. Thermal problems on Composite structures)

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Thermomechanical behavior of aeronautical structural carbon epoxy composite submitted to a laser irradiation
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In the frame of a study on aeronautic composite structures submitted to laser irradiation, we have assessed the thermo mechanical behavior of carbon epoxy composite.
Our samples were submitted with few seconds continuous laser irradiation at a wavelength of 1.07 μm. At such a wavelength the matrix is optically transparent but carbon fibers absorb the energy of the laser beam at the surface. The carbon fibers withstand ~1 kW/cm² power density but the matrix is completely burned. At higher power densities, an ablation of the fibers is observed. We have experimentally measured the irradiated surface temperature and the backside temperature of our samples during a 1.07 μm wavelength laser continuous illumination with a power density in the range of 0.1 to 2 kW/cm². The thermal transfer inside the material has also been characterized.
For an illumination with intensities lower than 1 kW/cm² we have measured a weak dependence of the front side temperature with the power density. Such weak influence of the laser intensity is due to the exothermic degradation of the matrix which provides during the laser illumination a power density in the range of 200 W/cm² similar to the laser flux. With a higher power density we observed a stabilization of the front side temperature around 3500 K.
The thermal front propagation was also observed with a specific set-up based on an infrared camera equipped with a macroscopic objective observing the lateral face of a sample during the laser irradiation. The behavior of the matrix composition which included epoxy based resin and a lot of additives (i.e. plasticizer, delaying agents, and surfactants, etc.) has also featured some internal ebullition phenomena. Such ebullition has been attributed to the additives thanks to a comparative experimental study on pure epoxy resin and matrix behavior. The resin is optically semi-transparent at the laser wavelength and shows an ablative behavior. The matrix is an optically diffusive media due to the inclusions of micro bubbles of additives within the resin. These inclusions which have lower degradation temperature compared to the epoxy resin one induced an internal ebullition inside the epoxy based matrix. These internal ebullition phenomena create local overpressures speeding up the delaminating phenomena of the composite.
We have used a simple simulation model based on finite elements which allow us to study the thermal behavior of the interaction between a laser beam and carbon epoxy composite. Our model uses two phases, burnt or unburnt materials, which have been experimentally characterized in terms of density, thermal conductivity, mass losses, thermal capacity and enthalpy of degradation.
In parallel, we have studied the thermo-mechanical behavior of our samples. Based on simple cantilever mechanical tests, we have measured the Young's modulus factor of our samples during a laser illumination. We have demonstrated a simple linear dependence of the mechanical degradation of carbon epoxy composite material and the laser deposed energy.
Such laser irradiation experiments can be used to assess the mechanical resistance of a composite structure exposed to a fire.

7830 | Investigation of the thermal effects on the dynamic properties of polymer concrete in curing process (26. Thermal problems on Composite structures)

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The purpose of this study is to measure damping of polymer concretes by increasing the curing temperature. The polymer concretes consisted of epoxy monomer, hardener and aggregates. The polymer concrete specimens were made by changing the curing temperature. Curing time was monitored using a dielectric sensor. The dynamic properties of the polymer concrete specimens were measured by using beam-transfer function method. The influences of the mixing ratio of epoxy resin and aggregates were investigated with different curing temperatures. To identify the effects of the temperature in curing process, the viscosity of the epoxy monomer was measured. Finally, proper curing temperatures in each mixing ratio were discussed.

7891 | Temperature influence on fatigue and dynamic properties of epoxy laminate composites (26. Thermal problems on Composite structures)

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This paper presents results of epoxy laminate composites testing in fatigue and dynamic and tests, including impact test. The tests were performed in high and negative temperature. Laminates were reinforced with glass, carbon, basalt and aramid fiber mat, and was fabricated with different technologies, such as manual method and Light RTM process.

8112 | Thermo-mechanical behavior of thick-walled laminated tubes used in High Voltage applications (26. Thermal problems on Composite structures)

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This paper gives a theoretical background and provides numerical calculations for the analysis of the thermo-mechanical behavior of thick-walled cylinders. The multi-layered composite tubes are frequently used in the High Voltage industry as vital components of the circuit breaker technology, since they provide high-pressure resistance and offer good thermal and electrical insulation properties. Such as structures are formed by the epoxy resin liner, which isolates the pressurized gas from the environment, and the fiber-reinforced overwrapping to ensure superior stiffness and fatigue resistance.
The paper presents the procedure aiming to characterize the mechanical behavior of the multi-layered cylindrical components, which are exposed to the axial load, uniform pressure and high thermal gradient. The work shows that mutli-layered tubes exhibit axial-torsional coupling when the off-axis plies are present. It is especially important for electrical power applications, where high pressure of the ionized gas and the temperature change throughout the tube's wall can produce torque, axial strains, and finally may drive to the delamination of layers. The paper studies the relation between geometrical dimensions (such as layers' thickness and helical angles), coupling coefficients, and mechanical stresses. It extends the theory provided by Lakhnitskii, Pagano and Herakovitch, and delivers the practical, design-oriented suggestions for the successful development of multi-layered cylinders under thermo-mechanical load. The provided analytical model was validated by the FEM analysis showing very good agreement.

8123 | A new HSDT for the thermoelastic bending analysis of laminated plates (26. Thermal problems on Composite structures)

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This paper presents a thermoelastic bending analysis of laminated composite plates by using a new higher-order shear deformation theory. This formulation contains only 5 unknowns as the first order shear deformation theory, which is a less number compared with other known higher-order shear deformation theories with stretching effect. The nonlinear term of the temperature field is independent of the shape functions of the displacement field. The governing equations for thermoelastic bending analysis are derived by employing the principle of virtual works. These equations are then solved via Navier-type, closed form solutions. The accuracy of the present theory is ascertained by comparing it with various available solutions in the literature.

8125 | Comparative study on thin and thick walled cylinder models subjected to thermo-mechanical loading (26. Thermal problems on Composite structures)

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The mechanical behavior of the pressurized steel vessels or cylinders made of the homogenous material is very well elaborated. The literature provides the thick wall model based on Lamé theory, which covers the principle stresses in all three directions, and the thin wall model, neglecting the radial stresses. Normally, it is assumed that if the r/t ratio between tube's radius and the wall thickness is more than 10, the radial stresses are an order of magnitude smaller than the remaining stress components, thus the simplified, thin wall model could be successfully applied. The error can be further reduced if the middle radius is used instead of the internal one. This simple approach may not work however, if the composite cylinder is considered. In this case, the stress components are not related directly to the r/t ratio, but are associated with the layers' material properties (which may be different for various plies), as well as their geometrical dimensions (thicknesses and fiber orientations) and the load types. For this reason, it is frequently accepted that the r/t ratio cannot be treated as the only factor allowing to select the appropriate calculation model.
This paper recalls the thin and thick wall theories for laminated tubes, and provides the parametric study allowing to estimate the difference between models for various geometrical, material and load settings. The axial forces, uniform pressure and thermal gradients were considered during the study. The generalization of the achieved results allowed to propose a new criterion for proper model selection, which incorporates simple forms of geometrical, stiffness and load factors. Thanks to the applied approach the estimation of the radial stress importance is now possible for laminated cylinders subjected to complex loading.

8126 | A new quasi-3D HSDT for the thermoelastic bending analysis of laminated plates (26. Thermal problems on Composite structures)

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This paper presents a thermoelastic bending analysis of laminated composite plates by using a new quasi-3D HSDT. This formulation contains only 5 unknowns as the first order shear deformation theory, which is a less number compared with other known higher-order shear deformation theories with stretching effect. The nonlinear term of the temperature field is independent of the shape functions of the displacement field. The governing equations for thermoelastic bending analysis are derived by employing the principle of virtual works. These equations are then solved via Navier-type, closed form solutions. The accuracy of the present theory is ascertained by comparing it with various available solutions in the literature.

8150 | Thermo-Mechanical analysis of the FRP strengthened masonry wall substance coated with PCM plastering mortar (26. Thermal problems on Composite structures)

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Composite materials such as Fiber Reinforced Polymers (FRPs) have become popular during the last years for externally bonded reinforcement of masonry structures. These materials have several advantages such as light weight and ease of application which have made them interesting in rehabilitation projects. The efficiency of FRPs in improvement the performance of masonry structure has also been proved in several experimental and numerical studies. However, recent studies have shown that the thermal incompatibility between the FRPs and masonry substrates can lead to FRP delaminations and bond degradation during the service life of the structure.
This paper presents the results of a comprehensive thermo-mechanical numerical study on the thermal incompatibility problem in FRP-strengthened masonry components. A set of parametric studies have been performed on the effect of thermal cycles on different masonry walls strengthened with CFRP and GFRP composites. The effect of renderings on protection of the strengthened system against thermal variations has also been investigated. Two types of rendering mortars are considered in the analysis. The first mortar is a normal cement based plaster mortar and the second one is a mortar incorporated with phase change materials (PCM) material. Several studies have proven the thermal energy capturing associated to the incorporation of phase change materials (PCM) into plastering mortars for application in buildings, in view of thermal regulations. However, its effect in protection of these strengthening systems against thermal incompatibilities remain an open issue.

Keywords: Masonry wall; Composite materials; Shear strengthening; plastering mortar, phase change materials (PCM).

8151 | Experimental assessment of light weight aggregate composites impregnated with phase change materials for pavement structure applications **(26. Thermal problems on Composite structures)**

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Phase changing composites for thermal energy storage were made of porous materials (light weight aggregates), coating materials (waterproofing solutions) and organic phase changing materials (paraffin PCMs) by means of impregnation method.
This research work aimed experimental investigation of the composite materials with the goal of highlighting behavioral differences in regard to the composites without PCM. For that purpose three mortars were built: one with recourse to conventional mortar; and two with PCM. Each of mortars was coated on the surface of the pavement layer (made of grouted macadam that considered as a bottom layer). Three samples were monitored when subjected to freezing temperature profile, in order to understand the effect of the PCM incorporation.
Experimental studies on the impregnation method, characterization of the distinct material and thermal performance of the composites arrived in the following conclusions.
The impregnation method is effective in loading porous materials with phase changing materials; and it's simple procedure. This paper confirmed that, the organic phase changing materials and inorganic porous materials are suitable materials for the phase changing composites with respect to large thermal energy storage density and feasibility of incorporation. The results indicate that additional of PCM composites improves the thermal inertia as well as delayed freezing in the pavement layer. This technique may help to extend the service life of pavement structure, by reducing freeze/thaw damage through the incorporation of phase change materials (PCMs). However, it should be stressed that the development of PCM composites is still in its infancy, and there are many questions that will need to be answered in the future before such composites are ready for real-world applications. This research will help to serve as part of a foundation for such studies.

Keywords: phase change materials (PCMs), light weight aggregates (LWAs), composites, Freeze/thaw test, drying test, desorbing test.

8169 | An experimental study on bond strength of circular concrete-filled steel tube at elevated temperature **(26. Thermal problems on Composite structures)**

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This paper presents results from an experimental study on the effect of temperature on bond strength of circular concrete-filled steel tubes (CCFTs) in the absence of shear connectors. In CCFTs, the confinement effect from steel tube increases concrete compressive strength, and the core concrete restrains the local buckling of steel tube. To attain this beneficial composite action, bond stress plays a critical role in it. However, there is a lack of knowledge to account for the bond stress while CCFTs under fire attack. To examine the bond stress characteristic in CFTs, the push-out tests have been carried out on 15 CCFTs in the fire condition. The CCFTs specimens, made of different strength of steel tubes and dimensions, have been tested to evaluate bond strength in 30 - 600oC temperature range. Based on the results of push-out tests, it is shown that CCFTs possess negligible bond strength beyond 300 oC. The bond strength decreases significantly in 100–600oC temperature range, and only retain 40%, 15% and 5% of their original values at 100, 300 and 600 oC, respectively. The results from push-out tests also indicate that CCFTs exhibit similar bond stress–slip response at both room and high temperatures. Data from the tests is utilized to propose empirical relations for variation of bond strength of CCFT with temperature.

8207 | High temperature effect on impact behavior of sandwich wall boards with GFRP face sheets and a foam-web core **(26. Thermal problems on Composite structures)**

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In this paper, the impact behavior of sandwich wall panels with GFRP face sheets and a foam-web core at several temperatures (20oC, 50 oC and 80oC) was studied experimentally. Impact tests were performed by a drop weight instrumented impact tower. Sandwich wall boards were impacted at varied impact energies ranging from 20 J to 60 J. Variation of the impact responses such as maximum contact load and deflection, contact time and absorbed energy versus impact energy are summarized. The test results demonstrated that the ambient temperature significantly affects the impact behavior of sandwich wall panels. Furthermore, compression-after impact behavior of sandwich wall panels were also investigated at room temperature. Compared to an undamaged sandwich wall panel, the residual compressive strengths of damaged wall boards decreased sharply, which were less than half of the original strength.

8551 | DETERMINATION OF OPTIMUM INSULATION THICKNESS IN BUILDINGS WITH USING DIFFERENT TYPES OF INSULATION MATERIALS IN ÇORUM CITY (26. Thermal problems on Composite structures)

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DETERMINATION OF OPTIMUM INSULATION THICKNESS IN BUILDINGS WITH USING DIFFERENT TYPES OF INSULATION MATERIALS IN ÇORUM CITY

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ABSTRACT

The aim of the study is to investigate the optimum insulation thickness of the seven buildings insulated in recent years with using different types of insulation materials and wall types in Çorum city. Stone wool, expanded polystyrene (EPS) including Neopor and standard EPS with having different thermal conductivities were carried out as insulation materials, while natural gas was used as fuel. The annual heating requirement was based on heating degree-days (HDD) by considering the average of six years. In addition to this, the costs of the insulation materials used and energy, efficiency of the heating system, the lifetime, the current inflation and discount rates were evaluated in the determination of optimum insulation thickness. It was found that optimum insulation thickness of seven buildings insulated with thickness of among 3 cm and 6 cm varied around 7-12 cm depending on the wall structure and insulation cost for stone wool, Neopor and standard expanded polystyrene with the usage of natural gas. Two different types of composite wall structure appeared in these buildings. One of these consisted of inner plaster, hollow brick, insulation material, outer plaster and other one included inner plaster, pumice stone, insulation material , outer plaster. Moreover, one of the seven buildings was chosen as sample building and application of expanded polystyrene(Neopor with the thermal conductivity of 0.033W/mK) , extruded polystyrene and stone wool to sample building gave optimum insulation thicknesses 10.61 cm, 7.88 cm and 7.15 cm with using natural gas as fuel respectively.
Keywords: optimum insulation thickness, insulation materials, fuel, energy saving

INTRODUCTION

Energy demand increases in worldwide due to fast population growth (1). Energy consumption must be minimized because of the limited energy sources and energy saving has to be the most significant strategy of the countries(2). Energy can be saved more efficiently with sharing the renewable sources to obtain the living standard in industrialized countries and to increase the situation in developing countries.(3,4).
Generally, four main sectors including industrial, building, transportation and agriculture can be considered for energy consumption(5). Heating and cooling energy requirement of a building is approximately 60% of the total energy consumed in buildings [6–7]. For this reason, thermal insulation of external walls in buildings seems as an indispensable solution for energy saving.

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8604 | THERMO-VISCOELASTIC ANALYSIS OF GLARE (26. Thermal problems on Composite structures)

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In recent years, extensive work is done on design aspects of Fibre metal laminates (FMLs) like fatigue, crack propagation, residual strength, etc. However, the viscoelastic response of FMLs are not studied yet. Integrated fuselage panels made of FMLs exhibit stress relaxation in thermal processes like the cure cycles. Curing is used for making the laminates from prepreg layers and Aluminium sheets or for adding reinforcements (doublers and stringers) to the already cured laminates. The thermo-viscoelastic response of the material contributes to the generated residual stresses and shape deviations after manufacturing. The shape deviations during assembly need to be minimised, since the residual stresses produced in manufacturing and assembly influence the mechanical performance regarding the load capacity, fatigue life, residual strength and damage tolerance of the component. Accordingly, a

predictive model is needed to adapt the mould to produce accurate integrated panels from glass fibre reinforced aluminium laminates (GLARE).
In the first phase, primary modelling and experiments on FMLs with non-symmetric lay-up of prepreg layers were performed from which the results are already published in previous papers[1,2]. The research methodology was also presented in ECCM16[3].
Epoxy FM-94 used in prepreg layers of GLARE, has a temperature dependent and viscoelastic response in aging and thermal environments. For the purpose of predicting the residual stresses after cure cycles of GLARE panels, the material properties of the constituents were needed to be determined. Some material characterization procedures have been followed. Thermo-Mechanical Analysis (TMA) is carried out on the epoxy material (FM-94) to find the glass transition and thermal expansion properties. Time/temperature dependency of the stiffness parameters are determined using Dynamic-Mechanical Analysis (DMA). Accordingly, the thermo-elastic and thermo-viscoelastic response of the epoxy adhesive part of GLARE was determined. In order to get the response for unidirectional fibre-epoxy composite (prepreg), self-consistent micromechanics equations are used in the Carson domain. Thermo-viscoelastic response of the composite layer is obtained in the time domain with an inverse transform which can be used in the analysis of residual stresses of GLARE and also the response to thermo-mechanical loadings.
Shrinkage occurs in all GLARE constituents during the cool down process and the time-temperature dependent response of the prepreg layer should be considered in the analysis. The residual stresses and distortions of GLARE panels are predicted after curing using the developed thermo-viscoelastic model. Some panels with non-symmetric layups are manufactured and the resulting curvatures are measured (Figure 1) using digital image correlation (DIC). With comparing the model predictions to the measurements, the modelling accuracy is observed and the prediction improvement due to considering the stress relaxation of the material is evaluated. The derived time-temperature dependent response of the prepreg layer can also be used in the prediction of the material responses in other long-term applications and/or thermal environments.

Figure 1: Warpage of a non-symmetric GLARE after cure measured by DIC (layup: Al-0/0/0-Al-90/90/90-Al , dimensions: 98×22 cm2)

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8618 | The Sound Absorption and Thermal Insulation of Fiber-Reinforced Thermoplastic Composites (26. Thermal problems on Composite structures)

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The thermoplastic composites are very popular constructional materials because of their easy secondary processing, possibility of utilization, attractive price and mechanical properties comparable to hardening plastics composites. Depending on application, the physical and mechanical properties of thermoplastic composites should be appropriate. The wide range of thermoplastic composites is closely connected with the variety of components and the diversity of the structures obtained.
In this study the thermoplastic composites reinforced by different fibers were designed as the sound and thermal insulating material destined for motorcars. The influence of a kind of reinforcing and matrix fibers on sound absorption coefficient and thermal insulation was determined.
Two kinds of fibers were used to obtain composites. As a material for composite matrix polylactide or polypropylene fibers were used. As the reinforcement viscose or waste cotton fibers characterized by the destruction point at 174 - 190C were used.
In order to obtain a the composites the multilayer system of hybrid nonwoven was pressed. Each kind of nonwoven consisted of reinforcing Vi or CO fibers and matrix PLA or PP fibers.
Depending on the mass per square meter of the given nonwoven, the number of its layers in the package was appropriately selected.
The acoustic properties of composites were measured by means of a small-sized impedance tube type 4206 (Brüel&Kjaer, Denmark) using two ¼-inch Condenser Microphones Type 4187.
The investigations of thermal insulating properties of composite samples were carried out using the registration of infrared radiation of the material after heating by infrared camera FLIR SC 5500.
The comparison of the results of sound absorption coefficient with the results of the temperature difference between outside surface of composite and heating plate surface shows, that the composites characterized by higher sound absorption are also characterized by higher thermal insulating properties. This fact is important for composite application as a sound and heat insulating material e.g. in automobiles or room walls.
It was obtained that the blend of polypropylene and cotton fibers is the best material for production of sound absorbing and heat insulating thermoplastic composites.

8635 | Application of Kubelka-Munk-Theory in the heating process of thermoplastic polymer matrix composites (26. Thermal problems on Composite structures)

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Key Words: thermoplastic polymer matrix composite, Kubelka-Munk-Theory , heat source, infrared irradiation;.

Composites with thermoplastic matrices show favourable material properties and offer remarkable advantages in terms of processing [1]. Especially good forming properties and high design freedom make them particularly relevant for cost-effective manufacturing. Typically high-performance consolidated composite sheets (precursors), where woven fabrics are used as reinforcement are heated up by infrared radiation ensuring short heating times until the matrix melting temperature is reached [2]. Then the sheet is transferred from the heating station into the tool, where it will be formed in function of its future application. The process efficiency depends on the time interval which is necessary for heating up the composite sheet. Consequently, it is of high interest to predict the heating behaviour of infrared irradiated composite sheets. Heating rates are depending on the material's property (matrix and fiber

combination) used, sheet thickness and radiator system. Especially the combination of material and radiator system, i.e. wavelength of the emitter, influences the penetration depth of the radiation into the material and further controls the heating time of the composite.
The challenge in modelling the heating behaviour of composite sheets is the material and radiator dependent optical depth where the photonic wave is transformed into a thermal wave and a heat source is generated. Due to the heterogeneous material, reflectance of the photonic irradiated wave takes place, especially at fiber- matrix interfaces and therefore scattering phenomena are involved. In the current work the authors apply Kubelka-Munk Theory [3,4] for describing the optical characteristics of the composite and solve the radiation problem with finite difference method. Kubelka-Munk has been calibrated with experimental data obtained by infrared flash experiments and compared with simulations made by using Beer-Lambert Law. Kubelka Munk model is implemented in Abaqus. It will be shown that the simulation approach is able to describe the thermal wave generation in a transition layer and consequently the infrared heating behaviour of thermoplastic composite sheets for various sheet thicknesses can be predicted.

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8662 | Influence of different type of carbon filler on structure, mechanical and thermal properties of rigid polyurethane foam (26. Thermal problems on Composite structures)

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"Influence of different type of carbon filler on structure, mechanical and thermal properties of rigid polyurethane foam"
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Rigid polyurethane foam feature low weight, porous structure and high density of cross links. Due to their properties they are very promising for structural applications. The major drawback of these polymers is flammability. During their decomposition toxic gases are emitted. To improve their properties different type of filler are used. The aim of this work was to reduce flammability while improving strength. To achieve the objective different types carbon filler were applied and their impact on structure, mechanical and thermal properties of rigid polyurethane foam was evaluated.
In this study, we used polyurethane system supplied by BASF, multi walled carbon nanotubes supplied by Nanocyl and graphite supplied by GRAFITBERGBAU KAISERSBERG G.m.b.H. Nanotubes were dispersed in polyol by three roll milling, graphite was mixed with polyol by mechanical stirring. For structure control of foam and their composites, scanning electron microscopy and X-ray computer tomography were utilized. Mechanical properties were determined by three point bending test. Thermogravimetry analysis was made for thermal stability evaluation. Limiting oxygen index and smoke density were also measured.
The results revealed that addition of graphite significantly improve fire resistance of foam, however it bring also a decrease in mechanical properties. Carbon nanotubes influence the foam structure, i.e. they change porosity degree and pore size. They, if in small weight amount, improve the bending strength and just slightly increase LOI and reduce smoke density.

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9044 | Evolution of ultra-fine TiC-inclusions in TiC-NiCr cermet powders synthesized at different volume content of binder and high-energy impacts (26. Thermal problems on Composite structures)

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The use, in thermal spraying and, in particular, plasma spraying of composite powders with particles formed by very hard inclusions in a metal alloy matrix presents a promising strategy in synthesis of wear- and corrosion resistant coatings. At present spraying of cermet powders WC-Me (Me=Co, CoCr, etc.) with the help of HVOF became widely spread. But, usage of such powders in plasma spraying is very problematic due to tungsten carbide degradation

(WC→W2C→W) at increased temperatures. At the same time, great prospects open when using the tungsten-free cermet powders (TiC-Ni, TiC-NiCr, etc.) for plasma spraying of wear- and corrosion resistant coatings as compound of titanium carbide is stable up to its melting point.
One of the main characteristics of cermet powder is the dispersion of their internal structure at specific volume content of the highly rigid components, which in many aspects determines the properties of the cermet coatings and their service life. The increase in structural dispersion results in an increase in such key properties of coatings as hardness, impact elasticity, wear- and corrosion resistance, and hardness. The increase of dispersion of the highly hard component of the cermet composite down to submicron-scale and nano-scale levels is a promising direction in the development of long-service life ceramic-metal coatings operated under extreme conditions. The conventional powder metallurgy methods (mechanical grinding, mixing and sintering under free or isostatic conditions, etc.) do not enable one to attain the above dispersion parameters due to many technological limitations, including high power consumption of respective technological processes.
Greater prospects at production of the composite powders open when using the self-propagating high-temperature synthesis (SHS) initiated in mechanically activated powders component, uniformly mixed with inert powder of given volume content. Synthesis of cermet powder for thermal spraying is possible both in a free mode of combustion of powder composition of initial elements, and in the mode of combustion under simultaneous dynamic loading. The final powder is obtained by subsequent mechanical grinding of synthesized compact and sizing.
In the present work it is shown that increase in dispersion of structure of cermet, synthesized both in free mode, and under pressure, other things being equal, is provided due to acceleration of reaction of titanium carbides high-temperature synthesis in the original powder composition of titanium with carbon and metal binder. The latter is reached by the preliminary mechanical activation (MA) of metal components of the original powder composition. For the first time the influence of volume ratio of the inert component (NiCr) on the evolution of the TiC inclusions size distribution in the TiC-NiCr cermets synthesized both in the free mode of combustion, and under pressure is studied.

9122 | Effect of Epoxy Structures on Thermal Conductivities of Liquid Crystalline Epoxy/Alumina Composites (26. Thermal problems on Composite structures)

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Various epoxies (two commercial epoxies, bisphenol Adiglycidyl ether (DGEBA) and 3,3',5,5'-tetramethyl-4,4'-biphenol diglycidyl ether (TMBP), and a series of synthesized liquid crystalline epoxies (LCE), typically 4,4'-bis(4-hydroxybenzylidene)-diaminophenylenediglycidyl ether (LCE-DP) and other LCEs) and 4,4'-diaminodiphenylsulfone (DDS) were employed as a base epoxy resin and a curing agent, respectively, to investigate the effect of backbone structure of epoxy on the thermal conductivity of epoxy/alumina composite. Alumina (Al2O3) of commercial source was applied as an inorganic filler. The DGEBA structure has an amorphous state and the TMBP structure shows a crystal phase. On the other hand, LCE-DP structure exhibits a liquid crystalline phase. The curing behaviors and thermal conductivities are very dependent on the molecular structure of epoxies. The heat of curing of epoxy resin was measured with dynamic differential scanning calorimetry (DSC). Thermal conductivity was measured by a laser flash method and the experimental values are compared with values predicted by theoretical models. It was found that the thermal conductivity of the LCE-DP structure was higher than that of the commercial epoxy such asTMBP and DGEBA and the experimental data fits well with values predicted theoretically.

9199 | The Effect of Temperature on Mechanical Properties of Carbon/Epoxy Composites (26. Thermal problems on Composite structures)

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This paper reports an experimental study for evaluating the effect of the temperature on mechanical properties of carbon/epoxy composites. Temperature environments were simulated to have a range of -40°C from 220°C using environmental chamber and furnace. The effect of temperature on mechanical properties of composites was measured for longitudinal and transverse tensile properties, in-plane shear properties and interlaminar shear strength. For low temperature, all mechanical properties were increased compared to properties of room temperature. The longitudinal tensile properties were moderately decreased with the increase of temperature. However, transverse tensile, in-plane shear properties and interlaminar shear strength showed a significant drop due to phase transformation behavior of the matrix after 140°C. Unusually, the value of tensile property near 100°C was increased compared to baseline property. This behavior was a direct result of postcuring of the epoxy resin due to exposure to high temperature.

9466 | Thermal shock crack patterns modeling and explanation (26. Thermal problems on Composite structures)

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A finite element based numerical model was developed and applied to simulate the thermal cracking behavior of brittle solids subjected to thermal shock. The heterogeneity of brittle solids at the mesoscopic level is modeled by the Weibull distribution method. Furthermore, the constitutive law of the meso-element is defined by using continuum damage mechanics to describe its mechanical (crack) behavior. The finite element method is used to analyze thermal stress, and the maximum tensile stress criterion is used as damage thresholds. The cracking behavior, including random initiation and propagation of microcracks, and the formation of more or less equal spaced surface cracks, are well represented and captured by this numerical model. Furthermore, the effect of thermal conductivity on cracking pattern is also discussed. Simulation results are consistent with observations from experimental tests. The physically realistic crack patterns obtained from these numerical simulations in this study clearly indicate that the proposed model is potentially a very useful tool to study cracking behavior of brittle solids subjected to thermal shock.

7540 | Finite element modeling of carbon nanotube agglomeration in polymers (27. Modeling Nano Composites)

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It has been confirmed from numerous experimental works that agglomeration is a critical manufacturing parameter that counterbalances the efficiency of carbon nanotube (CNT) reinforcement of polymers. As intensive research to improve manufacturing performance is evolving, the development of models

capable to simulate the effect of CNT agglomeration is of great importance. In this paper, a finite element (FE) model of a CNT agglomerate was developed. The geometry modeled belongs to a cubic representative volume element (RVE) which consists of the CNT agglomerate surrounded by the matrix. Initially, the geometry of the RVE is created using the TexGen geometrical processor, which has enhanced capabilities in modeling waved fiber-shaped entities as it is used for modeling textile composites, and then, transferred into the ANSYS FE code. The CNTs and the matrix are modeled using solid elements. By loading the RVE at different axes and planes and applying periodic boundary conditions the effective elastic properties of the CNT/polymer composite are derived. The parameters considered in the FE model of the agglomerate are: number of CNTs, CNTs' diameter and length and waviness amplitude. Using the RVE, a parametric study on the effect of these parameters on the effective elastic properties of CNT/polypropylene composite was performed.

7618 | Study on splaying phenomenon in the electrospinning nanoporous fibers process (27. Modeling Nano Composites)

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Electrospinning provide a straightforward method to produce ultrafine fibers, where electrostatic forces on a charged polymer jet elongate it into thin fibers before solidification. Charge is induced on the liquid surface by an electric field, mutual charge repulsion causes a force directly opposite to the surface tension. As the jet accelerates and thins in the electric field, radial charge repulsion results in splitting of the primary jet into multiple filaments.
In the electrospinning nanoporous fibers process, radial charge repulsion results in splitting of the primary jet into two filaments as the jet accelerates and thins in the electric field, we call this phenomenon as splaying. The "splaying" phenomenon has been observed by scanning electron microscopy (SEM). And the theory of fluid hydrodynamics is used to theoretically study this phenomenon. The experimental data correspond well to the results obtained by applying theoretical analysis. The results offer in-depth physical understanding and show that the surface of fibers exhibits many isolated pores which are oval in shape and elongated in the direction of fiber axis, and the ratio of pore width to pore length is varied along with the variation of the internal pressure of the jet. In addition, a simplifying gas-liquid two-phase flow model was established in order to research the formation mechanism of electrospun porous nanofiber. Based on the model, the effects of various spinning parameters on quality of product, such as the number of nanopores and diameter, will be systematically carried out.

7817 | PREDICTING FRACTURE BEHAVIOR IN NANO-GRAPHENE REINFORCED POLYMERS (27. Modeling Nano Composites)

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The nano-scale interaction between polymer molecules and nanoparticle is a key factor in determining the macro-scale strength of the composite. In recent years numerous efforts have been directed towards modeling nanocomposites in order to better understand the reasons behind the enhancement of mechanical properties, even by the slight addition (a few weight percent) of nano-materials. In order to better understand the local influence of nano-particle on the mechanical properties of the composite, it is required to perform nano-scale analysis. In this context, modeling of fracture in nano-graphene reinforced EPON 862 has been discussed in the current paper. Regarding fracture in polymers, the critical value of the J-integral (JI), where the subscript I denotes the fracture mode (I=1, 2, 3), at crack initiation could be used as a suitable metric for estimating the crack driving force as well as fracture toughness of the material as the crack begins to initiate. However, for the conventional macroscale definition of the J-integral to be valid at the nanoscale, in terms of the continuum stress and displacement fields and their spatial derivatives - requires the construction of local continuum fields from discrete atomistic data, and using these data in the conventional contour integral expression for atomistic J-integral. One such methodology is proposed by Hardy [1] that allows for the local averaging necessary to obtain the definition of free energy, deformation gradient, and Piola-Kirchoff stress as fields (and divergence of fields) and not just as total system averages. Further, the atomistic J-integral takes into account the effect of reduction in J from continuum estimates due to the fact that the free energy available for crack propagation is less than the internal energy at sufficiently high temperatures when entropic contributions become significant [2,3]. In this paper, the proposed methodology is used to compute J-integral using atomistic data obtained from LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator). As a case study, the feasibility of computing the dynamic atomistic J-integral over the MD domain is evaluated for a graphene nano-platelet with a central crack using OPLS (Optimized Potentials for Liquid Simulations) potential. For model verification, the values of atomistic J-integral are compared with results from linear elastic fracture mechanics (LEFM) for isothermal crack initiation at 0 K and 300 K. Computational results related to the path-independence of the atomistic J-Integral are also presented. Further, a novel approach that circumvents the complexities of direct computation of entropic contributions is also discussed [4]. Results obtained from the bond-order based ReaxFF [5] potential for 0.1 K and 300 K are also presented, and show good agreement with the predictions. Application of the J-integral scheme for nano-graphene reinforced EPON 862 is also discussed.

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7979 | Predicting Mechanical Properties of Fuzzy Fiber (27. Modeling Nano Composites)

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A multi scale modelling procedure is developed to predict mechanical properties of fuzzy fiber consisting of a carbon fiber coated with carbon nanotubes. The developed multi-scale modelling starts from nano scale lasting to macro scale. Carbon nanotube is modelled at nanoscale and the interphase region between carbon nanotube and surrounding polymer is modelled at micro scale using cohesive zone technique. The cohesive zone is simulated using finite element modelling. The results of cohesive modelling approach for the interphase are compared with those obtained from nano-scale continuum modelling approach. For sake of simplicity the intermediate phase between carbon nanotube and surrounding polymer is conducted by developing an interface. The, carbon nanoube and developed interface is converted to the equivalent fiber. Distribution of carbon nanotubes around carbon fiber is treated as random parameters at macro scale. Thus, stochastic multi-scale modelling is conducted to obtain effective properties of investigated fuzzy fiber. The results of multi-scale modelling are compared with micromechanical rules and concentric cylinder approach. The efficiency of developed multi-scale modelling in comparison with other theoretical approaches is presented implying on importance of taking into account interphase region and random parameters.
Finally, predicted mechanical properties by multi-scale modelling are compared with available experimental measurements implying on proper modelling procedure.

8993 | Viscoplastic model analysis about the influence of Graphene Nanoplatelets in the Poly(Lactic Acid) time-dependent mechanical behaviour under hydrolytic degradation (27. Modeling Nano Composites)

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Several biodegradable polymers are used in many products with short life cycle. Important applications of these are found in the biomedical field, where biodegradable materials are applied on biomedical devices, such as suture fibres or scaffolds that temporarily replace the biomechanical functions of a biologic tissue, while it progressively regenerates its capacities. Moreover, biodegradable polymers can be applied for components of automobiles, trains and airplanes in order to obtain “green products”, following ecological recommendations and eco-design philosophies. In the case of commodity products, biodegradable plastics claim clear environmental advantages in several brief use applications, mainly in their final stage of life (waste disposal), which can clearly be evident through life cycle assessment. In some applications, a constant or dynamic load applied to the component can further reduce its life cycle due to creep or fatigue cumulative damage. Hence, the reinforcement of these polymers with graphene may enhance the mechanical properties and change the time-dependent mechanical behaviour. In this work, experimental results and calibrated viscoplastic constitutive models based on those results are presented and discussed, enabling the comparison of the time-dependent mechanical behaviour between pure polylactic acid (PLA) and PLA reinforced with 2 wt.% of graphene nanoplatelets (GNP) under hydrolytic degradation. GNP are a commercial product with similar properties to single layer graphene, but much less expensive and easily obtainable by simple and reproducible methods.
The morphology of both materials was analysed via scanning electron microscopy (SEM). From this analysis it is shown that GNP are well dispersed and embedded in PLA matrix, with completely exfoliated platelets and small agglomerates being observed. Monotonic tensile tests under different strain rates, loading-unloading cycles and relaxation tests are used to access and compare the time-dependent mechanical behaviour of both materials before and after 32 weeks of hydrolytic degradation. It was observed that after 32 weeks of degradation the mechanical properties of the composite PLA/GNP 2wt.% were more affected, comparing to pure PLA. The composite PLA/GNP 2 wt.% became more fragile than pure PLA, whereas the difference of mechanical behaviour between both materials, before hydrolytic degradation, was small. Furthermore, the material parameters of the Bergstrom-Boyce time-dependent constitutive model, which combines hyperelastic springs and viscoplastic dashpots, were calibrated based on these experimental test results. And, the influence of GNP was discussed, considering how those parameters were modified.

6933 | Free Vibration Analysis of Composite Beams with Overlapping Delaminations under Axial Compressive Load (28. Vibrations)

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Analytical solutions have been developed to study the free vibration of composite beams with two overlapping delaminations under axial compressive load. The delaminated beam is analyzed as seven interconnected Euler-Bernoulli beams using the delaminations as their boundaries. The continuity and equilibrium conditions are satisfied between the adjoining regions of the beams. The bending-extension coupling effects are also considered in the analysis. Lower and upper bounds of the natural frequencies of the delaminated beams are identified by assuming totally ‘free’ and totally ‘constrained’ deformations of the delaminated layers, respectively. The influence of the axial compressive load on the natural frequencies and mode shapes of the delaminated beams are investigated. Results show a monotonic relation between the axial compressive load and the natural frequencies of the beam, with the load significantly influencing the first vibration mode shape. Comparison with published analytical and experimental results verifies the validity of the present solutions.

7623 | Nonlocal Timoshenko beam theory for frequency analysis of nanotube with attached concentrated biomolecules and different boundary conditions (28. Vibrations)

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Carbon nanotubes (CNTs) constitute a prominent example of nanomaterials and nanostructures and possess extraordinary mechanical and physical properties, which lead to a variety of applications in many different fields as nano-oscillators, nanoelectronics, nanocomposites and nanosensors. Several investigations have shown that CNTs possess extraordinary strength, as well as superior electrical and thermal conductivities. Moreover, such outstanding properties make CNTs promising candidates for resolution mass sensor and several studies have investigated the use of CNTs as a mass sensor [1-4]. Several researchers implemented continuum models to study the vibrational behavior of CNT-based mass sensor to avoid the difficulties encountered during experimental characterization of nanotubes as well as the time-consuming nature of computational atomistic simulations. Although the classical continuum methods are efficient in performing mechanical analysis of CNTs, their applicability to identify the small-scale effects on carbon nanotubes

mechanical behaviours is questionable. At this point, the non-local elastic continuum models are more pertinent in predicting the structural behavior of nanotubes because of being capable of taking in the small-scale effects.
Nanosensors are simple engineering devices designed to detect and convey informations about nanoparticles and biomolecules. The nanosized mass sensors are based on the fact that the resonant frequency is sensitive to the resonator and the attached mass. The change of the attached mass on the resonator causes the resonant frequency to deviate from its original value. The key challenge in mass detection is in quantifying the changes in the resonant frequencies due to the added masses. Recently, mass detection based on the resonating nanomechanical tools has been subject of growing interests. Along this line, several authors have performed the frequency analysis of CNT-based mass sensors, using the nonlocal Euler-Bernoulli beam theory [1-2] and nonlocal Timoshenko beam theory [3-4].
The present note deals with the dynamic analysis, based on the nonlocal Timoshenko theory, of the single-walled carbon nanotube (SWCNT) bounded at the ends, with translational and rotational elastic constraints, and attached mass, located in a generic position. Closed-form non local frequency expression is derived; the natural frequencies are calculated and numerical results for different boundary conditions are performed.

