Polymer Testing 32 (2013) 413–425

Contents lists available at SciVerse ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Property modelling

Tensile properties of semi-crystalline thermoplastic polymers: Effects of temperature and strain rates

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A R T I C L E I N F O

Article history:
Received 23 October 2012
Accepted 5 December 2012

Keywords:
Tensile properties
Thermoplastic polymer
High-speed deformation
Static
Finite element analysis
Strain rate

A B S T R A C T

This work deals with the study of temperature and time dependency of tensile properties of a PA 12-based polymer. The range of variation of parameters in experiments was linked to in-service conditions of components manufactured with this material (temperature interval from −25 °C to 50 °C and average strain-rate magnitudes from 0.00028 s^{-1} to 9.4 s^{-1}). For tests with different temperatures and low speed, an electro-mechanical machine, Zwick Z250, equipped with an incremental extensometer was used. To study the effect of strain rate at medium speeds, a servo-hydraulic system, Schenk PC63M, equipped with a strain-gauge extensometer was used, while at high speeds a servo-hydraulic machine, Instron VHS 160/20, equipped with a high-speed camera for strain evaluation by digital image correlation was employed. The changes of the rate of deformation with strain as well as elastic modulus variation with strain were studied. An increase in the elastic modulus and yield strength was observed with a drop in temperature and an increase in the strain-rate, temperature having a stronger influence on the variation of mechanical properties. The collected data was assembled in an elasto-plastic material model for finite-element simulations capable of rendering temperature- and strain-rate-dependency. The model was implemented in the commercial software Abaqus, yielding accurate results for all tests.
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1. Introduction

The studied material is a polyamide 12-based semi-crystalline thermoplastic polymer primarily designed for low-temperature applications [1]. Due to its viscoelastic nature, test conditions such as temperature, strain rate or humidity can cause significant variations in mechanical properties [2–5]. The aim of this study is to develop a virtual material model capable of predicting the material's behaviour for various loading scenarios.

In recent years, the development of specialized numerical analysis software allowed the evaluation of complex structures with relative ease, thus becoming an indispensable tool for product design. Material modelling can be obtained with the help of the various constitutive formulations such as elasticity, hyperelasticity, hypoelasticity, inelasticity, damage initiation and propagation models, complex engineering features (fracture mechanics) etc., implemented in software [6]. These generic formulations may or may not produce accurate results for a given material and many require customized experimental procedures for parameter determination. This issue can be solved with the help of mathematical models that can be designed for specific material behaviour [7] and implemented by means of user-defined subroutines [6]. The drawback of this solution is that it requires additional programming skills as well as additional compiling software [6,8].

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0142-9418/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.polymertesting.2012.12.002

FFEMS Fatigue & Fracture of Engineering Materials & Structures
ORIGINAL CONTRIBUTION doi: 10.1111/ffe.12333

Low-cycle fatigue behaviour of polyamides

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Received Date: 17 April 2015; Accepted Date: 15 June 2015; Published Online: 2015

ABSTRACT This work investigates a decrease in mechanical properties of a polyamide-based polymer, previously subjected to low-cycle fatigue tests in strain control. Variations in its tensile stress response under monotonic loading and instantaneous elastic modulus were studied in relation with three loading parameters of low-cycle fatigue under strain control pre-treatment, that is, number of cycles (5000, 10 000 and 50 000), frequency (3, 5 and 7 Hz) and reference strain (0.025, 0.035 and 0.045 mm mm^{-1}; a constant amplitude of 0.0075 mm mm^{-1} was maintained). The tests (static and cyclic) were performed with a servo-hydraulic testing machine Schenk PC63M equipped with a strain-gauge extensometer. A significant softening in tensile stress response (32%) was observed after 1000 cycles with a decrease of 44% recorded after 50 000 cycles; the levels of frequency and the reference strain level within the test envelope have, instead, a small effect.

Keywords low-cycle fatigue; polyamide; softening; tensile properties; thermoplastic polymer.

NOMENCLATURES σ = Instantaneous stress
σ_0 = Initial stress

INTRODUCTION

The investigated material is a polyamide-based semi-crystalline thermoplastic polymer, designed for low-temperature applications.[1] Analysis of products manufactured from this material, before and after several hours of service, highlighted a noticeable difference in their mechanical properties. Hence, a study is required to determine the influence of cycling-loading-induced softening on both material's and product's behaviour, in order to underpin quality improvement through design optimization.

In order to explain the softening behaviour of polymers, it is necessary to understand various types of deformations they undergo because of their particular macromolecular structure.

The generic term 'plastic strain' or 'permanent strain' used in literature[2–4] refers traditionally to irreversible deformation observed at the time of the experiment. Because of the viscous nature of polymers, a part of this remnant strain is recovered with time after tests were performed through the process of relaxation. This is a consequence of the structure of this class of materials as they are composed of two phases: a crystalline phase (atoms arranged in ordered patterns) and an amorphous one (entangled macromolecules).[3] The irreversible deformation that such polymers undergo is manifested through the slippage of atomic planes (similar to metal plasticity[5]) or by macromolecular chain scission.[4]

The elastic component of polymers' deformation can be decomposed into instantaneous elasticity and delayed elasticity. The former is recovered immediately after loading stops, while the latter is recovered in time and can manifest through a number of molecular phenomena such as viscous flow (the movement of macromolecules past one another), Thirion relaxation (a relaxation of the trapped entanglements in elastomeric networks) or molecular relaxation (a stress relief caused by high temperatures).[4]

If a specimen undergoes deformations at constant stress below the tensile yield point, the ratio of permanent strain to reversible one (elastic and viscous) is rather small. If stress is maintained for a longer period of time, the delayed deformation grows until it reaches saturation,[3,6] while the instantaneous elastic strain and the permanent strain remain constant. If the specimen is strained towards yielding, the permanent deformation steadily increases until it gains a linear increase with

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Polymer Testing 49 (2016) 121–127

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Material properties

Evaluation of the mechanical and morphological properties of long fibre reinforced polyurethane rigid foams

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ARTICLE INFO

Article history:
Received 10 October 2015
Accepted 16 November 2015
Available online 1 December 2015

Keywords:
PUR foams
Glass fibre
Mechanical properties
Microstructure
Long fibre injection

ABSTRACT

This paper examines the effect of glass fibre reinforcements on the mechanical and morphological properties of polyurethane rigid foams. The processing parameters of the polyurethane foam were maintained constant while the influence of the filler was evaluated in terms of fibre mass content variation (5%, 10% and 20%) and fibre length variation (12.5 mm, 25 mm and 50 mm). Tests were carried out in compression, three-point bending, tension and shear for all material configurations, the variation in fibre mass content having a larger influence on mechanical properties than fibre length. The structure of the specimens was investigated using Scanning Electron Microscopy and Computer Tomography in order to investigate the filler influence on morphology and the scatter in results.

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1. Introduction

Polymer-based foams represent a class of materials characterized by low specific mass, reduced heat transfer, good impact resistance and energy absorption compared to compact polymer structures [1,2]. Because of these characteristics, they have a wide range of applications: thermal insulation (insulation materials for buildings), floatation (components in ship hulls), packaging, automotive (interior padding of car bodies) or sports industry (padding and cushioning of safety equipment) [1,3]. Due to several advantages regarding the ease of manufacturing, reduced price and good mechanical properties, polyurethane rigid foams are regarded as one of the most used cellular materials for the above mentioned applications.

Another important application of PUR foams is as part of structural components of mechanical assemblies, namely sandwich panels [4]. Developed in the mid-20th century for aerospace applications, sandwich structures experienced broader uses in recent decades due to their advantages over monocoque structures: lighter weight, smaller lateral strains in bending, good buckling strength and high fatigue life [5,6]. Because of these characteristics, sandwich panels have extensive use in various industries such as aerospace [7], terrestrial, rail and naval transportation [8,9].

Considering the degradation modes of sandwich panels, the reduced mechanical properties of the core determine its failure in most loading scenarios [10]. In order to determine the augmentation of sandwich structure characteristics, it is worthwhile to consider improvement of the mechanical properties of rigid foams that constitute the core of these structures, without significant increase in specific mass (i.e. using higher density foams) [11,12]. Following several studies which investigated the process of degradation of rigid foam sandwich cores, fibre/filler reinforcement proved to be one of the most efficient methods of improving their mechanical and thermal characteristics [13–15].

This study used a process of automated Long Fibre Injecting (LFI) of polymeric foams, technology that was developed for integration in a novel, time- and energy-efficient manufacturing concept that deals with the automated production of complex composite parts [16–19]. The Long Fibre Injection unit's design also allows for integral, automated sandwich panel construction, the injected PUR foam also having the role of generating the facets by impregnating woven fibreglass mats or continuous fibre-reinforced textiles, and so eliminating several disadvantages associated with sandwich panels (such as delamination) [20].