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7627 | Determining of Characteristics of Susbsystems of Mechatronic System by Exact and Approximate Methods and Their Correction (28. Vibrations)

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The main aim of this paper is to compare the transients of characteristics of the discrete –continuous mechatronic system obtained by exact and approximate methods torsional vibrating complex mechanical subsystems and to answer to the question – if the method can be used to nominate the characteristics of mechatronic systems.
The mechatronic system composed from many mechanical subsystems having the same length and variable cross section, loaded by the focused moment was analysed. Two cases of attachment the complex system: free and one side strengthen where examined. The main subject of deliberation was to determine the flexibility of the mechanic system with constant cross section using the exact and approximate methods. Next the method comparison and the correction of approximate method where made. As far as the mechatronic system flexibility determinations concerned the approximate methods has been chosen. Two cases of attachment the systems were considered. The research of subsystems establishes the foundation to complex systems analysis with cascade structure.
Analysing the diagrams of characteristics of confirmed system it has been determined that in case of approximate method the resonance frequencies cover with those which have been determined with exact method. However the values of the characteristic in other areas are different. Therefore there is the mistake of approximate method, which in case of studying the single systems does not have any influence because in resonance areas the characteristic values of the system approach to the infinity. However the difference in values of flexibility within two methods has the great influence on the result of complex systems. That is why it was necessary to correct the results of approximate method.
The characteristic of the elementary subsystems using the approximate and approximate methods has been determined according to accepted frequencies and the correction coefficient. The frequencies where chosen from the spectrum in which the synthesis of complex systems will be conducted. It is very important that the difference of flexibility values in the spectrum was minimal. The coefficient of the correction has been determined according to the flexibility values of chosen points and it is equal to quotient of flexibility calculated using the exact method across the flexibility delivered by using the approximate method. The coefficient of the correction is the zero-dimensional quantity. After determination of the correction coefficient the medium value has been calculated which has been afterwards considered in correlation of dynamic characteristics.
The problems presented in this paper, that means the analysis of mechatronic and mechanic complex systems is however the introduction to the synthesis of torsional vibrating mechatronic systems with assumed frequency spectrum.

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7657 | Dynamic Characterization of a Composite Concrete/GFRP Slab (28. Vibrations)

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In the last decades there was a great advance on the application of new materials to Civil structures, among which fiber reinforced polymer (FRP) materials stand out. Initially the FRP have been used to strengthen deteriorate structures, but more recently they are also being utilized in the construction of new structural systems. Innovative systems that combine concrete with FRP materials have been mainly employed in bridge and footbridge systems. A composite slab system formed by a fiber-reinforced concrete top laid on GFRP I-section pultruded profiles, for footbridge application, is being developed at the Federal University of Santa Catarina (UFSC), in Brazil. Such system provides lighter and more slender structures as compared to conventional concrete structures, which can be more sensitive to dynamic loads, leading to excessive vibration. It becomes then important to study the dynamic behavior of such system, induced by human activities, and for that it is necessary to know its dynamic characteristics, such as natural frequencies, vibration modes and damping. In this work, the dynamic characterization of a representative strip of the slab system under development at UFSC, performed analytically, experimentally, and numerically, is presented. The fundamental frequency of the slab strip was initially obtained by means of the analytical solution of an equivalent continuous beam, based on Fourier Series. For the experimental analysis, three prototypes of the representative strip have been built: one using wide-flange and two using regular I-section profiles. In this analysis, the fundamental frequency and the damping coefficient of the composite slab were obtained using the heel drop test. Finally, in the numerical analysis, three finite element models were utilized in order to get the natural frequencies and vibration mode shapes: a refined model, using 8-noded solid elements and 4-noded shell elements; a simplified model, using 4-noded shell elements and frame elements; and a Timoshenko beam model. At the end of the work a comparison of the different analyses in terms of

fundamental frequency is performed, showing a very good correlation of analytical, experimental and numerical results.

7797 | Tolerance modelling of three-layered composite structures with a periodic microstructure (28. Vibrations)

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Introduction
In this note the vibration analysis of three-layered composite structures is performed. Objects under consideration are three-layered plates, which upper and lower layers fulfil all conditions of Kirchoff's type thin plates theory and are considered to be identical. Both plates are connected with each other by elastic, Winkler's type material that can be described with certain elasticity modulus k. In addition, it is assumed, that both outer layers and the middle one can have certain periodic microstructure, determined by the diameter of small repetitive elements, called periodicity cells.
The behaviour of such structures is described by partial differential equations with highly-oscillating, periodic and non-continuous coefficients. Hence, the vibration analysis brings many difficulties.
In order to improve composite structures it is vital to develop a convenient tool for special engineering problems analysis. A lot of models were proposed. The asymptotic homogenization method, developed by Kohn and Vogelius [2], allows to perform the analysis of periodic plates behaviour. However, this approach neglects the effect of microstructure on the behaviour of composite material. In order to take into account this effect, tolerance averaging technique, cf. Woźniak and Wierzbicki [3], Jędrysiak [4], can be used.

Modelling foundations
The tolerance averaging technique has been developed and described by Woźniak and Wierzbicki [3]. It is based on some introductory concepts, like: a periodicity cell, an averaging operator, a tolerance-periodic function and a slowly-varying function.
There are two main assumptions of the tolerance modelling. The first of them is the micro-macro decomposition of the outer plates deflections u1(x,t), u2(x,t). According to it, plate deflections can be written as sums of macrodeflections W1(x,t), W2(x,t) and fluctuation shape functions w1A(x,t), w2B(x,t). The second one is the tolerance averaging approximation, in which it is assumed that certain terms can be treated as equal with a respect to given tolerance parameter.
The assumptions above are fundamental for the analysis of plates under consideration.

The aim of the contribution
The main aim of the contribution is to formulate governing equations of three-layered composite periodic plate using the tolerance averaging technique, and to present vibration analysis in several calculation cases.
The starting point of the tolerance modelling procedure is a system of equations of motion for the outer plates of the structure. These equations are based on simplified approach, proposed by Szcześniak [1].
After some manipulations using the tolerance modelling assumptions, the system of partial differential equations can be transformed into system of equations with constant coefficients, where macrodeflections W1(x,t), W2(x,t) and fluctuation amplitudes v1A(x,t), v2B(x,t), A,B=1,2..N, are the basic unknowns. This system of equations stands the tolerance model equations of three-layered periodic plate structures and allows to investigate the effect of the microstructure size in dynamic problems of these plates.
Several calculation examples has been performed, assuming that both of the plates are identical and only the higher plate is affected by external loading p.

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8033 | Nonlinear Dynamic Characteristics of MSMA-KNN Vibration Energy Harvester (28. Vibrations)

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Magnetic shape memory alloy (MSMA)-K0.5Na0.5NbO3 (KNN) is a kind of novel magneto-electric composite materials. It is made up of MSMA substrate and KNN piezoelectric layer. MSMA-KNN vibration energy harvester has many advantages, such as small size, high mechanical-magneto-electric conversion efficiency, long service life, and environment-friendliness, which make it be applied as green energy widely. Although various achievements have been reported, the theoretical results of the dynamic characteristics of MSMA-KNN vibration energy harvester are not abundant because of the complex nonlinear characteristics of MSMA and KNN piezoelectric ceramics. In this article, nonlinear coupling dynamic characteristics of MSMA-KNN vibration energy harvester are studied.
To obtain the dynamic characteristics of MSMA-KNN vibration energy harvester, the constitutive models of MSMA and KNN piezoelectric ceramics should be built. There are hysteretic phenomena in MSMA and KNN piezoelectric ceramics. In this study, improved Van der Pol items are introduced to explain the hysteretic phenomena of MSMA and KNN piezoelectric ceramics. The hysteretic strain-voltage curves of KNN piezoelectric ceramics are described, and the coupling relationship among strain, stress, magnetic field intensity and frequency of MSMA is provided in partial least-square regression method. The analyze results of principal component and forecast test based on experimental data indicate that the constructive models describe the real behaviors of MSMA and KNN piezoelectric ceramics well.
According to the Hamilton principle, the nonlinear dynamic model of MSMA-KNN vibration energy harvester is developed. The expression of the system's dynamic response is obtained. The system fundamental frequency is revised using complex normal form method, and the influence of the disturbing parameters is investigated. Local and global bifurcations of the system are analyzed, and the criterions determining the homoclinical bifurcation are obtained. The numerical results of the system response and phase diagram show that:
1) If the initial condition is located outside of the large unstable limit cycle, the vibration amplitude increases to infinite, which means the structure can finally be destroyed;
2) If the initial condition is located inside of the small limit cycle, the motion of the beam is bounded, therefore the structure may stay safe;
3) If the initial condition is located inside of the large limit cycle and outside of the small limit cycle, the amplitude decreases to a certain value, and the

system keeps vibrating around the positions of steady state;
4) Amplitude jumping phenomena is observed in the change of parameters, which means that the vibration amplitude of the system can be controlled through adjusting system parameters.
The expression of Melnikov integral of the system is given based on the revised fundamental frequency, and the prediction accuracy of the threshold value of chaotic motion is improved. The numerical results show that the system's motions change from a periodic way to chaos when the conditions vary, and chaotic attractor is diffused when the intensity of excitation.
The mechanical-electric coefficient of MSMA-KNN vibration energy harvester is determined. The effects of parameters on the dynamic characteristics and mechanical-electric coefficient are analyzed. Finally, the results of theoretical analysis and numerical simulation were proved by experiment. The results obtained in this study are helpful for engineering applications of MSMA-KNN vibration energy harvesters.

8186 | Vibration analysis of a composite concrete/GFRP slab induced by human activities (28. Vibrations)

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In recent years the use of fiber-reinforced polymeric (FRP) materials has gained wider space in the CivilEngineering sector, due to some favorable characteristics such as resistance to corrosion and fatigue and alsolightweight, which leads to high specific strength and stiffness. FRP materials have been initially employedto retrofit structural elements, but nowadays they are also applied in the construction of new structuralsystems, particularly in bridge and crosswalk systems. Innovative systems that combine concrete with FRPmaterials lead to lighter and more slender structures as compared to conventional reinforced concretestructures, which can bring about vibration problems. In this work, a study on vibration analysis of acomposite slab subjected to human activities, such as walking and jumping, is presented. The slab iscomposed of a fiber-reinforced concrete top laid on GFRP I-section pultruded profiles, filled in with foamblocks. The study embraces experimental and numerical analysis using the Finite Element Method. In theexperimental analysis, two prototypes of 0,80 m width, representing a slab strip, are utilized. The prototypesare subjected to walking and jumping by several volunteers, using different kind of shoes. In the FE analysis,a dynamic loading, simulating the walking and jumping carried out in the tests, was applied. For bothanalyses the responses are presented in the time and frequency domain. At the end of the work, experimentaland numerical results are compared, and a few conclusions on the dynamic behavior of the composite slabare drawn.

8715 | Flutter characteristics of curved sandwich panels with CNT reinforced face sheets using an accurate higher-order theory (28. Vibrations)

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In recent years, non-structured, non-metallic materials have spurred considerable interest in the materials community partly because of their potential for large gains in mechanical and physical properties as compared to standard structural materials. In particular, carbon nanotube/polymer composites may provide order-of-magnitude increase in the strength and the stiffness when compared to typical carbon fiber/polymer composites (Jia et al., 2011). Due to these reasons, structures made of such materials have great potentials in the construction of future supersonic/hypersonic space vehicles and reusable transportation systems. Among the various structural constructions, the sandwich type of structures are more attractive due to their outstanding bending rigidity, low specific weight, excellent vibration characteristics and good fatigue properties. These sandwich constructions can be a candidature for the requirement of lightweight and high bending stiffness in the design. A typical sandwich structure may consist of a homogeneous core with face sheets. To improve the characteristics of these structures, the face sheets can be laminated composites (Whitney, 1972), functionally graded materials (Zenkour, 2005) or polymer matrix with reinforcements (Ugale and Singh Mishra, 2014). The definite advantages offered by the carbon nanotube reinforced composites (CNTRCs) over the carbon fiber-reinforced composites have prompted the engineers to design and analyze sandwich structures with CNTRC facings (Tjong, 2009).
In view of the above, here, the flutter characteristics of sandwich shells with carbon nanotube (CNT) reinforced face sheets are investigated using QUAD-8 shear flexible element developed based on higher-order structural theory. The formulation accounts for the realistic variation of the displacements through the thickness, the possible discontinuity in the slope at the interface, and the thickness stretch affecting the transverse deflection. The in-plane and rotary inertia terms are also included in the formulation. The first-order high Mach number approximation to linear potential flow theory is employed for evaluating the aerodynamic pressure. The solutions of the complex eigenvalue problem, developed based on Lagrange's equation of motion are obtained using the standard method for finding the eigenvalues. The accuracy of the present formulation is demonstrated considering the problems for which solutions are available. A detailed numerical study is carried out to bring out the efficacy of the higher-order model over the first-order theory and also to examine the influence of the volume fraction of the CNT, core-to-face sheet thickness, shell thickness and the aspect ratio, shallow/deep shells, and the temperature on the flutter boundaries and the associated vibration modes.

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8762 | PPF MIMO Control of a Composite Carbon Fiber Plate (28. Vibrations)

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Active vibration control of a free-edge rectangular sandwich plate is proposed and tested. The experimental setup consists of a honeycomb panel having a carbon-fiber reinforced polymer (CFRP) outer skins and a polymer-paper core, subjected to an orthogonal disturbance, due to an electrodynamics exciter and controlled by Macro Fibre Composite (MFC) actuators and sensors. MFC parches consist of rectangular piezoceramic rods sandwiched between layers of adhesive, electrodes and polyamide film. The MFC actuators and sensors are controlled by a programmable digital dSPACE controller board. The control algorithm proposed in this paper is based on the Positive Position Feedback (PPF) technique and is successfully applied with different combinations of inputs/outputs (Single Input Single Output, MultiSISO, Multi Input Multi Output) in order to control the first four normal modes. The control appears to be robust and efficient in reducing vibration in linear (small amplitude) and nonlinear (large amplitude) vibrations regimes, although the structure under investigation exhibits a relativity high modal density, \emph{i.e.} four resonances in a range of about 100Hz. The control strategy allows to effectively control each resonance both individually or simultaneously.

8900 | Numerical analysis vibration suppression of FGM beam with piezoelectric layers (28. Vibrations)

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This paper presents a methodology to use the software ANSYS in active vibration control of a functionally graded (FGM) beam with integrated piezoelectric actuation layer. The FGM beam material is assumed to be functionally graded in the thickness direction according to the power low distribution. First FGM beam with piezoelectric layers is modeled using APDL language in ANSYS. Through the modal analysis the first six rank frequencies has been extracted. velocity feed back analysis feedback controller is introduced to realize the vibration control through a closed loop. Results for various volume fraction indexes are presented.

8931 | Plate Vibrations Using Static Analysis (28. Vibrations)

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The vibration analysis of structures is a widely researched area. Hundreds of papers were published on the topic. The problem can be divided into two groups: the first group includes cases for which an analytical solution is known, and the second group includes cases with no known analytic solutions. Benchmark solutions for the cases in the second group are highly desired for validation and comparison of existing and future numerical solutions. In this work using a new method, the solutions for the natural frequencies are found by performing a static analysis. Starting from the equations of motion for a structure supported by elastic foundation, we realize that the foundation stiffness and the inertia of the mass have opposite effect on the solution for the vibrating structure: The difference of these two factors is treated as a generalized elastic foundation parameter, and it can have a positive or negative value. In either case, one can solve the displacements under a given concentrated load. Then, the solution for the vibration frequencies of the plate is equivalent to finding the values of the negative elastic foundation that will yield infinite deflection under a point load on the plate. This deflection will be infinite if the structure losses its stiffness, or in other words, the generalized foundation is causing the structure to be unstable. Then, the solution for the vibration frequencies is equivalent to finding the values of the negative elastic foundation that will yield infinite deflection under a point load. Several examples, for rods, beams and plates, are given in this work. The exact values for the natural frequencies of vibration are obtained with smaller computational effort.

9095 | Variable Kinematic 1D Theories for Flutter Analysis of Wings and Blades (28. Vibrations)

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According to Collars definition, aeroelasticity is ”the study of the mutual interaction that takes place within the triangle of the inertial, elastic, and aerodynamic forces acting on structural members exposed to an airstream, and the influence of this study on design”. In the past, the fluid-structure interaction (FSI) has brought to catastrophic events due to sudden failures of bridges, airplanes, helicopters, etc. A correct and safe design must require, therefore, an accurate prediction of aeroelastic phenomena. Unfortunately, FSI analyses are, in most cases, too computationally expensive. Hence, a trade off between accuracy and cost is often mandatory. Although based on restrictive assumptions, the strip theories developed in the first half of the twentieth century have been extensively combined with simplified structural models, in order to provide reliable aeroelastic tools for preliminary analyses [1-3]. Moreover, a proper description of the kinematics is of primary importance for the prediction of instabilities especially when dealing with complex-shaped structures made of anisotropic materials. In this paper, refined beam theories obtained through the Carrera Unified Formulation (CUF) [4,5] have been combined with unsteady aerodynamic models to perform flutter analyses of wings and blades. The displacement field over the beam cross-section is obtained by an expansion of arbitrary functions, F (x,z),

u(x, y, z, t) = F (x, z)u (y, t), = 1, 2, ...,M (1)

in which u (y,t) is the displacement vector and M stands for the number of terms in the expansion. The governing equations written in terms of ”fundamental nuclei” have been derived in a weak form through Hamilton’s Principle and solved by means of the Finite Element (FE) method. The analyses have aimed to evaluate the effects of the sweep angle and lamination scheme on flutter conditions. The results have been compared, when possible, with solutions obtained from two-dimensional theories, experimental tests and aeroelastic analysis carried out with Doublet Lattice Method. These comparisons have revealed that the unsteady theories combined with the 1D CUF elements can represent a valuable and cost-effective tool for the preliminary study of the aeroelasticity of complex-shaped blades and wings.

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9339 | Nonlinear vibrations of viscoelastic laminated composite shells by using 3rd order shear deformation theory (28. Vibrations)

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A geometrically nonlinear theory is developed for shells of generic shape allowing for third-order shear deformation and rotary inertia by using five parameters: in-plane and transverse displacements and the two rotations of the normal; geometric imperfections are also taken into account. The novelty is that geometrically nonlinear strain-displacement relationships are derived retaining full nonlinear terms in all the five parameters. These relationships are presented in curvilinear coordinates, ready to be implemented in computer codes. Higher order terms in the transverse coordinate are retained in the derivation so that the theory is suitable also for thick laminated shells. The theory is applied to viscoelastic laminated composite circular cylindrical shells complete around the circumference and simply supported at both ends. Large-amplitude forced vibrations under radial harmonic excitation are investigated and results are compared to those obtained by using viscous damping. The Kelvin-Voigt viscoelasticity model is used and it introduces quadratic and cubic nonlinear dissipation terms in addition to linear damping.

9404 | A novel spectral dynamic stiffness method for exact modal analysis of composite plates and plate assemblies with mass and spring attachments (28. Vibrations)

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A novel method named spectral-dynamic stiffness method (S-DSM) is developed in this paper for exact free vibration analysis of composite plates and their assemblies with mass and spring attachments. The method has no restrictions and is completely general to handle complex plated structures with any arbitrary boundary conditions, and importantly the method gives exact results within any frequency range with high computational efficiency.
Modal analysis of plate structures with spring and mass attachments have been a significant problem in many areas. Such an analysis is very important to avoid resonance or undesirable dynamic phenomena. The applications of research on this topic include, but not limited to, building, bridges, ships, aeroplanes, space structures, armoured vehicles, automobiles, machines, robots, optical beam pointing system and etc. The masses and/or springs attached to the parent structure usually change the dynamic behaviour significantly. Of course, the analytical or exact solution of such systems is without doubt a demanding problem which has received only sporadic coverage in the literature. For the first time, the problem has been addressed in an elegant way by a novel S-DSM method, which utilises the procedure of the dynamic stiffness method combined with the benefits of the spectral method.
At first, by using the spectral method, the shape function of a plate element in an exact sense is derived, which satisfies the governing differential equation exactly and provides complete flexibility to describe any arbitrary boundary conditions. The dynamic stiffness (DS) matrix of a composite plate element with unspecified boundary conditions is developed systematically using symbolic manipulations. A plate structure with complex geometry can thus be accurately represented by an overall DS matrix assembled by using elemental DS matrices of different geometry or material parameters. The attached masses and/or springs are then formulated as extra dynamic stiffnesses in the frequency domain that are superposed onto the overall DS matrix of the parent structure. Arbitrary boundary conditions are prescribed accurately upon ensuring DS matrix for the whole structure. As the solution technique, the Wittrick-William (WW) algorithm is enhanced to compute the natural frequencies of the complete system. The problem of solving the natural frequencies of a fully clamped plate is an essential, but fundamental prerequisite in the application of the WW algorithm. This difficult problem is resolved by some novel techniques which enable the current method to compute the natural frequencies efficiently within any desired accuracy and frequency range (from low to high). It is ensured by the algorithm that no natural frequency of the structure is missed. Mode shapes are also recovered accurately. For illustrative purposes, the current S-DSM is applied to complex engineering composite plate structures with mass and/or spring attachments. Exact results (accurate for all figures presented) for representative cases are given in the paper. The method is shown to be highly efficient with as much as 100-fold advantage over conventional finite element method. With less than 1% of computation time required by the usual finite element method, the S-DSM provides more accurate results. The research is of great significance in the design of plate-like composite structures especially in solving frequency attenuation problems for all frequency range.

5608 | Seismic Earth Pressures of Retaining Wall from Large Shaking Table Tests (29. Experimental Methods)

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To ascertain seismic response of retaining wall in the Wenchuan earthquake, large shaking table tests are performed and an acceleration record is acted in 3 directions. In the tests, acceleration time history recorded at Wolong station in the Wenchuan earthquake is used to excite the model wall. Results from the tests show that the location of dynamic resultant earth pressure is 0.35-0.49H from toe of the wall for road shoulder retaining wall on rock foundation, 0.33-0.42H for embankment retaining wall on rock foundation and 0.46-0.77H for road shoulder retaining wall on soil foundation. Besides, dynamic earth pressure increases with the increase of ground shaking from 0.1g to 0.9g and the relationship is nonlinear. The distribution is close to for PGA less than 0.4g, but larger for PGA larger than and equal to 0.4g, especially on the soil foundation.

6716 | Influence of graphite on the tribological behaviour of Al 6061 hybrid composites (29. Experimental Methods)

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This paper reports a study on the tribological behaviour of Al 6061 hybrid composites fabricated by liquid casting technique. Aluminium matrix composites with several reinforcements (hybrid) are finding increased applications because of improved mechanical and tribological behaviour and therefore are better alternate for barely reinforced composites. Al 6061 matrix were reinforced with SiC and graphite particles were studied. Addition of graphite with aluminium is decreased the wear rate, but it results in reduce the mechanical properties. SiC can be beneficially used as a succeeding reinforcement to trounce the problem of strength lessening of graphite reinforced composites. Dry sliding wear tests were conducted by using pin on disc apparatus with varying sliding distance and load. The scanning electron microscope is used to analyze the worn surfaces. Results indicate that the wear rate of the hybrid composite is lower than that of the matrix alloy and Al-graphite composites. Mechanical properties are also increased as compared to base alloy and graphite reinforced composites. Al 6061 hybrid composites have superior wear and mechanical properties than that of Al 6061-graphite composites. The optimized parameters of aluminium hybrid composite were found by Taguchi's L9 orthogonal array experimentation.

6717 | Influence of Al2O3 and graphite on the tribological and mechanical behavior of Al 6061/Al2O3(p) /Gr(p) hybrid composites (29. Experimental Methods)

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This research investigates the influence of Al2O3 and graphite on the tribological and mechanical behavior of Al 6061/ Al2O3/ graphite hybrid composites. The investigation reveals the effectiveness of incorporation of graphite in the composite for gaining wear reduction and Al2O3 for improving mechanical properties. The Al 6061 was reinforced with Al2O3,Graphite and fabricated using liquid metallurgy route was investigated. The Ceramic particles along with solid lubricating materials were incorporated into aluminium alloy matrix to accomplish reduction in both wear resistance and co-efficient of friction. The Al 6061/ Al2O3/ Graphite hybrid composite was prepared with 2, 4, 6 & 8 % Al2O3 along with 5 Wt. % graphite particles addition. The wear tests were carried out using pin on disc apparatus. The presence of Al2O3 in the Al 6061 hybrid composite has contributed towards the improvement in hardness and wear reduction of Al 6061. The presence of graphite in the hybrid composite has been capable to work for wear reduction and reduction in the co-efficient of friction of the hybrid composites. As a result the effect of graphite in the hybrid composite exhibited a quality of wear reduction and effected reduction in the co-efficient of friction. The worn surfaces were analyzed through SEM.

6882 | Experimental analysis of slim-floor composite systems (29. Experimental Methods)

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Composite elements are constituted by two or more components of different materials working together to resist the loading applied to the structure. In the case of elements comprised of steel and concrete, there is always a steel profile combined with concrete in order to use the advantages of both materials. The traditional composite floor consists of composite beam, composite slab placed on the top flange of the beam and shear connectors to provide the composite behavior. Taking this concept into account, the slim-floors systems have the slab supported by the bottom flange of the beam. This detail produces an important advantage of this solution due to the reduction of overall height of the floor. The steel profiled sheet used in this system is usually three times higher than the usual ones. As the steel profiled sheets for using in slim-floors systems are not produced in Brazil, this study presents the development of a steel profiled sheet with trapezoidal cross section to be used in this solution. Bending tests with specimens of the produced slim-floor were carried out aiming to evaluate the strength and the behavior of the obtained composite structure. The specimens presented satisfactory strength and behavior, indicating that the solution could be used in multistory buildings in Brazil.

7539 | Traction-compression biaxial testing for shear failure determination of a chopped glass reinforced polyester (29. Experimental Methods)

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There is a big variety of testing methods for determining shear properties in composites. In this work we propose to evaluate if the traction-compression biaxial testing by means of cruciform specimens is suitable to develop pure shear tests. Tasks as the shear strength, the shear strain and the shear modulus in the moment of failure are estimated. The studied material is a chopped-glass reinforced polyester whose behaviour is linear and quasi-isotropic, but different under tension and under compression. The experimental failure values are plotted in the traction-compression stress quadrant and they are contrasted with the Maximum stress, Maximum strain, Tsai-Hill and Tsai-Wu failure criteria.

7721 | Bond Properties of Arch-type Steel Fibre-reinforced Cementitious Composites (29. Experimental Methods)

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Cementitious composites are brittle and fracture under tensile or dynamic load. It is difficult to prevent the generation and development of cracks in composites over time. To compensate for the intrinsic disadvantages of cementitious composites, steel fibre has been used as a reinforcing material. The bond properties of cementitious composites have been enhanced using steel fibre of various shapes, including hooked ends, enlarged ends, crimped, and twisted. Among these, the hooked-ends steel fibre has generally been used. However, this fibre caused a dramatic decrease in the pull-out resistance strength under applied tensile stress after initial cracking of the cementitious composite along the straight part of the fibre, which was followed by the hooked end of the fibre. For this reason, hooked-end fibre cannot sufficiently improve the mechanical properties of cementitious composites. Thus, arch-type steel fibre was used to improve the pull-out resistance of cementitious composites in this study. The pull-out resistance properties of arch-type steel fibre-reinforced cementitious composites were evaluated according to JCI SF-8. Results showed that the pull-out resistance of arch-type steel fibre-reinforced cementitious composites was superior to that of steel fibre-reinforced composites.

7736 | Experimental studies focus on the drilling-induced damages when cutting high-strength T800S/250F CFRP (29. Experimental Methods)

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High-strength T800S/250F CFRP is commonly identified as an innovative composite material with the sufficient ability of characteristic enhancement and energy consumption for manufacturing advanced aircraft structures in modern aerospace industry. However, mechanical drilling of high-strength CFRP is still characterized as a highly cost and time-consuming task among the manufacturing sectors due to its extremely poor machinability. The inherent nature of the fiber/matrix system typically results in severe geometric imperfections and serious hole damages in drilling, e.g., irregular hole diameter, fiber pullout, delamination, as compared to conventional low-strength CFRP cutting cases. The drilling-induced damage commonly plays a pivotal role in determining the final composite-part acceptance or rejection prior to its post-application. Revealing the mechanism dominated the hole damage formation and distribution would provide a beneficial guideline for its controlling and elimination in actual production. Based on this, the main objective of the work aims to characterize the distribution of drilling-induced damages and to correlate them to the used cutting conditions when drilling high-strength T800S/250F CFRP. The multiple aspects of hole damages and geometric defects were carefully quantified versus the input cutting parameters. After that, some key conclusions were drawn from this study.

7758 | Application of resorbable PGF/PLA composite for orthopedic implants: In vitro characterization of mechanical properties (29. Experimental Methods)

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Completely bioresorbable materials are attractive alternatives for metallic materials. Metallic prostheses have many adverse effects which can be resolved using biocompatible, bioresorbable and bioactive materials such as magnesium and their alloys, polymer, ceramics, bio-glass and their composites. Among these materials, polymers such as polylactic acid (PLA), polyglycolic acid (PGA), lactic-co-glycolic acid (PLGA), poly-L-lactide (PLLA) and polycaprolactone (PCL) are known as excellent materials for the use of medical devices due to their unique characteristics. However, pure polymers provide insufficient strength and stability for weight bearing long bone fractures. Poor material properties of these polymers (1-4 GPa) could allow excessive interfragmentary movement at the fracture site which would deteriorate the healing process of bone fractures. For load bearing long bone fractures, the initial material properties of prostheses matching to the cortical bone (10-20 GPa) or higher is necessary for the bone structure integrity and successful bone healing. Also appropriate degradation rate of a material is required to ensure the optimal stress transfer at fracture site. Therefore, bioresorbable materials with higher Young's modulus (such as hydroxyapatite, calcium phosphate etc.) are used to reinforce the bioresorbable polymers to make construct composite materials, which exhibit appropriate initial material properties to provide enough stability to the weight bearing long bone fractures. The material properties of these composites can be tailored using different volume fractions of reinforcements to achieve the desired material properties. Completely bioresorbable composites degrade when exposed to the human body fluid. The degradation rate of these materials can be controlled using various techniques such as different manufacturing processes, fiber treatments and coatings. For successful bone healing, an appropriate degradation rate of material is required to transfer the body weight gradually to the fracture site.
In our study, the properties of pure polymer and bioresorbable glass fiber-reinforced composite materials were studied. Composite materials were fabricated using phosphate glass fibers (PGF) and polylactic acid (PLA) and other types of reinforcements such as hydroxyapatite (HA) to determine the degradation mechanism and physicochemical changes under the in vitro conditions. Two types of composites were fabricated to evaluate their performances; one was homogenous material and other was functionally graded material (FGM). In vitro degradation tests of PLA and PGF/PLA composites were carried out in saline buffer solution (SBF) at 37 °C to simulate the in vivo conditions. Characterizations of composites were performed to evaluate the various properties (such as tensile and flexural tests, water accumulation, mass loss etc.) during the degradations study.

7815 | Flexural behaviour of unidirectional composite laminates with different tensile and compressive strength (29. Experimental Methods)

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Key words: carbon fiber reinforced, unidirectional laminate, three-point bending test, failure mode

The composite materials have been traditionally used in the aerospace and aeronautical industries in the hardest working conditions. Nowadays, the use of these materials has increased in a large number of applications such as wind energy, shipbuilding and automotive industries. In these applications, reinforced fiber composites usually have the compression strength lower than the tension strength. Hence, these composite laminates reinforced with fibers develop different failure modes depending on the relationship between the tensile and compressive strengths and the thickness of the laminate. In this work, experimental tests have been performed in order to analyse the flexural behaviour of unidirectional composite laminates manufactured from

carbon fiber prepreg using a hot platen press and a vacuum system.

7841 | Microstructure and Mechanical Properties of Magnesium based Composites produced by SPS sintering (29. Experimental Methods)

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The decrease in the world energy resources combined with a global trend towards a reduction of the greenhouse gas emission, have contributed to grow the scientists' interest in structure lightweighting. This approach particularly concerns the sectors of civilian and military transport. In this problem, magnesium appears to be a promising candidate, with a density respectively 30% and 75% inferior to those of aluminium and steel - main structural metals used. In addition, magnesium offers other advantages like good specific strength, thermal stability and damping resistance. However, its low ductility and mechanical strength associated to a high oxidation sensibility, represent limiting parameters for using it as structural material. Therefore, magnesium is rarely employed in its pure form. It is generally alloyed with elements such as aluminium, rare earths and zirconium, and strengthened through the introduction of ceramic reinforcements.

This study aims to implement the powder metallurgy process, especially Spark Plasma Sintering (SPS), for developing magnesium alloys reinforced by ceramic particles. Contrary to the usual foundry process, powder metallurgy ensures a fine microstructure control through the powder synthesis and sintering steps. Based on this advantage, materials with high mechanical strength can be obtained.

In this study, attention is focused on the influence of the sintering conditions and the reinforcements ratio and size, on the microstructure and mechanical properties of the developed composites. The conducted mechanical characterisation includes quasi-static and dynamic tests (Split-Hopkinson pressure bar), as well as ballistic tests.

7937 | THE MECHANICAL BEHAVIOR OF EPOXY PARTICULATE COMPOSITES (29. Experimental Methods)

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The aim of the present paper is to describe the experimental tests designed and conducted in order to analyse the mechanical behaviour of epoxy particulate composites, better known as fillers.
The fillers are two-component composites characterized by type, size and a variable amount of glass microsphere randomly embedded in an epoxy matrix. The microspheres may be full or empty of gas inside, depending on the desired characteristics of the filler. The proportion and the peculiar properties of the two components affect the particle-composites mechanical behaviour.
The fillers application field is the coating of hull and superstructure of yachts in order to mould the surface and protect it from corrosion. Since the outer layer of a yacht will be painted to obtain a shiny surface, the filler should be perfectly levelled, faired and smoothed. Moreover, the fillers should be stiff in order to avoid paint's deformation, but at the same time soft enough in order to avoid cracking. Due to the geometry irregularities of the hull and superstructure shells and to the harsh environmental loads, the displacements to which the yacht structures are subject may be considerably high, possibly causing cracks on coating.
Several works, which investigate on the micromechanical behaviour of similar composites, are presented in literature. Nevertheless, the studies focus on the effect of debonding between particles and matrix or on the influence of the inert shape and dimension. The study presented in this paper is instead a macromechanical analysis regardless the fillers' internal mechanic.
Experimental tests were designed and conducted on six fillers with specific chemical and micromechanical structure. The laboratory procedure consisted in two tests to define the behaviour of the fillers subject to compressive and tensile stress.
The aim of the compressive test was to analyse the trend of load-displacement curves of different composites under pressure, in order to underline the stiffness and the breaking point related to filler specimen shortening.
The three point bending test has supplied the elongation of the filler specimen and the corresponding load when applying a constant displacement at midspan. In order to evaluate the mechanical response of fillers subject to tensile stress, layer thicknesses of a specimen made of steel and filler were studied such that the composite was entirely under tension.
Results are repeatable and consistent for each filler, so it is possible to outline the characteristic load-displacement curves under compressive and tensile stress. The trend of such curves provide information about the stiffness and allows a comparison among the analysed composites.
The filler shows a non-linear trend of the displacement-load law when the specimens are under compression, therefore it is not possible to define a constant elastic modulus. Conversely, applying a tensile stress, the trend of displacement-load curves is almost linear and stiffness parameters can be properly defined.
The tests results provide a comparison between fillers allowing the mechanical characterization of the materials and understanding which features are preferable depending on the type of application.
Further set of tests will be carried in order to verify the mechanical behaviour of the entire coating cycle of yachts and, in particular, to analyse the interaction between filler and painted layers.
While it will be interesting to investigate actual operating condition of these materials, testing a full/large scale panel characterized by irregular geometry usual of shipyard practice, the current work also provided input data and preliminary validation of numerical models useful in hull structural design of large yachts.

8138 | Infrared thermography to evaluate thermoplastic composites under bending load (29. Experimental Methods)

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Infrared thermography (IRT) is a non-contact, non-intrusive technique which detects thermal energy radiated from objects in the infrared band of the electromagnetic spectrum. Such energy is transformed into a temperature map, which can be exploited for many purposes in many different application fields. In particular, an infrared imaging device can be used to monitor the entire existence of a product, from its manufacturing process to completion as well as in-service life.
In this work, IRT is used to investigate composite materials which are based on a polypropylene matrix, which may be neat, or modified by addition of a relatively low amount of a specific compatibilizing agent, and reinforced with glass or jute fibres. IRT is used with a twofold function:
- for nondestructive evaluation of materials before and after cyclic bending;
- to monitor thermal effects developing when the material is under load, either cyclic bending, or quasi-static bending.
The obtained results show that:
• The presence of a compatibilizing agent in the matrix amplifies the material thermal response to cyclic bending.
• It is possible to follow the failure under quasi-static bending from the formation of the initial crack, to its enlargement and final material collapse.
In particular, the comprehension of thermal effects may be useful to get information about the laden material behaviour in view of assessing the material performance.