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http://dx.doi.org/10.1016/j.polymertesting.2015.11.007
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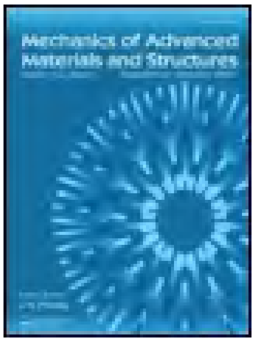

Mechanics of Advanced Materials and Structures

ISSN: 1537-6494 (Print) 1537-6532 (Online) Journal homepage: https://www.tandfonline.com/loi/umcm20

Numerical and experimental investigations on the mechanical properties of cellular structures with open Kelvin cells

Dan Andrei Şerban, Radu Negru, Sorin Sărăndan, George Belgiu & Liviu Marşavina

To cite this article: Dan Andrei Șerban, Radu Negru, Sorin Sărăndan, George Belgiu & Liviu Marșavina (2019): Numerical and experimental investigations on the mechanical properties of cellular structures with open Kelvin cells, Mechanics of Advanced Materials and Structures

To link to this article: https://doi.org/10.1080/15376494.2019.1669093

Published online: 08 Oct 2019.

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https://www.tandfonline.com/action/journalInformation?journalCode=umcm20

Investigations on the influence of the triaxial state of stress on the failure of polyurethane rigid foams

Dan-Andrei Şerban, Radu Negru, Hannelore Filipescu & Liviu Marşavina

ONLINE FIRST

Continuum Mechanics and Thermodynamics

ISSN 0935-1175

Continuum Mech. Thermodyn.
DOI 10.1007/s00161-020-00924-x

Springer

Continuum Mech. Thermodyn.
https://doi.org/10.1007/s00161-020-00934-9

ORIGINAL ARTICLE

Dan-Andrei Şerban · Gabriel Furtos · Liviu Marşavina · Corina Şoşdean · Radu Negru

Numerical modelling of the mechanical behaviour of wood fibre-reinforced geopolymers

Received: 31 March 2020 / Accepted: 1 October 2020
© Springer-Verlag GmbH Germany, part of Springer Nature 2020

Abstract In this work, the mechanical behaviour of composite materials consisting of fly ash-based geopolymer reinforced with wood fibres is investigated for compressive and flexural loadings. The gathered test data were used to calibrate constitutive models for the geopolymer, consisting of the exponential Drucker–Prager yield criterion coupled with the concrete damage plasticity model. The numerical analyses were performed in the commercial software Abaqus, the results being compared with experimental data, yielding good correlations.

Keywords Geopolymer composites · Wood fibre reinforcements · Experimental tests · Numerical simulations · Concrete damage plasticity

List of symbols

b	Specimen width
c	Cohesion (shear strength)
d	Crosshead displacement
$\left(\bar{e}^{\mathrm{in}}\right)^{\mathrm{c}}$	Logarithmic equivalent compressive inelastic strain
$\left(\bar{e}^{\mathrm{in}}\right)^{\mathrm{t}}$	Logarithmic equivalent tensile inelastic strain
E_0	Loading slope (initial Young's Modulus)
E'	Unloading slope
F	Recorded load
G	Flow potential
h	Specimen height
I_1^{σ}	First invariant of the stress tensor
J_2	Second invariant of the deviatoric stress tensor
l	Specimen length

Communicated by Andreas Öchsner.

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Published online: 18 October 2020

Arch Appl Mech
https://doi.org/10.1007/s00419-018-1492-5

SPECIAL

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Numerical study of the behavior of magnesium alloy AM50 in tensile and torsional loadings

Received: 5 July 2018 / Accepted: 5 November 2018
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

Abstract In this work, a numerical simulation of the behavior of the magnesium alloy AM50 in tension and torsion is performed. Preliminary experimental procedures were carried out in order to determine the material characteristics and the stress–strain response. Based on the experimental data, three material models were developed: linear elastic with isotropic plasticity, linear elastic with Johnson–Cook hardening and the Ramberg–Osgood model and their accuracy and computational time were investigated.

Keywords Magnesium alloy AM50 · Tensile · Torsion · Finite element analysis

1 Introduction

Magnesium alloys are a class of materials with a range of applications in several industrial fields such as automotive industry, aero-spatial industry and transportation because of their good mechanical properties at low specific weight [1,2]. Having densities around 1740 kg/m^3, magnesium alloys are the lightest structural metals currently used [3]. Historically, the first applications of magnesium alloys as structural components were as aircraft hulls in German planes of the First World War, due to their lighter weight in comparison with aluminum [4]. Another important advantage of magnesium alloys over steel and aluminum is the good tolerances obtained in die-casted components, which allow the fabrication of complicated geometries [3]. The main disadvantage of magnesium alloys is their flammability, which poses real challenges in mechanical processing [2].