8600 | Bond behavior of cement matrix-based composites for strengthening of masonry structures (29. Experimental Methods)

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The seismic risk mitigation of masonry buildings is one of the recent challenges of the scientific research. As regards historical buildings, the strengthening techniques have to be used according to the basic principles of conservation, that require non-invasive, reversible and compatible interventions.
Experimental assessments highlighted how technology of composite materials with epoxy matrix presents some disadvantages when applied to masonry walls: delamination phenomena, impossibility of application on humid surface, lack of transpiration and deterioration at high temperatures.
Textile reinforcements applied with inorganic matrices are currently receiving great attention for strengthening masonry structures thanks to the overcoming of the disadvantages typical of polymer matrix composites [1-2]. As the development of cement matrix-based composites for structural reinforcements is still at an early stage, the mechanical properties of such materials need to be properly investigated [3].
The paper presents an experimental study on the bond behaviour of different strengthening composite systems carried out by double shear tests on samples made of two brick blocks and two sheets of cement matrix-based composites. The experimental analysis focused on three different composites constituted by carbon, PBO and glass fiber textiles, each coupled with a different cement mortar. The constituent materials of tested samples were mechanically characterized: direct tensile tests on textile samples, three point bending tests and compression tests on cement mortar samples. Double shear tests were carried out involving three different bond lengths in order to identify an effective anchorage length. In particular, for each type of composite, six tests were performed for each different bond lengths (150, 200 or 250 mm). On a sample having 200 and 250 mm anchorage lengths, strain gauges were glued to a composite sheet in a longitudinal direction every 25 mm, in order to evaluate, for each composite, the strain distribution and to get indications on the activation and propagation of the debonding phenomena and on the effective anchorage length.
Double shear tests allowed to study the effectiveness of the bond between brick and cement matrix and between reinforcement textile and cement matrix. The response under shear loads was investigated by the relationship between ultimate load in the reinforcement sheet and relative displacement between reinforcement and substrate. Furthermore, the failure modes were also analyzed.
The results of the experimental campaign evidence that, in all three composites, the debonding phenomena occur at the fibers/matrix interface after tensile fractures in the matrix and fibers/matrix slip. In particular, three mechanical features are involved: mortar tensile strength, adhesion between textile and mortar and frictional adhesion among threads of a single yarn.
The experimental results confirm the effectiveness of cement matrix-based composite materials, both in terms of ultimate load and strain capacity. The comparison highlights that the PBO and glass composites exploit better textile properties, as the ratio between ultimate loads and textile tensile force demonstrates.
Increases of ultimate load, at varying bond length, occurred only for glass composites while an increase of strain capacity concerned all types of composites varying bond length. As regards the strain performance the best results were obtained by glass composites.

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8763 | experimental study on nonlinear dynamics of circular cylindrical shell (29. Experimental Methods)

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In this paper an experimental study on nonlinear dynamics of a circular cylindrical shell is presented. An ad hoc setup of the experiment has been built up in order to investigate the linear and the nonlinear dynamic behaviour of a circular cylindrical shell, and to study the combined effect of compressive static and a periodic axial load for different combinations of loads. The thin walled structure is investigated experimentally with an impact test to identify the mode shapes; moreover, interesting nonlinear phenomena have been observed close to one of the resonances and they are presented for the different

parameter combinations. Chaos is found and a very well defined softening behaviour can be observed together with a quasi periodic and multiple periodicity. Non linear dependence of the response on the preload parameter is observed.

8767 | Investigation of Sintering Condition and Mechanical Property of Al-Si-Cu-Mg/SiCp MMC Fabricated by Powder Metallurgy (29. Experimental Methods)

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Recently, the lightweight materials have been received a great deal of worldwide attention due to the significant increase environment-related issue and energy depletion. Especially, Al-Si binary alloy components by powder metallurgy have higher ductility and excellent corrosion resistance. In addition, ceramic reinforcement in this system is highly effective for wear resistance. However, as the fraction of reinforcement increases, mechanical property can decrease because of their low formability and sinterability.
To solve these problem above mentioned, gas atomized Al-Si/SiCp and commercial Alumix231 powder were used in this study. These two kinds of powder were blended with turbulent mixer in specific ratio. Thermal behavior of blended powder was estimated by differential thermal analysis (DTA). Sintering with two variables (temperature and time) was proceeded by Hot-press technique with 70MPa pressure at vacuum atmosphere to optimize condition of sintering. Microstructures and phases of each powder and sintered body were identified by X-Ray Diffraction (XRD), Optical Microscope (OM), Field Emission Scanning Electron Microscope (FE-SEM) and Energy Dispersive X-Ray Spectroscope (EDS). Mechanical property of sintered body manufactured with each condition was estimated by universal testing machine. Wear property of sintered body fabricated with optimized condition was analyzed with Pin-on disc type wear tester. Variables of wear tests were set with vertical load and linear speed.
In the results of DTA, four endothermic peaks were occurred. Specimen sintered at 580ºC during 1hr had the highest ultimate tensile strength and elongations. Optimized condition was set by the result of tensile test. In the result of wear test, as vertical load and linear speed increases, wear rate increased and different wear behavior like oxidation, layer-form, layer-fracture, Fe-alloying and melting occurred at each condition.

8886 | Influence of the pressure dependent contact area between electrode and composite surface on the electrical conductivity- novel approach to eliminate imperfect contacts in the testing procedure (29. Experimental Methods)

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In this work, the influence of the pressure dependent contact area between electrode (made from alumina foil and rubber) and composite surface on the electrical conductivity of PMMA/ carbon black (CB) composite samples was investigated. It was found that the electrical conductivity dependent on the applied pressure with the testing device and CB volume fraction (ϕ) of the composite. In addition, one observed that the logarithm of electrical conductivity exhibits a linear relationship with ϕ^(-1/3) regardless of the pressures, indicating the presence of tunneling mechanism in the PMMA/ CB composites. Furthermore, it was found that the electrical conductivity shows a specific relationship with the pressure regardless of the CB concentrations. Based on this relation, the maximum electrical conductivity of the PMMA/ CB composites at a given CB volume fraction at infinite pressure can be revealed by extrapolation. Thus, a novel approach is given to eliminate strong variations in conductivity measurements on composites due to imperfect contracts.

8959 | Microstructure and Wear Resistance of Semi-solid 7050 and TiB2/7050 Composites Produced by Serpentine Tube Pouring Technique (29. Experimental Methods)

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Recently, the development of semi-solid metal (SSM) for manufacturing wrought aluminum alloys with higher strength has attracted considerable interest. Compared with traditional casting aluminum alloys, however, the change of solid fraction as a function of temperature for wrought aluminum alloys is too sensitive to produce semi-solid wrought aluminum alloys slurries. On the other hand, semi-solid alloys slurries are known to be stirred in order to destroy or hinder the formation of dendrite grains. Unfortunately, it is not easy to stir the wrought aluminum alloys due to the fact that the dendrite-like grains of these alloys are fairly developed during their solidification process. In this study, 3, 6 and 9 wt.% TiB2/7050 composites slurries with globular grains were synthesized successfully by in-situ reaction and serpentine tube pouring techniques. The results showed that the in-situ TiB2 particles and serpentine channel are beneficial to increase number of solidification nuclei and to promote uniform distribution of a-Al nuclei. Moreover, the experimental results showed also that the wear resistances of TiB2/7050 composites were improved simultaneously. The wear rate of 9 wt.%TiB2/7050 composite was decreased 79% than that of 7050 alloy under 100 N applied load, 30 min sliding time and 0.15 m/s sliding velocity.

9158 | Synthesis and dielectrric and magnetic properties Spinel Ferrite Nanoparticles and Polymer Nanocomposites Structures (29. Experimental Methods)

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The complex dielectric permittivity was measured by Agilent 4287 A RF LCR Meter at room temperature in the frequency range of 1 MHz-3 GHz. The real part of dielectric constant was calculated from the equation , where Cp is the parallel capacitance, d is the inter electrodes distance, is the permittivity of free space, A is cross-sectional area. The coercivity (Hc) of a magnetic material is usually its magneto-crystalline anisotropy. CoFe2O4 is hard magnetic materials. So, its magnetic moment value is higher than other samples. By the results of these samples can be clarified that Co referred to the anisotropic properties of Mn. From hysteresis curves, it can be seen that these nanoparticles observe typical super paramagnetic ‘S’-like shape at room temperature for all samples. The magnetization value is decrease with increasing Co contents. These results can be explained that Co attributed to the anisotropic properties of Mn. It can be said that these structures are used for EMI and absorbing materials.

9173 | Improving tensile strength of lime-treated clay using polypropylene fibres (29. Experimental Methods)

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Adding polypropylene fibres is an accepted practice for controlling shrinkage in concrete mix design. This work is aimed at investigating improving tensile strength of lime treated subgrade soils where cracking and shrinkage are significant factors contributing in disintegration of clay rich subgrades. A series of laboratory tests were conducted to investigate the indirect tensile strength for a range of fibre reinforced lime- treated sections of clay samples. Preparation and mixing techniques of fibres was found to have role in the level of improvement. To optimize gain in tensile resistance, different concentrations and fibre geometry were studied. It is concluded that adding fibre to lime-treated clay will enhance clay subgrade performance and minimize cracks and shrinkage. Level improvement was found variable and subject to fibre concentration and fibre geometry.

9217 | Mechanical characterization of continuous fiber reinforced thermoplastic composites: Challenges and recommendations (29. Experimental Methods)

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Continuous carbon fiber reinforced composites are considered in transportation to maximize weight reduction of the car body. For cost effective mass production of composites, some technical challenges must be overcome. In particular, automated processing concepts applicable to composites are needed. Continuous fiber reinforced thermoplastic composites are characterized (or distinguish themselves) by promising performance, good processability and high potential for cost effective light weight structures enabling mass production. In addition, recycling of such structures is considered as favorable compared to thermoset solutions. Current car part design must be revised in order to fully use the benefit of these complex materials. For that purpose, reliable mechanical characterization is fundamental. Most of the existing testing approaches and standards were established for characterization of unidirectional or multidirectional laminates based on thermosetting resins. Some of these testing methods are not directly applicable to thermoplastic composites. Innovative appropriate testing approaches and standards are needed in order to obtain reliable mechanical characterization of these materials. This paper presents the development made in the last years towards characterization of the mechanical properties of continuous fiber reinforced thermoplastic composites giving emphasis on interlaminar fracture toughness and in-plane shear properties of woven thermoplastic composites.

9227 | Fast fabrication method and evaluation of performance of Hybrid FRTPs for applying them to automotive structural members (29. Experimental Methods)

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Thermoplastic resins used as a matrix of fiber reinforced thermoplastics (FRTPs) are composed of high polymers that remain highly viscous even at a higher temperature than their melting points. As a result, they need a higher temperature, a higher pressure and longer process time to allow them to bond with fibers that require large and specialized facilities.

In this paper, a fabrication method of vacuum assisted resin transfer molding method (VARTM) for hybrid fiber reinforced thermal plastic (FRTP) was introduced. In order to fabricating hybrid FRTP with the VARTM, glass and carbon fabrics were used as reinforcement and in-situ polymerizable epsilon caprolactam (ε-caprolactam) was used as the matrix. The obtained HFRTP had neither voids nor unfilled parts because the ε-caprolactam was very low viscosity before polymerization. The Fabrication method of HFRTP proposed in this presentation showed a quicker fabrication time compared with conventional fabrication methods without expensive facilities.

In order to apply this hybrid FRTP to automotive structures, the performances of HFRTP showed not only superior mechanical properties but also suitable for high-speed molding, namely, within a few minute process time because they could be released from the mold without a cooling process.

9335 | Effect of friction stir process parameters on microstructure and sliding wear behavior of Cu/B4C surface composite (29. Experimental Methods)

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An attempt was made to synthesize Cu/B4C surface composite using friction stir processing (FSP) and to analyze the influence of tool rotational speed on microstructure and sliding wear behavior of the composite. The tool rotational speed was varied from 800 to 1200 r/min in step of 200 r/min. The traverse speed, axial force, groove width and tool pin profile were kept constant. Optical microscopy and scanning electron microscopy were used to study the microstructure of the fabricated surface composites. The sliding wear behavior was evaluated using a pin-on-disc apparatus. The results indicate that the tool rotational speed significantly influences the area of the surface composite and the distribution of B4C particles. Higher rotational speed exhibits homogenous distribution of B4C particles, while lower rotational speed causes poor distribution of B4C particles in the surface composite. The effects of tool rotational speed on the grain size, microhardness, wear rate, worn surface and wear debris were reported.

6712 | Porous piezoelectric ceramics (30. Porous and cellular materials)

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Common sensor applications made use of porous piezoelectric ceramics and piezoceramic-epoxy-hybrid materials. Characteristic for this sensors are a high figure of merit (FoM) and a high hydrostatic strain coefficient gh. The effect of different pore structure and distribution on piezoelectric properties of the piezoceramic-epoxy-hybrid materials is determined.
Processing is carried out by the Indirect solid free form fabrication negative structures (PLA) with mono- and bimodal pore structure filled with a 48 Vol% PZT injection mold and sintered at 1250 °C / 2h. Additional pores are filled up with epoxy resin forming the hybrid material. Polarization is carried out on metallized samples at 30°C and 3 kV/mm. The increase of pore diameter and porosity from 9 to 35 % decrease the d33 between 10 % and 40 % in dependence from mono- or bimodal structures. Results from impedance measurement, relative permittivity ε33T/ε0 and the d31 are strongly influenced by the interface between ceramic and polymer. Depending on the mono- and bimodal structure the ε33T/ε0 as well as ｜d31｜ decrease to approximately 90 % or 80-90% of the reference value (1530 or 17 pC/N), respectively. In comparison to the d33 the decrease of the ｜d31｜ and the ε33T/ε0 is twice higher. By varying the pore size distribution the figure of merit (FoM) and the hydrostatic strain coefficient gh are set so that there is a different approach of usage: monomodal for actuators or hydrophones and bimodal for sensors.

6905 | Influence of composition, strain rate and temperature on mechanical properties of novel 16Cr7Mn6Ni-TRIP-matrix composite 196 cpsi honeycomb structures under compressive deformation (30. Porous and cellular materials)

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Through powder metallurgy processing route and cold extrusion fabricated 16Cr7Mn6Ni steel 2D square-celled honeycomb columns with reinforcements of 0-10 Vol.-% MgO partially stabilized Zirconia (Mg-PSZ) were investigated in quasi-static and dynamic out-of-plane compression tests. The insertion of Mg-PSZ particles in the high-alloyed metastable austenitic matrix causes an increase of specific yield strength and strain hardening to certain deformation degrees. By adjusting different strain levels microstructure evolution with regard to strain-induced martensitic transformation and steel/ceramic interactions as well as the deformation mode of 196 cpsi columns are recordable in particular. A decrease of test temperature to -60 °C implies the reduction of stacking fault energy and results in a higher driving force for the TRIP- (TRansformation Induced Plasticity-) effect accompanied by changes in deformation characteristics. Furthermore, failure behavior of cell walls and outer skin differs with increasing volume fraction of Mg-PSZ. In comparison to similar structures consisting of AISI 304 CrNi steel the energy absorption capability of 16Cr7Mn6Ni steel/composite is up to 50 MJ/m^3 higher which makes them more favorable for crash absorbing elements.

7011 | Multiscale structure of (Al2O3)CoAlO/CoAl porous ceramometal composites (30. Porous and cellular materials)

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A multiscale structure of two CoxAlyOz ceramometal (cermets) with aims to get a high porosity or the mechanical strength was examined by a combination of XRD, SEM with EDX techniques, NMR (59Co and 27Al), and the textural measurements. The strong CoAlO/CoAl monolith cermet prepared by Co and Al powders mechanical alloying followed by the hydrothermal treatment and a calcination under the air was revealed to be composed of two parts. The first metallic cores were presented by Co metal and Co-Al alloy, and the second oxide matrix contained the mixture of spinel CoxAl3-xO4 structures and cobalt oxides. The interface between these two cermet parts was represented by alumina shell protecting the metallic core against further oxidation. On the other hand, the ceramometal Al2O3/CoAlO/CoAl prepared by mixing the Co-Al mechanical alloying product and a pure aluminum hydroxide with subsequent hydrothermal treatment and the calcination under the air was found to consist of three main parts. The first showed the cobalt-free large porous alumina globules surrounded by the second oxide part represented by spinel CoxAl3-xO4 oxides. The third one was the oxygen-free metallic part consisting of cobalt-based metal particles covered by Co-Al oxide. An enhanced microwaves adsorption caused by a random distribution of metallic particles distributed through oxides and the high porosity provided the catalyst activity prepared from porous cermet in the reaction of the hexane dehydrogenation.

7707 | Compressive Behaviour of the Sandwiches with Aluminium Foam Core and CFRP Skins (30. Porous and cellular materials)

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The main advantage of the sandwich technology is the combination of low weight with high strength value and high energy absorption capability. Therefore, the use of these structures is suitable for several applications in the transport industry (automotive, aerospace, shipbuilding industry) and civil works. These panels enable also a wide range of material selection in order to construct the entire structure. While sandwich structures with polymeric foams have been applied for many years, recently there is a growing interest on a new generation composite sandwiches with metallic foam core.
The aim of this research was the analysis of the edgewise compressive behaviour of the sandwiches consisting aluminium alloy foam core and carbon fiber reinforced plastic (CFRP) skins in order to compare the results in terms of absorbed energy applying various strain rate values. In the study, the skins were manufactured via Vacuum Infusion (VI) method and those were bonded to the foam using a polyurethane based commercial adhesive. The CFRP skins with two different thicknesses (t=1 and 1.5 mm) which were obtained using two and three layers of [0º/90º] 2x2 plain woven carbon fabric and the

aluminium foam core with two different thicknesses (h=10 and 15 mm) were used in order to combine the composite sandwich panels.
The edgewise compression tests were realized by a universal test machine applying three different constant loading rates of 3, 5 and 7 mm/min for each typologies. A comparison database was reported respect to the effect of strain rate values and the thickness values of aluminium foam core and skin materials in terms of absorbed energy and energy efficiency values obtained the integration of the stress-strain curves. The failure mechanisms of the panels are also evaluated in order to clarify the edgewise compressive response.
The obtained experimental results presented that the sandwiches with aluminium foam core are great energy absorbers and the use of them can lead to a weight reduction of the vehicles, providing an adequate structural strength under operating conditions.

7767 | Effect of interlayer on the effective performance of piezoelectric composites with porous matrix (30. Porous and cellular materials)

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Abstract: A multi-step micromechanics method is developed to evaluate the performance of the 1-3 piezoelectric composites with porous matrix. Firstly, the porous polymer matrix is homogenized using the Mori-Tanaka method. Secondly, the piezoceramic fibre coated with piezopolymer is homogenized to obtain a piezocomposite fibre. Finally, the porous matrix with embedded piezocomposites fibre is analysed using the Mori-Tanaka method for piezoelectric composite. A study is performed to examine the effect of the piezopolymer interlayer between the matrix and the piezoceramic fibre on the performance of the composites. In addition, the effect of the porosity on the composite performance is also studied. Results from the study show that the interlayer between the matrix and piezoceramic fibre can degrade the performance of the piezocomposites. However, the presence of porosity can significantly improve the performance of the composite.

7833 | POLYURETHANE FOAM LOCLLY REINFORCED WITH FIBERS FOR CRYOGENIC APPLICATION (30. Porous and cellular materials)

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Liquefied natural gas (LNG) is mainly carried by membrane type LNG ships, whose cryogenic containment system (CCS) is insulated with sandwiched type thermal insulation boards. The insulation boards should not only have the cryogenic reliability against thermal load, but also have high thermal insulation performance for safe and efficient transportation of LNG. Although fiber reinforced polyurethane foam (RPUF) has been widely used for the core of insulation boards due to its reasonable mechanical properties with relatively low cost, the cryogenic reliability of RPUF with high thermal conductivity are remaining concerns in marine fields.
Conventionally, the RPUF has been produced via a free rise process resulting in material waste and cracks on the surface during trimming operation, which decreases the cryogenic reliability of RPUF. Therefore, in this study, an acceleration has been applied to the mold during curing operation to make chopped fiber glass reinforcement align with mold surfaces with gradient fiber volume fraction. The optimal acceleration magnitude and processing time were investigated experimentally by measuring flexural strength and modulus at both the room (25oC) and cryogenic (-150°C) temperatures. The statistical analysis was conducted by the Weibull distribution considering the brittleness of RPUF at the cryogenic temperature. The foam cell configuration and fiber alignments were observed with CAM and SEM analyses. From the experimental results, it was found that the molding process with the mold acceleration much increased the structural performance of the RPUF much, especially at the cryogenic temperature. Therefore, the RPUF fabricated with the developed molding process will improve both the reliability of the LNG cryogenic containment system during the voyage of LNG ships.

7882 | Organic-inorganic hybrid aerogels as composite materials for the emerging applications (30. Porous and cellular materials)

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The state-of-the-art in the field of organic-inorganic hybrid aerogels designed for the emerging applications will be reviewed. Aerogels are a unique class of microporous materials with very low density. Typical aerogel consists of 95 - 98% air while the remaining 2-5% of the volume is a thin, delicate structure of the material, eg. silica, coal etc. Aerogels are characterized by low density of solids (1.9 kg/m3), low thermal conductivity (0.01 - 0.3 W/mK), low speed of sound propagation (100 - 300 m/s), low dielectric constant (1.007 - 2.0), low refractive index (1.0 - 1.4) as well as very high specific surface area (600 - 1500 m2/g). Due to these properties aerogels which are currently intensively studied by various research centers can found multiple applications such as thermal insulation, acoustic and electric (carbon aerogels are good conductors), catalysts, thin film dielectrics, molecular detectors, "super" electrical capacitors, absorbers, etc. The most intensively studied are primarily silica aerogels but also a broad spectrum of aerogels based on other metallic or organic materials, including carbon aerogel based on the graphene. Despite the large research activity in this area and the time elapsed since obtaining the first samples of aerogel only silica aerogel has been implemented into industrial production. Due to the limitations caused by the high price this material has very limited use. Several organic components can be build in the structure of aerogel. The sol-gel process has been recognized as the most successful method to synthesize hybrid organic-inorganic composites since the mild conditions of this process are ideal for avoiding damage of the organic components. Original methods of synthesis of organic-inorganic hybrid aerogels can be proposed using synergy of very rich silicon compounds chemistry and the possibility of precise steering of sol–gel process. The variety of inorganic and organic precursors available, as well as the multiplicity of strategies to the synthesis of hybrid sol-gel materials, broaden the range of structures and properties achievable and allow to enlarge the area of possible applications. The most widely used organic components are polyurethanes, acrylic resins, epoxides, cellulose and chitosan.
The effect of organic component will be presented and discussed based on the results of supermolecular structure examination, thermal conductivity, porosity and mechanical properties measurements as well as dust release evaluation.

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7909 | Performance evaluation of APM (Advanced Pore Morphology) foam filled tubes (30. Porous and cellular materials)

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The current trend in transport industry is to increase the use of lightweight materials and integrate them into vehicle designs in order to improve the fuel economy efficiency and reducing the vehicle weight, without comprising other attributes such as the cost, performance, comfort, safety, corrosion and recyclability. The thin-walled walled structures filled with cellular materials have been developed and tested already in past to achieve the lightweight construction and improve the vehicle crashworthiness. The use of foam material adds some further possibilities for structure design but also introduces some technological issues. The structures are generally designed to follow the desired behaviour, to avoid unwanted vibrations and to increase their impact energy absorption. This research work was focused on filling of a simple thin-walled structure with advanced pore morphology (APM) foam. The APM foam consists of elements with sphere-like interconnected closed-cell porous structure and integral skin with 5 mm in diameter. The APM foam elements were fabricated by heating small precursor material in a continuous belt furnace, based on powder compact foaming method. Two lightweight structures were prepared and tested using the APM foam elements: (i) non-bonded APM foam filled tubes were prepared by pouring the APM foam elements into an empty Al-alloy tube (without any bonding); (ii) polyamide-bonded APM foam filled tubes were prepared by pouring the APM elements coated with polyamide into an empty Al-alloy tube and then submitted to a heat treatment curing the polyamide. Axial compressive crush performance of these two composite structures was studied and evaluated using uniaxial compression tests, exploring their deformation and failure mechanisms. The axial crush performance of the APM foam filled tubes was compared to that of the empty tubes (with and without heat treatment). The results demonstrate a significant influence of the adhesive bonding on their compressive behaviour.

7972 | Indium-silica composite as an efficient heterogeneous green catalyst for multi-component and solvent-free reactions (30. Porous and cellular materials)

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Over the past few years, indium (III) salts have received increased attention as a novel type of green Lewis acid water-tolerant catalyst for organic synthesis. As homogeneous catalysts, indium (III) salts have been widely used and investigated in cycloaddition reactions, Friedel-Crafts reactions, Mannich reactions and allylation reactions but just a few examples of supported indium salts as heterogeneous catalysts have been reported in the literature.
In this work, we describe the synthesis, characterization and application of a new indium-silica composite (In-SiO2). The In-SiO2 was synthesized by using the sol-gel method, starting from tetraethylorthosilicate and indium chloride as precursor. The amount of indium in the In-SiO2 was estimated by using the EDS elemental analysis, which was performed using seven different SEM images. The obtained average result was 1.0 ± 0.1 mmol of indium per gram of composite. From the x-ray photoelectron spectroscopy it was possible to identify that the indium (III) is bonded to the silica in a covalent way, forming Si–O–In bonds. The 3d5/2 and 3d3/2 peaks of In3+ in In-SiO2 composite appear close to the InCl3 reported values, but slightly shifted to oxide species. Additionally, the oxygen 1s spectrum shows two components, one at 533.4 eV in major proportion, which is compatible with the oxygen of SiO2, and a second minor peak that appears at 531.6 eV. This minor peak presents an intermediate value between the reported SiO2 and In2O3 values. These results suggest that the ions link with unsaturated oxygen and chloride forming Si–O–In–Clx species, where x = 1 or 2. From the N2 adsorption desorption isotherms, it was obtained a BET specific surface area of 424 ± 15 m² g-1 and the pore size distributions, obtained from BJH and also from DFT analyses, show a fraction of mesopores with diameter between 2 and 4 nm. These characteristics allow the use of In-SiO2 composite as heterogeneous catalyst. Therefore, the In-SiO2 was applied as catalyst in one-pot multi-component A3-coupling of different aldehydes, amines and acetylene leading to propargylamines with excellent yields in solvent free condition. The catalyst shows recyclability, even after four cycles, according to green chemistry statements.
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8091 | Preparation of porous alumina-zirconia, mullite-alumina and mullite-zirconia composite ceramics by starch consolidation casting and characterization of their elastic properties via impulse excitation (30. Porous and cellular materials)

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Alumina-zirconia (AZ), mullite-alumina (MA) and mullite-zirconia (MZ) composite ceramics in the form of cylindrical rods have been prepared from aqueous suspensions by starch consolidation casting using corn starch as a pore former (in amounts of 10 – 50 vol.% for AZ and 20 – 50 vol.% for MA and MZ composites, related to solids). After firing at 1500 °C (AZ) and 1600 °C (MA, MZ), respectively, the bulk density has been determined from the sample geometry (mass-to-volume ratio) and via the Archimedes technique (weighing of the water-saturated sample in water and in air). Based on the

theoretical density of the solid composite (dense phase mixture) the total porosity was determined. The porosity ranges are 1–42 % in the case of AZ composites, 45–58 % for MA composites and 26–40 % for MZ composites. Young's moduli have been determined via the impulse excitation technique (IMCE RFDA 23) using the resonant frequency signal. It is shown that the porosity dependence of Young's modulus is far below the upper Hashin-Shtrikman bound and the power-law prediction (Gibson-Ashby relation for open-cell foams) and that our exponential relation provides the best parameter-free estimate (prediction) of effective Young's moduli. In the case of alumina-zirconia composites also high-temperature Young's moduli have been measured using high-temperature impulse excitation equipment (IMCE RFDA 23 with furnace HT 1600). The measured curves are compared with predictions based on previously determined master curves for the temperature dependence of pure alumina and zirconia ceramics. It is shown that when the temperature dependence can be decoupled from the porosity dependence of the Young modulus, and the master curves for the temperature dependence of the normalized Young's moduli of the end members are known, it is possible to predict the temperature dependence of the Young's moduli of dense two-phase ceramic composites of arbitrary composition. Further it is shown that, since the porosity dependence of materials with porosities below 60 % and essentially convex and approximately isometric pore shape usually obeys our exponential relation, it is possible to reliably predict effective Young's moduli of two-phase composites for arbitrary composition, porosity (< 60 %) and temperature (< 1400 °C).

8098 | On the mechanical characterization of Spruce and Beech material parameters under impact loading. (30. Porous and cellular materials)

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Wood like many other cellular materials can be used as an energy absorber. To perform accurate simulations and numerical predictions of the global response of a structure, an accurate wood material model is essential. This paper presents the preliminary results of an experimental investigation to characterize the mechanical properties of Spruce and Beech wood materials. Different apparatus are used to cover a large range of strain rates and they were analyzed to evaluate the strain rate effects and to understand the complex failure mechanisms of wood under compression. The interest focuses principally on specific key parameters, namely: the ultimate compression strength, the stress plateau and the densification regime. The studied specimens have been chosen of similar shapes and dimensions to assess material parameters and therefore reduce the size effects on the material behavior. For the quasi-static analysis a universal tension-compression machine was used. While for the impact analysis, a dynamic actuator has been used to handle intermediate strain rates whereas high-rate experiments were conducted using the compression Slip-Hopkinson bars. Wood is characterized in the three orthotropic directions with a particular attention given to the longitudinal one. For this direction, the results dispersion seemed to be somewhat larger than the other directions but can be justified based on the analysis of the experimental images obtained with the high-speed cameras.

8184 | Investigation of novel magnetic porous glasses based composites (30. Porous and cellular materials)

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A new type of the magnetic porous glass-hosted multiferroelectrics nanocomposites was synthesized. This is a report of the first experimental proof of properties of the ferroelectric materials incorporated in magnetic porous glasses with the controlled pore size. This new system exhibits a very small electrical conductivity which allows us to examine the dielectric and the magnetoelectric properties of the magnetic porous glasses. This exceptional electrical properties show a good potential for a novel group of multiferroic. The magnetic experiments of empty magnetic porous glasses and with multiferroelectrics nanocomposites demonstrate the Verwey transition in a magnetite. The specific heat was measured using the DSC method and the anomaly of the ferroelectric phase transitions was indicated. We report on the magnetic properties of multiferroic nanocomposites investigated by EPR at two frequencies (X, S band). Both the temperature and the frequency dependencies of the narrow and broad resonance lines fulfilled a condition for the superparamagnetic behavior of porous glasses with ferroelectric particles inside.Finally, the ferroelectric phase transitions in both TGS-Fe20MAP and NaNO2-Fe20MAP were observed. The results of NaNO2 embedded into magnetic glasses exhibit a ferroelectric hysteresis loop as a irrefutable proof of the ferroelectricity in multiferroelectrics nanocomposites incorporated in magnetic porous glasses. It was shown that the ferroelectric nanocomposites obtained on the basis of porous glasses exhibit both ferroelectric and ferromagnetic properties.

8245 | Acoustic Luneburg lens as Sonar (30. Porous and cellular materials)

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Luneburg lens is a gradient index lens that focuses the incoming wave on the opposite side of the lens perfectly without aberration. We developed a two-dimensional acoustic Luneburg lens by changing the refractive index of the medium inside the lens. The refractive index of acoustic wave is decided by mass density and bulk modulus. The modulus of the lens is supposed to be constant, and then we changed the density inside the lens. The lens has porous structure with a cylindrical shape of hundreds of circular aluminum columns. We tested the ability as sonar in the air. It focuses the incoming acoustic wave on the edge of the opposite side of the lens as well in the frequency range of 1,000Hz ~ 3,000Hz. The ability of the acoustic Luneburg lens as sonar was checked by VU meters in the air. It showed a dynamic response depending on the motion of the acoustic source accurately. It could be a strong candidate of a next generation of sonar. It increases the amplitude of the incoming sound wave by 3 - 5 times, and the amplification corresponds to the sound level difference of 10 - 15dB. It can be used as an acoustic window deep underwater, too.

8608 | Platinum nanoparticles stabilized by ionic silsesquioxane dispersed on silica. Synthesis, characterization and

catalytic properties **(30. Porous and cellular materials)**

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Ionic silsesquioxanes are silica based hybrid materials with high organic content. They can be obtained by sol-gel synthesis method, from the gelation of organosilanes that contain ammonium quaternary groups. The presence of ionic groups in their structure provides appreciable water solubility. Additionally, the ionic silsesquioxanes present a silica moiety that contains silanol groups (Si-OH). This characteristic allows obtaining dispersion of ionic silsesquioxanes, with strong adhesion, in inorganic matrices, such as silica, alumina or other metal oxides. Recently, it was reported that ionic silsesquioxanes can be applied as metal nanoparticle stabilizers and also as metal nanoparticle size controllers, allowing the obtainment of aqueous dispersion of noble metal nanoparticles, which remain stable for several months. The synthesis of metal nanoparticles with controlled size is a subject of scientific and technological interest, due to its several applications. In the present work, an ionic silsesquioxane that contain the ionic 1,4-diazoniabyciclo[2,2,2]octane chloride group was synthesized and it was used as stabilizing agent to obtain platinum nanoparticles, in aqueous dispersion. The ionic silsesquioxane/platinum nanoparticle system was immobilized on silica matrix. The silica containing the platinum nanoparticles was characterized by Transmission Electron Microscopy and Nitrogen Adsorption-Desorption Isotherms. The obtained platinum nanoparticles showed diameters lower than 5 nm and they were homogeneously dispersed on the silica matrix. By analyzing the nitrogen isotherms it was possible to observe a high surface area and a BJH pore size distribution in the mesoporous region. Therefore, the material presents appropriate characteristics to be used as catalyst. The silica containing platinum nanoparticles was applied as heterogeneous catalyst for the reduction reaction of p-nitrophenol to p-aminophenol, using NaBH4 as reducing agent. The rate of conversion was accompanied by UV-Vis spectroscopy. The results showed that silica containing platinum nanoparticles stabilized by ionic silsesquioxane has high catalytic activity for the reduction of p-nitrophenol to p-aminophenol, with easy recovery.

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8654 | Effect of replacement of metakaolin on the physical properties of fly ash-based light-weight foamed geopolymer (30. Porous and cellular materials)

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Geopolymer concrete is concrete which does not utilize any Portland cement in its production geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering application and commercial production of geopolymer concrete. In this study, light-weight foamed geopolymer of fly ash/metakaolin composites were fabricated and its physical properties were analyzed. Especially, the observed mechanical and physical properties according to the amount of metakaolin, Si/Na ratio. NaOH solution was used an alkali-activator and curing temperature was 70°C.

8695 | Fabrication and Mechanical Properties of Aluminum Infiltrated Open Cell Structured NiCrAl Foam Composites (30. Porous and cellular materials)

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Al matrix composites reinforced with different materials from matrix are promising materials for structural applications due to their light weight and high strength not only at room temperature but also at high temperatures. For manufacturing these composites, solid-state processes (powder metallurgy) and liquid-state processes (melt infiltration, compo-casting and squeeze casting) have been conventionally used. However, these composites manufactured by above processes have problems such as low ductility and toughness. Hence, development of new technique that can simultaneously obtain high strength and high ductility is required.
In this study, we have tried to fabricate Al/NiCrAl 3D net-work structured composites. NiCrAl open cell structured foams with cell size of 450, 1200, 300 um and Al powders of 30 – 40 um were used as raw materials. We inserted Al powders into open cell structured NiCrAl foam using vibration method and then cold pressed under a pressure of 50 MPa. These cold compacts were sintered by spark plasma sintering or hot rolling.
Microstructures were identified by optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD). Tensile samples with a gage portion of 25 mm in length and 6 mm in width were prepared by an electro-discharge machine. Tensile properties were performed at room temperature and high temperatures with a strain rate of 10-3 s-1.

8766 | Numerical analysis of pore size distribution effects on compressive deformation behaviors of porous metals for biomedical application (30. Porous and cellular materials)

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Porous metals are getting attention in the biomedical industries due to their low elasticity, which is advantage to prevent the reduction in bone density called as the stress shielding effect. Powder metallurgy methods are used to fabricate porous metals for biomedical applications due to good controllability of microstructures compared with conventional casting methods. To make the artificial pores in microstructure, the organic materials, which are called as binder, are added in pre-mixed powder and burned out during sintering process. Since the properties of the porous metals are strongly influenced by their microgeometries such as pore shape, pore size and interactions between them, a detailed understanding about relationships between the microstructure and properties is required for design and further development of these materials. On the other hand, micromechanical modeling of porous metals continues to play a substantial role in the understanding new materials systems. The use of representative volume element approach, together with finite element analysis can be useful for the investigation and analysis of microstructural factors of porous metals.

In this present work, pore size distribution effects on compressive deformation behaviors of powder metallurgical porous metals was investigated. Representative volume elements of porous microstructures, having different size distributions of pore, were reconstructed using random sequential adsorption algorithm. The compressive deformation and fatigue properties were analyzed using three-dimensional finite element method. The numerical results suggested that consideration of pore size distribution can give qualitative information on deformation behaviors of porous metals, and thus may helpful to design and optimize of the biomedical materials.

9015 | Sound absorption using composite layered medium for noise control (30. Porous and cellular materials)

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New sound absorbing method utilizing layered-shaped medium is proposed. Conventional sound absorbing materials converts sound energy into thermal energy due to the porosity and tortuosity. New sound absorbing model has helical-like shape in layered format with composite materials, and it absorbs incident sound energy through the change of the air cavity between layers. Acoustic impedance and sound absorption coefficients using impedance tube are measured for comparing to conventional sound absorbing materials. According to the result of sound absorption coefficient, layered medium absorption coefficient exhibited better sound absorbing properties. A simple method of improving the sound absorption and transmission especially at low frequencies after incorporating periodic formation is proposed and verified through experimentation.

9028 | Rapid Rotomolding of Integral Skin Celullar Polymeric Composites (30. Porous and cellular materials)

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The traditional rotational molding process was relatively recently deliberately modified to advantageously produce foamed plastics products, culminating with the fabrication of integral-skin polymeric composite moldings that are characterized with adjacent, but clearly distinct, layers of non-cellular (encapsulating) and cellular (encapsulated) polymeric structures, normally consisting of identical or compatible polyolefin grades. This paper focuses on investigating and understanding the scientific fundamentals that would, enable the decoupling of the process of the formation and shaping of the solid polymeric skin from the process of the development and propagation of the foamed polymeric layer or core the solid skin is supposed to encapsulate. As a result, an innovative extrusion-assisted rotational foam molding processing approach that exploits the synergistic effects resulting from the deliberate conjunction of extrusion melt compounding and traditional rotational molding was successfully developed to address and alleviate the identified technological weaknesses of the conventional rotomolding process: the lengthy processing cycle time, the large energy consumption, and the lack of means for real-time process control. Several processing concepts went through a number of refinements and developments the latest of which has been prototyped, experimentally characterized, and verified. This rotational foam molding method has been recently patented and is referred to as Rapid Rotational Foam Molding (RRFM).This novel rapid rotational foam molding process is expected to advance the scientific knowledge in the field and influence the direction of thought and activity by creating the scientific and engineering potentials for eliminating the blowing agent nature-related limitations in the manufacture of advanced ultra lightweight multi-layered ultra low-density rotationally foam molded cellular composites with or without nano-fillers. The resulting new classes of ultra lightweight integral-skin rotationally foam molded cellular composites will be characterized with dramatically improved mechanical, strength-to-weight, insulative, and morphological properties that are currently not achievable.

9064 | On energy absorption behaviour of a metallic tube with honeycomb core (30. Porous and cellular materials)

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Sandwich structural members in the form of columns, beams and plates or panels are increasingly finding their structural applications in many fields of engineering predominantly due to their high strength to weight ratio. Besides, their applications in crash worthiness and mitigation are on steady rise primarily due to their high specific energy absorption and damping. The focus of this research is to analyse the specific energy absorption behaviour of an aluminium tube filled with a pattern of honeycomb core. This paper presents a detailed parametric study based on nonlinear finite element analysis on different thickness and pattern of honeycomb core within the tube which reveals a suitable one for increased specific energy absorption and crash efficiency as compared to a standard plain tube. The methodology of analyses and results are expected to be more relevant and significant to crash mitigation in automotive and aircraft applications.

9092 | The mechanical properties of a friction-stir-welded aluminum alloy (6005A) having a double skin structure for railway applications (30. Porous and cellular materials)

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This study describes friction stir welding (FSW) for double skin structure for the applications of railway car body fabrications. Typical double skin (hollow) structures made of aluminum alloy (6005A) were prepared for FSW, for which mechanical properties were evaluated with tensile tests and hardness measurement. A comparison is made with the conventional metal inert gas (MIG) welding method. The results showed that FSW produced significantly higher tensile/yield strengths than those of MIG. Various material characterizations such as X-ray diffractions (XRD) and electron backscattered diffraction (EBSD) were conducted to evaluate the microstructure of the welded parts.

9155 | BI-MATERIAL LATTICE WITH HIGH STIFFNESS AND STRENGTH FOR LOW THERMAL EXPANSION (30. Porous and cellular materials)

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Systems in space are vulnerable to large temperature changes when travelling into and out of the Earth's shadow. Variations in temperature can lead to undesired geometric changes in sensitive applications requiring very fine precision, such as sub-reflector supporting struts. To suppress such failures, materials with a low CTE over a wide range of temperatures are needed. Besides low CTE, these materials should also provide desirable stiffness, strength and extraordinarily low mass.

Bi-material lattices have been proposed as a potential family of low CTE materials [1, 2]. Lattices can deform by either bending or stretching of their constituents. The majority of low CTE lattice materials have low structural performance as they are bending dominated. Their mechanical performances are not well suited to fully satisfy the severe requirements of a space mission, such as ultra-light weight, extraordinary stiffness and strength. Lattices that axially deform under loading are more weight-efficient and thus suitable in lightweight structural applications [3]. In 2D, a triangle is generally the basic unit cell of most stretching-dominated lattices, as it is the only rigid polygon that can be constructed from inextensional pin-jointed struts. If the CTE of a triangle can be tailored, then a stretching dominated lattice can be modified to obtain a low, or even zero, CTE structure. In this paper we use triangular tessellation to create low CTE bi-material lattices. If a second material is introduced into these stretching dominated lattices, zero CTE can be achieved via compensation of thermal expansion and member rotation at the nodes. For certain topologies, the process can lead to a zero CTE in a specific direction at the cost of a large thermal expansion in the others. Thermal and mechanical anisotropy can thus become beneficial if the application requires it.

Asymptotic homogenization method is used in this work to characterize the mechanical and thermal performance, in particular stiffness, strength and CTE, of bi-material lattices. Four quadrant charts are used to map and compare designed low thermal expansion concepts with current structural concepts in literature. Proof-of-concept lattices are currently fabricated and their thermo-mechanical properties will be tested. The results show that the CTE can be tailored in a family of robust stretch-dominated lattices to avoid major penalization of their mechanical property.

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9174 | Effect of micropore clustering on mechanical properties of sintered porous metals (30. Porous and cellular materials)

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In a microstructural point of view, clustering of microstructure such as a segregation of secondary phase, reinforcement and pore, is phenomena that should be avoided. Non-uniform distributions of microstructural factors degrade the properties of materials. Porous metals fabricated by powder metallurgy also have the problems with clustering of pores, which are essentially occurred in sintering process. One of them is clustering of artificial pores and the other is clustering of micropores between sintered necks. Evolution of the micropores take place at areas near grain boundary due to insufficient driving force of diffusions so that micropores isolate inside of the grains. It is generally agreed that the clustered pores act as stress concentration site, and therefore influences significantly the mechanical properties such as the yield strength, the onset of damage, the ductility and fatigue crack growth. For this reason, a detailed understanding about relationships between the microstructure and properties is required for design and further development of materials. In present study, micropore clustering effects on mechanical properties of sintered porous metals was investigated. Representative volume elements (RVEs) of porous microstructures, having different magnitudes of clustering, were reconstructed using random sequential adsorption (RSA) algorithm. The compressive deformation was analyzed using three-dimensional finite element method (FEM).

9180 | Experimental Evaluation of Behavior of a Sandwich Structure With Metal Foam Core by Penetration of Spherical Punch. (30. Porous and cellular materials)

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The main objective on this work is study the behaviour presented by a sandwich structure, composed by two out layers in aluminium sheets, separated by a core in metal foam also in aluminium by penetration of a spherical punch. The structure is composed by two different materials, each one presents a different mechanical behaviour separately [1, 2]. The set up used in the present experimental work is composed by a punch, with a radius r, which imposes a displacement/force to a specimen fixed in its boundary. In these tests, were considered specimens with four different length; 25 mm, 50 mm, 75 mm and 150 mm. The values of force/displacement of the punch were registered and analysed.

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9182 | ANALYSIS OF COMPOSITE MEMBRANES IN THE SEPARATION OF EMULSIONS SUNFLOWER OIL/WATER (30. Porous and cellular materials)

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Among many membranes studied there are the ones called composites, which have as the main feature a combination of properties of different materials, for example, the combination of inorganic and organic. In a tangential flow process, the ceramic tube (supporter) is responsible for the mechanical strength of the membrane, yet the selective barrier of the membrane is established by the polymer to be impregnated into the inside of the tube. This study aims at the preparation of composite membranes α-alumina/polyamide 66 (PA66) to apply in processes of microfiltration in demulsification of water. For this purpose, ceramic tubes of α-alumina were impregnated internally with a solution of polyamide 66 (5% w/v) being formic acid used as solvent in the preparation of the polymer solution. The hydraulic characterization tests were conducted with pure water solutions and water-oil concentrations of 50, 100 and 200 mg · L-1. The tests were performed for the ceramic support (MD0), membrane of one (MD1) and two (MD2) PA66 layers, using a pressure of 150, 200, 250 and 300 kPa. The oil retention for the ceramic tube was approximately 55-80% for the membrane layer varied between 84-94% and the membrane with two layers maximum efficiency reached 98%.

9350 | Fabrication and Characterization of Fe doped TiO2 Membranes for Ultrafiltration (30. Porous and cellular materials)

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Fe doped TiO2 nanoparticles have been synthesized using a reverse micelle and sol- gel technique combined with metal alkoxide hydrolysis and condensation. The size of the particles and the thickness of the coating can be controlled by manipulating the relative rates of the hydrolysis and condensation reaction of TTIP within the micro-emulsion. The average size and distribution of synthesized Fe doped TiO2 nanoparticles was about in the size range of 10-20nm and Fe particles are 1-3nm. The intermediate layer of membranes was made with spherical SiO2 about 100nm. Fe doped TiO2 composite membranes were fabricated by slip casting. The FE-SEM image show the microstructure of the Fe doped TiO2 composite membranes was homogeneous. Average pore size of the support was about 0.125㎛ and the pore size distribution was narrow. The average pore size of the Fe doped TiO2 composite membranes have smaller than that of TiO2 composite membranes. It was observed that Fe doped TiO2 composite membranes showed a crack-free microstructure and narrow particle size distribution even after heat treatment up to 1100°C.

7672 | Crashworthiness of Carbon/Aramid fiber filament winding composite tube (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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Fiber reinforced composites with light weight did not exhibit the ductile failure mechanism which was related to metals. FRPs absorb lots of energy through progressive crushing modes by a combination of multi micro-crack, bending, delamination and friction. FRPs with half weight of traditional metals while absorb more than doubled energy. But FRPs were not used as energy absorption components in wide range; one of the most important reasons is their high manufacturing cost.
In this study, carbon fiber and aramid fiber were chosen as reinforcements and common epoxy resin was chosen as matrix to manufacture five types of different structures and raw materials of carbon/aramid and carbon/carbon fiber reinforced composite tubes through high productive and low cost winding method. Then specimens were dealt under 100°C condition for 100 hours, 200 hours and 400 hours treatment respectively. After that, energy absorption ability was tested by quasi static compression tests and microscope observation of cross section was taken to analyze the mechanism of failure. By optimizing different hybrid method, ratio and reasonable geometry shape of composites, low cost and high energy absorption components could be manufactured to put to use on vehicles.

7706 | Failure modelling of braided frames under bending loads (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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Braided structures consisting of carbon/epoxy composite are regarded as one promising concept for producing low cost, high quality components with improved damage resistance. Whilst composite structures can exhibit excellent energy absorption capability under compression, brittle fracture modes limit their energy absorption capacity during bending failure. Therefore, a virtual approach is beneficial to support the design process of large braided structural components securing sufficient safety standards for crash and impact events. In this scope an explicit simulation approach was developed by applying a macroscopic description for the braided material. The simulation was validated using the building block approach, investigating the numerical prediction capability of bending failure of braided frames. Presented results show potentials and limitations of a macroscopic explicit description for failure modelling of braided structures.

7713 | Calibration and validation of Ladeveze ply model for predicting the crush performance of energy absorbing structures made of carbon-fiber reinforced plastics (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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Lightweight car design is an important research field that will contribute to the reduction of emissions and the slow-down of climate change. Many researchers seek the replacement of metallic materials by fiber reinforced plastics to significantly reduce the weight of car body. While automotive engineers rely increasingly on performance predictions by simulation, predicting the behavior of composites structures in crash events remains a challenge. This paper presents a methodology for predicting the crash performance of energy absorbing cones made of unidirectional carbon fiber-epoxy laminates. The Finite Element simulations are performed with VPS/PAM-CRASH using the Ladeveze ply model for multi-layer shell elements. The material model parameters are derived from five experiments on flat specimens. Crash can simulation predictions are then compared to results of drop tower tests in terms of deformation and impact force histories.

7928 | Transition of longitudinal compressive failure mode in a unidirectional carbon fiber reinforced plastic (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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Kink-band failure is a typical mode of longitudinal compressive failure for unidirectional carbon fiber reinforced plastics (UD CFRP). It results from in-phase micro-buckling of fibers within the polymer matrix and is known as the primary cause of its low compressive strength. Many researches on the microscopic failure mechanism have been reported to reveal the resultant compressive strength. However, the transition of longitudinal compressive failure modes from fiber crush (pure compressive failure of the fiber) to kink-band failure has not clarified.
In this study, the transition between the two failure modes was studied using model composites. Carbon fibers were aligned and embedded in an epoxy matrix and the compression test was performed. The number of carbon fiber was changed from one to several thousands, by which the effect on compressive behavior was investigated. Longitudinal compressive failure mode was fiber crush when the number of carbon fiber was small. By contrast, it was kink-band failure when the number of carbon fiber was relatively large. The longitudinal compressive failure mode changed from fiber crush to kink-band with increasing number of fibers. Kink-band parameters, i.e. kink-band width and kink-band angle, were also changed dependent on the number of fibers, which could affect resultant compressive strength. The transition of longitudinal compressive failure mode and influencing factors to kink-band parameter was discussed.

8613 | The effect of defects on the crashing characteristics of CFRP square tubes (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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Experimental and numerical investigations into the crashing characteristics of weave carbon fiber reinforced plastic (CFRP) square hollow tubes with different holes in the walls were presented in this paper. The radius, the shape (circular, square and rhombic) and the location (opposing and adjacent) of the holes were varied respectively, and the significance of their effect on the peak force, energy absorption and failure mechanics of the tubes were evaluated under the axial crushing tests. It was shown that a slight influence in the peak force and a significant reduction in the energy absorption capability were occured in the tubes with defects compared to those without defects. The radius had a stronger influence on the crashing characteristics than the shape and location. The increase in radius of hole led to the about exponential reduction in specific energy absorption. The finite element analysis closely predicted the failure modes of the tested specimens, and showed a significant stress and strain increase around the holes under the crushing, thereby causing the mid-length collapse of tube.

9029 | Experimental characterization of hybrid material systems consisting of sheet metal and advanced composites (31. Crashworthiness of Textile Composite (Yu-Qiu (Amy) YANG, Donghua University, China))

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1. Introduction
Motivated by efficiency goals and upcoming strict EU-regulations for CO2 emissions [1], lightweight design plays an increasingly important role in automotive engineering.
Novel materials are one way to reduce the weight of the body-in-white while simultaneously meeting the growingly stringent crash safety requirements. Advanced composites like carbon or glass fiber reinforced plastics (cfrp/gfrp) exhibit weight specific crashworthiness characteristics that, though strongly dependent on the composite's constituents and their arrangement, mostly outrival those of metals [2–4]. Metals in turn offer relatively cost efficient solutions with well understood and stable energy absorbing mechanisms. This study explores the possibilities to form synergetic "hybrid" combinations of those different types of materials aiming to exploit their respective benefits in future crash structural applications.
Studies by Bouchet et al. [5], Wang et al. [6], Kim et al. [7] and Bambach et al. [8] that focus on hybrid steel or aluminum crush tubes externally reinforced with advanced composites have found a significant weight saving potential compared to conventional solutions. Uriayer [9] and Mildner [10] performed quasistatic tension and bending tests on hybrid coupon specimens to isolate material effects and found a bilinear response in the stress-strain curve before and ductile behavior after laminate fracture, which generally indicates auspicious characteristics for automotive crash structural applications.
The main goal of this extensive study is to experimentally identify basic mechanisms within hybrid material systems on a coupon level. Different loading conditions and the effects of a broad variation of major material parameters are being investigated. A full bibliography will be included in the final paper.
2. Experimental procedures
The coupon specimens consist of a flat sheet metal strip with a composite laminate adhesively bonded to its surface. The variation of material parameters results in a broad set of hybrid material combinations and includes the type of steel and reinforcing fibers as well as the layup and the thickness of the laminates. The specimens are tested under quasistatic and dynamic tension and 3-point-bending (from both sides) on Instron machines. Additional experiments are at the planning stage.
3. Results
A number of different constitutive mechanisms during loading and controlled failure can be observed. One striking example would be the effect of the

loading direction on the bearable load and thus the total energy absorbed in 3-point-bending. Having the cfrp-laminate on the pressure loaded side results in twice the amount of absorbed energy during plastic deformation than vice versa. The full scope of findings and their implications concerning hybrid automotive crash structural applications will be discussed in the final paper.

7710 | Prestressed Concrete Beams under Fatigue Loading with Strengthened with Textile Reinforced Concrete (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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A large part of the existing highway bridges in Germany exhibits calculative shear capacity deficits under static and cyclic loading. More structures are expected to demand refurbishment and strengthening within the next years, especially due to the current conditions of many older road bridges in Europe. Since a re-construction of the respective bridges is not reasonable or financially feasible in many cases, the assess-ment and development of effective strengthening methods becomes more important.
Many strengthening methods have proven to be suitable for the shear strengthening of bridges, e.g. addi-tional external prestressing, additional concrete layers, additional steel reinforcement in slots or glued CFRP-stripes (Carbon Fibre Reinforced Polymer). However, the applicability and effectiveness of these methods are also influenced by some disadvantages. Besides these common strengthening methods, the use of textile reinforced concrete (TRC) offers an innovative alternative for strengthening measures by combining the advantages of lightweight glued CFRP-stripes and additional concrete layers, which pos-sess better bond characteristics and lower temperature sensitivity. As the textile reinforcement does not require protection against corrosion, thin layers of reinforcement are possible.
For the above reasons, two full scale tests on I-shaped prestressed concrete beams (h = 0,7 m, l = 6,5 m) under cyclic shear loading were carried out at the Institute of Structural Concrete at RWTH Aachen Uni-versity. Previous tests on identical non-strengthened beams served as a reference for the tests on members strengthened with textile reinforced concrete. The paper presents the test results with regard to the effec-tiveness, advantages and possible fields of application of this innovative strengthening method.

8081 | The Effect of Fiber Entanglement on Dry Carbon Fiber Tows (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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One of the main drivers of the limited use of carbon fiber composites is the raw material cost. To bring this cost down, tows with higher fiber counts (~50k fibers) are becoming more popular. These so-called “heavy tows” carry with them several challenges in manufacturing and a decrease in performance. One aspect that affects the performance and manufacturability of heavy tows is the degree of fiber entanglement. Highly entangled tows may increase the manufacturability because it binds the tow together, but non-aligned fibers result in decreased stiffness in the tow axial direction in the final part. The present research looks at the effects of entanglement on the mechanical response of a dry tow under different loading conditions using multiple models, such as a representative volume element (RVE) and a fiber-scale finite element model. Comparison is made between the models with and without entanglement, and finally compared with laboratory experiments which contain entanglement. Finally, conclusions will be drawn about the necessity of including entanglement in predictive models to predict the behavior of dry carbon fiber tows during manufacturing.

8146 | Improving adhesion at the fibers/matrix interface in FRCM for masonry strengthening (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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Structural reinforcement system constituted by coupling of network (carbon, PBO, glass, or basalt fibers) and inorganic binder (either cement or lime based) seems to acquire an increasing interest in applications to masonry structures, due to many advantages compared to more traditional reinforcement systems. The effectiveness of these interventions strongly depends on the bond between strengthening material and masonry, on the fibers/matrix interface, as well as on the mechanical properties of the masonry substrate.
This work aimed at studying the effectiveness of a pre-treatment finalized to improve the bond between fibers and inorganic matrix, in particular carbon and basalt net. This special treatment would be able to improve the bond between the net and the matrix, keeping the network flexible and easy to apply. This pre-treatment consists in pre-impregnating the net with epoxy resin, and then in sandblasting the impregnated net itself in order to improve adherence with inorganic matrix.
In fact, experimental works reported in the literature show that the main problem of FRCM is the debonding at fibers/matrix interface, and this is due to the lower adhesive capacity of the inorganic matrix (compared with that of epoxy resin in FRP), and also because the matrix is unable to completely wet the fibers. Consequently, only the outer filaments of a roving can really have an adhesion to the surrounding concrete while the rest can slip easily within the roving at low friction (the so called ‘telescopic effect’). The relatively slippage between the filaments reduces the transfer of stress fibers/matrix and the effectiveness of this reinforcement system. The use of a pre-impregnated and sandblasted net with improved adhesion can reduce the slippage effect with a consequent increase of the mechanical properties of the reinforcement.
Preliminary results showed that this technique could be very promising for improving reinforcing ability of FRCM with respect to conventional FRCM reinforced by means of carbon net.
The mechanical properties of the FRCM systems were studied by means of two different tests: tensile tests on composite reinforcement system and debonding tests of the strengthening applied to masonry substrate.
For the tensile test, the specimens are constituted of two layers of mortar and a layer of fiber grid located in the middle with an overall thickness that is no more than 10 mm. After 28 days of curing the tensile tests were carried out under displacement control, with an initial rate between 0.1 and 0.6 mm/min and, after the cracking phase, a rate increased to 0.5-1.2 mm/min, on five samples for each reinforcement system.
For testing the debonding with respect to masonry substrate several “double-lap” tests were carried out. The general scheme of the “double-lap” test set-up consists of a steel frame composed of two transversal beams (or a beam and a plate) connected by two or four bars. The alignment between the specimen and the loaded ends were ensured by means of spherical joints in order to avoid normal stresses at the reinforcement-to-substrate interface. Furthermore, in order to guarantee equal loading of the two composite strips, the textiles were placed around a cylinder with a diameter equal to the

distance between the two textile strips. By doing so, the total load can be equally subdivided between the two sides of the specimen. The slippage between substrate and reinforcement was derived after the test by post-processing test data. Tests were carried out under displacement control at a rate lower than or equal to 0.3 mm/min, on five samples for each reinforcement system.

8587 | Intraply Shear Characterisation of Carbon/Epoxy Prepregs for Automotive Press-forming Applications at Appropriate Temperatures and Strain Rates (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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After the recent environmental regulations about the low carbon dioxide emissions to the atmosphere, the automotive industries have been seriously working to develop lightweight composite body structures for the new commercial cars. The nature of work for the automotive industries necessitates developing high volume manufacturing processes and very short cure cycle materials. The present work is carried out in the scope of VARCITY project. Intraply shear behaviour on the newly developed Carbon/Epoxy based thermoset prepregs has been studied. Two different types of prepreg materials having 2x2 twill weaves with aerial weights of 240gsm and 400gsm have been investigated. The viscosity of the resins and prepreg cure cycles in the press-forming processes are also different. The shear characterisation has been made at the strain rates and temperatures relevant for the prepreg compression moulding process and also appropriate for high volume manufacturing of structural composites. The two de fact standard tests of 'picture frame' and 'bias extension' have been used for measuring the shear behaviour of prepregs. It has been observed that the intraply shear behaviour as well as the drapeability of thermoset prepregs is largely dependent upon the selection of testing parameters. Further to the above, the tests have also been conducted on the dry fabric reinforcements of the two selected prepregs. The results have been compared with the temperature dependent behaviour of the prepregs. It has been found that the shear behaviour of the dry fabric falls at some stage in-between the prepreg material temperature dependent states. It can be concluded with these investigations that the resin that resists at some stage to the scissoring of the woven reinforcement assists to shear more easily on another state of the material. Some further investigations related to the stitched aligned-fibre thermoset prepregs are also in progress.

8707 | Tribological characteristics of Carbon/PVDF composites (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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Carbon fibers are widely used as low friction material such as bearing material because of its advantageous mechanical, chemical, and frictional properties. Poly(vinylidene fluoride) as matrix of composites has low friction coefficient due to high electro-negativity of fluorine. However, the Carbon/PVDF composite has poor interfacial interaction between PVDF and carbon fiber. In this study, the carbon fiber was sized using the PVP (Polyvinylpyrrolidone) to improve the interfacial interaction due to strong dipolar interaction between the carbonyl group (C=O) of PVP and C=F2 group of PVDF. The interfacial interaction between PVDF and PVP sized carbon fiber was investigated by short beam shear (SBS) test. The tribological characteristics of Carbon/PVDF composites were studied using a pin on disc tester and the wear mechanisms of the Carbon/PVDF composites are discussed based on the SEM result of the worn surfaces.

8719 | Investigation of the Acoustic Insulation of Polyester and Acrylic Fabrics Coated with White Tuff Stone Powder (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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In this study; polyester microfiber, polyester and acrylic fabrics were coated with the white tuff stone powder (Alacatı stone) with different particle sizes. And then, the acoustic insulation of samples was investigated on the bases of fabric types. Furthermore, the effect of particle size on acoustic insulation of samples was investigated. Sound absorption coefficient of materials was measured in accordance with ISO 10534-2 standard by using a measuring instrument of Brüel & Kjaer Impedance Tube, which is based on two microphone transfer function method.
According to the results, it is advised that the white tuff stone powder can be used in building textiles in order to increase acoustic insulation properties of the walls.

Keywords: White Tuff Stone, Polyester Microfiber, Polyester Fiber, Acrylic Fiber, Acoustic Insulation, Coating.

8722 | The Evaluation of Thermal and Acoustic Insulation of Different Particle Size Perlite Coated Materials Having Gecko Properties (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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In this study, different particle size perlite coating material applied to polyester microfiber fabric in order to provide thermal and acoustic insulation. Besides this work, the back side of this fabric was coated with a polymer having gecko effect and therefore the fabrics had permanent sticking properties. The acoustic and thermal insulation properties of the samples were analysed.
In order to improve the thermal and acoustic insulation properties, the perlite was used together with polyurethane based coating material, isocyanate based cross linking agent and acrylic based synthetic thickener materials. In order to provide gecko effect, polyacrylic based polymeric material was used.

Key word: Perlite, Thermal and Acoustic Insulation, Gecko Effect.

8800 | A new method on the elastic properties of stitched composites (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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Stitched composites strengthens the Z-direction mechanical properties by add stitches in the thickness direction, overcoming the weak impact resistance, damage tolerance and low defects in thickness direction of the traditional laminate, which has a wide range of applications in engineering practice. Accurately predict the mechanical properties of stitched composites, is a prerequisite for its application and development. In this paper, a stiffness model is developed he flow around the column - suture analogy model. Compared with experiments, the predicted data fit well.

9209 | Analysis and modelling of physical and mechanical properties of 2D and 3D circularly braided composites. (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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This paper gives an overview of the main characteristics of circular braid manufacturing processes with special attention to the interaction between process parameters and structural, mechanical properties of braided preforms. Circular 2D and 3D interlock processes are considered.
The analytical relationships between specific parameters of the manufacturing process and the structural characteristics of the braid in the case of complex- shaped mandrels are described.
Analytical modelling approach of the influence of process parameters, corresponding to a transient or a steady state production phase, on the final structure of braids is presented too. The model is successfully compared to other analytical models found in the literature. Additionally, the analytical model is validated experimentally for the case of 2D and 3D circular braiding processes run in transitory stage.

The analysis of the structure of the braid in the final composite is approached using non-destructive tests, such as X-ray tomography, allowing through the depth analysis of the composite product in the case of different braided composites.

Mechanical properties are estimated on braided composite tubes using classical testing and extensometry methods. Individual or combined tensile, torsional and internal pression tests allow to analyse the variation of the mechanical properties as a function of the braiding angle. The terms of a generalised Hooke's law are established, based on a plain stress approach. Elastic constants are obtained depending by an optimization step considering the relations ships relative to the different tests.

9698 | Minimum-weight design for three dimensional woven composite stiffened panels using neural networks and genetic algorithms (32. Textile Structural Composites (Prasad Potluri, University of Manchester, UK))

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The paper describes an optimization strategy applicable for the design of structural components made of 3D woven composites. This type of materials includes several design variables describing the material topology that can be used to optimize specific structural performance indices. However, any optimization strategy requires a multi-scale hierarchical approach ranging from the description of the fibers, the yarns, the mechanical properties of the material at the scale of a Representative Volume Element, till the macro-mechanical properties of the structural component. Consequently, the optimization could result computationally expensive, especially in the case of non-linear structural problems.

A modeling strategy is here proposed for the multi-scale analysis and optimization. The procedure is based on combining the commercial code Abaqus for the Finite Element analysis, and ad hoc developed scripts written in Matlab and Pyton language for the optimization. In particular, artificial neural network techniques are utilized to generate an approximate response of optimum structural design in order to increase efficiency and applicability. The artificial neural networks are integrated with genetic algorithms to optimize mixed discrete-continuous design variables for 3D woven composite structures.

The proposed procedure is then applied to the multi-objective optimal design of a stiffened panel made of 3D woven composite subject to buckling and post-buckling requirements.

7537 | Interpenetrating phase composites: new opportunities for multifunctional materials (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Recent advances in aerospace, automotive, defense, energy, and semiconductor industries require new materials and structures to have superior combinations of high performance, light weight, affordability, and versatility. This promotes the development of innovative multifunctional materials that integrate at least one other function beyond the mechanical. Composite materials can be designed to have integrated thermal, electrical, magnetic, optical, mechanical and possibly other functionalities to provide a unique combination of the individual capabilities. Interpenetrating phase composites (IPCs), also known as co-continuous composites, have been proposed to improve the dispersion and to increase the volume fraction of reinforcing phase(s) over conventional composite materials. Here, we demonstrate the potential to design and fabricate periodically ordered polymer IPCs. These IPCs are shown to have a unique combination of stiffness, strength, and energy absorption, as well as damage tolerance. The results provide guidelines

to advance the digital design (materials by design) and manufacturing concepts (advanced manufacturing) into the realm of engineered materials with desired properties and further to create multifunctional materials. For example, the periodic nature of the structures enables mechanically tunable phononic band gap materials, and tunable sensors in tissue engineering.

7662 | Development of organic aerogels reinforced with carbonaceous nanomaterials (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Aerogels are currently claimed as one of the most promising materials for different applications such as aerospace, high temperature insulation, cryogenic applications, refrigeration systems, outdoor clothing and building insulation [1]. Aerogel [2,3] is a synthetic porous ultralight material derived from a gel, in which the liquid component of the gel has been replaced with a gas. Basically, an organic polymer aerogel is an aerogel with a framework primarily comprised of organic polymers. They are generally less crumbly and brittle than inorganic aerogels. The most common method to obtain wet gels is sol gel process [4,5]. Nevertheless, the resulting products have some disadvantages such as low porosity, low flexibility and low lightness. However, the freeze-drying method, in which the pore liquid is frozen and then sublimed in vacuum, allows the production of porous aerogels with interesting insulating behavior [6]. This method is simple, low-cost and environmentally friendly. Up to date, few works have been reported about the freeze-drying process to produce organic aerogels [7-9].
Carbonaceous nanomaterials are widely employed as reinforcements to form carbon-reinforced composites which have exhibited enhanced mechanical, electrical and functional properties compared to monolithic materials [10]. Carbon nanofibers or nanotubes (CNF, CNT), carbon nanospheres (CNS), reduced graphene oxide (RG) and, graphene oxide (GO) exhibit outstanding physical and mechanical properties, including high surface to volume area, high Young´s modulus, low coefficient of thermal expansion and an entangled structure. Therefore, the mechanical properties and the thermal and the electrical conductivity of the organic aerogels could be enhanced with the addition of these nanomaterials.
In the present study, the synthesis of carbon nanostructured-reinforced aerogels were studied using freeze-drying method. Furthermore, the physical, morphological and mechanical properties of the final aerogel composite were evaluated using different characterization techniques (X-ray diffraction (XRD), N2 adsorption/desorption static volumetric apparatus, transmission electron microscopy (TEM), emission scanning electron microscopy (ESEM), thermogravimetric analyzer (TGA), dynamic mechanical analyzer (DMA), IR spectroscopy (FTIR) and Helium pycnometry).

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7749 | Mechanical and rheological characteristics of carbonyl iron based magnetorheological elastomer composite (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Magnetorheological (MR) elastomer composites, composed of magneto-responsive magnetizable particles such as carbonyl iron dispersed in an elastomer matrix, are one of the most interesting smart composite materials along with MR fluids, while in the MR elastomers the matrix is an elastic body and in the MR fluids the matrix is a liquid medium [1]. Along the magnetic field directions, the particles orient themselves under an applied magnetic field. Mechanisms that give both MR elastomers and MR fluids physical properties of interest for applications take place as a function of the applied field intensity and of the magnetic properties of the particles [2]. Thereby, MR elastomers can be used in practice such as engine mount, shock and vibrations absorbers, etc [3].
In this work, both isotropic and anisotropic composite magnetorheological (MR) elastomers were fabricated based on silicone rubber and well chosen proportions of MR suspensions which are based on silicone oil, stearic acid and soft-magnetic iron carbonyl, and then plane capacitors were manufactured. Among various magnetic materials of magnetite, iron oxide and carbonyl iron (CI) particle, the CI was selected due to its high magnetic permeability and low hysteresis in this study. In the case of the anisotropic MR elastomer sample, it was cured while an external magnetic field was being applied. Therefore the CI particles were pre-aligned in the direction of the applied magnetic field. The influence of the magnetic field intensity upon the obtained capacity of capacitors is studied. From the capacity and rheological measurements, the tension state and the deformation induced by the transverse magnetic field intensity inside composite MR elastomers are determined. MR effect of these MR elastomer samples was measured using a rotational rheometer under external magnetic fields [4]. Results showed that as the magnetic field strength increases, storage moduli depending on the angular frequency are observed to be increased at a constant shear strain.

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Keywords: Magnetorheological, Elastomer, Composite, Carbonyl iron

7768 | Vibration of Porous Beams with Embedded Piezoelectric Sensors and Actuators (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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A micromechanics-based method is proposed to study the vibration of porous beams with embedded piezoelectric sensors and actuators. The proposed method is a two-step process. First, the porous polymer matrix is analyzed using the classical Mori-Tanaka method. Next, the piezoelectric sensors and actuators embedded in the porous beam are analyzed using Eshelby's equivalent inclusion method. The natural frequency of the beam is determined from the variational principle in Rayleigh quotient form. In addition, the Euler-Bernoulli beam theory and Rayleigh-Ritz approximation technique are used in the analysis. A parametric study is conducted to investigate the influence of the volume fraction, shape and orientation of the pores on the natural frequency of the beam. The results of the study show that the presence of porosity can significantly affect the natural frequency of the beam.

7883 | Electrostatic Adhesion in Composite Structures (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Efficient load bearing structures are, for the most part, optimised for a given load case or operational environment. As a result, off-design point operation leads to a performance compromise. Introduction of structural functionality could increase the adaptability of global structures or products and minimise this compromise. The concept of adaptable structures could be applicable for a range of applications, from aerospace components to consumer products. This paper considers the incorporation of existing electroadhesive technology, primarily used (to date) in wall climbing robotics, for the purpose of providing reversible adhesion within composite structures. The use of controllable internal structural connectivity to introduce variable global stiffness to composite structures is investigated in some detail. Further potential applications of electrostatic latching of composite structures are also considered. Flexible copper-polyimide laminate material is etched to produce the electroadhesive elements, allowing for high resolution interdigitated electrode designs with thin film dielectric coatings down to 25 µm in thickness. The use of glass fibre reinforced epoxy pre-preg allows for the incorporation of the electrode elements during the primary manufacturing process, showing scope for value-added structural functionality, with minimal additional fabrication complexity.

8035 | Plasmonic and Carbonaceous Composite Nanostructures for Versatile Applications (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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In the presentation we introduce a comprehensive approach for the design and synthesis of multifunctional hybrid nanomaterials that have been systematically tailor-designed to seek their potential applications as key elements in green nano- and bio-technology. Representative subject areas of interest include energy conversion and storage, environmental remediation, optical (bio-)sensing, light-emission, and memory devices. Of the numerous methodologies to achieve these goals, we actively utilize complementary self-assembly processes to construct well-defined hybrid nanoscopic objects suitable for target-oriented applications. Recently, we also pay special attention to surface plasmons as a versatile platform,[1,2] based on which target-oriented properties can be obtained by integrating plasmonic nanostructures into the elements of optical (bio-)sensors, photovoltaic devices, photocatalysts, and light-emitting materials.
Another class of advanced functional composite nanomaterials include hybrid carbonaceous materials fabricated from 'direct carbonization' of block copolymer templates containing inorganic precursors. This protocol opened a creative pathway to the generation of hierarchical carbon-semiconductor inverse opals, mesoporous structures and 2D nanopatterns, which showed viable function and enhanced performance in solar cells, photocatalysis, electrocatalysis, sensing, etc.[3-6]
In surramy, I'll introduce our recent activities with a special focus on the synthesis and applications of active nanomaterials for highly selective/sensitive sensing, plasmonic dye-sensitized solar cells, visible light active photocatalysis, and enhanced fluorescence.

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8166 | Potential of Cyanoacrylate as Structural Adhesive for Fibre Reinforced Polymer Composites (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Many research articles [1-3] have been published on the propensity of the fibre reinforced polymer (FRP) composite material to develop micro-cracks. This type of damage has been reported as the genesis of progressive failure, debonding, macro-cracks, structural disintegration etc. in composite. One way of mitigating this minuscule damage is through autonomous repair--developing a smart structure with inherent damage repair capabilities. This methodology is also known as self healing. The effectiveness of the named intrinsic repairing technique mainly depends on the capabilities of the repairing chemical(s) in; bond strength, shelf life, prerequisite treatment, curing time and condition, and viscosity. Among the potential adhesives available, few meet the stringent conditions necessary to carry out an autonomous healing.

This article reports the potentials of cyanoacrylate (CA) adhesive as a structural adhesive for FRP materials. CAs are well known to be rapidly curing, single part adhesives. This makes them ideal for autonomous repair of composites to counteract early damage progression. The tests reported in this article examine the influence of the CA on the mechanical response of functional self healing glass-polyester samples. The samples were subjected to pre and post-repair flexural tests for damage initiation and evaluation of the adhesive effectiveness. The results indicate that the adhesive was instrumental in the recovery of the samples' mechanical properties. Also, the effects of the interactions between the polymer matrix and the adhesive, and the glass fibres and adhesive were experimentally investigated. These were carried out after the fracture toughness of the CA bonded glass-polyester coupons had been determined through double cantilever beam test. It was found that the CA adhesive profoundly enhanced the mode-I fracture toughness of the FRP samples.

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8523 | Multifunctional composites with radar absorbing and flame retardant properties (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Many different properties can be combined to create a new item with composite materials due to their suitability for achieving multi-functionality with the best characteristics of different materials. In this study, the aim is the formation of a novel material for applications across different scientific disciplines. In this regard, two types of materials were added to a polymer matrix to obtain radar absorbing and flame retardant properties. In order to reinforce an epoxy, barium hexaferrite particles and huntite/hydromagnesite minerals were utilized for multifunction property. By adding those materials to the polymer matrix (resin) with different loading level, different types of coated samples were obtained. Subsequently, the samples were characterized by radar absorbing test and flame-retardant test besides other characterization tests; FTIR, SEM, XRD, scratch, surface profilometer, etc. It was concluded that these materials exhibited a synergetic beneficial effects.

8553 | Hybrid epoxy/carbon fibre composites containing nano/micro silica particles (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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The work describes the manufacturing and testing of novel hybrid epoxy/carbon fibre composites (CFC) with silica micro and Poly Diallyldimethylammonium Chloride (PDDA)-functionalised nanoparticles. A specific chemical dispersion procedure was applied using the PDDA to avoid clustering of the silica nanoparticles. The influence of the various manufacturing parameters, particles loading and mechanical properties of the different phases has been investigated with a rigorous Design of Experiment (DoE) technique based on a full factorial design (2131). The matrix phase reinforced with silica nanoparticles provided superior tensile modulus (10%) and strength (7%) compared to the specimen with silica microparticle dispersions. However, the use of 2wt% of silica nanoparticles provided not only an increase in tensile modulus but also a decrease of the tensile strength of the matrix phase. The tensile modulus of pristine epoxy resin was increased when adding silica particles. The use of silica nanoparticles was seen as beneficial for the tensile strength only at a 1wt% loading. PDDA functionalised silica nanoparticles were able to provide a homogenous dispersion, with a decrease of the apparent density and enhancement of the mechanical properties in the hybrid CFCs. The apparent density of the CFCs reduced nearly of 3% when the silica microparticles were replaced by silica nanoparticles. The particle loading increasing leads to reduce the density of CFCs. The main factors influencing the tensile modulus were the silica particle sizes and their weight loading, with higher stiffness when the CFCs were manufactured using 2wt% of silica nanoparticles. An interaction effect significantly affected the tensile strength, revealing superior strength when using 2wt% silica nanoparticles. The interaction between factors significantly affected the flexural modulus and strength of the CFCs, showing improved mechanical performance when 2wt% loading of silica nanoparticles was added.The microstructural analysis and correlation between the tensile modulus and strength data indicated a strong matrix/fibre adhesion existing in the CFCs. The strength of the hybrid composites is strongly influenced by the interfacial condition, while the modulus is more affected by the stiffness of the matrix. The hybrid CFC reinforced by 2wt% of silica nanoparticles coated with PDDA demonstrated superior mechanical properties compared to the reference pristine condition (without particles). For these new hybrid CFC silica composites, the flexural modulus featured a significant improvement (47%), and a noticeable enhancement of the tensile strength (5.6%).