In the automotive industry, the main applications of Mg are cylinder covers, transmission housings [5] engine blocks [6], steering wheels [5] and high-performance car bodies [7]. Due to their very good casting properties, magnesium alloys are used in the fabrication of complex parts, which present a significant number of stress concentrators. The analyses of such geometries through the finite element method represent an important step in designing such products, in order to avoid a premature failure of the products.

The aim of the study is to evaluate three material models which are extensively used in finite element analyses: linear elasticity with isotropic plasticity, linear elasticity with Johnson–Cook hardening and the Ramberg–Osgood model. Preliminary experimental procedures were carried out in tension and torsion, and the resulting data were used in calibrating and evaluating the material models.

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Published online: 15 November 2018

Fatigue & Fracture of Engineering Materials & Structures
ORIGINAL CONTRIBUTION
doi: 10.1111/ffe.12535

Low-cycle fatigue behaviour of ductile closed-cell aluminium alloy foams

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Received Date: 2 August 2016; Accepted Date: 9 September 2016; Published Online: 17 October 2016

ABSTRACT This work investigates the fatigue response of a class of ductile closed-cell aluminium alloy foams, known by their commercial name Alulight M8. In order to determine the yield stress of the used foams, preliminary experimental tests were performed, at room temperature, in monotonic compression on cylindrical specimens of 25 mm diameter and 25 mm height, with a loading speed of 10 mm/min. Fatigue tests were performed in uniaxial compression on cylindrical specimens (25 mm × 25 mm) with a stress ratio of $R = 0.1$, at a frequency of 10 Hz. The peak stress was varied from 110 to 135% of the yield stress in compression. Tested specimens were cut from the same cylindrical bar, and the density of the investigated material was 500 kg/m^3 ± 10%, or a total of 18 specimens being investigated. With the gathered experimental data, S–N curve was generated, and the effect of cellular structure (e.g. structure irregularity–the number and the size of cells) being investigated and discussed.

Keywords closed-cell aluminium foams; compression–compression cyclic tests; low-cycle fatigue; plastic collapse, structure irregularity.

NOMENCLATURE

- b =Specimen's solid skin thickness
- $C1\ldots C15$ =Initiated cracks in microstructure
- CBD =Crush-band degradation
- D =Specimen's diameter
- E =Young's Modulus
- H =Specimen's height
- H_0 =Specimen's height after tests
- L =Length of cylindrical bar samples
- LCF =Low Cycle Fatigue
- LP =Length of plateau
- N =Number of cycles
- N_f =Fatigue life
- R =Stress ratio
- t =Cell-wall thickness
- $W1\ldots W4$ =Cell-walls
- I, II, III =Analysed cells from which the crack initiates
- ε =Monotonic nominal axial strain
- ε_d =Monotonic densification
- σ =Monotonic stress
- $|\sigma|_{max}$, $|\sigma|_{min}$ =Magnitudes of the maximum and minimum nominal applied stresses
- σ_p =Monotonic plateau stress
- σ_y =Monotonic yield stress
- ρ =Foam density
- ρ_s =Solid material (Aluminium) density
- λ Stretch

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ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 457–466

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Assessment of collapse diagrams of rigid polyurethane foams under dynamic loading conditions

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A R T I C L E I N F O

Article history:
Received 6 July 2016
Accepted 18 December 2016
Available online

Keywords:
Closed-cell polyurethane foams
Dynamic compression tests
Mechanical properties
Collapse diagrams
Finite element analysis

A B S T R A C T

This paper investigates the collapse diagrams (energy-absorption and efficiency diagrams) under dynamic compression tests (drop tests) with an impact loading speed of 3.09 m/s. Experimental tests were carried out at room temperature on seven different types of closed-cell rigid polyurethane foams with densities of 40, 80, 100, 120, 140, 145 and 300 kg/m^3 respectively. Based on the measured load–displacement curves, authors plotted the variation of peak stress, energy-absorption and efficiency attributes with respect to density for each type of foam, highlighting the optimum foam density (100 kg/m^3). The influence of density and loading direction (in-plane and out-of-plane) on the main mechanical properties are also discussed. Following the investigations it was observed that both efficiency and energy absorption diagrams shows similar results, leading to the conclusion that both methods are reliable. Considering the test setup, a finite element analysis model was developed that aimed to replicate the experimental procedures. Simulations were performed in the commercial software Abaqus/Explicit using the implemented Elastic/Crushable foam constitutive model and using the static and dynamic test data for calibration. The energy-absorption and efficiency diagrams obtained from simulations were compared with the experimental data.