8666 | Aligned discontinuous fibre hybrid composites (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Keywords: Discontinuous reinforcement, Aligned short fibre composites, Intermingled hybrids

Abstract
Hybrid composites, made with different types of fibres that provide a balanced suite of modulus, strength and ductility, allow avoiding catastrophic failure that is a key limitation of composites. The aim of this research is to manufacture intermingled hybrid composites using highly aligned discontinuous fibres to achieve pseudo-ductility through fragmentation of the lower elongation constituent. The HiPerDiF (High Performance Discontinuous Fibres) method [1], recently developed at the University of Bristol, is a unique fibre orientation method that uses a momentum change of fibres suspended in a low-viscosity fluid to achieve a high level of fibre alignment. It was previously noted that tensile modulus, strength and failure strain of aligned discontinuous fibre composites were close to those of continuous fibre composites provided that the fibres are accurately aligned and their length is sufficiently long compared to the critical fibre length [2]. This novel process can also produce a wide range of hybrid preforms or prepregs with different fibre mixing ratios. In this work, the overall stress-strain response of intermingled hybrid composites is investigated with variations of fibre type and ratios by the HiPerDiF method. To analyse the experimental results, the modelling approach developed by Jalalvand et al. [3] for continuous fibre hybrids is applied to intermingled aligned short fibre hybrid composites. The experimental results show that combining high modulus carbon and E-glass can result in a very good pseudo-ductile tensile response.

Acknowledgements
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8670 I MASTERBATCH OF CELLULOSE BASED POLYMER COMPOSITES (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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In the last two decades the number of reviews and scientific papers published on cellulose research increased exponentially. This is due to the fact that cellulose has been recognized as an emerging renewable material owing to their fascinating physico-mechanical properties derived from its structure. In addition, irrespective of its source, cellulose is biodegradable, presents low toxicity and it is a natural raw material, which can answer to the unwearying and increasing demand of environmentally friendly, sustainable and biocompatible products from consumers, industries and governments [1-3].
The available research works provide a depth analysis and comprehensive knowledge about issues as cellulose extraction, preparation, chemical composition, treatment, morphology, properties and characterization. Furthermore, its suitability for use in very different application areas such as additives in food, reinforcing agents for use in bio-based composite materials, biodegradable films and barriers for food and pharmaceutical packaging, texturing agents in cosmetics, porous dense aerogels for electronics and medicine, medical implants and devices, automotive components, among others that were also investigated in detail and properly reported in literature [1-6]. It is well recognized that cellulose is very attractive for use as reinforcement in the preparation of bionanocomposites. Therefore, it is common to see weak filler-matrix interactions because cellulose presents compatibility problems with hydrophobic matrices. Its highly hydrophilic surface leads to low resistance properties which are not intended in many potential applications. The improvement of compatibility with non-polar materials requires chemical modifications, so there are still some challenges related to cost-effective methods to produce cellulose biocomposites, due to its difficult dispersion in a polymer matrix and interfacial adhesion. Therefore, more research targeting using environmentally-friendly and industrial practicable methods of cellulose modification is required. In this work composites of carrot cellulose dispersed in PEO matrices were prepared without addition of any coupling agent. The initial idea was to demonstrate if that blend can or cannot have a masterbatch function. Synthetic polymers, such as PE and PCL, were added to masterbatch.
Another topic which requires more attention from research community is the processability of cellulose with thermoplastic materials. Thermoplastics can be processed by usual technologies such as extrusion, injection molding, sheet extrusion, blow molding and thermoforming. A bioextruder equipment was used in this work to process masterbatch biocomposites. Processed and non-processed cellulose polymer composites were analyzed by DSC, TGA, FTIR, SEM and DMA.

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8998 I FULLY COUPLED NONLINEAR ELECTRO-THERMO-VISCOELASTIC ANALYSES OF SMART COMPOSITES (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Ferroelectric ceramics of fibrous and particle shapes are often added in polymer matrix to form flexible and compliant electro-active composites. The ferroelectric ceramics experience hysteretic polarization response under cyclic electric fields while the polymer matrix exhibit viscoelastic response. Both ferroelectric inclusions and viscoelastic matrix can dissipative energy when subjected external electrical and mechanical stimuli, which is converted into

heat and thus increasing the temperature of the composites. The properties of materials generally depend on temperatures; thus, the dissipative effect leads to a fully coupled electro-thermo-mechanical response in active composites.
This study presents a simplified micromechanical model to predict the effective electro-thermo-mechanical behaviors and time-dependent micro-macro field variables due to coupled heat conduction and nonlinear electro- thermo-mechanical deformation of smart composites that takes into account the dissipation of energy from the viscoelastic constituents and hysteretic polarization response of ferroelectric ceramics. The studied active composite comprises of ferroelectric fibers dispersed in polymeric matrix. A nonlinear rate-dependent constitutive model for describing hysteric polarization and strain responses is used for the ferroelectric fibers, while the matrix is assumed to follow linear viscoelastic response. The constitutive model for the heat flux follows the classical Fourier law. A time integration algorithm for simultaneously solving the equations that govern the heat conduction and electro-viscoelastic deformations of isotropic materials is developed. The algorithm is then incorporated with the micromechanical model together with the macroscopic energy equation to determine the effective coupled electro-thermo-viscoelastic response of the active composites. The integrated micromechanical-FE framework is used to analyze coupled heat conduction and deformations of electro-viscoelastic composite structures. The effect of mismatches in the properties of the constituents in an active composite on the effective field coupling responses in the active composite is studied.

9167 | Optimization of constrained viscoelastic damping treatments (33. Multifunctional and smart composites (Rui Moreira, Univ. Aveiro, Portugal and Ever Barbero, West Virginia University, USA))

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Viscoelastic damping treatments are efficient solutions for passive vibration control of light structures. When constrained layer damping configuration is used, especially when following a partial location procedure, it is difficult, even for the experienced designer, to identify the optimized design parameters. Thickness of layers, location of damping patches and material properties should be properly selected in order to maximize damping effect, while reducing treatment cost, added weight and structural modification in general.
This work explores the use of generic algorithms as an optimization tool in order to identify general guidelines to aid the structural engineer during the design of partial damping treatments or treatments with variable thickness.
A general result, based on the analysis of strain energy of homogeneous damping layer, was observed. According to the results obtained, the distribution of the shear strain energy developed inside the viscoelastic layer for an homogeneous distribution is a good indicator for the best location strategy or defines a good trial configuration for a variable thickness treatment.

7556 | The CGSM for static finite element analysis of composite structures with variability (34. Probabilistic methods (Marcin Kaminski, Univ. Lodz, Poland))

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In this paper, the Certain Generalized Stresses Method (CGSM) is developed for probabilistic analysis of laminated composite structures modeled by finite elements. The material properties are considered as random parameters and are represented by random fields. A random field is discretized by the Karhunen-Loève expansion and two approaches are used: the midpoint method and the local average method. The CGSM is based on the assumption that the generalized stresses are stable even with the presence of uncertain parameters. An explicit expression of the displacement at a point is obtained by using Castigliano's theorem. The mean value, the standard deviation and the distribution of the displacement can be evaluated by a Monte Carlo (MC) Simulation using this expression. For calculating the variability of a displacement, only two nominal finite element analyses with the standard finite element software Abaqus are required, then a post-processing stage is performed. In addition to the displacements, the variability of strains, stresses and failure criteria can also be evaluated. Two examples, a two-layer bending plate and an eight-layer bending plate, are studied. The results are compared with those obtained by the direct MC Simulation, considered as a reference, and those presented in the literature. The comparison shows that the CGSM + MC approach provides quite accurate results and highlights the high computational efficiency of the method proposed.

8284 | 2 AND 3D PROBABILISTIC HOMOGENIZATION OF THE CARBON FIBER-REINFORCED POLYMERS (34. Probabilistic methods (Marcin Kaminski, Univ. Lodz, Poland))

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The main aim of this paper is determination of basic probabilistic characteristics of the homogenized elastic properties [1] for the perfectly periodic carbon fiber reinforced polymers. The homogenization problem, solved thanks to the Stochastic Finite Element Method implemented according to the stochastic perturbation technique, is related to the cubic Representative Volume Element (RVE) as well as to its 2D counterpart, where the plane perpendicular to the fiber direction is considered. The 3D homogenization scheme is based on numerical determination of the strain energy of the CFRP Representative Volume Element under uniaxial and biaxial constant deformations and a comparison to the homogenized RVE and this is done thanks to an application of the FEM system ABAQUS with its 8-noded brick solid finite elements [3]. The entire series of the solutions are numerically available in the FEM context because of an application of the Response Function Method (RFM) [2], where polynomial approximations of the homogenized tensor components in addition to randomized material parameters of the CFRM composite are recovered in the system MAPLE thanks to the Weighted Least Squares Method scheme. Alternatively, the 2D simulation is based on the stress averaging over the RVE that result from its static equilibrium under periodicity conditions on the outer edges of the CFRP cell and specific stress boundary conditions at the carbon fiber – polymer matrix interface. Once more, the RFM is applied to determine the additional polynomial representations of the effective elasticity tensor in 2D model with respect to random Young moduli and Poisson ratios of both CFRP components. It is necessary to mention that all these material characteristics of the CFRP are assumed as Gaussian with the given expectations and some intervals of the admissible stochastic fluctuations (coefficients of variation smaller or equal than 0.20 each time). We investigate numerically (1) if the resulting homogenized characteristics are also Gaussian and (2) if both homogenization methods return the same results in the context of probabilistic analysis. We determine expected values, coefficients of variation, skewness and kurtosis for all available components of the effective elasticity tensor in 2 and 3D homogenization problems – all as the functions of the coefficient of random dispersion for the input random parameter. It needs to be underlined that the correlation effect for various material parameters can be taken into account also but the lack of the additional experimental data lead to the lack of these cross-correlations in our model. Probabilistic method engaged to this computation is dual – contains both the generalized stochastic perturbation technique of the tenth order as well as semi-analytical technique implemented in the symbolic computer program and

consisting in direct determination of probabilistic characteristics from their integral definitions. Further SFEM computational studies will concern stochastic ageing influence of both components (especially for the polymers) on the effective parameters of the CFRP composites and also numerical simulation of the stocahstic interface defects on probabilistic homogenized characteristics of such composites.

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8547 | On the efficiency of fibrous reinforcement as a function of matrix crack density (34. Probabilistic methods (Marcin Kaminski, Univ. Lodz, Poland))

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Recently, a connection between the tensile strength of brittle matrix composites and crack density (or crack spacing) has been discovered Rypl et al. (2013). In particular, significant increase in reinforcement efficiency (up to 100%) has been experimentally measured in tensile tests with textile reinforced concrete. Such a high value indicates that this effect has to be taken into account in structural design.
The present paper provides the theoretical background for this phenomenon and explains it by employing a multiscale semi-analytical model of a crack bridge with multivariate random parameters. We show that the increase in strength depends on the level of heterogeneity of the fibrous reinforcement. In general, the reinforcement heterogeneity can be caused by randomness in fiber stiffness, fiber geometry, bond strength or by the use of hybrid reinforcement. Since these causes occur rather frequently in practice, the model is applicable to a large class of composite materials.
Knowing that the crack spacing of brittle matrices can be controlled by the reinforcement ratio, the matrix tensile strength, the addition of particles etc., a quantified dependency of the reinforcement efficiency on the crack spacing provides the engineers with an additional control parameter for material design and optimization.
In order to validate the model, we use experimental data published in Rypl et al. (2013) and employ a calibration-validation procedure. Tests with three levels of reinforcement ratio are available so that the model is calibrated using a particular reinforcement ratio and predictions made for the other two configurations are validated.

9142 | A Diffuse Approximation model for stochastic free vibration analysis of laminated composites (34. Probabilistic methods (Marcin Kaminski, Univ. Lodz, Poland))

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This paper addresses the effect of random variations of basic input parameters on composite laminated shell's natural frequencies. Material and geometric properties such as longitudinal and transverse elastic modulus, longitudinal and transverse shear modulus, Poisson's ratios, mass density and ply-orientation angle are considered as stochastic input variables. A variant of Latin Hypercube Sampling combined with Diffuse Approximation is adopted to reduce the sampling size and computational cost. The finite element method is applied to represent the mechanical model of laminated composite shells. Output is considered as the frequency domain composed of first three natural frequencies. Statistical analyses are carried out to indicate the results of proposed method. Furthermore, the proposed method is compared with a benchmark problem and its accuracy is confirmed through convergence studies and error analysis.

Keywords: Laminated composites, Free Vibration, Stochastic analysis, Diffuse Approximation

7518 | Study on Behavior of Compresive Deformation and Failure of Mo Fibres Reinforced TiAl Based Composites (35. Fibre metal laminates and composites)

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The effect of temperature and loading direction on the behaviors of compress deformation and failure and the properties of Mof/TiAl composites were studied. It showed that the yield strength of composites reinforced by unidirectional fibers in longitudinal direction was superior to that in normal direction, and that the yield strength of composites reinforced by unidirectional fibers in normal direction was close to that of composites reinforced by orthogonal fibers. The compressive yield strength of composites decreased with the increase of temperature. In addition, there was a long steady-state flow stage in the composite compressed at high temperature, and the flow stress-strain curves moved down with the increment of temperature. The samples cracked at the Mo/δ interface along the axial direction of fibers under the compression in longitudinal direction, however, the fibers in the composite did not fracture and were bended only. The matrix fractured in shearing mode in the direction of maximum shear stress, and the crack deflected as meeting the fibers and then propagated along the Mo/δ interface, as a result, the interface was debonded. While compressing in the normal direction, the composites reinforced by unidirectional fibers and those reinforced by orthogonal fibers both occurred shear failure in the direction which is with the axial angle of 45 degrees.

7519 | Deformation and fracture behavior of Mof/TiAl composites under uniaxial tensile loading (35. Fibre metal laminates and composites)

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The Mo reinforced fiber preforms were prepared by powder slurry casting and Mof/TiAl composites were fabricated by vacuum hot pressing. The interface

structure of composites and the behaviors of deformation and fracture were studied. The tensile deformation and fracture process and mechanism were analyzed based on. The results showed that the deformation and fracture process of composites can be divided into three stages under the longitudinal direction tension. In the first stage, the deformation of the whole composites came from the jointly elastic deformation of the matrix and fibers thus they carried the load together; in the second stage, when the load increased to the breaking strength of the matrix, lots of microcracks initiated and propagated within the scope of the entire length of the samples, and finally the quantity of the cracks reached saturation with the increasing of the load， in this stage, the load carried by the matrix decreased gradually while fibers increased slowly; in the third stage, the fibers carried the load alone. The load-bearing of composites reached maximum after the necking of fibers. Then the fibers initiated cracks in the necking place which resulted in the bearing capacity of composites falling sharply. After the fibers broke and uprooted from matrix, composites were completely fractured. The tensile fracture surface showed that the intergranular and transgranular mixed fracture mode occurred in the composite.

7675 | Experimental versus analytical-numerical study of buckling and postbuckling of open cross section FML profiles (35. Fibre metal laminates and composites)

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The literature research confirmed the lack of works devoted to buckling and post-buckling analysis of Fiber Metal Laminates thin-walled profiles. There is a relatively large number of publications devoted to material properties and post impact behavior of FML members but only a few works deal with buckling problems. The increasing area of FML structure applications what includes thin-walled profiles as load carrying members and stiffeners, focuses the research interest on the stability of this structures. In many practice applications of these elements the stability resistance decides on the load capacity more than their strength. Laboratory experiment seemed to be the best way of investigation of thin-walled structure behavior which has given additionally the opportunity to validation of analytical and numerical tools and further development of modeling and computation of FML structures.
In modern engineering applications one can find FML profiles as stiffeners or stringers of open cross section shape. Therefore, it was decided to perform the research of complex panels of flat walls as the channel section, Z-section or hat profiles are. For investigations devoted to buckling and nonlinear post-buckling behavior of indicated structures three approaches were employed. For comparison reason the FML profiles were tested in the laboratory, modeled and computed with application of finite element method and finally assessed according to asymptotic Koiter's theory with application of own procedure and software. Within the theoretical approaches two composite plate theories were employed and compared i.e. classical laminate plate theory and first order shear deformation theory. In laboratory tests the strain gauge technique and laser displacement measurement were exploited.
Among the performed laboratory tests and numerical and theoretical analysis there were some chosen parameters investigated. It was: number of composite layers in FML stack, composite layers mutual orientation, imperfection sensitiveness, component material properties and the profile shape itself. Analyzed open cross section profiles were subjected to axial compression load where the simply support constrains were assumed on the loaded profile edges. In all methods applied there were critical loads determined as well as a post-buckling equilibrium path.
Presented experimental studies allowed for verification of applied computational methods – in particular in the frame of constitutive modeling. The credibility of computational techniques in application for thin-walled structures is especially important in the case when these members are used in the constructions of high security regime.

7703 | On suppressing the indentation failure of glass-epoxy cross ply laminates by elasto-plastic interleaves (35. Fibre metal laminates and composites)

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Title: On suppressing the indentation failure of glass-epoxy cross ply laminates by elasto-plastic interleaves

The present article primarily focus on indentation response of hybrid cross ply glass fibre reinforced composite laminate. In the physical context of normal localized transverse loading like indentation and impact, the local stress concentration arising due to the elastic mismatch of differentially oriented adjacent unidirectional plies was believed to be the major triggering factor for severe resultant damage in conventional composite. During indentation load, matrix cracks are originated at the loci of maximum tensile stress developed perpendicular to the fibres and these multitude tiny cracks are continue to progress towards the interlaminar region and finally causes delamination.

From the lessons of fibre metal laminates (FML), a class of hybrid interply metal bonded composite laminate; the enhancement in impact resistance was known mainly attributed by the plastic deformation of metal layer. Besides, it was well-known that the plastic yielding can smooth the stress concentrated regions by redistributing the loads. The present article has been stepped off from this base to incorporate plastic interleaves to the composite laminates to investigate the influence of final indentation failure. Keeping the overall laminate thickness as constant, case studies based on different volume fraction of plastic interleaves and distinct stacking sequence are performed in order to attenuate the indentation failure more effectively. Furthermore, a contribution of each layer to energy absorption has been quantified through virtual indentation experiments using ABAQUS FE platform. The obtained results reveal the plastic deformation of interleaves would weaken the interlaminar stress concentration and thereby delay the indentation failure of composites. Also, compared to agglomerated stacking sequence, the performance of distributed stack laminate is substantially enhanced.

Keywords: Hybrid composites, Indentation, Fibre metal laminate, Finite element simulation.

7886 | Application oriented design of thermoplastic hybrid laminates (35. Fibre metal laminates and composites)

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Due to their specific characteristics and their great structural variety fibre and fabric semi-finished products with thermosetting and thermoplastic matrices are indispensable in lightweight construction. In addition to the good lightweight properties, many applications require additional defined properties, such as ductility, impact and crash behaviour, damping properties and burn-through properties. To fulfil these sometimes contradictory demands fibre-reinforced plastics (FRP) are combined with metals to create so called hybrid laminates (HL). Previous research projects regarding HL´s mainly dealt with thermosetting plastics as matrix material.
A new approach is the use of thermoplastic components. The different profiles regarding properties could fulfil new requirements, even economic ones. Having said that the suitability for mass production as well as the formability need to be mentioned in particular. In addition to the metal layers the thermoplastic matrix allows for a moulding in a hot state and thus provides a certain freedom of designing the laminates. They also provide good damping properties combined with excellent mechanical properties.
The production of hybrid thermoplastic laminates is characterised by a great freedom in regards to the design. The resulting property profiles allow for an exploitation of different areas of application. Varying factors are for example the materials used, which allow a variation of the metallic component, the fibre type as well as the thermoplastics. The number of layers and their thicknesses can be adjusted, which also determines the metal volume content. In addition to the previously mentioned there are a lot of other adjusting parameters. The result is that every hybrid laminate in each structure has its own very specific properties. The article sets out to determine the general influences of individual factors and assess them. This allows a reduction of development steps for future cases of utilisation by developing an application oriented design.

7906 | Intrinsic Manufacturing of Metal-FRP-Hybrid Structural Automotive Components by Resin Transfer Moulding (35. Fibre metal laminates and composites)

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Keywords: Automotive lightweight construction, Hybrid material, Multi material design, FRP, Fibre reinforced plastic, Resin Transfer Moulding.

The sparing use of resources and the avoidance of pollution emissions are globally recognized tasks of the international community. In this context, especially the development of lightweight concepts becomes important. In the automotive sector hybrid systems contribute to reduce the weight of structural components. In this case different materials are combined to a single part in order to allow a symbiotically usage of the specific advantages of each material. The manufacturing of high-strength multi-material structural parts, which are consisting of metal blanks and local fibre reinforced plastic (FRP) patches in highly loaded areas of highest stress, is a promising approach. Hybrid systems can offer a large weight saving potential, if technological, mechanical and economical aspects are considered.The wall thickness of the metallic component can be reduced by using this load-adapted structure, so that the parts can be up to 35% lighter than mere steel approaches (Lauter, 2012). As further advantage the costs of hybrid structures can be effectively reduced due to the limited usage of high-priced carbon fibre reinforced plastic (CFRP). For example, they can be manufactured in large volumes by using the resin transfer moulding (RTM) process.
The research focuses at the Chair for Automotive Lightweight Construction (LiA) at the University of Paderborn include high-performance materials for the use in automobiles and new manufacturing processes for lightweight structures. One important research field is the investigation of hybrid materials and their processing. Until now it is not possible to produce hybrid components directly with a conventional RTM process. The single-components have to be manufactured and then assembled. In addition to the process-related disadvantages this leads to coercible adding weight into the structural components. To make hybrid components attractive and available for automotive mass production a fundamental knowledge is required, for example approaches for reducing cycle times or eliminating additional assembly processes.
This paper will show basic technological investigations in the field of the direct manufacturing of hybrid materials and structures by RTM-technology. This means, a one-step production without additional assembly processes can reduce time and costs significantly. In this process, a resin system is injected into a dry textile preform on a sheet metal surface. In this paper the following tasks will be discussed. First, possible applications of an intrinsic hybrid component in the automotive sector will be confirmed. Depending on the application, specific requirements on the process and the structural components will be made. Second, research results regarding tool design, process parameters, for example the curing temperatures, cycle times and process pressures will be illustrated and discussed. Possible influences of variable process parameters on the bond strength of adhesive connections will be investigated by tensile tests. In addition, sealing concepts and the bonding between sheet metal and FRP especially regarding the boundary layer will be investigated in the context of the production technology. Finally, detailed concepts for high-volume processing of structural automotive components made of hybrid systems will be discussed.

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8088 | Closed Form Solution to Estimate the Residual Stresses and Warpage During Cure of GLARE (35. Fibre metal laminates and composites)

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Although, extended work is done on design aspects in recent years, the effects of manufacturing processes on Fibre metal laminates (FMLs) are not yet studied in detail. Integrated fuselage panels made of FMLs encounter deviations in shape and residual stresses after cure and post-cure processes. The shape deviations need to be compensated during assembly and the residual stresses produced in manufacturing and assembly reduce the mechanical performance regarding the load capacity, fatigue, residual strength and damage tolerance of the component. A predictive model is needed to adapt the mould to produce accurate integrated panels from glass fibre reinforced aluminium laminates (GLARE).
In the first phase, primary modelling and experiments on FMLs with non-symmetric lay-up of prepreg layers were performed from which the results are already published in previous papers [1, 2]. The research methodology was also presented in ECCM16 [3].
For the purpose of predicting the residual stresses after cure cycles of GLARE panels, the material properties of the constituents were needed to be determined. Some material characterization procedures have already been followed. Thermo-Mechanical Analysis (TMA) is carried out on the epoxy

material (FM-94) and time/temperature dependency of the stiffness parameters are determined using Dynamic-Mechanical Analysis (DMA). Accordingly, the thermo-elastic and thermo-viscoelastic response of the polymeric part of GLARE was determined.
During cool down process in composite laminates, contraction or shrinkage occurs in all constituents of the material. The time-temperature dependent response of the prepreg layer can be used in the analysis of residual stresses during the cool-down part of the cure cycle and in the prediction of the material responses in other applications and/or thermal and aging environments.
Besides the major part of residual stresses that are produced during the cooling part of the cure cycle, residual stresses are developed during cure (before cool-down) due to the "curing effects" including:
- Evolution (increase) of the epoxy stiffness with degree of cure
- Cure (chemical) shrinkage of the epoxy that in the fibre direction is restrained by the fibres but it will produce strains in the directions normal to the fibres

The focus of this paper is the solution to estimate the residual stresses and distortion during cure of FMLs considering the above mentioned curing effects. Modelling is based on Classical Laminate Theory incorporating the effects from the whole cure cycle including curing and cool-down parts. The evolution of the prepreg properties and also the developing cure shrinkage are considered in the equations during cure of GLARE. The stiffness of the prepreg layers is presented as a function of degree of cure. As a result, development of residuals stresses during cure and the curvature of non-symmetric panels after the polymer cure are predicted within a closed form solution of governing equations. Results are formulated for both free curing (without mould) and constrained curing in a vacuum bag on a mould in an autoclave. The analysis presented in this paper is a novel approach on FMLs which can be extended to any composite laminate. The final curvature of some non-symmetric panels are calculated. The accuracy of the model predictions are shown by comparing them to the experimental measurements.

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8786 | Study On Effect of Anodizing on Interfacial Properties of Aluminum-Carbon Fiber Laminated Composites (35. Fibre metal laminates and composites)

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Fiber Metal laminates, (FMLs) is a combination of metal with fiber and polymeric resin laminates. Aluminum-Carbon fiber laminated composite is one of the FMLs composites that preferably to be applied in engineering fields due to its dimension stability and properties consistency. However, if the aluminum is not well-treated, a corrosion event may occur on the interfacial region when exposing the FMLs to humid environment due to electrode potential between the two materials. Besides, the applied treatment may also improve the interfacial strength of the laminated composite to perform an efficient load-transfer mechanism on the laminate systems. In this research, an anodizing treatment was used on the aluminum surfaces to encounter the corrosion event as well as improving the interfacial strength of the laminated composites. The laminated composites were exposed in two different conditions which were in an extreme temperature (80 degree Celsius, 95%RH) and in a corrosive temperature (35 degree Celsius, 45%RH, 5% sodium chloride) for 1000 hours to study the effectiveness of the anodized layer in preventing or inhibiting the corrosion event and to analyze its strength. From the experiment done, it is observed that the interfacial region of laminates with the anodized treatment was still intact but there were major delamination failure occurs on the laminates without the anodized treatment. Furthermore, the strength of laminates with the anodized treatment only shows a minor decrease as in range of 10% to 15% after exposure in both environments. In comparison, the laminates without the anodized treatment show a major decrease of strength as in the range of 45% to 60%. Therefore, it shows that the anodized layer is suitable to inhibit corrosion event that cause delamination failure, as well as maintaining the strength of aluminum-carbon fiber laminates composite systems.

8954 | Stress intensity factor of a cylindrical interface crack in multilayered composites under torsion (35. Fibre metal laminates and composites)

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Cylindrical composites are a kind of functional materials widely used in engineering. The interfaces in them are key parts but at the same time weak regions. These weak regions are generally subjected to various damages such as debonding or cracking. Therefore, fracture analysis is of great significance for the design and optimization of these composites, and has absorbed the attention of many researchers.
In this paper we investigate the problem of a cylindrical interface crack in a multi-layered cylindrical composite of finite thickness under torsion. Fourier transform technique and state-transfer method are applied and the mixed boundary value problem of the interface crack under torsion is reduced to solving a Cauchy singular integral equation. The method of Lobatto-Chebyshev collocation is adopted to solve the singular integral equation numerically. The shear stress near the crack tip has been obtained in an explicit form and the stress intensity factor is determined. The current model may be used to deal with the case of homogeneous cylinder by setting the properties of all the layers to be the same; also this model can be applied to simulate functionally graded cylinder.
Numerical results of the stress intensity factor are discussed to reveal the coupled effects of the geometrical and physical parameters on the interfacial fracture behaviour. The preferred values for the thickness ratio and the stiffness ratio are obtained, which provide necessary reference to the optimal design in engineering.

Keywords: Cylindrical interfacial crack; multilayered composites; Fourier transform; singular integral equation.

9224 | FEM simulation of bending aspect in Fiber Metal Laminates **(35. Fibre metal laminates and composites)**

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Over the last decades the development of the aviation industry has forced the significant progress in the field of modern and lightweight aircraft structures. A big expanding range of new materials applications like polymer composites entails closer look at the failure mechanisms of these materials. One of the newest materials with superior quality are Fiber Metal Laminates (FML). They are hybrid composite materials composed of interlacing layers of thin metal sheets and fiber reinforced adhesives. The biggest advantage of FML materials is excellent fatigue strength and high resistance to impact loadings. FML is still in an evaluation stage. Specific properties of Fibre Metal Laminates is determined by the type of metal alloy and composite, layer thickness, number of layers in a laminate, and the fibre orientations.
Generally FML's are adhesively bonded structure. Adhesive joining is static strength which is the most frequently taken into account. This is a highly important indicator determined values and types of loads which may be applied to the adhesive line in operation. The knowledge of problems between components allows the engineer to design the bond appropriately and determine operating conditions, i.e. loads, where the joint will retain required properties. Appearing failure loads are realize to be of utmost importance. The analytic methods of adhesive bonding are based on bending analysis. Nowadays is possible to use very attractive tool like Finite element analysis (FEA), which expands the possibilities of examining materials in different conditions.
The aim of preliminary research was to analyse stress distribution in Fiber Metal Laminates applying Finite Element Method and the numerical tool being ABAQUS/Standard programme. The results were verified with the results of experimental tests.
The analysed laminates was based on 3/2 layers (3 aluminium layers and 2 glass/epoxy layers). The modelling method ensures high quantitative and qualitative consistency with the results of simultaneously conducted test (comparing failure force values for experimental and numerical tests). It was modelled the distribution of the Tsai-Hill's and Hashin's criterions. The dominant failure in structure was compression load then the fibers are interrupted. There were no changing in aluminium layers.

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9225 | Failure analysis of Fiber Metal Laminates after bending strength test **(35. Fibre metal laminates and composites)**

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Fiber Metal Laminates are a group of hybrid materials with potential use among air structures, which can replace traditional metal alloys or fiber reinforced polymer composites. This is a fairly new group of materials over which, there are still ongoing research. Fibre Metal Laminates (FML) are consisting of alternating layers of thin metal sheets and polymer composites. They possess superior properties of both metals and fibrous composite materials. Fibre Metal Laminates are characterized by excellent damage tolerance: fatigue and impact and their characteristics, high strength, low density, corrosion and fire resistance. For apply these materials not only in aerospace manufacturing it is still needed to provide some research about behavior in structure in different conditions. For example during bending in a particular state of stress, depending on the state of the material and the bending conditions, it is desirable to obtain complex loading conditions, thereby producing a mixed nature of damage. So the aim of the research was carried out bending strength test on the selected hybrid FML's based on aluminium with carbon and glass fibers reinforced epoxy composites. The laminates could be then characterized from the standpoint of their microstructure, selected strength properties and fractographic analysis of failure.
The results after preliminary studies have shown that the impact of surface preparation of metal layers in a fiber metal laminates has the nature of destruction in an attempt to bend. The important factor which influence on the properties of the laminate as a whole, is to provide high adhesive properties of the composite-metal connections. Destruction laminates indicates the complexity of the process of degradation of these materials similar to carbon and glass/epoxy polymer composites. Orientation of reinforcing fibers have an influence on the size of the destruction of the laminate structure which may have a decisive effect on the ability of forming laminates. In all structures, occurrence of cracks were observed in the tension zone but in the compression zone, there were no visible damage.

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9384 | Effect of thermal cycling on the mechanical behaviors of Fibre Metal Laminate based on carbon fibre reinforced polyimide **(35. Fibre metal laminates and composites)**

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Effect of thermal cycling on the mechanical characteristics of Fiber Metal Laminates (FMLs) was studied in this work. The FMLs tested in this work were manufactured by hot press process, utilizing titanium and carbon fiber reinforce PMR polyimide. Thermal cycling treatment was conducted in compressed air heating-cooling equipment ranged from -65 oC to 135 oC. Scanning Electron Microscope (SEM) was used to observe the cross sections of the FMLs after thermal cycling. Tensile and interlaminar shear tests were performed on specimens after 0, 250, 500, 750 and 1000 cycles, respectively. SEM

showed that the FMLs stay unbroken after thermal cycling. The interface of the titanium/prepreg was continuous and no visible delamination or microcrack was observed. The results of the tensile and interlaminar shear tests did not show any significant difference among the tested specimens, indicating that the thermal cycling did not affect the mechanical behaviors of the FMLs.

9391 | The Preparation and Properties of Novel Fiber Metal Laminates Based on Aluminum-lithium Alloy (35. Fibre metal laminates and composites)

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The novel fiber metal laminates (FMLs) based on aluminum-lithium alloy was prepared to improve its damage tolerance and stiffness. The aluminum-lithium sheets were rolled to 0.3mm by cold forming, and then aged to T3 and anodized in phosphoric acid. Moreover, the novel FMLs based on aluminum-lithium alloy, together with conventional Glare, was prepared by an optimized process. The interlaminar properties of FMLs were characterized by floating roller and interlaminar shear methods. Meanwhile, the mechanical properties were evaluated by tensile and bending test. The fatigue crack growth (FCG) was also investigated. The results indicated that the aluminum-lithium alloy was mainly strengthened by δ' phases at T3 state and exhibited rough micro morphology after anodized. The novel FMLs and conventional Glare presented similar density and quite excellent interlaminar properties. But for mechanical properties, the novel FMLs exhibited slight strength increase and obvious modulus improvement than Glare regardless of the fibers plies and sampling direction. A better resistance to FCG of the novel FMLs was also verified.
Keywords: aluminum-lithium alloy; fiber metal laminates; Glare; preparation; properties;

6991 | Discrete ply modelling of failure scenario of open-hole tensile test (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The Discrete Ply Modelling (DPM) method, previously applied with success to out-of-plane loading such as impact or pull-through, is used to model open hole tensile tests. According to the literature, this kind of test is relevant to assess the efficiency of a modelling strategy. Four different stacking sequences are
tested and the failure scenario and patterns are well predicted. The main advantages of DPM are the very small number of parameters required and the robustness of the models. The main drawback is the computation cost.

7093 | Static and dynamic analysis of bending-torsion coupling of a CFRP sandwich beam (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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A new and promising way of dynamic and aerodynamic behavior optimization of an helicopter rotor blade is to introduce a coupling between bending and torsion inside the blade. A preliminary approach with a sandwich beam has been selected in order to be able to analyze all the inducted phenomena. A sensibility study has been performed for ply orientations on the elastic and inertia couplings terms. It appears that a maximum effect of the ply angle on the bending-torsion elastic terms occurs approximately at an angle of 20° or 70° and can reach up to 26% of the torsional rigidity. An another solution was found by splitting the chord length into 4 and fulfilled them with different arrangements of foams densities (65, 80, 125 and 200 kg/m3). Calculations show that smooth graded density foam generates less angle of torsion than the presence of a brutal density gradient. The combination of the ply orientation and density graded core together can rather improve or cancel the coupling effects. From a static point of view, two optimal configurations have been found. A dynamic study has then been performed in order to characterize the beams presenting good interest for bending torsion coupling. This characterization is used to study the influence of technologies on the modal frequency placement, modal deformations and frequency response functions. An experimental/numerical comparaisonn was performed and a methodology for analysing real blades defined.

7121 | Digital Image Correlation and Thermography analysis of notched CFRP under tension (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The notch studied is a “two-bay crack” which means that the notch cuts two zones of the fuselage, separated by two frames and a stiffener, through the entire thickness. This large notch can be the result of a strong engine dysfunction. However, to simplify, in a first approach, the specimen is a flat plate with a center notch. Similar plate with open holes are also investigated.

A new experimental technique to identify the sequence of failure mechanism on such plates is proposed. Different techniques of damage in situ, such as

the use of strain gauges, the infrared thermography or digital image correlation, and post-mortem monitoring, as micrographs under microscope X-ray radiography or by C-Scan are to be used.
A set of open-hole laminates with specimen of different diameters (6.35mm, 3.175mm and 1mm) with a constant width to diameter ratio (5) and then a set of “structural coupons” with 30mm “U-notch”, all under uniaxial tension, have been tested. Thanks to the monitoring with the Digital Image Correlation (DIC) combined with thermography analysis, pre-failure damage such as delamination and fiber failure have been detected and correlated with the acoustic noise emissions and the stress/strain curves. So the failure scenario can be correctly identified for future validation of numerical analysis.
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7123 | Discrete Ply Modelling analysis of notched CFRP under tension (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The notch studied is a “two-bay crack” which means that the notch cuts two zones of the fuselage, separated by two frames and a stiffener, through the entire thickness. This large notch can be the result of an engine dysfunction.To begin with, the specimen is a flat plate with a center notch. Plate with open hole are also investigated.

The objective is to develop a finite element model to simulate the experimental tests. This model is part of a series of advances established in the ICA (Bouvet et al., 2012), (Achard et al., 2014), highlighting an original scale model based on observed damage phenomena. This led to the development of an original model of the laminate based on both solid and interface elements ("Discrete Ply Model"). This type of modeling has been adapted to the particular problem of notched CFRP laminates under tension.

First, A work on the mesh generation linked to DPM specific mesh constraints has been performed to correctly represent the notch shape. A satisfactorily correlation of the tests has been obtained.

7126 | THE VERTEX PROJECT: COMPLEX LOADING ANALYSIS AND VALIDATION OF COMPOSITE STRUCTURES (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The VERTEX project (see http://www.institut-clement-ader.org/vertex/) is funded by ANR (French Government). The consortium includes Institut Clément Ader, LMT Cachan, ONERA, Airbus Group Innovation, HOLO 3 and LMS Siemens. It aims to develop a new methodology for analyzing, testing and validating composite structures. The scale of analysis is the second level of the pyramid of tests with specimens of 400 x400 mm2. The choice of this scale allows a unique positioning for investigating structural details and a wide range of fundamental problems. Moreover, the peculiarity of VERTEX is to propose a method of analysis or validation by static tests under complex loading (tension / compression / shear /internal pressure) that involves an experimental and theoretical dialogue between scales. The methodology will allow an improved and extended testing / calculation dialogue which is a mandatory step towards the Virtual Testing. These two issues are major issues of competitiveness that will enable significant and reduced economic gains and security design cycles for any composite structure of new generation. This methodology will also have the ability to discriminate the predictive nature of the different approaches in the literature. Because of its universal nature, using instrumented test will allow industry and the scientific community to validate composites research or technology at reasonable costs in view of the limited size of the specimens.

7188 | BEARING RESPONSE OF CFRPs : COMPARATIVE STUDY OF WOVEN AND UD FABRIC QUASI ISOTROPIC LAMINATES UNDER STATIC AND FATIGUE LOADS (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Minimizing fuel consumption and increasing payloads is the constant design driver of all helicopters. CFRPs, with their exceptional mechanical properties, could be used to produce hybrid drive system components, hence involving metal-composite joints.
Pin contact bearing tests are used in this research to evaluate the loss of stiffness and strength of such hybrid design . Tests under high cycle fatigue, at room and high temperature, under low and high frequency are to be conducted. Both woven and UD fabric quasi-isotropic laminates are studied, so as to have insight into the strengths and weaknesses of these two types of materials. The first experimental results (static) show that, at room temperature, three main behaviors can be observed. The bearing failure can be defined as the sudden drop in stiffness resulting from the compressive failure of the load-aligned fibres. Stopped tests were conducted and tomography analysis are performed. Fatigue test results at ambient temperature will also be presented.

7774 | Flexible cell culture device made of organically modified montmorillonite (OMMT) reinforced silicone rubber composites (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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In the process of tissue differentiation, mechanical stimulus imposed on cells or tissues is the key factor to determine the speed and tissue phenotype. The type and magnitude of mechanical stimulus can control the developing pathway of tissues. The relationship between mechanical stimulus and tissue differentiation is well organized and utilized for various purposes. The aim of this study is to design and fabricate a new type cell culture device which works in-vitro environment and gives tissues appropriate mechanical stimuli for effective and desirable tissue differentiation. To achieve human body environments with large deformation electroactive polymers (EAPs) such as silicone rubber were used for the driving part of a cell culture device. EAPs are a sort of smart materials which react electrical energy with large deformation and vice versa. To enhance the mechanical performance of EAP cell culture device under the simulated human body environment 5wt% of organically modified montmorillonite (OMMT) was added to the silicone matrix. For large deformation and various types of mechanical stimuli, EAPs need a special electrode with flexible and low electric resistance. Polymer based electrode PEDOT:PSS with alcohol sugar (Xylitol) and other additives was used to fabricate flexible electrode. The weight ratios of Xylitol and additives were controlled and resistance of the electrode according to those ratios was measured and the optimal composition was found. To give various mechanical stimuli corrugated shape of silicone film was prepared and the deformation pattern was observed after imposing high level of voltages. Moreover, various patterns of electrodes were tried to get most appropriate deformation of the cell culture device.

7780 | A study of the composite conductive materials for a bipolar plate **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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This paper reports the composite conductive materials used in a bipolar plate of fuel cell by using an extrusive-compressive forming method. The composite conductive materials formed by a 22.5 wt.% of carbon black, 52.5 wt.% of graphite, and 25 wt.% of polypropylene (PP) have a low specific weight, low cost, and high electric conductivity. It can be formed in particle shape after the kneading and extrusion procedure to increase the density of the composite materials. The results show that the composite conductive materials have a bending strength of 20.5 Mpa, a surface conductivity of 138 S/cm2, and a melting index of 1.92 g/min. The experimental results confirmed that the composite conductive materials can be applied to manufacturing a bipolar plate of fuel cell.

7808 | Preparation of $Al_2O_3/CaAl_{12}O_{19}/ZrO_2$ composite ceramic material by the hydration and sintering of $Ca_7ZrAl_6O_{18}$-reactive alumina mixture **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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A ceramic material of composition belonging to the Al_2O_3-$CaAl_{12}O_{19}$-ZrO_2 compatibility field was obtained as a result of hydration and sintering of the mixture of Al_2O_3 and $Ca_7ZrAl_6O_{18}$ powders. The hydrated Al_2O_3-$Ca_7ZrAl_6O_{18}$ mixture products were studied by XRD, DTA-TG-EGA and FT-IR after 14 days of curing and hydration at 50°C. C_3AH_6, $Al(OH)_3$ and $CaZrO_3$ compounds were formed upon hydration. $CaZrO_3$ and the lime-rich calcium aluminates formed as transient phases during hydration and dehydration processes were converted to CA_6 and ZrO_2 in the presence of an excess of Al_2O_3 during sintering at 1500°C. The Al_2O_3-based dense refractory composite material was investigated by XRD, FT-IR, SEM-EDS and mercury porosimetry. The sintered ceramic microstructure consists of a homogeneous distribution of zirconia grains in an alumina matrix reinforced with the calcium hexaaluminate phase. The presence of Al_2O_3, $CaAl_{12}O_{19}$ and ZrO_2 in the synthesized material was confirmed by XRD and FT-IR techniques. By applying the mercury intrusion porosimetry technique, the heterogeneous pore size distribution of the refractory composite material was determined. Characterization of the reaction in the Al_2O_3-$Ca_7ZrAl_6O_{18}$-H_2O system, its dehydration behavior and phase changes are important from the point of view of possible application of $Ca_7ZrAl_6O_{18}$ in high alumina refractory castables technology.

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7898 | Benefit of a Damage Tolerant Design consideration and the role of SHM in the Structural Analysis of a Large Civil Aircraft Spoiler **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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The spoilers in the several large civil aircrafts are used as lift dumper, control the roll moment and bring the aircraft to halt by breaking the airflow over the wing during landing. In this study, the spoiler of Airbus A340/A330 is used as a case example which is made of carbon fibre reinforced composite material, instead of the traditionally used metallic materials. The spoiler is a sandwich design lightweight structure which consists of laminated upper and lower skin and honeycomb core between them. They are attached to the wing by hinges and actuator bearing which forces the spoiler into the airflow at desired angle. These type of lightweight structures design require the suffice knowledge of loads acting on them, the stresses and strains and the possible damages that may occur during its operation. The current design approach for such structures is Safe-Life design approach where the damage growth in the structures is not considered. However, this type of design concept limits the applicability of composite structures, since they have high residual strength and tend to exhibit good fatigue resistance as compared to metallic structures. That is why, this article presents the damage tolerant design approach for the considered spoiler where it is assumed that the damage may always be present in the structure and needs to be taken into account in design. Therefore, critical loads acting on the spoilers are obtained by performing static analysis on the finite element model at retracted as well as extended position. Furthermore, understanding and predicting the behaviour of damaged structure during the structural analysis is the key aspect of

damage tolerant design, so that the identification, assessment and repair of the damage in the structure can be carried out, supported by the static analysis. For this purpose, an appropriate structural health monitoring method is selected to evaluate the structural changes (e.g. strain developing in the structure, structural impedance or temperature changes, etc.) on the spoiler and identify the damages respectively, based on the results of the static analysis (e.g. optimal sensor selection, suitable measurable value and optimal sensor placement). Finally, the appropriate structural repairing technique, such as patch repair and scarf repair, for the damages identified in the spoiler due to the existence of different types of load during its service life is discussed.

7918 | State of the Art – Adaptive Structures, Highly Integrated Structures (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The reduction of weight and costs are two of the most important challenges for different branches of mechanical engineering, especially for the automotive, aeronautical and aerospace industries. One of the major objectives for future development within these last areas is to reduce fuel consumption. By doing this, not only will life-cycle costs be reduced, but also other negative consequences, such as high energy consumption and environmental impact, could also be diminished. One promising solution for reaching this goal, but which has not yet really been implemented in the industry, is the use of highly integrated light weight structures.

Highly integrated structures allow using different materials in a compliant structure in order to optimize the solution for the given requirements and thus reduce weight.

One specific case of highly integrated structures, which represent one of the most interesting applications, is adaptive structures. These types of structures have the capability of integrating different types of materials in the structure itself and also of integrating different functions within one structural component. Examples of these are system functions for changing the overall shape of the structure if necessary or for control engineering purposes, making it possible to simplify the whole system and considerably reducing weight.

The purpose of the paper will be to present an overview of the state of the art in multi-material, highly integrated structures, focusing on the advances in adaptive aircraft structures.

7947 | Folded hierarchical sandwich structures made of self-reinforced polymers (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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One typical way to obtain higher stiffness and strength to weight ratios within structural applications is to use sandwich structures containing lightweight cellular cores. The latest research on improving the overall mechanical performance of sandwich structures focuses on developing novel core configurations in order to gain a better behaviour of the core in out-of-plane compression and in-plane shear. Examples of such efforts include composite corrugated cores [1], hierarchical corrugated cores [2-4], square honeycomb cores [5], rhombic and kagome honeycombs [6], pyramidal lattice truss cores [7-11] and hierarchical pyramidal lattice cores [12]. Although many of these structures provide competitive weight specific stiffness and strength, they are usually difficult and costly to manufacture. Within this study a novel 2nd order hierarchical sandwich structure and its manufacturing principle are proposed. The whole hierarchical structure is made of a recyclable material – different forms of poly-ethylene terephthalate: poly-ethylene terephthalate fibre reinforced poly-ethylene terephthalate (SrPET) and poly-ethylene terephthalate foam. The manufacturing path is developed such that it can be implemented within a continuous production line. A numerical model is developed and validated experimentally in order to evaluate the mechanical properties of the proposed structure in out-of-plane compression and in-plane shear loading conditions. Optimization techniques are implemented within the validated numerical model in order to find out the optimal geometric parameters for specific loading conditions.

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8064 | An investigation of the effect of silk fabric structure on the mechanical property of the insert molded FRP (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Applications of FRP are widespread; it's used as exterior roofing material for individual resident terraces and carports, or lighting materials such as the interior surface material for bathroom doors or room-partitioning windows. Polycarbonate, which is a type of GFRP lighting materials, has strong physical properties but looks unpleasant, due to the visible glass pattern. In order to solve this problem we have developed a decorative molding technology using kyo-yuzen (Kyoto-made, paste resist-dyed kimono fabric) as a reinforcing material, consisting of silk cloth used to make Japanese kimonos. By incorporating this method fused with traditional Japanese design, the glass pattern can be utilized as a pattern in its own right. In the kimono industry, cloth with soft and elegant textures is preferred over vivid finishing. This is expressed in the Kyoto-based Japanese word "han-nari", which means not only "soft and elegant", but "gorgeous".
In this study, we have focused on the conventionally-overlooked artistic qualities of FRP. By combining superior FRP functionality produced with high technology and the unique Japanese sense of aesthetics originating in ancient times, we developed these new concepts in FRP-applied products, then combined them with Japanese traditional craftworks, such as kyo-yuzen. That is called "Artistic FRP". We think that mutual support is necessary for the progress of both science and the arts, allowing a new artistic, scientific, and technological culture to be actualized.

At current study, 6 types of the different lamiantion structure composite were molded with 4-5 layers of glass mat fabrisc and 1 layer of silk fabric. In some of them , gel coating was add in single or double faces of the composites. 3 point bending tests (normal bending, low/high cycle bending , crepe, after degradtion of hot water and sunshine) and impact were carried out. In particurally, the effect of the thickness with diffrent twist of the silk fabrics on the mechanical property of insert molded FRPs was discussed.

8065 | Robust design of composite golf shafts considering fiber orientation errors in stacking process (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Since golf became one of the popular sports, related industries have grown very rapidly. Performance of the golf club is dependent on the club head, shaft and grip. Especially, The golf shaft is the important part to determine the dynamic characteristics of golf clubs. Now, laminated carbon composites are widely used for golf shafts due to the light weight and controllable mechanical properties.
Generally, composite golf shafts consist of several materials with different orientations by sites to control the kick point and bending stiffness. Fiber orientations might be different from the desired design during wrapping process on the tapered mandrel because layout design tends to be easy to cut the materials without considering the mandrel shape. By using in-house material properties (which were obtained empirically), they have compensated for designing the layout of composite golf shafts.
Therefore, we investigated the fiber orientation errors in stacking process and its effect on the dynamic performance of composite golf shafts.
We calculated the real fiber orientation of each layers of each sites in stacking process by CAD software. Then, we calculated the dynamic behaviors of composite golf shafts with and without considering the fiber orientation errors by finite element analyses. Finally, we suggested the design method of composite golf shafts considering fiber orientation errors with respect to the mandrel shapes.

8068 | Deep Drawing of Low Density Sandwich Laminates (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Low density laminates find their applications in various fields due to the premium mechanical and physical properties such as flexural stiffness and comparable specific strength. One of the most necessary needs is to investigate the behavior of the sandwich layers under different loading conditions. Therefore, in this study the effect of different skin/core combinations of the deep drawability will be presented. Moreover, different setting conditions of the laminate layers were utilized i.e. different skin sheet thickness in the same laminates with varying contact with the forming tool. One of the most interesting points in this study is investigating the flow behavior of the core layer at different thickness combinations. The deep drawing behavior was characterized in terms of the strain distributions especially the thickness reduction. The thickness reduction was determined using metallographical methods as well as optical 3D forming analysis.
The results revealed a significant effect in varying the core thickness at constant skin thicknesses in terms of the thickness reduction. With increasing the core thickness, the thickness reduction increases, too, leading to high cracking probabilities at the bottom/sidewall rounding. Moreover, the limiting draw ratio (LDR) is negatively influenced with increasing core thickness. The core subjects to different thickness reduction profiles based on the thickness; the thicker is the core, the lower degree of thickness reduction uniformity results. The results of the metallographical investigation were compared to the ones of the optical forming analysis.

8116 | AlSi/SiCp+GRp hybrid composites obtained by suspension method (36. Design and application of composite structure

(Bruno Castanié, Institut Clément Ader, France))

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Composites obtained on the basis of light metal alloys are a new group of engineering materials. Applying the reinforcement in the form of particles, fibers, or porous ceramic shapes allows to obtain materials with new properties compared to the unreinforced matrix material. Composite materials based on aluminum alloys have a higher hardness, improved wear resistance under the conditions of friction, a low coefficient of thermal expansion while maintaining low density of the base alloy matrix. Liquid phase technologies based on connection between the liquid metal and the reinforcing phase allows to produce composites reinforced in both the volume and in the area of locally increased loads.

The paper will be presented the suspension method (stir-casting) of obtaining the AlSi/SiCp+GRp. The procedure developed by the authors allows obtain the suspension of the composite on a semi-technical scale which enable casting of more than 30 pcs. in one cycle of composite pistons for air compressor.

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8119 | THE SELECTION OF THE PHASE COMPOSITION OF THE COMPOSITE DESIGNATED FOR PISTONS (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Increasingly, the composite materials of aluminium matrix alloy are applied to the production of structural components and machine parts, such as slide bearings, brake discs, sleeves and pistons. The strong interest both in the theoretical studies and the practical use of such composite materials are result from a number of their creative properties, which can be designed by the proper selection of reinforcing components and technological parameters. The presence of the ceramic reinforcement (i.e: SiC, Al2O3) has a beneficial effect on the properties of matrix alloy, particularly on its hardness, wear resistance, thermal conductivity and thermal expansion. Unfortunately, at the same time increase wear and reducing the durability of cutting tools were observed. Therefore, most new studies focuses on the formation of structure and properties of hybrid composites. Such composites (i.e: Al/SiCp+Cp or Al/SiCp+GRp) have a better physical, mechanical, and tribological properties than the composites which are reinforced by only one type of reinforcements. It has been shown that graphite particles may create a protective lubricating layer between two contact surfaces during sliding. The possibility to obtain of lubrication effect is very important and useful from the point of view of the machining of the finished composite product. Therefore the possibility of machining the external surfaces of products produced of composite materials is the key to proper selection of the type and volume fraction of reinforcing phases.

In the article the results of selection of the phase composition of the composite materials designated for pistons will be presented. The investigations showed, that the correct selection of chemical and phases composition in such composite materials must take into consideration necessity to obtain both the advantageous casting properties of composite suspensions as well as possibility of pistons machining surface.

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8701 | Effect of Composite Structure on the Ablation Behavior of Carbon/carbon Composites Modified by [Mo-Si-C-X(X=Al,Ti)] System (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The Cf reinforced carbon substrate composites (Carbon/carbon, C/C) are attractive materials for use in ultra-high temperature structural components in aerospace vehicles. However, the C/C composites will be subjected to thermochemical ablation by oxidation and evaporation due to high temperature and oxygen-enriched environment, and also mechanical erosion by high-pressure gas and high-velocity grains. It is the hot issues that development of effective oxidation or ablation protection for C/C composites. For potential long time (＞600s) application between 2000-2400°C, previous research indicated that the ablation resistance of C/C composites was significantly improved by addition of Mo-Si-C-X(X=Al,Ti) system, which include high-melting-point MoSi2, Mo(Si,Al)2, (Mo,Ti),Si2, Mo5(Si,Al)3C, SiC and so on. And many paper pay attention to the effect of phase constituent on the properties of final composites. As reported by Yin et al., the ablation rates of C/C composites with 3D fine-woven-pierce preform were higher than those of the C/C composites with unidirectional fiber needled preform. However, there’s little systematic work about the effect of intrinsic composite structure which are directly related to the ablation resistance.

In this paper, we focus on the effects of composite structure on the ablation behavior of composite with Mo-Si-C-X(X=Al,Ti). Three C/C composites modified by Mo-Si-C-X(X=Al,Ti), with different fiber architecture in performs and the same density, were prepared by chemical vapor infiltration (CVI) and reactive melt infiltration (RMI). Sketches of the three kinds of carbon fiber architectures are fine-weave pieced perform (FWPP) in which a plurality of layers of woven fabric were stacked parallel to X–Y plane and the resulting stack of fabric layers was pierced in the Z-direction with a plurality of rods to provide a mutually orthogonal structure; needle integrated preform (NIP) which was fabricated by a threedimensional needling technique, starting with repeatedly overlapping the layers of 00 non-woven fiber cloth, chopped fiber web, and 900 non-woven fiber cloth with needle-punching step by step; chopped web needled perform (CWNP) that was randomly stacked by chopped fiber webs with needled bundles of carbon fibers.

Firstly, we study the effect of composite structure on microstructures of final composites from same infiltrating alloy, including morphologies, phase constitute and distribution, element distribution. Especially study the interface of between carbon and heterogeneous phase. Then under the same ablation condition by oxy-acetylene flame, compare the ablation properties of three C/C modified Mo-Si-C-X(X=Al,Ti). Study the features of ablation morphologies from different samples. Analyze the ablation behavior, then give the ablation mechanism.

8705 | Development of carbon fiber/polypropylene composite bipolar plates for polymer electrolyte membrane fuel cell (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Polymer electrolyte membrane fuel cells (PEMFCs) have the potential to play a major role as energy sources for transportation and portable applications because it features a high power density at a relatively low operating temperature. Bipolar plates are accounts for a great part in weight, volume, and cost of PEMFC. Generally, bipolar plates need high electrical conductivity, flexural strength, gas tightness, and chemical stability. Among various materials, carbon fiber reinforced thermoplastic composite bipolar plates have been attracted by the researchers owing to its excellent corrosion resistance, high flexibility, and easy fabrication process. But the molten viscosity of thermoplastic resins is extremely high, which makes it difficult to impregnate thermoplastic resin into fiber bundles. In this study, a bipolar plate for PEMFCs was fabricated by using carbon fiber/polypropylene (PP) composites. Carbon fiber/PP prepregs were prepared by using PP sol impregnation method to improve the degree of impregnation. The interfacial contact resistance was measured with respect to the surface treatment of the composite bipolar plates. The total resistance, flexural strength, and gas permeability were investigated by using four point prove method, three point bending test, and unsteady-state permeability measurement method. Moreover, unit cell performance assessment was conducted with the thermoplastic composite bipolar plates and the results were compared with the commercial bipolar plate.

8706 | Design of the composite journal bearing for turbine/generator application (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Composite journal bearings for turbine/generator application have been increasingly employed in industry because the composite bearings can solve the white metal's endemic problems such as abrasive wear, wiping, tinoxide damage, cavitation erosion, and corrosion. Especially, in the oil cut situation the white metal bearing was stopped by rotor seizure and induced serious failure on the rotor.
In this work, two different materials, carbon/phenolic composite and carbon/epoxy composite, were used to fabricate composite journal bearings. The tribological characteritics and interlaminar shear strength at high temperature which are required properties for the journal bearing were compared. Nonlinear stress analysis with ABAQUS was conducted to compare the failure indexes at the composite liner and adhesive layer of each composite journal bearings. To verify the FE-analysis results, oil cut tests of the journal bearings were performed and damges were monitored by SEM and C-scan method. Based on the results of FEA and oil cut test, the criteria for the optimized operating condition of the composite journal bearing was suggested.

8736 | Design of Filament-wound Elbows Based on Non-geodesic Winding Patterns (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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More recently, filament-wound elbows have emerged as an attractive alternative to joints for piping, cylinders, pressure vessels, etc., where the connection between two unparallel composite parts is required. It is desirable to develop an effective design method to improve structural performance and load carrying capacity of filament-wound elbows while satisfying their windability. For winding a rotationally axisymmetric body, a reference fiber trajectory is repeated continuously by indexing the axis of rotation, opposed to an elbow, which is an open-ended asymmetric body. In this paper two winding methods were applied to produce filament-wound composite elbows, which are the whole application of non-geodesics, and the application of geodesics for the torus section and non-geodesics for cylindrical end sections. The resulting winding patterns were numerically simulated using computing language MATLAB. Tsai-Wu failure indices of the composite elbows obtained using various initial winding angles were calculated using finite element software ANSYS and the burst pressure of the elbow was predicted. The results reveal that the whole application of non-geodesics leads to better structural performance of the composite elbows than the partial application of non-geodesics for cylindrical end sections. The present non-geodesics-based method provides a useful reference tool for design and production of filament-wound composite elbows.

8742 | NUMERICAL ANALYSIS OF A MASONRY PANEL REINFORCED WITH PULTRUDED GFRP PROFILES (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The particular characteristics of pultruded FRP profiles, such as the reduced mass, the durability and the ease of erection makes them particularly suitable for the use in the field of the reinforcing of traditional masonry structures, with particular regards for historical constructions in seismic areas. The structural reinforcement of these buildings through the use of pultruded FRP profiles represents an efficient solution, not yet sufficiently explored, that allows realizing non-invasive and reversible interventions for the improving of the structural performance with the addition of a very limited structural mass. The paper presents a numerical study concerning a hypothesis of reinforcement of a traditional masonry building through the installation of a pultruded FRP frame adjacent to the masonry structure and connected to it with mechanical fasteners. The behavior of the connection between pultruded FRP members and masonry and of the pultruded frame joints is particularly investigated. The numerical analysis represents a preparative work in view of a planned

experimental test on a masonry panel reinforced with pultruded FRP profiles.

8941 | Definition of complex mechanical testing through numerical simulations and the use of an advanced behaviour law (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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This work is part of the VERTEX project, a consortium of research laboratories (ICA, LMT, Onera) and industrials (Airbus Group Innovation, LMS Samtech, Holo3) which purpose is to develop a novel multiscale analysis and validation method applied to relatively large specimens. The choice of this characteristic size of specimens allows to study a whole new range of fundamental and industrial problems. This is made possible by the development of a new bench for mechanical testing, able to submit large specimens to complex triaxial loadings. In that regard, the VERTEX project falls well within the problematic of Virtual testing. This approach is supposed to replace the large and expensive test campaigns that the aeronautical structures have to undergo in order to be certified, resulting in substantial economic gains for the aeronautic industry. But this goal will only be achieved if the material models and numerical simulations are proven to be robust and predictive. The VERTEX project is aimed at providing a more accurate understanding of the phenomena involved in the degradation of composite structures when submitted to complex loading, as well as evaluating the performance of the material models on uncommon test cases.
In order to achieve this goal, the VERTEX project will focus on three different scientific problems. The first one consists in analysing and modelling the phenomena involved in the propagation of large cuts in a composite plate. The second one is related to the prediction of the failure of specimens with complex shapes (technological specimens). Finally, the third topic is focused on composite structures submitted to complex loadings, resulting in complex failure patterns. The present work is a part of this final research axis.

Precisely, the goal of this task is to propose materials models able to describe the overall behaviour, including damage and failure, of a composite laminated structure made of unidirectional plies. In this work, we thus propose an advanced damage model , which allows to predict (i) the non linear behaviour of the material before the appearance of meso-damage (matrix viscoelasticity, non linear elasticity in fibre direction, …), (ii) the evolution of matrix cracking density and the associated local microdelamination (from the tips of the cracks), and finally (iii) the final failure of the structure, caused by a steep fall of the material properties (softening behaviour) following the failure of a single ply. This “micromechanical-based hybrid mesoscopic “ (MHM) model is used for an approach written at the ply scale but with some micromechanical aspects introduced at the mesoscopic scale. The progressive aspect of the laminate failure is taken into account, i.e. after the first ply failure, the mechanical properties of the failed ply are degraded progressively, which reduces the effective stiffness of the material and leads to the overloading of the neighbouring plies, thus leading to more ply failures, and so on.

In this work, we will first present the formulation of the model, both in terms of material behaviour and of the prediction of failure. Then we will review the process of the identification of materials parameters based on simple mechanical tests. We will show that great attention has been paid to the simplicity of this process, in order to facilitate the implementation of this model in commercial FE software. Finally, we will show how this advanced model has been used to define the experimental tests (type of loading, shape of the specimen, specific stacking sequences) that would exacerbate the different failure mechanisms and exhibit the couplings between them. This test campaign is planned to be performed in order to validate the models, and/or identify their weaknesses.

8950 | Measurement of regularised boundary conditions on a composite plate with Stereo Digital Image Correlation (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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This study is part of a project that aims to perform tests on composite plates of dimensions 500 x 500 mm² in order to validate damage models. This sample size allows an original scale of structural details and allows treating fundamental problems. The drawback is that non conventional testing resources in which instrumental ad hoc resources have to be used. In this project the boundary conditions needed by the partners in order to validate a damage model will be given by an optical measurement method. For a plate model, boundary conditions are displacements but also rotations. A stereo correlation method is more likely to measure the displacements of the upper skin, and the rotations are not directly estimated. For instance, the rotations can be obtained by a posteriori numerical differentiation. Since the measured displacement is noisy, smoothing techniques are required even if they usually do not consider the mechanical nature of the measured field. In this work, a plate finite element model is preferred to regularise the stereo correlation measurement. A dedicated FE Stereo DIC method has to be developed accordingly.

More precisely, Digital Image Correlation (DIC) [Horn and Schunck (1981), Lucas and Kanade (1981), Sutton et al. (1983)] consists in measuring the displacement field u between two images, f and g in two different loading conditions (at t0 and t1). The displacement field measured on the images is assumed to correspond to the actual displacement of the object. Finite element interpolations have been proposed which allow bridging more efficiently numerical models and experiments [Sun et al. (2005), Hild and Roux (2006), Fehrenbach and Masmoudi (2008), Hild and Roux (2012), Passieux et al. (2014)]. Classically, the optical flow problem is written in a weak form over a region called Region of Interest (ROI) which is usually defined by a subset of the reference state image f.

For one increment of Stereo Correlation [Lucas and Kanade (1981), Kahn-Jetter and Chu (1990), Luo et al. (1993), Orteu et al. (2010)], two image registrations are performed independently. Both correlation problems involves unknowns that are not directly related to the physical (3D) displacement U calculated after triangulation and shape variation. Thus, in FE studies, it is difficult to do an Integrated Correlation with a mechanical model in which the unknown is a 3D displacement [Besnard et al. (2012), Réthoré et al. (2013)].

8956 | Structural Design Optimization of CFRP Chopper Disks (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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Structural Design Optimization of CFRP Chopper Disks

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The Institute of Lightweight Structures of the Faculty of Mechanical Engineering of the Technische Universität München has been designing and producing carbon fiber-reinforced polymer (CFRP) chopper disks for over a decade, specialising in designs for light disks with a high rotational speed. Chopper disks are commonly used in neutron “Time-of-Flight” spectroscopy. They are disks with one or more apertures rotating around an axis parallel to the neutron beam, reaching operational speeds of up to 22,000 rpm, correlating with accelerations of up to 200,000 g at the edge of the disk.
Up to now, the disks have been produced using a quasi-isotropic laminate layup in an autoclave process. In order to achieve an increase in performance, three aspects have been investigated. First, a shape optimization of the apertures has been made, which directly impacts stress distribution. Second, the layup stacking sequence and orientation has been optimized regarding strength constraints. Finally the influence of the mass distribution on the dynamical behaviour of the disk has been studied.
The mathematical basis of the optimization allows for the simultaneous consideration of stiffness, strength and mass constraint throughout the optimization process, leading to disks with an optimal mass and stiffness distribution. For a description of the detailed structural dynamic behaviour of the whole system, which comprises the disk itself, the collar, the shaft and the bearings, several numerical analyses have been carried out. Finally, dynamic tests have been performed, which are in accordance with the numerically determined natural frequencies.

8992 l Design, testing and finite element analysis of the new tank-container with composite tank for multimodal transportations of chemically aggressive fluids and petrochemical products (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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A complete cycle of design, manufacturing and finite element strength analysis of tank-container with fiberglass composite tank for multimodal transportation of chemically aggressive fluids and petrochemical products is presented. The tank-container has been designed for road, rail and offshore transportation that places high demands on the structure in accordance with ADR and IMDG requirements. The tank was manufactured by use of the both filament winding and vacuum infusion technologies. The tank capacity is 24 cubic meters by volume and 32 tons by cargo. A geometry of the wound layers was calculated by CadFil filament winding software. After that, a 3D finite element model was developed for representation of actual layups and geometry of the wound and infused composite layers of the tank. All requested normative load cases were analyzed by the model. Due to asymmetry of the applied loads for some load cases, total volume of the tank-container was included into the FE model as shown at the figure. Besides normative load cases the FE simulation of the dynamic crash test was carried out by coupled Eulerian-Lagrangian analyses. As a result of such dynamic simulation the threshold SRC curves were obtain to guarantee the requested minimum 4g longitudinal acceleration at low front fittings of the container frame. Strength analysis of a manhole and valves was carried out as well. For verification of the developed FE models, the calculated results were compared with inner pressure 0.6 MPa and crush tests data. Subcomponent tests were carried out as well for analysis of the critical zones of the structure and verification of the models.

9042 l Edge effects modeling in the design of laminated beams with curved inherent configuration (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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In the design of laminated beams, which height is much smaller than its width, must take into account great normal and tangent stresses, which occurs near side edges. These stresses can result in beam failure near side edges. Using curved layers is the way of decreasing values of these stresses. Method introduced by author in [1,2] is used for edge stresses calculation in this article. Method is based on solving of theory elasticity three-dimensional problem with asymptotic expansion assistance. Stiffness functions are introduced in cross beam section. Stresses are found in finite sums of products of stiffness functions and beam deflection derivatives. There is need to solve some auxiliary problems in beam section in order to find stiffness functions. These problems are two-dimensional, they are solved by finite element method. Finally, all six stress tensor components are found with high accuracy. Analysis of these stresses allows to choose curvature data for the purpose of reducing the value of interlayer stresses by beam designing.

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9079 l A Hybrid Sandwich Design for Supporting a Large Vessel in the Ship Repair Industry (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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In this study, a suspension component has been designed using periodic cellular metals to replace the conventional material in ship-repair industry. Wood has long been recognized versatile in structural applications. In addition to its reputation as a lightweight material, wood material has been also utilized for supporting heavy vessels in the ship-repair industry. In practice, multi-axle freight cars, which support and pull the massive bodies to dry land, are employing wood blocks as suspension components. However, it might be more desirable to replace the blocks by engineering metal since the durability issue such as distortion from repeating wet-and-dry states can be raised. Accordingly, a hybrid sandwich design, a multilayered corrugated core structure with metal foam, is proposed. The structure is designed so as to have equivalent stiffness and strength to those of wood blocks. Finally, the out-of-plane structural performance is verified via Finite Element Analysis (FEA) and some experiments.

9133 | Large sandwich structures fire tests modelling (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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The SOLAS (Safety Of Life At Sea) allows using alternative designs for passenger ships if they satisfy the FTP code requirements (Fire Tests Procedures), among which the ISO 834 fire test. In order to reduce the number of tested structures, shipyards want to compute the thermo mechanical behavior of their composite structures made of composite skins and balsawood core. The first step consists in reproducing the standard fire test using numerical simulation, which implies that the material properties are known up to decomposition. The second one deals with using fitted data from a typical case to apply them to another one. A review of literature reveals that data provided cannot be used to feed numerical model and to validate results, especially when data come from sample scale materials and are used to model large scales such as panels from naval industry.
The topic of this paper is to explain the encountered issues, the origin of the problems and tracks to solve them. First of all, experimental tests for composite materials fire reaction are not well dedicated to these insulating materials, due to the size of their representative volume. Boundary conditions are not accurately estimated, regulatory values are commonly used. Balsawood exhibits large variations in its properties. Thus, prediction of thermomechanical behaviors for panels is not reliable, compared with experimental results when available. Numerical modeling must be able to provide sufficient realistic results to be used for designing.
The second challenge is to be able to achieve large scale models with a reduced cost in terms of time and disk space. The third one consists in describing the mechanical behavior of materials when they degraded. Structural stiffness of sandwiches comes from skins. When the heated skin degrades and cannot contribute to sustainability, the sandwich has lost a great part of its stiffness. Depending on the mechanical load and the thermal one the failure modes differ and the time to failure evolves.
This paper intends to explain which care has to be taken in order to obtain a good accuracy, without tuning input data. The aim is to show that using very complex models or decomposing composites behavior from elementary constituents (fiber, resin) will not necessarily help to describe more accurately the behavior of large structure sandwich panels.
In a first part, the article explains which phenomena take place when material is burning, how they are modeled in equations and how to determine properties to supply with input data. Then, the initial equations are modified in order to reduce the size of the numerical model and the computational time. A comparison is done between the two models for a laminate structure under different intensity of fluxes.
In a second part, focus is maintained on the evolution of mechanical behavior under fire. Experimental tests are mainly conducted under compression because mechanical load is essentially supported by fibers and the fibers cohesion is held by resin stiffness. Usually, resin behavior under temperature is measured and this result is used as input data to model the mechanical behavior. This provides quite satisfying results for small scale structure but cannot be used for larger ones. Thus, the paper intends to show which data are suitable to describe more physically the loss of mechanical properties.
As a last part, the impact of mechanical delamination on heat transfer will be tackled. This is supposed to change considerably the distribution of temperature especially at low fluxes.

9273 | Effect of patch shapes on fatigue life of aluminumpanel repaired with bonded composite patch - An experimental Study (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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In this work, we studied the fatigue crack growth behaviour of cracked aluminum 2024-T3 plates repaired with bonded composite patch. We also, investigated the effect of different patch shapes on the fatigue life and repair efficiency of aircraft structures (or cracked aluminum plates) bonded with composite patch. The fatigue behaviour of crack emanating from unrepaired v-notched thin aluminum platesare studied to compare with the repaired ones. The effect of stress ratio on the repair efficiency is also studied in this investigation. The obtained results show that the repair performance is very much affected by the patch shapes. The square patch has the maximum efficiency,however, the inverted arrow has detrimental effects on the fatigue life.
Keywords: Al 2024-T3; bonded composite patch; fatigue life; repair efficiency

9347 | Aeroelastic Instability Analysis of a Composite Wind Turbine Blade (36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))

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An investigation to explore the effect of static aeroelasticity of a composite wind turbine blade on power production of the wind turbine is presented. Blade element momentum (BEM) theory is employed to determine aerodynamic loading. Accuracy of BEM code is acquired by comparing with real field measurements. This loading is in terms of pressure distribution along the blade length and is applied on the blade. Then, by using finite element method static behavior of blade is obtained. Displacement of the blade as changes in angle of attack is used in BEM code to determine new aerodynamic load.

This iterative procedure is continued till convergence is met. At the rated wind speed deformed blade decreases pressure distribution and consequently leads to reduction in output power.
Dynamic aeroelasticity instability is also investigated which may occur for an industrial wind turbine blade. Due to the large size of the blade and application of composite materials which causes more flexibility, importance of aeroelastic analysis becomes more pronounced. The aerodynamic loading is applied to the 3D finite element model of the blade. In order to detect dynamic response of the blade, transient analysis is done in FE commercial package. Then aerodynamic loading is updated according to the deflected blade. This process is continued for a period of time and flapwise, edgewise and torsional deflection is determined. It is concluded that dynamic instability may occurred near cut-out wind speed for the specific wind turbine blade selected as a case study.

9482 | Design of a representative test probe of the state of stresses in the structural joint of the fuselage with main landing gear and wing-strut, of a two seat-aircraft built with composites **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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The objective of this research is to design a test probe able to reproduce the mechanical behavior of the structural joint of the fuselage with the main landing gear, and the lower segment of the supporting strut of the strut-braced, high wing of the Stela-M1 aircraft, originally designed by Aeromoragon in Spain, and afterwards adapted and constructed by Aeromarmi SA de CV in Mexico. The fuselage, the wing, the stabilizers, the control surfaces, and the main landing gear are fabricated with C-Ep composites. The test probe under study considerably simplifies the geometry of the original structural joint configuration and is designed in accordance with the method originally proposed by Collombet et al from Université Paul Sabatier (Toulouse III) . Moreover, other methodologies are included in order to better understand the design problem, such as the Quality Functions Deployment. The parametric design of the test probe is achieved by means of a numerical analysis based on the Finite-Element Method. This research is based on previous studies that determine the flight loads, the safety factor of the structural joint under study for the most critical in-flight scenario, the quantification of external forces, reactions, and stresses of the associated structural elements.

9553 | Optimum graphite foil coating on carbon/epoxy composite bipolar plates for vanadium redox flow batteries **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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Composite bipolar plates (BPs) for hydrogen fuel cells and vanadium redox flow batteries (VRFBs) are coated with expanded graphite foils to decrease electrical contact resistance of BP. The bipolar plates of vanadium redox flow batteries are exposed to sulfuric acid vanadium electrolytes under cell voltage. When the cell voltage exceeds the potential of the water electrolysis, the water penetrated in the bipolar plates can be decomposed into hydrogen and oxygen, which might cause delamination of the graphite coating layer. From the two types of graphite foil such as the pyrolytic graphite and expanded flake-type graphite, the former has less water absorption because it has a single cleavage plane and its graphene sheets are partially covalently bonded. In this study, the fabrication of the carbon/epoxy composite bipolar plate coated with pyrolytic graphite is optimized. The effects of porosity of coating layer on the properties of composite bipolar plate are verified. The bonding between the coating and the composite was experimentally investigated. In addition, the aspects of damages on pyrolytic graphite coating due to electrical aging is investigated with respect to the porosity of graphite. The changes of graphite coating layer after electrical aging are analyzed both physically and chemically, from which the optimal coating condition is determined.

9559 | Light weight hybrid composite tie bars for PEMFC and VRFB **(36. Design and application of composite structure (Bruno Castanié, Institut Clément Ader, France))**

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The stacks of energy conversion system such as proton exchange membrane fuel cell (PEMFC) or energy storage systems such as vanadium redox flow battery (VRFB) stack are compacted with tie bars to decrease the electrical contact resistance and to prevent the leakage of fuels or electrolytes from the stack. Since the sealing performance might be deteriorated under long operation time by creep deformation of the stack, it is important to maintain consistent clamping force under the deformation of the stack for the long-term reliability.
In this work, a light weight hybrid composite tie bar was developed using carbon/epoxy and glass/epoxy composites with steel thread fasteners to achieve high elastic strain and to provide consistent compaction pressure over long operation time. Based on the finite element analysis (FEA), the configuration of carbon/epoxy and glass/epoxy composite rod with the steel thread fasteners was determined to minimize the stress concentration considering the manufacturing of the tie bar. The mechanical properties were experimentally obtained and the change of clamping forces under creep condition was investigated whose results were compared to that of the conventional steel tie bar.

Keywords: light weight hybrid tie bar, PEMFC, VRFB, manufacturing of tie bar.