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1. Introduction

Cellular materials such as polyurethane (PUR) foams play an important role in many passive safety applications (from commercial to military) helping to improve safety and weight reduction (lightweight structural components) [1]. Their structure shows great capacity to absorb impact energy [2,3]; good thermal, electrical and acoustic properties; high workability and very low specific weight compared with other materials with similar mechanical characteristics [4,5].

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http://dx.doi.org/10.1016/j.acme.2016.12.009

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Theoretical and Applied Fracture Mechanics 91 (2017) 148–154

Contents lists available at ScienceDirect

Theoretical and Applied Fracture Mechanics

journal homepage: www.elsevier.com/locate/tafmec

An engineering approach to predict mixed mode fracture of PUR foams based on ASED and micromechanical modelling

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ARTICLE INFO

Article history:
Received 28 February 2017
Revised 22 May 2017
Accepted 11 June 2017
Available online 12 June 2017

ABSTRACT

The Averaged Strain Energy Density (ASED) criteria is applied herein to reinterpret the fracture data of PUR foams. Four type of specimens were used in fracture tests. The ASED parameters were determined based on micromechanical models. The volume control for cracked components is represented by a circle with the centre at the crack tip for all type of fracture modes. It was also demonstrated that the SED parameters obtained from pure mode I could be applied successfully for mixed modes and mode II. This approach represents an useful engineering tool for the assessment of brittle fracture of components made of cellular materials.

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1. Introduction

Polyurethane (PUR) represents a class of polymeric materials composed of a chain of organic units joined by urethane links. At low densities polyurethanes (30–300 kg/m^3), show a cellular structure with closed cells. They are used to manufacture flexible, high-resilience seating, rigid foam insulation panels, microcellular foam seals and gaskets, high durable elastomeric wheels and tires, automotive suspension bushings, and cores for sandwich structures. The properties of these materials are highly influenced by the properties of solid material, by the cellular structure topology and the relative density [1,2]. Rigid PUR foams crushes in compression, while in tension fail by propagating of single crack [3]. The presence of notches or cracks caused a linear – elastic behavior in tension up to fracture and a brittle failure. So, the fracture toughness of rigid foams represents an important mechanical property for design of structures containing such materials.

Several studies proposed analytical models to predict the fracture toughness of cellular structures and to provide a micromechanical link between fracture toughness and relative density of foam, dimensions of cellular structure and mechanical properties of solid material contained in the struts and faces of cells [1,4–8]. Considering simplified and complex cell structures, numerical investigations were performed to predict the fracture toughness of cellular structures for different types of foams [9–13]. Experimental determinations of fracture toughness of different types of foams were performed. Fowlkes [14] used centre and double edge cracked plates, single edge crack tensile specimen and double cantilever beam specimen for determination of fracture toughness of PUR foam with 88 kg/m^3 density.

A linear correlation between Mode I fracture toughness K_{Ic} and relative foam density ρ^*/ρ_s was observed by Danielsson [15] on PVC Divinycell foams, and by Viana and Carlsson on Diab H foams [16]. Brittle fracture without yielding produced in Mode I was observed in experiments. Kabir et al. [17] used the procedure described by ASTM D5045 [18] for determining the fracture toughness of PVC and PUR foams. They investigated the effect of density, effect of specimen size, effect of loading rate and effect of cell orientation. Density has a significant effect on fracture toughness, which increases more than 7 times when the foam density increases 3.5 times. Burman [19] presented mode I fracture toughness results for two commercial foams Rohacell WF51 (density 52 kg/m^3) and Divinycell H100 (density 100 kg/m^3), determined on Single Edge Notch Bending (SENB) specimens. He also presented some results on Mode II fracture toughness determined with the End-Notch Flexure (ENF) specimen. The mode I fracture toughness for PVC foam was determined in [20] using single edge notched bend specimens loaded in three and four point bending, respectively. Static and dynamic mode I fracture toughness of PUR foams was determined on single edge notched specimens and an increase with relative density was also observed [21].

However, less studies presented the fracture of foams under mixed mode loading. Hallström and Grenestedt [22] investigated mixed mode fracture of cracks and wedge shaped notches in expanded PVC foams. Noury et al. [23] investigated three different densities of PVC foams using Compact Tension specimen with Arcan grips to produce mixed mode conditions. The ratio between

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http://dx.doi.org/10.1016/j.tafmec.2017.06.008
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