6758 | Non-Local Beam Theory for Micro- and Macro-Structural Responses **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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This paper presents the developments of the non-local sandwich beam theory that can be used to assess the micro- and macro-structural response of the beam in terms of displacements and stresses. The theory utilizes homogenization-localization and modified couple stress beam theory developed by Reddy. The homogenization considers all steps of the derivation of the prevailing differential equations from displacements through strains and stresses to external loading. This enables accurate localization process that recovers the microstructural effects from the homogenized solution of the beam bending and couples them to the global response. This allows the prediction of the local failure within the beam. The theory is presented as well as some case studies that are supported by experiments: the shortest beams have only four unit cell along their length, while in the longest we approach the situation where the unit cell length is infinitely small in comparison to the beam characteristic length. The presented theory can be utilized to deformations and predict stresses accurately within all cases between these two extreme situations. It also converges to the physically correct solutions in case of infinite and zero shear stiffness; especially the limit of zero shear stiffness is important as there the traditional Timoshenko beam theory fails to predict the response correctly. Present theory can be extended to different microstructures and further to plates. The benefit of the presen

6805 | Dynamic prediction fatigue life of composite wind turbine blade **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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In this paper we are particularly focusing on the dynamic crack fatigue life of a 25 m length wind turbine blade. The blade consists of composite materiel (glass/epoxy). This work consisted initially to make a theoretical study, the turbine blade is modelled as a Timoshenko rotating beam and the analytical formulation is obtained. After applying boundary condition and loads, we have studied the stress, strain and displacement in order to determine the critical zone, also show the six first modes shape to the wind turbine blade. Secondly was addressed to study the crack initiation in critical zone which based to finite element to give the results, then follow the evolution of the displacement, strain, stress and first six naturals frequencies as a function of crack growth. In the experimental part the laminate plate specimen with two layers is tested under cyclic load in fully reversible tensile at ratio test (R=0), the fast fracture occur phenomenon and the fatigue life are presented , the fatigue testing exerted in INSTRON 8801 machine. Finally which allows the knowledge their effect on the fatigue life, this residual change of dynamic behavior parameters can be used to predicted a crack size and diagnostic of blade.

6840 | A FINITE ELEMENT FOR LAMINATED GLASS PLATES WITHIN THE FIRST ORDER SHEAR DEFORMATION THEORY **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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Photovoltaic modules are usually composed from front and back glass plates as well as a solar cell layer embedded in a soft polymer.

One feature of these laminated modules is the difference in properties of the rela-tively stiff skin layers and the thin and compliant core layer. Let Gs be the shear modulus of the glass skin layer and Gc the shear modulus of the polymeric core layer. The ratio Gc/Gs for materials used in photovoltaics is in the range between 10-5 and 10-2, depending on the type of polymer and the temperature. For classical sandwich applications this ratio is in the range of 10-2 and 10-1. To perform the structural analysis, the authors developed a first order plate theory and demonstrated that this theory provides accurate results for a wide range of shear stiffness of the core layer. The key step concerning this theory is the computation of the effective transverse shear stiffness of the laminate from the properties of the layers.

This contribution discusses a new approach to compute the transverse shear stiff-ness of the laminate for the analysis of laminated glass plates according to the first order shear deformation theory (FSDT). A user-defined finite element is developed within an ABAQUS subroutine. Several benchmark tests illustrate the efficiency of the developed element. The results are compared with the results according to the layer-wise plate theory. They show a good performance of the FSDT for a range of shear moduli of the core layer.

6899 | Vibration Analysis of Laminated Thick Plates by an Improved Hierarchical Finite Element Method Using Reddy's Third-order Shear Deformation Theory **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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Reddy's third-order shear deformation theory is famous as a typical high-order shear deformation theory for its simplicity and high accuracy in analysis of thick plates. The hierarchical finite element method (HFEM) is a typical p-version finite element method. The HFEM is famous for its high accuracy, simple pre-post-processing, not requiring a change in the mesh to improve the accuracy of the solution, etc. However, the HFEM is also known as having numerical stability problems in irregular domains while using high-order orthogonal polynomials. In this paper, an improved version of HFEM was used, where the numerical stability problem was overcome by using the techniques of a differential quadrature finite element method (DQFEM). The improved HFEM has both high accuracy and efficiency due to the simplicity and high accuracy of the DQFEM. The results obtained by the improved HFEM for vibration of laminated thick plates based on Reddy's third-order shear deformation theory was compared existed exact solutions for vibration of the plates, which validated the high accuracy and efficiency of the improved HFEM. The improved HFEM have the potential of becoming the mainstream in developing finite element software in future.

6918 | Some fundamental problems of multiscale asymptotic expansion method (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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In present study, a few of fundamental problems of the widely used multiscale asymptotic expansion method have been discussed and some important conclusions about the expansion term or the order of the expansion method and the influence function as well as the physical implication of each perturbed term have been arrived at, and this study forms the mechanical basis for the application of the multiscale asymptotic expansion method. Some numerical experiments are conducted to validate the conclusions.

7529 | Gradual degradation in two-phase polycrystalline ceramics due to time dependent thermal loading (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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This work focuses on the description of gradual degradation of the two-phase metal–ceramic composites (MCC - brittle grains WC joined by the plastic binder Co) due to time dependent thermal loading, including the modelling of a real material internal structure. Experimental observations of the WC/Co composite subjected to mechanical loading indicate that the stress concentrations in MCC took places in the plastic binder Co (e.g. dimple rupture across the binder or in the binder near the binder/carbide interface). Under thermal loading the heat transfer in mainly through metallic interfaces, where the stress concentrations are present due to different thermal properties of both phases. They are sources of damage initiators at the binder/carbide interface caused by the mismatch in the coefficient of thermal expansion.
This paper presents micromechanical modelling of gradual degradation process of the MCC response due to heat transfer with the application of the Finite Element Analysis (FEA). The deformation process of the material comprises elastic deformation of brittle grains and elasto-plastic deformation with damage of inter-granular layers. The different contents of metallic phase were taken into account.
The analysis of micro-samples with imposed mechanical boundary conditions leads to the conclusion that the level of volume content qualitatively changes the behavior of the MCC including deformation, rotation of grains, and level of plastic strains and damage process.

7544 | Computational Modeling of Female Pelvic System To Understand The Mechanics of Pelvic Organ Prolapse (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Pelvic Organ Prolapse (POP) is a deformity of the female pelvic system, usually caused by weakening of the pelvic floor muscles due to remarkable events such as multiple child births and menopause combined with morbid obesity. In POP, either the bladder slips on the vaginal canal (Cystocele) causing urinary incontinence, the rectum slips on the vaginal canal (Rectocele) causing constipation problems, or the uterus slips into the vaginal canal and eventually protrudes out of it (Uterine). POP hampers the daily activities, sexual life and wellbeing of an individual. As per 2010 statistics, 300,000 POP surgeries were performed in the U.S. only. Out of these, 60% of the patients were diagnosed with prolapse relapse conditions. A closer look into the problem reveals that these POP surgery failures can be attributed mainly to the lack of understanding among medical practitioners on the biomechanics of the pelvic system. There has been few attempts in literature to understand the mechanics of POP using computational modelling. Mainly, cystocele and rectocele prolapse conditions, and the pelvic region changes during child birth have been studied using phenomenological models. This current work aims to understand the mechanics of POP using a realistic full scale finite element model of the female pelvic system. The results of varying degree of prolapse with the changes in the vaginal tissue properties would be presented.

7564 | ADVANCED APPLICATIONS FOR LAMINATED DOUBLY CURVED SHELLS WITH VARIABLE CURVATURES (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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The paper aims to describe laminated composite doubly-curved shells and panels with variable radii of curvatures using differential geometry. In this way the geometry of the shell or panel is described mathematically through certain predefined parameters that depend on the geometry under consideration. The mechanical model is based on the well-known Carrera Unified Formulation (CUF) with the curvature effect included in the formulation. Furthermore, the theoretical model developed by the authors allows to consider variable mechanical properties along the shell surface and variable shell thickness (according to a given smooth function). In addition, complete revolution shells are defined as special cases of panels by enforcing the kinematical and physical compatibility conditions at the closing meridian. The solution is given in terms of displacement parameters using two advanced theoretical approaches: the equivalent single layer and the layer-wise approach. It is a very well-known fact that collocation methods (known also as mesh-less or mesh-free methods) have some limitations in treating special problems in engineering, since they can only deal with regular geometries. At the same time one of the most important features of these techniques is connected to their high accuracy and stability for solving partial differential systems of equations. It could be of interest for some applications to use collocation methods in order to solve a certain numerical problem when distorted geometry and material or load discontinuities are taken into account. Thus, the governing partial differential system of equations for laminated composite doubly-curved shells and panels is solved by using the Generalized Differential Quadrature (GDQ) method and related ones. The authors employ both the free vibration

analysis and the static analysis with the recovery procedure for evaluating the through the thickness strain and stresses at each point of the 3D solid shell for these advanced engineering problems. The accuracy of the present technique is verified through several comparisons with analytical and numerical finite element models.

7613 | Structural Essentials for Modular Hybrid Wind Turbine Blades (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Innovative modular blade concepts require robust computational analysis to sift through design options. The robustness is exercised by coherent simplification of complex material and structural attributes of hybrid composite construction. The static, vibration and impact response of a novel large modular blade is proposed and carefully studied with a commercial code (Abaqus) addressing material heterogeneity, geometric tapers, hybrid architecture and unique joints. The numerical results confirm that by selecting multi-segment blades and taking advantage of hybridization both in fiber reinforcement (glass and carbon) as well as architecture(tape and textile) architecture in the design, one gains simplified manufacturing and installation procedures without sacrificing single-blade response.

7666 | Layerwise mixed least-squares finite element models for free vibration analysis of multilayered piezoelectric sandwich composite plates (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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This work provides an assessment of a finite element model based on layerwise mixed formulation using least-squares applied to plate sandwich structures with skins made of piezoelectric layers and the core with composite angle play laminate layers. The extension to free vibration analysis is developed. The model assumes a layerwise variable description of displacements, transverse stresses and in-plane strains, taken as independent variables. The layerwise mixed formulation enables the fulfilment of the so-called C0z, yielding, for free vibration analysis a symmetric quadratic eigenvalue problem. The present model has nine degrees of freedom (dof) per node in the core and in the upper and lower piezoelectric skins thirteen (nine to mechanical and four electrical) per node.
The numerical examples show that the model predictive capabilities are in excellent agreement with three-dimensional exact solutions and also with available alternative models, from very thick to very thin sandwich piezoelectric plates.

7934 | Electro-Mechanical Analysis of a Layered Hollow Sphere with Functionally Graded Piezoelectric Material (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Electro-Mechanical Analysis of a Layered Hollow Sphere with Functionally Graded Piezoelectric Material.

Nowadays, piezoelectric materials are widely used in sensor technology. Amongst variety of types, piezoceramics have been demonstrated as efficient tools for sensing applications. Piezoelectric ceramics are more versatile so that their physical, chemical, and piezoelectric characteristics can be tailored to specific purposes. Typical applications include undersea sonar systems, high-resolution ultrasonic imaging, non-destructive testing, materials evaluation, medical diagnostic analyses and measurements, and therapeutic treatments [1]. Functionally Graded Materials (FGMs), that have been recently explored in coating technology, are generally nonhomogenous composites with continuous variation of the constituents from one surface of the material to the other. In such material, the composition and structure gradually change over volume, resulting in corresponding changes in the properties of the material. This gradual change in composition eliminates the mismatch of material properties between the base structure and coating layer, which is the main reason for cracking, debonding, and in some cases eventual failure of the structure [2]. The efficiency of FG coating within a spherical pressure vessel has been recently studied by authors in which the role of graded coating in enhancement of through-the-thickness stress distribution is investigated [3]. In the present study, a layered spherical sensor is electro-mechanically studied within the context of elasticity theory. The sensor has been considered as a sphere with two layers: an outer layer composed of a homogeneous material and an inner layer made of piezoceramic. It is also assumed that the piezoelectric layer has graded composition resulting in graded electro-mechanical properties. The gradation is realized along the radial direction and based on a power function. Results including through-the-thickness stress components and electrical potential are presented for different gradation parameters. Also, results are compared with those of a layered sensor with non-graded piezoelectric layer. At the end, the role of gradation in piezoelectric layer and its effect on the overall behavior of the sensor is discussed.

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8082 | Numerical modeling of piezoelectric composite plates using NURBS as the field functions (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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The variational method based on the minimization of the potential energy is extremely efficient and accurate for the solutions of complex engineering problems in structural mechanics. The potential energy comprises strain energy, kinetic energy and the work done on the structure by the body and external actions. Characteristics of piezoelectric laminated plates in bending and vibrations are examined in this paper by the variational method in which the displacement fields are required as a priori. Consequently, the Non-Uniform Rational B-Spline (NURBS) functions are considered to describe both the geometry and displacement fields. The method is developed on a first order shear deformable piezoelectric plate described in the Cartesian coordinate system. For such a plate, the distribution of the in-plane mechanical displacement components vary linearly in the thickness direction, while the transverse displacement component is kept uniform. However, it is known that the electric potential varies nonlinearly through the thickness, even if the mechanical behavior of the plate is linear elastic. This nonlinear distribution of the electric potential is accommodated by dividing the piezoelectric layer into a number of sub-layers and assuming linear variation in each layer. The matrix equation of motion is then deduced by the Hamilton's principle including electric and elastic variables in the potential energy functional.
The piezoelectric plates are analyzed under the cylindrical bending condition for both sensor and actuator modes and the obtained results are corroborated with those from the literature. The mechanical displacements and electric potential do not change in one of the in-plane axes of the piezoelectric plate in cylindrical bending condition, which is achieved in this study by setting to zero the displacement component in the y-direction, rotation of the normal about the x – axis, and the electric potential in the y - direction. Next, the skewed cantilevered sandwich trapezoidal plates are analyzed statically under mechanical and electrical loadings followed by the free vibration analysis. The first five fundamental frequencies are reported for different skew angles and taper ratios. The investigation is continued to investigate the forced vibrations by the Newmark's direct integration method. The fast Fourier transforms are applied to the response-time histories to examine the participation of natural modes under different dynamic loading conditions. In this context, the point impulsive mechanical and electrical loads are found to set off many natural modes compared to step and half-sine loads. The proposed numerical method has been developed such that very complex shaped piezoelectric sandwich plates can be investigated efficiently and reliably. The piezoelectric circular sandwich plates are also analyzed and the natural frequencies from the present numerical method are compared with the analytical solutions found in the literature. Additional results for elliptic plates are also obtained and discussed in this study. Owing to very high order continuity within a segment, the NURBS curve appears to outperform the finite element methods. Numerical comparison has revealed that the number of the degrees of freedom in the present model is less than one tenth of a commercial finite element code for the same accuracy.

8143 | Static, vibration and buckling of composite beams using a quasi-3D theory (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Composite materials are increasingly being used in various engineering applications due to their attractive properties in strength, stiffness, and lightness. Finite element models originally developed for one-layered isotropic structures were extended to laminated composite structures as equivalent single-layer models. These models are known to provide a sufficiently accurate description of the global response of thin to moderately thick laminates and considered in this paper. In company with the increase in the application of composite materials in engineering structures, many beam theories have been developed for predicting the response of laminated composite beams. Since the shear deformation effects are more pronounced in these structures, the first-order shear deformation theory and higher-order shear deformation theories should be used. It should be noted that in these theories the thickness-stretching effect is ignored, which is especially significant for thick composite beams. A quasi-3D theory, which includes both shear deformation and thickness stretching effects, assumes that the in-plane and out-plane displacements are a higher-order variation through the thickness. In this paper, static, vibration and buckling of composite beams using a quasi-3D theory is presented. The axial and transverse displacements are assumed to be cubic and quadratic variation through the thickness. Governing equations of motion are derived from the Hamilton's principle. A two-noded C1 finite element with six degree-of-freedom per node which accounts for shear, normal deformation effects and coupling coming from the material anisotropy is developed to solve the problem. Numerical results are performed for symmetric and anti-symmetric cross-ply composite beams. The effects of fiber angle and lay-ups on the shear deformation and thickness stretching parameters as well as axial–shear–flexural–stretching response are investigated.

8188 | Exact vibration solutions of refined theories of variable order for laminated and FGM plates and shells (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Owing to the mathematical complexity of exact analytical methods, structural problems are mostly solved using numerical techniques.
However, exact solutions, when available, can be highly relevant as a reference for validating numerical methods on their convergence and accuracy.
In addition, analytical models can be highly appealing to speed up the preliminary design phase when huge parametric and optimization studies need to be carried out.

The present work is aimed at presenting an efficient, unified and somehow automatic method to
determine exact eigenfrequencies of composite laminated and FGM plates and shells with Levy-type boundary conditions.
Exact solutions of 2-D refined theories of variable order are obtained in the form of single trigonometric series.
In particular, both higher-order equivalent single-layer and layer-wise theories are considered.
The novel procedure introduced here overcomes the shortcomings of the previous formulations which were limited to plate and shell models

derived from a single theory with fixed kinematics (i.e., fixed order).
Using the present approach, the solving equations must not be re-derived when a different order of the theory is adopted and thus the mathematical effort required to obtain analytical solutions is substantially reduced.

It is shown in the paper that, by writing the assumed plate/shell model using an index notation related to the order of expansion of in-plane and out-of-plane displacements, the equations of motion and boundary conditions can be expressed in a compact form which is invariant with respect to the order of the kinematic theory.
The Levy method applied to the previous form yields a set of governing equations written in terms of 3×3 matrices, called fundamental nuclei of the formulation, which again do not depend on the order of the theory.
The nuclei are then appropriately expanded according to the order of the model and the resulting equations are put into a first-order state-space representation.
The frequency values are finally obtained by substituting the general solution of the state equation into the set of boundary conditions and solving the related homogeneous system.

Comparisons with exact 3-D and other 2-D approaches are provided for specially orthotropic and FGM rectangular plates and cylindrical/spherical panels with at least one pair of opposite edges simply supported.
New exact frequency values for both thin and thick plates and shells are also presented which can be useful as benchmark values for future comparison.

8189 | GEOMETRICALLY NONLINEAR ANALYSIS OF SOFT CORE SANDWICH - STRUCTURES (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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In this work a finite element model is presented for geometrically nonlinear analysis of sandwich plate-shell structures, with a soft core sandwiched between stiff elastic layers. The finite element is obtained by assembling all element-layers through the thickness using specific assumptions on the displacement continuity at the interfaces between layers, but allowing for different behavior of the layers. The stiff elastic layers are modelled using the classic plate theory and the core is modelled using the Reddy's third order shear deformation theory. The present finite element model is a non-conforming triangular flat plate/shell element with 24 degrees of freedom for the generalized displacements. This simple and fast element model proves to be efficient and is applied in the solution of some illustrative shell examples and the results are presented and discussed.

8201 | DYNAMIC ANALYSIS OF SOFT CORE SANDWICH STRUCTURES USING KRIGING MODELS (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Sandwich structures with soft cores are widely used in applications where a high bending stiffness is required without compromising the global weight of the structure, as well as in situations where good thermal and damping properties are important parameters to observe.
As equivalent single layer approaches are not able to describe realistically the kinematics and the stresses distributions of this type of sandwiches, where shear deformations and the extensibility of the core can be very significant, layerwise models may provide a more adequate solution.
Additionally and in connection with this multilayer approach, different shear deformation theories can be selected according to the nature of the material that constitutes the core and the outer layers or skins.
The present work illustrates the use of different shear deformation theories using a multilayer approach implemented through kriging based finite element models. The performance of these models will be illustrated through a set of test cases.

8594 | CREEP DEFORMATION AND FRACTURE PROCESSES IN MAGNESIUM METAL MATRIX COMPOSITES (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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The major current area of growth for the use of magnesium alloys is in the high volume commercial automotive sector, where there is an incentive for weight savings to maximize fuel economy and minimize emissions. To achieve additional substantial increases in the use of magnesium alloys in the automotive industry, it is necessary to utilize magnesium alloys in the engine and transmission components. However, these applications require a greater improvement in the high-temperature strength and creep resistence than is possible with the currently available commercial magnesium alloys. In practice, the creep resistence of magnesium alloys tends to be limited at temperatures above ~ 400 K.
Marked improvement in the creep properties of monolithic magnesium alloys can be potentially achieved through the production of composite materials where the matrices consist of conventional alloys which are strengthened through the introduction of non-metallic short fibres, particles, or hybrid reinforcements. This paper reviews the creep characteristics of the two representative magnesium monolithic alloys (AZ91 and QE22) and their various discontinuous composites. It was found that both of the short-fibre reinforced AZ91 and QE22 composites exhibit better creep resistance than their

monolithic alloys due to an effective load transfer in which part of the external load within the matrix is transferred to the reinforcement. Indirect composite strengthening may be caused by microstructural effects leading to a threshold stress that increases the creep resistance. Potential microstructural effects include changes in the dislocation arrangements, a matrix compositional variation, or a reinforcement transformation. The results suggest that direct composite strengthening controls the creep behaviour of the short-fiber magnesium composites when the matrix microstructure is constant and stable and composites have good fibre/matrix interface bonding. Indirect composite strengthening in the short-fiber composites may be caused by a dispersion of fine particles in the matrix of the composite, which inhibits dislocation motion and leads to a threshold stress that increases the creep resistence. However, indirect reinforcement effect can also produce weakening as it was found in the case of particle-reinforced QE22+SiC composite due to enhanced precipitation of Nd-rich phases at the SiC/matrix interfaces. Similarly, comparison between AZ91 and QE22 magnesium hybrid composites reinforced with short carbon fibre and SiC particulates has shown, that the creep resistance of the hybrid reinforced AZ91 alloy was considerably improved by comparison with the unreinforced matrix alloy. By contrast, no beneficial effect on the creep resistance of the hybrid reinforced QE22 alloy was found. Thus, since the interfaces between the matrix and reinforcement play an important role in the creep properties, the understanding of the interfacial microstructure is very useful for the selection of reinforcement. The characteristics of the interfaces between the matrix and the reinforcement phase in magnesium matrix composites strongly influence the interfacial bond integrity. To obtain composite materials with the desired microstructure and properties, the interfacial reactions should be controlled through selecting an appropriate matrix alloy, conducting an appropriate surface treatment of the reinforcement and correctly controlling the process parameters. Therefore, the appropriate choice of composite matrix and the corresponding reinforcement is of paramount importance. Creep behaviour and creep resistence may be substantially influenced by the development of creep damage and fracture processes. Fractographic investigations of both short-fiber composites failed to reveal either substantial creep fiber cracking and breakage or any debonding at the interfaces between the fibers and the matrix at the lower applied stresses.

9003 | Size effect on the free vibration of geometrically nonlinear functionally graded micro-beams under electrical actuation and temperature change **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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This paper investigates the free vibration characteristics of functionally graded micro-switches under combined electrostatic, axial residual stress and temperature change, with an emphasis on size effect, the influence of volume fraction profile parameter, the effect of geometric nonlinear deformation due to mid-plane stretching and temperature change. The micro-switch considered in this study is made of either homogeneous material or non-homogeneous functionally graded material with two material phases. Take into consideration the temperature-dependency of the effective material properties, the Voigt model is used to simulate the material properties of the functionally graded materials (FGMs). The principle of virtual work and modified couple stress theory is used to derive the nonlinear governing differential equation. The eigenvalue problem which describes free vibration of the micro-beam at its statically deflected state is then solved using differential quadrature method (DQM). The natural frequencies of clamped-clamped micro-switches are obtained. The solutions are validated through direct comparisons with experimental results reported in previous studies. A parametric study is conducted to show the size effect, material composition, temperature change and the effects of geometric nonlinearity for the natural frequencies of clamed-clamped micro-switch.

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9327 | Nonlocal Continuum Theories for Shell Structures **(37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))**

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Nonlocal Continuum Theories for Shell Structures*

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Abstract
This paper is an extension of the work of Prof. JN Reddy related to nonlocal beam and plate theories [1-3]. A nonlocal continuum formulation for shell structures is presented. The first-order and third-order shear deformation shell theories [4] are reformulated by using the nonlocal constitutive equations of Eringen [5]. The equilibrium equations are derived and a variational formulation is obtained in terms of generalized displacements to be used in finite element formulations. Analytical solutions for bending are shown to understand and to discuss the nonlocal behavior effect in first and third-order theories of shells.

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9340 | NON-LINEAR VIBRATIONS OF LAMINATED AND SANDWICH RECTANGULAR PLATES WITH FREE EDGES (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Large-amplitude (geometrically nonlinear) forced vibrations of completely free sandwich composite rectangular plates are investigated experimentally. Harmonic excitation is applied by using an electro-dynamic exciter and the plate vibration is measured by using laser Doppler vibrometers. A scanning laser Doppler vibrometer is used for experimental modal analysis since it provides non-contact vibration measurements with very high spatial resolution. The large-amplitude vibration experiments are carried out by using a single point Laser Doppler Vibrometer and a stepped-sine testing procedure. The non-linear frequency response curves are obtained by increasing and decreasing the excitation frequency in very small steps at specific force amplitudes controlled in a closed-loop. The experimental results are compared to numerical simulations obtained by a refineed reduced-order models and show very good agreement. The nonlinear damping is experimentally obtained as a function of the vibration amplitude.

9367 | On Damage Mechanics of 3D Orthogonal Woven Composites: Experiment and Numerical Modelling (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Damage of composite materials has been always an area of investigation for many researchers due to the complexity of the damage initiation and evolution processes. Three-dimensional (3D) composite materials are even more complex when it comes to the several elementary damage mechanisms [1,2,3] compared to laminated two-dimensional (2D) composites. In this paper, investigation of damage initiation and evolution of 3D orthogonal woven carbon fiber composite (3DOWC) is carried out both experimentally and numerically. The 3DOWC unit cell investigated is shown in Figure 1; it consists of 8 warp layers (yarns parallel to the weaving direction), 9 weft layers (yarns transverse to the weaving direction) and 2 binders (through thickness yarns).

Figure 1 3DOWC unit cell (binder yarns goes all the way through the thickness) produced using TexGen Software [6]

Meso-scale homogenization of the representative volume element (RVE) is utilized to predict the elastic mechanical behavior for 3DOWC and further extended to simulate the damage initiation and evolution effect on the global behavior in tension. Three different damage mechanisms are investigated for the yarns (longitudinal fiber breakage, transverse cracking, shear diffused damage) while one damage mechanism is introduced to simulate the matrix damage “cracking”. The major assumption of the model is simplifying the 3DOWC unit cell without the binders as a (0/90) cross-ply laminate which enables the continuum damage model (CDM) to be applied for different loading conditions and evaluate the damage level on the meso-scale as function of the cracking density in the material [4, 5]. This can directly correlated afterwards with the applied stress/ strain as function of the energy release rate for the accumulated cracks. Results from the simulated RVE problem is validated against experimental results along the warp (0o direction) and weft (90o direction). This model is a predictive multi-scale bridge that can be extended for further 3D architectures and become efficient tool for researchers and industry.

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9387 | Effect of an inhomogeneous interphase zone on the bulk modulus of a particulate composite containing spherical inclusions (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Keywords: elasticity; particulate composite; spherical inclusions; bulk modulus.

Nanoparticle reinforced materials, hollow particle filled composites as well as concrete are only some examples of particulate composites where the effective elastic properties are strongly affected not only by the elastic moduli of the two phases and the volume fraction of the particles, but also by the geometric characteristics and elastic properties of the interphase zone. As an example, due to manufacturing errors, flaws and defects can easily form at the interface between the matrix and the inclusions embedded to improve the effective stiffness of the composite material. As consequence, a transition zone around the inclusions forms and its thickness can be comparable with the inclusion characteristic size. In such cases, models based on the assumption of a sharp interface are not adequate.
This work deals with the derivation of the effective properties of particulate composites modelled as a suspension of elastic homogeneous spherical particles in a continuous matrix, taking into account the effects of an inhomogeneous interphase zone around the inclusions. In particular, the attention is focused on the derivation of explicit expressions for the bulk modulus.
In order to do this, the analysis employs the closed form analytical solution for the problem of a single hollow or solid sphere embedded in a matrix with an inhomogeneous interphase around the inclusion with elastic properties in the form of power-law in radial direction [1]. Assuming hydrostatic pressure the

elastic problem is solved in the framework of elasticity theory and the effective elastic bulk modulus is obtained using the energy method [2]. These results, recently obtained by the first author in [3], are investigated in this paper for very small and very large concentrations of inclusions.
In addition to the case of dilute suspension conditions, the non dilute case is also considered and, in order to do this, well-known approximation schemes for effective properties of particulate composites are studied and compared. As an example, the differential method and the generalized self consistent method are employed. The cases of voids or solid/hollow inclusions in a homogeneous matrix as special cases of the solution proposed are compared and a parametric analysis is performed to investigate the influence of the geometric characteristics and elastic properties of the interphase zone on the effective bulk modulus of the composite material.

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9488 | On micromechanics-based nonlocal modeling of elastic matrices containing multi-layer particles (37. Symposium on Mechanics of Composite Materials and FGM structures, celebrating the 70th Anniversary of Professor J. N. Reddy (Cristovao M. Soares, Carlos M. Soares, IST, Portugal, Samit Roy, USA))

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Within the mathematical modeling of the mechanical behavior of elastic composites, classical approaches usually treat the material as being macroscopically homogeneous with constant overall properties and develop constitutive equations relating suitable averages of microscopic stress and strain fields over a Representative Volume Element (RVE). As is well known, the accuracy of the related local constitutive equations depends on how large RVE, compared to the characteristic microstructural length of the material, is. A more comprehensive knowledge of nonlocal effects due to microstructure on the constitutive response of the composite requires a comparison with a nonlocal constitutive law.
In this context, the formulation of nonlocal modeling of interest here was that first developed by Drugan and Willis (J. Mech. Phys. Solids, 44, 497-524, 1996) and then generalized by Monetto and Drugan (J. Mech. Phys. Solids, 52, 359-393, 2004; J. Mech. Phys. Solids, 57, 1578-1595, 2009). Employing a generalization of the Hashin-Shtrikman variational formulation, these authors derived micromechanics-based nonlocal constitutive equations relating the ensemble averages of stress and strain for random linear elastic two-phase composite materials consisting of an isotropic matrix containing isotropic heterogeneities and presenting macroscopically an either isotropic or transversely-isotropic behavior. In particular, completely explicit results for the case of homogeneous (rigid or elastic) inclusions and voids were derived and discussed.
In this work, the attention is focused on elastic multi-layer particles. These can correspond to inhomegeneous inclusions made up of two or more different materials, as well as homogeneous inclusions with a sufficiently thick interphase surrounding them at the interface with the matrix. The principal objective is to analyze the nonlocal effects of such specific internal microstructure on the macroscopic properties of the composite. In order to do this, the preceding formulation is here readjusted to taking into account the inhomogeneity of the particles.

6727 | On the optimal design of tensegrity lattices (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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We study acoustic applications of tensegrity structures, which are related to the design and manufacture of innovative periodic lattices and phononic crystals. The extreme hard/soft behaviors of tensegrity prisms is exploited to manufacture periodic lattices supporting special types of solitary waves. Such waves feature extreme compact support, in correspondence with a stiffening response of the unit cells ('atomic scale localization'); or alternatively rarefaction pulses, when instead the unit cells exhibit a softening-type behavior. The self-stresses of the basic units are finely tuned in order to switch the local response from softening to stiffening, according to given anisotropy patterns. Future extensions of the present study involve the design of locally resonant materials incorporating tensegrity concepts, and the manufacture of tensegrity microstructures through 3d printing.

7839 | Hierarchical composite lattice structures (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Hierarchical structures can be yielded by the hybrid of stretch- or bend-dominated construction at different length scales, which forms stretch-stretch-hybrid and stretch-bend-hybrid hierarchical lattice structures. A flowchart was subsequently summarized to help evaluate the structural efficiency. Fabrication techniques for stretch-stretch-hybrid and stretch-bend-hybrid hierarchical composite pyramidal lattice (CPL) structures were both developed, and compression performance was tested to validate the prediction models for the mechanical properties of the two structures. After building up the failure mechanism maps, each hierarchical structure was optimized and then evaluated by comparing with that of other competing topologies. Both the optimized hierarchical structures were found to be as efficient as optimized hollow CPL structure and superior to other constructions, such as honeycomb and corrugated core. Effects of constructions at two different length scales was assessed: the macroscopic topology determined the efficiency of the hierarchical structures while the mesoscopic topology had little effect. Finally, the application potential together with manufacturability of these hierarchical structures were discussed.

Key words: Lattice structure, Composites, Hierarchy, Compression, Structural efficiency

7842 | The effect of different valency cations on the sintering process of magnesium oxide composites (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Magnesium oxide (MgO) is an ionic compound with relatively high melting point (2825°C) and is one of the most important materials used in the production of ceramics having the ability to withstand high temperatures. Pure MgO powders are hard to be densified into compacted ceramic sinters through the standard processing route via pressureless sintering due to their high melting point. Therefore, it is necessary to introduce second phase – sintering aids i.e. small additions of various compounds that allow good densification at a relatively lower temperature during sintering.
This paper presents results of a research on the effect of metal oxides (Al2O3, Cr2O3, TiO2, WO3, MoO3) and metal fluorides (NaF, CaF2, AlF3) addition on the sintering process of pure magnesium oxide. Experimentally obtained results and phases were compared with compounds predicted by the equilibrium phase diagrams.
The MgO-based dense refractory composite materials obtained by the reactive sintering of MgO powder with additives at 1500°C and 1600°C were investigated by XRD and SEM-EDS. Mercury intrusion porosimetry (MIP) has been widely used to the characterization of the pore structure of MgO-modiefeid phase ceramics. The microstructure of sintered high purity MgO ceramics consists of a homogeneous distribution of refractory crystalline secondary phases in the magnesia matrix.

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8636 | Vibro-acoustic optimization of sandwich panels involving hexagonal honeycomb cores (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Sandwich panels are extensively used in automotive, naval and aerospace industry. These structures have high stiffness-to-weight ratios and are usually made of a moderately thick, lightweight core surrounded by glass or carbon-fiber composite skins. The core can be made of polymer foam or more complex structures involving aluminium or resin honeycomb constructions. Although the material and geometrical properties of the panel are usually designed to provide specific stiffness and density characteristics, structural optimization also concerns acoustic radiation efficiency in order to improve the acoustic comfort. Therefore, there is an increasing need for reliable optimization tools for design engineers, providing fast vibro-acoustic evaluation of large-scaled structures involving composite components.

In this context, the knowledge of accurate wave dispersion characteristics in two laminated orthotropic skins connected by 3D cellular honeycomb core is a key information for the prediction of the acoustic transmission parameters. Numerical methods for analyzing the vibrational behaviour of complex composite or periodic panels in a broadband frequency range were extensively investigated in the last decade. Analytical approaches suffer some drawbacks in the medium-frequency range, since they often involve an equivalent homogeneous layer for the honeycomb core, and cannot handle some wave localization effects occurring at higher frequencies. Therefore, numerical methods were recently developed to perform wave analysis in advanced periodic waveguides defined using classical finite element packages (FEM). Among others, the Wave Finite Element Method (WFEM) has been successfully applied to predict the radiation efficiency of numerous thick layered structures. Nevertheless, these models involve homogeneous orthotropic layers for the honeycomb construction, and may become inaccurate when the wavelengths are reaching the periodic cells dimensions.

This paper focuses on the influence of the meso-scale parameters of the hexagonal honeycomb construction on the vibro-acoustic response of the sandwich panel. Refined finite element models are developed for the periodic cell. The WFEM, which combines FEM and the Periodic Structures Theory (PST) is applied to evaluate the wave dispersion characteristics. Since numerous degrees of freedom are involved to ensure accuracy in a broadband frequency range, an interpolatory wave-mode model order reduction (MOR) is applied to perform fast optimization of the acoustic transmission. Therefore, the effects of several geometrical and material parameters of the honeycomb core on the Sound Transmission Loss (STL) and the acoustic coincidence frequency are investigated. Furthermore, this paper investigates the use of wave-based methods in the framework of structural optimization of composite panels involving advanced components.

8737 | Mechanical properties of multi-scale lattices made of hierarchical material (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Lattice materials have been extensively used as a core material in sandwich structures, energy absorption and packaging purposes. Due to their excellent stiffness and strength at low density, they are now being used in infrastructure applications and sports goods industries as well. With an aim to produce ultra- light yet stiff and strong lattice materials, recent research in this area mainly focuses on the mechanical properties of lattices with structural hierarchy. These hierarchical lattices are made of smaller lattices at finer scales, and can be manufactured by current rapid prototyping techniques. In this work, stiffness and the strength properties of novel multi-scale lattices made out of hierarchical material, are investigated. Theoretical approach is employed to develop the expressions for the stiffness and strength properties of such hierarchical lattices. The enhancement of these properties are compared to those of the single scale lattices.

9026 | Mechanical response of an auxetic cellular sheet under plastic deformation (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Most materials, when stretched in one direction, shrink in the lateral direction. The ratio of lateral contraction to the extension in the direction of the applied load is termed as the Poisson's ratio of the material. Positive Poisson's ratio is a norm; however, in the past 25 years materials with negative Poisson's ratio have also been developed. Such materials are often structured and are known as auxetic. Negative Poisson's ratio is interesting in many situations—increased shear stiffness, an increased indentation resistance, enhanced resistance to cell-wall buckling, greater flexural strength have been reported, for example. These properties have made them useful for several applications such as those in military, sensor and actuators, filters and biomedical contexts. In this paper, we consider structures with apparent auxetic behaviour having potential application in the context of cardiovascular stents. The length of the stent can be shorter at the stage of deployment. During this phase, the stent must deform plastically necessitating elasto-plastic analysis during design. Moreover, instantaneous elastic recoil is observed during the stent deployment. The present work develops an analytical model to estimate the macroscopic effective properties of an infinite auxetic sheet under elasto-plastic deformation. Further, expressions for the elastic spring back are derived. An inverted hexagonal lattice made of material that exhibits hardening behaviour is considered. For the translational symmetry, we can assume that inclined members behave as fixed beam with point load and moment at the free edge. This obviates the need to carry out a full expensive analysis. Therefore, the study can be reduced to the elasto-plastic analysis of a cantilever beam with an inclined tip load and moment. Analytical expressions for the deflection of the cell-walls are derived by relating them to the stress distribution at each cross section. Because of the axial force, the neutral axis shifts. Therefore, the two sides of the cross section will not undergo plastic deformation at the same time. This result in three different regions along the cell wall. They are the elastic region, the primary plastic region—where only one side of the beam has plastically deformed, and the secondary plastic region—where both sides of the cell wall have undergone plastic deformation. The elastic contribution is subtracted from the solution obtained above in order to analyse the spring back when the load is removed. For the whole analysis, a novel linear elastic followed by hyperbolic plastic stress-strain relationship is assumed. The plastic non-linear behaviour is mathematically described by a rectangular hyperbola with asymptotes translated with respect to the reference system.
Finally, a model of a cylinder of infinite extent in the axial direction, obtained by folding such lattices, is considered. The lateral response of a 2-D lattice sheet under remote unidirectional stress is calculated using the analysis described above. This effect manifests as the axial shortening of the stents during ballooning. For common materials, the axial shortening is negative—thus they reduce in length, whilst for this class of material it is positive—thus, they expand radially and they elongate axially.
The nonlinear behaviour, due to plasticity, has been analytically calculated for an auxetic lattice structure and reported for the first time. A parametric study of the structural response for various shapes of cells is carried out, enabling us to assess the influence of geometric parameters on the macroscopic properties.

9035 | Structure-property relationship of additively manufactured lattice materials: micromechanics and measurements (38. Mechanics and engineering of lattice & structured material (Atul Bhaskar, Univ. Southampton, UK, and Sourish Banerjee, Univ. Southern Queensland, Australia))

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Structured or lattice materials are a class of materials made up of the tessellated periodic arrangement of matter. The lattice is made up of filaments that are produced using additive manufacturing. The arrangement of these filaments in a porous architecture, affords advantages when compared to their fully solid counterpart. Also it is inevitable for the manufacturing process under consideration to result in materials with porosity. Additive manufacturing techniques allow engineers and designers to fabricate bespoke materials and structures. The present research is focused on the Fused Deposition Modelling technique, which has been used to stack material in the so-called woodpile arrangement. In this technique, filaments are extruded through a nozzle whose position is controlled. The nozzle displacement is driven to positions contained in instructions lines known as the G-code. The G-codes needed to manufacture the desired lattice samples were generated using a MATLAB code. The MATLAB code takes as input the structural parameters such as: number of filaments, distance between filaments, number of layers and distance between layers. Samples were manufactured according to the ASTM standards with some modifications to avoid obtaining irrelevant data, such as the influence in the mechanical behaviour of the edges. The extruded filaments are deposited in a platform forming the first layer of the part to be fabricated. Changing the distance from the nozzle to the platform allows the next layer to be fabricated. Adjacent layers of semi-molten material solidify and thus bond together in this process. Parts with locally controlled mechanical properties can be fabricated with this manufacturing technique by changing the deposition orientation of the filaments.
The objective of this research is to characterise the mechanical properties of the lattice material described. In order to characterise the lattice structure, single FDM filaments were studied first. Tensile testing of these was performed and the measured mechanical properties are reported here. These properties have been then used to predict the apparent elastic properties of the complete lattice. Stress-strain curves of single FDM filaments are presented and discussed. Stress-strain curves obtained from the tensile testing of the complete lattice are also presented. The expected mechanical response of the complete lattice in tension is based on the single filament properties presented. While a considerable amount of works regarding the mechanical properties of fused deposited parts can be found in the literature, studies on the flexural properties have been very limited. This work also presents the prediction of the flexural load-deflection response of the particular lattice material described.
Due to the layer-by-layer principle of the manufacturing process, a model based on the Classical Laminate Theory is developed. The constitutive equations were obtained and the flexural stiffness matrix formed. The model is then validated with three point bending experiments. The elastic part of the curves is studied in this paper. The samples were treated as laminated beams, and manufactured under controlled deposition of filaments. The elastic response shows consistency and good agreement with the load-deflection relation predicted using the model developed using Laminate Theory. The measured and calculated load-deflection curves are presented.

6959 | Post-cracking response of hybrid beams consisting of glass-GFRP and glass-SRP. (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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This paper presents recent results of an experimental study of hybrid beams made of annealed glass reinforced with SRP (Steel Reinforced Polymer) or GFRP (Glass Fiber Reinforced Polymer) sheets or GFRP pultruded profiles. Tested beams are formed by float glass sheet glued between them and with

the reinforcement using common structural resins. The experimental program included material characterization tests, adhesion tests and four point bending tests.
The behaviour of the beams can be clearly seen: all beam specimens showed a pre-critical phase characterized by a linear phase until the first crack, after which there was a drop in the load followed by a rising of the load and the forming of new fissures which occurred in the beam until collapsing. Glass beams presented a progressive decrease of the bending stiffness from the elastic phase to the collapse.
In all the experiments the beams showed residual resistances and a great value of the ratio between final failure displacement and initial failure displacement which is indicative of a ductile behaviour.
The behaviour of these hybrid beams has also been studied using a specifically constructed analytical model that refers to the load-deformation characteristics of the beams at initial failure and at collapse. It was used to perform simulations in order to investigate the structural response of the hybrid beams to the varying of its characteristics.

7744 | The conception of cable-stayed footbridge with GFRP deck (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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Present footbridge structures in the world are like explosion of modern engineering calculation and material parameters. There are full of amazing architecture and extraordinary form and shape. Engineers predict that a new type of footbridge, a hybrid design in incorporating suspension and cable-stayed features, will revolutionize bridge design, as will high-strength. Light weight composite materials now being used and create new dimension of area. Glass Fibre Reinforced Polymer Composites, thanks to their beneficial properties and various advantages over traditional materials, have great potential as a material used in bridge engineering. During the last 30 years, they have proved useful in a few areas: they are commonly used to strengthen existing bridge structures; they can replace traditional materials for structural elements in hybrid bridge structures. Glass Fiber Retrofit Polymer makes new horizon in material technology, helps to rich new conception of structure with longer durability, low weight of deck, new creation of architecture line. The paper has described a few results of FEM analysis of cable-stayed footbridge with modular bridge GFRP deck system. The rules introduced in European standards require verification of natural frequency and level of vibrations of the footbridges. According to EN 1990/A1 verification the vibration comfort criteria should be performed when the fundamental frequency of the footbridge is less than 5.0 Hz for vertical vibrations and 2.5 Hz for horizontal and torsion vibrations. In the cases of medium and large span steel footbridges the fundamental vertical vibration frequency is very often less than 5.0 Hz. With these reasons the verification of the vibration comfort criteria becomes obligatory for almost all footbridges. Fundamental parameters determining the intensity of vibration perception by human are: vibrations amplitude, frequency characteristic of the vibrations, direction of the vibrations, vibrations impact time (exposure time), repeatability of the vibrations, human activity. It should be noted that the recommendations of the EN 1990/A1 exclude the impact of the frequency characteristic of the vibrations and type of human activity on the permissible amplitude of the vibration acceleration. In some cases, the vibrations with amplitudes equal to the values recommended in EN 1990/A1 can be clearly felt by walking and very clearly by standing pedestrians. It is necessary to define the appropriate and accurate criteria. The analyzed cable-stayed footbridge with GFRP composite deck is suitable with EN 1990/A1 normative rules.

7978 | Electric properties of the porous glasses and ferroelectric nanocomposites based on them (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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The porous glasses, the products of leaching of phase-separated glasses, are the subjects of the scientific investigations. It is caused not only by many problems connected with manufacturing of these glasses but also by very interesting properties depending on their structure and various application. After impregnation of the porous glass with the different substrates it is possible to obtain very promising materials which find the wide use in microelectronic and optoelectronic devices. One of the important factors is the control of technological processes as well as estimation effect of the glass processing on its properties. For many years all porous glasses produced have been based on alkali borosilicate glasses. First, the original glass is heated at high temperature in order to realize the separation into two phases. The phase-separated glass was etched in hydrochloric acid and rinsed in deionised water. The porous glass obtained is immersed into a solution containing ferroelectric substance (KNO_3). The microstructural changes appearing during formation of the porous glasses influence the physical and chemical properties of them. In the paper the results of measurements of electrical properties of porous glasses before and after impregnation by ferroelectric depending on their structure are presented. The measurements were performed successively after each stage of the technological process. The structure of the initial two-phase glasses, porous glasses and nanocomposites has been investigated by transmission electron microscopy (TEM) and X-ray diffraction (XRD) techniques. Also the porous space parameters have been studied by porosimetry (BET method). Electrical conductivity and dielectric permittivity measurements have been used to observe the electrical changes in the glasses after modification of their structure. The investigations were performed for dielectric (silica) and magnetic (Fe_2O_3 inside silica) matrixes.

This work was carried out as the Polish–Russian joint research project “Ferroelectric, magnetic and optical nanocomposite materials on basis of porous glasses” of the Inter Academic Scientific Cooperation Program (2014/2016) and in conformity with subjects of project no. 15-03-06258 of the Russian Foundation for Basic Research.

8063 | A study on the mechanical properties of insert molded FRP s with different inserting laminations of silk fabric (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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Applications of FRP are widespread; it's used as exterior roofing material for individual resident terraces and carports, or lighting materials such as the interior surface material for bathroom doors or room-partitioning windows. Polycarbonate, which is a type of GFRP lighting materials, has strong physical properties but looks unpleasant, due to the visible glass pattern. In order to solve this problem we have developed a decorative molding technology using kyo-yuzen (Kyoto-made, paste resist-dyed kimono fabric) as a reinforcing material, consisting of silk cloth used to make Japanese kimonos. By incorporating this method fused with traditional Japanese design, the glass pattern can be utilized as a pattern in its own right. In the kimono industry, cloth with soft and elegant textures is preferred over vivid finishing. This is expressed in the Kyoto-based Japanese word “han-nari”, which means not only "soft and elegant", but “gorgeous”.
In this study, we have focused on the conventionally-overlooked artistic qualities of FRP. By combining superior FRP functionality produced with high technology and the unique Japanese sense of aesthetics originating in ancient times, we developed these new concepts in FRP-applied products, then combined them with Japanese traditional craftworks, such as kyo-yuzen. That is called “Artistic FRP”. We think that mutual support is necessary for the progress of both science and the arts, allowing a new artistic, scientific, and technological culture to be actualized.

In particurally, the investigation of the effect of the inserting laminations of the silk fabric on the mechanical property of insert molded FRPs was carried out. 6 types of the different lamiantion structure composite were molded with 4-5 layers of glass mat fabrisc and 1 layer of silk fabric. In some of them , gel coating was add in single or double faces of the composites. 3 point bending tests (normal bending, low/high cycle bending , crepe, after degradtion of hot water and sunshine) and impact were carried out.

8114 | Optimal cold-bending and cold-lamination-bending of glass **(39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))**

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Laminated glass is a composite made of glass plies bonded together by polymeric interlayers with a process at high temperature and pressure in autoclave. Its bending properties are strongly influenced by the shear-coupling of the glass plies through the interlayer, whose response is viscoelastic in type. The modern architectural trend desires curved glass to build free-form building envelopes, for which the constituent panels can be obtained with “hot-bending” or “cold-bending” processes. Hot-bending consists in heating glass up to the softening point and curving it into the desired shape against a negative form. In cold-bending, initially-flat panels are elastically strained in the desired position and maintained into place with clamping strips or adhesives against an underlying frame. A more recent technique is “cold-lamination-bending”, which consists in curving the glass-interlayer assembly in the desired shape with provisional constraints and, only afterwards, performing the lamination process in autoclave. After that adhesion takes place, it is the bond of the glass through the interlayer that maintains the curvature, even when the constraints are removed. However, the curved laminate suffers an initial springing back followed by a relaxation due to the decay of the shear-coupling of the glass plies, as a consequence of the viscosity of the polymeric interlayer.
Here, the single-curvature cold-bending of a laminated glass panel is analyzed by using sandwich beam theory, developing for this particular case a method originally proposed by Newmark et al. [1]. The relationship between the design cold-bent shape and the spatial and temporal evolution of the state of stress in both glass and interlayer is discussed in detail. Results are compared with those obtainable with cold-lamination-bending. The model for this latter case considers that during the bending phase there is a relative shear-slip between the glass plies and the (not yet bonded) polymeric interlayer, which is treated as a distributed shear dislocation. The proposed approach [2] allows finding the time-dependent state of stress for any given assigned deformation. It is shown that “soft” interlayers (like PVB) undergo a noteworthy viscous release, which strongly reduces the initial distortion in a just a few months’ period; on the other hand, “stiff” interlayers (like Ionoplasts) can provide excellent bonding for the whole lifetime of the glazing.
For both the cold-bending and the cold-lamination-bending processes, different-in-type cylindrical deformations are analyzed in detail. A method is proposed to find which is the initial shape that, at a prescribed time, provides the desired state of stress in the materials. Remarkably, it is demonstrated that the simplest constant-curvature deformation, indeed the most used for these techniques, is associated with shear stress concentrations in the polymeric interlayer, eventually leading to delamination as observed in the practice. The higher the shear stiffness of the interlayer, the more critical is the corresponding state of stress: in the limit case of rigid interlayers, the shear stress becomes singular because lumped forces at the panel extremities are necessary to guarantee equilibrium.
Various possible shapes for cold-lamination-bending are compared in order to avoid such stress concentrations and, among all the considered cases, the optimal deformation is sinusoidal. For current geometric and material parameters, the difference between an arch of sinusoid and an arch of a circle cannot be appreciated with the naked eye. The aesthetics is not affected, but such small differences in the shape can provide so noteworthy advantages.
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8172 | ORGANIC –INORGANIC HYBRID MATERIALS DOPED WITH (Sm3+, Nd3+, La3+/(Eu3+) RARE EARTH AND LITHIUM IONS **(39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))**

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Silica-based organic-inorganic hybrid materials doped with samarium, neodymium, lanthanum / europium (Sm3+, Nd3+, La3+, Eu3+) rare earth and lithium ions were prepared by sol-gel method. Tetraethyl orthosilicate (TEOS), ethyl methacrylate, ethylene glycol dimethacrylate, ethyl acetoacetate, and

SmCl3•6 H2O, NdCl3•6 H2O, LaCl3•7 H2O, (EuCl3•6 H2O), LiClO4 were used as precursors and dopants, respectively. The materials obtained (ca 40 % of organic parts) were aged at room temperature and heat treated at temperature of 105°C. Scanning electron microscopy equipped with energy dispersive X-ray spectroscopy (SEM/EDS, Atomic Force Microscopy (AFM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR, KBr technique), 29Si MAS Magnetic Nuclear Resonance and X-ray Photoelectron Spectroscopy (XPS) methods were used for investigation of morphology, chemical composition and structure of the materials. The excitation and emission luminescence spectra were recorded at room temperature, using fluorescence spectrometer equipped with a pulsed Xenon lamp as an excitation source. The materials have revealed dominant photoluminescence emission bands resulting from electronic transitions of samarium (III)/europium (III) and the relatively weak from the neodymium (III) ions. According to the excitation and emission spectra, the occurrence of energy transfer from Nd3+ to Sm3+ and possible to Eu3+ ions is observed.

8638 | Modeling tensile properties of hybrid wood plastic composites reinforced by unidirectional glass fiber (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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In previous work, wood plastic composite (WPC) was reinforced by continuous glass fiber by a unique extrusion process. In this method, continuous glass fibers were impregnated by polyethylene melt and have been located into the extruded WPC profile while extrusion is running. The impregnation of glass fibers was conducted to produce a strong interaction between the glass fibers and the WPC. The results of mechanical tests showed that significant improvements in mechanical strengths could be obtained by the presented reinforcing method. This type of composite is regarded as a hybrid composite because two reinforcing fillers i.e. glass fibers and wood flour, are added into the polymeric matrix. In this paper, a model has been proposed to predict the tensile strength and modulus of the WPCs reinforced with unidirectional glass fibers. The methodology applied in this research considers the WPC as matrix and the glass fibers as reinforcements. Since WPC matrix is brittle, the rule of mixtures corresponding to the brittle matrix composites was used in this paper. Results indicated that the predicted tensile properties were in good agreement with experimental data.

8714 | On the experimental determination of dynamical properties of laminated glass and a comparison with a theoretical model (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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In this work we address experimentally the determination of the dynamical properties, mainly natural frequencies and damping factors, of laminated structural glass. Various specimens, coming from different productions and manufactures, are investigated. Damped free vibrations experiments are performed, where the initial excitation is provided by an instrumented hammer. The boundary conditions are free-free (the specimens lay on a very flexible sponge substrate). Various identification techniques, including experimental modal analysis (EMA) and last squares fitting of time histories (FHT), are used and compared between each other to check the reliability of the results. Using the EMA, we extract the modal parameters in most simple way and we compare them (those obtained by applying) with the classical analytic theory of beams in free vibration, both to comprehend the behavior of laminated glass and to test the instruments and the experimental set in terms of reliability and accuracy. We extract the same modal parameters also using the FHT technique, which is based on the observation that, in free vibration, any dynamical quantity of interest (displacement, velocity, acceleration) of a single mode behaves as a function of the amplitude, the damping coefficient, the natural frequency and the phase shift. We check this method using the classical statistic parameters and we reach a good level of reliability. This identification technique gives us some important results, regarding mainly the invariance of application of loads on laminated glass and the irrelevance of the interface damages of one specimen (i.e. small detachments). Eventually, we can also underline the influence of ageing on the damping of laminated glass, found and checked with FTH. We also check this identification technique moving the exciting point, reaching the same results in terms of frequencies and damping. In the following part, we compare the experimental results with a theoretical model which describes the behavior of laminated beams, as the ones tested of laminated glass, which are laminated using PVB. The main hypothesis of the model are that the beams behave according to the Euler-Bernoulli kinematics, the interface can only slide (detachment is not allowed), axial and rotational inertia are neglected. We can identify the dynamic parameter of laminated glass, observing its mechanical behavior strongly influenced by the velocity of the load and remarking the importance of its dependence on its own thickness.

8727 | Experimental analysis of laminated glass with different interlayers (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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It was carried out an experimental study of the behaviour of different interlayer, laminated glass subjected to static loads. Glass elements, obtained by two glass sheet having thickness of 4 mm, laminated with PVB, were compared with glass elements having the same thickness but laminated with SGP. The glass elements, 1100 mm length and 360 mm wide, were tested on four point bending test, with the same stress rate with an electronic hydraulic testing machine, in displacement control conditions. SGP laminated elements presented a higher stiffness than PVB laminated ones, in the initial elastic phase. Also in the post critical phase the SGP laminated elements had a good behaviour. The failure load didn't exceed the initial failure load. However the cracked sheet is able to bear the load, increasing the displacement. In the case of PVB laminated glass the failure happened with the collapse of the element, while for the SGP laminated glass elements, the interlayer was able to bear the load constant and to increase the displacement, without the sudden collapse. A finite element model, able to reproduce the elastic phase and the post critical phase, was performed. It was possible also to model the behaviour of laminated glass sheet, in the post critical phase, i.e. considering the cracked section. It was modelled the behaviour of the interlayer in the different conditions of time loading. The model in this case reproduced quite well the cracked glass behaviour.

Keywords: Interlayer, PVB, safety glass, SGP.

8923 | Flexural behaviour of long span laminated glass beams reinforced with stainless steel (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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In the past few decades architects and civil engineers have shown an increasing interest in the use of glass as a load bearing material. The glass industry tried to answer to this demand by developing stiff interlayers and by manufacturing longer glass elements. The research about the behaviour of glass as a structural material (encompassing low and unpredictable tensile strength and an inherent brittle failure) has also consistently increased, enabling a much better understanding about its behaviour. This knowledge has been recently gathered in a new a set of European design guidelines, a first step towards the development of an Eurocode in this field.

At the same time alternative technologies were developed to improve the safety and ductility of glass structures. One of the most promising ones consists of combining glass with other structural materials, such as concrete, wood, steel, fibre reinforced polymers (FRPs) and stainless steel. The technique relies on the same principles of reinforced concrete and its application to glass beams has been proven to improve the post cracking behaviour, in terms of both post cracking strength and post cracking ductility.

Previous studies on this type of reinforced glass members have included flexural tests on beams with different (i) shapes and areas of reinforcement, (ii) adhesives, (iii) number of glass panes, (iv) types of interlayers, and (v) types of glass (type of thermal treatment). Concerning the last parameter, previous studies have shown that the use of fully tempered glass decreases the post fracture behaviour of reinforced beams, since its cracking behaviour comprises very limited integrity preservation. However, it is still to know how much this type of glass can sustain, in terms of both interlocking compression and shear stresses after cracking. The vast majority of previous studies have been performed in small-scale specimens, generally with spans lower than 6 m (mostly due to manufacturing limitations). Although testing small-scale glass specimens has several advantages (e.g., in terms of experimental setup and possibility of testing more replicates), it raises several questions about the applicability of the results to real scale structures, moreover due to the brittleness of glass. In addition, in the case of reinforced glass beams, other questions can arise, namely about the representativeness of the type and amount of reinforcement, the type and amount of adhesive and, again, the possibility of extending the results to a larger scale.

This paper presents experimental investigations about the flexural behaviour of long span laminated glass beams made of fully tempered glass and reinforced with stainless steel bars applied on both tension and compression edges. Two simply supported beams were tested in four-point bending differing on the number of fully tempered glass panes and the type of interlayer material: (i) the first beam, with a span of 7.80 m and cross-section comprising three 15 mm-thick glass panes with 600 mm height bonded with interlayers of polyvinyl butyral (PVB), reinforced at both edges with a 40×20 mm stainless steel bar; (ii) the second beam, with a span of 8.00 m and cross-section comprising four 15 mm-thick glass panes with 700 mm height laminated with ionoplast (SentryGlas) interlayers, also reinforced at both edges, now with a 60×20 mm stainless steel bar. The main goal of the tests was to analyse the capacity of fully tempered glass to transfer stresses to the stainless steel reinforcement after cracking. To this end, the beams were reinforced with relatively high reinforcement areas: the cross-section of the stainless steel bars was designed to sustain at least 80% of the tensile forces expected to be transferred from the glass after the development of the first crack. The results obtained in this study are expected to provide a better understanding about the behaviour of reinforced glass beams made of fully tempered glass.

9189 I The strength of GFRP gratings under fatigue loading. (39. Glass composite structures (Emanuela Speranzini, University of Perugia, Italy))

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Glass Fibre Reinforced Polymer (GFRP) gratings are normally made by combining glass fibres with bonding matrixes such as vinyl ester, polyester and phenolic. GFRP grating is considered to be a potential alternative to steel in the offshore applications due to the high strength-to-weight ratio and high resistivity to corrosion. This paper present the experimental results on the effect of fatigue load to GFRP gratings made from moulding process with length of 760 mm, width of 300 mm and depth of 38 mm. A total of six GFRP grating specimens were tested under static and fatigue loads with span of 640mm. The specimens tested under fatigue up to 1 million cycles at 5Hz at the range not exceeding 40% of the static load to simulate the serviceability load in the offshore. All the specimens were tested to failure after 1 million cycles of fatigue load to observe the remaining strength of the GFRP gratings. It was found out that all the specimen show degradation in strengths and stiffness after tested to one million cycles fatigue load. The polyester GFRP grating shows the highest strength degradation followed by vinyl ester and phenolic.

7643 I An extended cohesive damage model for predicting multiple crack propagation in composite structures (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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An extended cohesive damage model (ECDM) for predicting multiple crack propagation in composite structures was presented in this paper. This developed ECDM model employed the concept for enriching the strong and weak discontinuities in composites from the standard extended finite element method (XFEM) to approximate the matrix crack and delamination or debonding in composites. Unlike the standard XFEM the enriched degree of freedoms are not required by the ECDM for improving the efficiency and convergent rate in multiple crack simulation. A shift Heaviside function was introduced into the ECDM to express existing cracks and crack propagation. The classical cohesive damage model (CDM) was used to overcome the problem of stress discontinuities at the front of crack and to control the crack propagation. Unlike the classical CDM used at artificial interfaces or boundaries in composite modelling, the ECDM is proposed to be used in whole modelling thus it makes a possibility that the ECDM can simulate the reality of multiple crack path. Verification of this novel model was completed using three standard fracture specimens, double cantilever beam (DCB), end load split (ELS) and mixed mode bending (MMB). As a complex example, a composite stiffened panel with multiple delamination and matrix cracks was investigated using the ECDM. This investigation presented that the ECDM modelling technique can avoid the complexity regarding multiple enrichment functions required by standard XFEM for simulating different cracks in fibre composites, and the artificial interfaces in standard CDM modelling for simulating delamination or debonding are no longer required. This is important in the fracture analysis of complicated structures in which the cracking path is unknown. This developed ECDM supplied an effective and efficient modelling technique in simulation of reality of multiple crack propagation in composite structures.

7645 I An extended cohesive damage element for simulating arbitrary damage propagation in fibre composites (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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This paper introduced an extended cohesive damage element (ECDE) for arbitrary damage analysis in fibre composites. By introducing a cohesive damage model (CDM) into the eXtended Finite Element Method (XFEM) and eliminating the enriched degree of freedoms (DoFs), the proposed ECDE was developed to exhaustively and effectively predict the arbitrary cracks in composites without a priority knowing of crack path. In this developed ECDE, standard shape function was adopted in the approach of partition of unity; a shift Heaviside function was introduced to express existing cracks and crack propagation; the additional DoFs for enriching strong and weak discontinuities were removed from the developed ECDE formulation. Therefore this developed novel ECDE can cope with multiple cracks such as matrix fracture and delamination in composites without solving additional DoFs in equilibrium equations. And this developed ECDE does not require any cross-scale embedments of CDM, allows discontinuities to exist within a finite element, rather than the element boundaries, which enable the ECDE to simulate the reality of arbitrary cracks in composites. This developed ECDE can significantly improve the efficiency and convergent rate in simulation of progressive damage propagation. Initial applications of the ECDE in simulation of arbitrary cracks were also given in this paper, including fracture modellings for a single element, a plate, a beam, standard fracture test specimens and a composite stiffened panel. This investigation shown that the developed ECDE worked very well when comparing the ECDE prediction with analytical and experiment work. Meanwhile, the great computing efficiency of the EDCE was proved by comparing the ECDE with XFEM. This developed ECDE supplied a robust numerical modelling tool for simulating arbitrary damage propagation in fibre composites.

7649 | AN EXTENDED FINITE ELEMENT MODEL FOR THE DELAMINATION ANALYSIS OF COMPOSITE LAMINATES (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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An extended finite element method (XFEM) is applied to the simulation of delamination in composite laminates. The proposed formulation can be employed to model the delamination in the multi-layered composite laminated plates with less computational effort. Composite laminates with arbitrary fibre orientations and stacking sequences are modelled by a first order shear deformation theory (FSDT). The XFEM approach is used to impose the discontinuity at an arbitrary location at the interfaces by enriching the approximated displacement field. In order to simulate the delamination growth, cohesive effects at the delamination plane are implemented into the XFEM-element using differences between the normal and extra degrees of freedom. The arc-length method with full Newton-Raphson iteration is adopted to solve the non-linear problem. Numerical studies are performed for a double cantilever beam (DCB) and end-notched flexure (ENF) tests. The obtained results are compared with those reported in the literature. Moreover, to determine the impact of the integration schemes on the reliability of the results in progressive delamination problems, results from different integration techniques are compared with each other.

8056 | Comparison of numerical and local partition methods in ADCB specimens (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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1. Introduction
It is well known from the scientific literature that the Asymmetric Double Cantilever Beam (ADCB) specimen is subjected to mixed-mode I/II load at the crack tip. In these samples the crack plane lies outside the laminate midplane.
The ADCB test is an alternative configuration to the MMB test (Mixed Mode Bending) to produce a mixed mode load state at the crack tip. This test configuration is as simple as pure mode I tests. Nevertheless, the mixed mode load state at the crack tip cannot be controlled by means of the test fixtures. In this test configuration, the position of the crack plane controls the mode I and mode II load levels at the crack tip.
The analytical determination of GI and GII in ADCB samples is not simple or straightforward and is usually based on partition methods.
In this work, the ADCB sample is analysed from different approaches. Numerical results obtained from Finite Element analysis (FE) are compared with the analytical local partition method (LP). Both results are also compared with an empirical formulation obtained in previous works.

2. Materials and methods
2.1. Material and samples
The material used to perform the numerical and analytical calculations was the Hexcel AS4/3501-6 unidirectional carbon fibre reinforced epoxy laminate. The dimensions of the samples were: 150 mm x 25 mm x 5 mm.

2.2. Finite Element Method
An Ansys package was used to perform the FE calculations. In order to calculate GI and GII energy release rates the Two Step procedure was followed. The following critical values where used to perform the FE analyses: GIc= 90.6 J/m2, GIIc=943.4 J/m2. These values where obtained experimentally in a previous work.
In order to determine the critical load for each run, a Benzeggagh- Kenane law was used.

2.3. Partition method
The analytical calculations were performed by means of the Local Partition method (LP). This method is an analytical approach based on a stress intensity factor calculation defined by K=KI+iKII . This formulation was used to perform the analytical calculation of GI and GII for the different crack plane positions considered in this work.

2.4. Empirical equation
An empirical formulation developed by Mollón et al. to calculate the mode mixity ratio was also used to compare results. This empirical formulation allows the calculation of GII/G rate as a function of the crack plane position.

3. Results and conclusions
FE, LP and empirical results, were in good agreement. The error in the determination of GI/G was in the order of 3% among all three models. The error in the determination of G between FE and LP methods was between 6% and 15% depending of the crack plane position.
The ADCB test configuration is a simple method to obtain mixed mode at the crack tip. The calculation of GI and GII by means of numerical, analytical and empirical formulations provided similar results.

8147 | Mode III of fracture in composites. A new device and formulations (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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This paper shows a new device for testing composite materials in mode III of fracture. This device lets to apply a quasi-pure mode III because there is not practically mode II. In other devices and tests of mode III of fracture there is an important component of mode II. An Optical 3D Deformation Analysys equipment has been used for measuring the displacements of differents selected points during the test in order to demonstrate that the mode II do not exist in this case. Also two different formulations based in the classical theory have been developed. One of them based in the theory of long beam and the other in the theory of short beam. So, different values of energy have been obtained.

8955 | Heat conduction in a layered composite with an interface crack using dual phase lag model (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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High-rate heat transfer has become a major concern in modern industries especially in material processing, such as the pulsed laser heat and ultrasonic waves, and accurate heat conduction analysis is of great importance for the material and structural integrity. For applications involving high power density, extremely short times or cryogenic temperatures, the classical parabolic heat diffusion theory becomes ineffective. Inherent defects in materials such as dislocations and cracks may disturb the temperature distribution when thermal loading is applied to the material, and singularities may be developed in the neighborhood of discontinuities.

In this paper, the heat conduction in a layered composite with an interface crack parallel to the boundaries is investigated by using the dual phase lag model. Fourier and Laplace transforms are applied and the mixed boundary value problem for the cracked structure under thermal loading is reduced to a singular integral equation. Numerical results show that the dual phase lag model parameters, the heat conductivity and the geometric size of layered structure have significant influence on the dynamic temperature field. The results obtained by the dual phase lag theory can be reduced to that by the hyperbolic model and that by the parabolic model.

Keywords: Layered composite, Interface crack, Dual phase lag model, Singular integral equation, Dynamic temperature field

8972 | Mixed mode I/II delamination growth of multidirectional composites with different delaminating interfaces (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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This paper reported an experimental study on the mixed mode I/II delamination growth in multidirectional laminates made of X850 carbon-fiber composite prepreg. The multidirectional laminates of four different stacking sequences respectively with +22.5°/-22.5°, +45°/-45°, 90°/90°, 0°/-45°, 0°/90° delaminating interfaces are designed. During the tests, various delamination propagation behaviors, including crack migration, intra-ply cracking, and bifurcation phenomenon were observed. The resistance effects of the four types of multidirectional laminates specimens were revealed by linking the specific crack growth behavior with the change of the critical strain energy release rates (SERR) in the R-curves. Additionally, transverse intra-ply crack angle between two neighboring interfaces were found to be significantly affected by the orientation of the in the θ-oriented interface ply where the transverse crack passed through, and an obvious law was that the larger the ply orientation was, the larger the crack jumping angle would be, and the transverse intralaminar cracks angle were approximately equal to the ply orientation. Then the delamination crack jumping morphology was interpreted with FE analyses concerning the interlaminar stress field in the vicinity ahead of the crack tip.
In this paper, the influence of different stacking sequences, especially the influence of orientations of upper and lower plies at the delamination crack propagation interface, were investigated. And it was found that the orientation of plies at the interface had a significant influence on the stress distribution along the crack growth direction. Moreover, high interlaminar shear stress would be brought forth at the vicinity of the crack tip when the delaminations crack propagated along the interface between plies of different orientations.
Traditionally, the delamination resistance of laminated composites is measured by critical SERR which are determine in tests. However, experimental tests are time-consuming and high in cost. In current work, the critical SERR were linked with 'characteristic length stress intensity factors' using the crack length as the medium, which is shown in the figure below. The detailed procedure are as following: 1) Obtain the critical SERR under a group of crack lengths through MMB (mixed-mode bending) test; 2) Calculate the 'characteristic length stress intensity factors' for the specimens with the above group of crack lengths through a FE analysis; 3) Find the relationship between the 'characteristic length stress intensity factors' resulted from the FE analysis and the critical SERR obtained from the test. Using the method of this paper, critical SERR of specimens with other dimension and arbitrary stacking

sequences can be determined by numerical method.

8984 | NUMERICAL APPROACHES FOR DELAMINATION IN CARBON-CARBON COMPOSITE LAMINATES (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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Carbon-carbon composite laminates are used in different engineering fields where structural efficiency and high temperature applicability are fundamental requirements. Low density and retention of good mechanical properties beyond 2000 °C make them ideal materials for thermal protection systems and engine parts in aerospace applications. Moreover, thanks to their excellent resistance to thermal shocks and frictional properties, they are adopted to manufacture brake disks in high performance braking systems, both for aircrafts and racing cars. However, the prediction of the structural integrity of carbon-carbon composite components can not be easily accomplished, especially in the cases of complex and severe load conditions, due to the occurrence of multiple damage and failure modes [1,2]. In particular, inter-ply delamination can be considered one of the most critical issues, as in the case of polymeric matrix composites. An additional difficulty is represented, for carbon-carbon laminates, by the presence of voids in the carbon matrix, originated in the densification processes, which can lead to very high porosity contents. The size and the morphology of such defects, which are known to affect the interlaminar properties of the material [3,4], depend on the manufacturing process and on the geometrical characteristics of the components. This work presents a series of experiments carried out to analyse delamination phenomena in carbon-carbon composite laminates used for high performance brake disks, with a relatively high thickness and complex lamination sequences. Three-point bending tests are performed on short carbon-carbon composite beams, with external surfaces reinforced by polymeric matrix composite laminates, so to avoid failures due to the in-plane stress components induced by bending. Non-linear responses, progressive development of interlaminar damages and changes of delamination planes due to intra-ply damages are reported and discussed. Other experiments are presented, involving coupons with cut-outs, where failure turns out to be characterized by delaminations developed in the zones of stress concentrations.
Such tests are first analysed by using linear finite element models, developed at the ply level, which are used to evaluate the state of stress in the specimens and to identify average levels of interlaminar shear strength, to be used in the design of carbon-carbon structural components. Thereafter, non-linear approaches based on application of cohesive zone models are developed, including in the models all the interlaminar layers that represent potential locations of damage development. Such models are used to carry out parametric studies to investigate the role of interlaminar toughness and strength in damage evolution and the effects of non-uniform mechanical properties, which are introduced to represent, at the scale chosen for the development of models, the influence of the largest defects in the matrix on the structural response.

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9125 | The effect of chisel edge on drilling-induced delamination (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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Drilling is one of the most important machining operations as numerous holes must be drilled in order to install mechanical fasteners for assembly in composite materials. The delamination is a major problem associated with the drilling fiber reinforced composite materials, which degrades the mechanical properties of these materials. In drilling, delamination is initiated when the drilling force exceeds a threshold value, particularly at the critical entry and exit locations of the drill bit. The chisel edge of twist drill is a major contributor to the thrust force which is the primary cause of delamination. The main objective of this paper is to study the effect of chisel edge and pilot hole on thrust force and delamination during drilling of glass fiber reinforced composites. For this purpose, two sets of experiments, with and without pilot hole, were conducted with different cutting conditions. The results show a great reduction in the thrust force when a pilot hole is present which removes the chisel edge contribution.

Keywords: Drilling, Composite materials, Delamination, Chisel edge.

9532 | FLOCK FIBER REINFORCED LAMINAR COMPOSITES FOR IMPROVED INTERLAMINAR SHEAR STRENGTH (40. Delamination (Jiye Chen, University of Portsmouth, UK))

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Studies have shown that inter-facially flocked z-axis oriented reinforcing fibers can dramatically improve the inter-laminar shear strength of Organic Polymer Laminar Composites (OPLC). To this end, the three flock process methodologies that have been developed for this purpose and are described: (a) “wet flocking”-z-axis flock is applied individually to each “wet” lay-up ply of laminar fibrous composite layer as it is being assembled, (b) “dry flocking”-flock is applied directly to “dry” fibrous reinforcing layer, the flocked “dry” layers are then assembled and the assembled layered mass is impregnated with fluid matrix resin and (c) “pre-flocked”-fibrous composite reinforcement layers (fabric or mat) are prepared by applying flock fibers to a lightly sized with adhesive fibrous reinforcement layer. After these flocked reinforcement plies have been cured, these “pre-flocked” reinforcement layers can be stored, warehoused, inventories, shipped and otherwise maintained until they are ready for fabrication processing into a laminar composite panels or structures.

Double Cantilever Beam (DCB) tests have been carried out on glass fabric, glass mat and jute (natural fiber) laminates whose inter-faces have been flock treated with the various (z-axis oriented) inter-layer fibers. Overall, increased fracture toughness of the OPLCs was observed for the composite panels prepared using all three flocking processes. However, among the three methodologies evaluated, the pre-flock methodology was found to produce the highest inter-laminar shear strength composite panels. It is herewith concluded that this “pre-flock” z-axis composite reinforcement methodology should be further developed as the most “user friendly” way of introducing flocked fiber reinforcement technology to the OPLC.

7852 | Methods for analysis of effective mechanical, thermal and electric properties of composite materials (41. Advances in numerical techniques for analysis of composites via homogenisation (Daniel Choi, Philippe Karamian, Vladimir Salnikov, University of Caen Lower Normandy (France)))

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In this contribution we will discuss the problem of efficient and reliable evaluation of effective properties of composite materials.
We present some results concerning the influence of the morphology of samples (distribution and geometric parameters of inclusions) on mechanical and thermal characteristics. We studied this in our previous works ([1, 2]) using mainly the combination of FFT-based homogenization techniques and stochastic methods of generation of representative volume elements (RVE, [3]). In particular we pay attention to modelling of various imperfections of inclusions using the extension of the generation procedure ([4]).
For electric properties we suggest an alternative to usual homogenization - a novel approach consisting in the analysis of a connectivity graph constructed from the geometric data of the studied samples. It turns out to be much faster and considerably more numerically reliable.
We explain advantages and limitations of all the mentioned methods and give some implementation, validation and benchmark details.
We comment on possible extensions of the presented work as well as on eventual industrial applications.

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8982 | Diseño de una probeta representativa de los esfuerzos en la unión fuselaje, montante y tren de aterrizaje de una aeronave biplaza fabricada en materiales compuestos (42. 1 Ibero-Americano de Materiales Compuestos (in Portuguese/Spanish only))

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El objetivo de esta investigación es la de diseñar una probeta capaz de reproducir el comportamiento mecánico de la unión del fuselaje con el tren de aterrizaje fijo y la parte inferior del montante del ala de la aeronave Stela M1 de diseño Español fabricada y rediseñada en México. El fuselaje, el ala, los empenajes, las superficies de control, y el tren de aterrizaje principal están todos fabricados con fibra de carbono y resina epóxica. Esta probeta una vez fabricada permitirá llevar a cabo ensayos mecánicos con una geometría representativa más simple que el segmento original de fuselaje. Para lograr el objetivo se adopta primeramente la metodología de las probetas representativas propuesta por Collombet et al (Universidad Paul Sabatier, Tolosa, Francia), se utiliza la metodología QFD para la comprensión del problema de diseño, y se lleva a cabo el dimensionamiento por medio de simulaciones numéricas realizadas con programas de cálculo con elementos finitos. Este estudio parte de varios análisis previos en los que se estimaron las cargas aerodinámicas para la condición de operación más crítica de la aeronave, la estimación de fuerzas y el coeficiente de seguridad en la unión que se está analizando. Este estudio es a su vez parte de un proyecto más general que busca estimar la vida útil de la aeronave.