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PREFACE

The doctoral thesis presents the experimental industrial research and the results obtained on improving the quality of phosphorus cast iron brake shoes for rolling stock. The experimental industrial research was carried out at the FOREVA Simeria foundry. The determinations of the qualitative and technological characteristics of the analyzed samples were performed within the Polytechnic University of Timișoara, Faculty of Engineering Hunedoara, respectively within the Research Institute for Renewable Energy Timișoara.

The doctoral thesis was carried out under the coordination of university professor. Phd. Eng. Ana Virginia SOCALICI, to whom, in this way, I would like to thank for all the support I have received, it has been a model of ambition and labor for me in recent years, because she knew how to work with me so as to make me like scientific research, she gave me support in absolutely any problem that arose during my doctoral studies and she became a mentor and a landmark of my professional career.

I would like to thank for the help I have received from the members of the guidance committee: associate professor Phd.Eng. Ana JOSAN, associate professor Phd.eng Marius ARDELEAN and head of works Phd.Eng. Vasile PUȚAN director of the Department of Engineering and Management.

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I also want to thank the management of the Department of Engineering and Management, of the Hunedoara Faculty of Engineering and of the Polytechnic University of Timișoara, for the support given throughout the years in which I conducted my doctoral thesis research.

Last but not least, I thank my family who in all the years of doctoral studies was with me in this process.

Part I

CURRENT STAGE OF KNOWLEDGE CONCERNING THE FONTS USED FOR THE CASTING OF BRAKE SHOES FOR THE ROLLING STOCK

CHAPTER 1
FONTS USED FOR THE CASTING OF BRAKE SHOES FOR THE ROLLING STOCK

The brake shoes used on the railway are manufactured in accordance with the provisions of UIC 832 and the additional requirements contained in the Specifications, No. 1/SMMR/SDT/2000, Brake shoes for motor and towed rolling stock, developed by the National Society of Romanian Railways (SNCFR) and approved by the Romanian Railway Authority (AFER) [1/3, 2/6].

For the rolling stock a phosphorus-alloy cast iron is used for the development of brake shoes. Cast iron for clogs has a stardite structure, which is a phosphor ternary eutectic (perlite, cemented and iron phosphide) [3/7.4/8.5/9].

In phosphorus-alloy gray cast iron, the phosphorus eutectic is very important, which is very hard and fragile. Phosphorus eutectic is influenced by the percentage of phosphorus and the elements that influence its segregation capacity (figure 1/1.7) [6/5, 7/13].

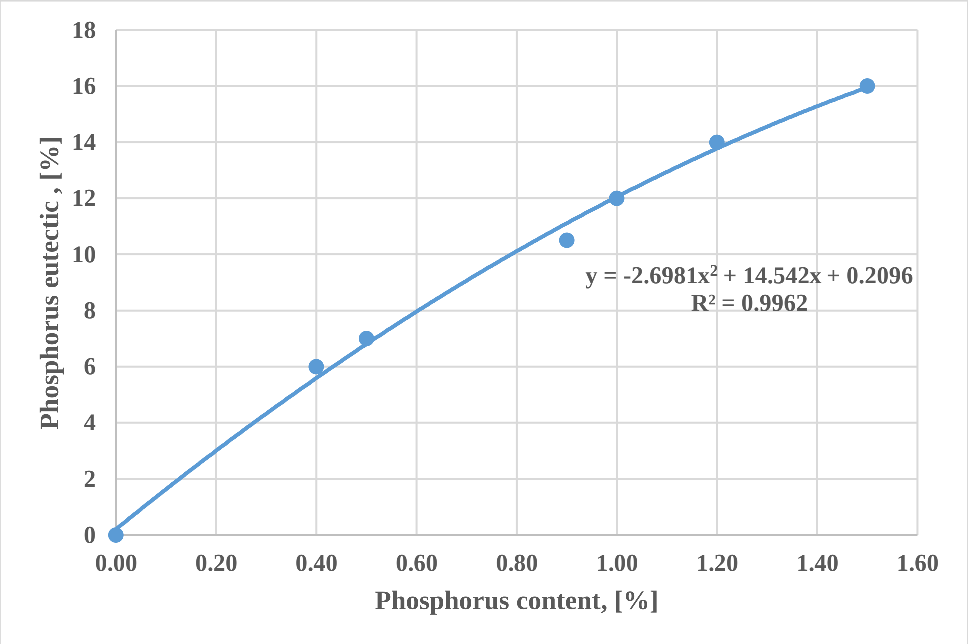

Figure 1/1.7. Variation of phosphorus eutectic in cast iron [6/5, 8/10]

In phosphorus cast iron, given the formation of starite, this being a constituent with a high hardness, an increase in their hardness is obtained (figure 2/1.10) [5/9, 6/5, 8/10, 9/12]. The quality of the brake shoes (especially the surface quality and the dimensional accuracy) cast in high density forms, is higher compared to the brake shoes obtained by any other classic method of formation. The P10 phosphorus cast iron, from which brake shoes are made, has superior characteristics. The influence of the phosphorus content of the cast iron from which the shoe is made is important, but the influence of the other components of the metallographic structure on the braking coefficient and wear must not be ignored.

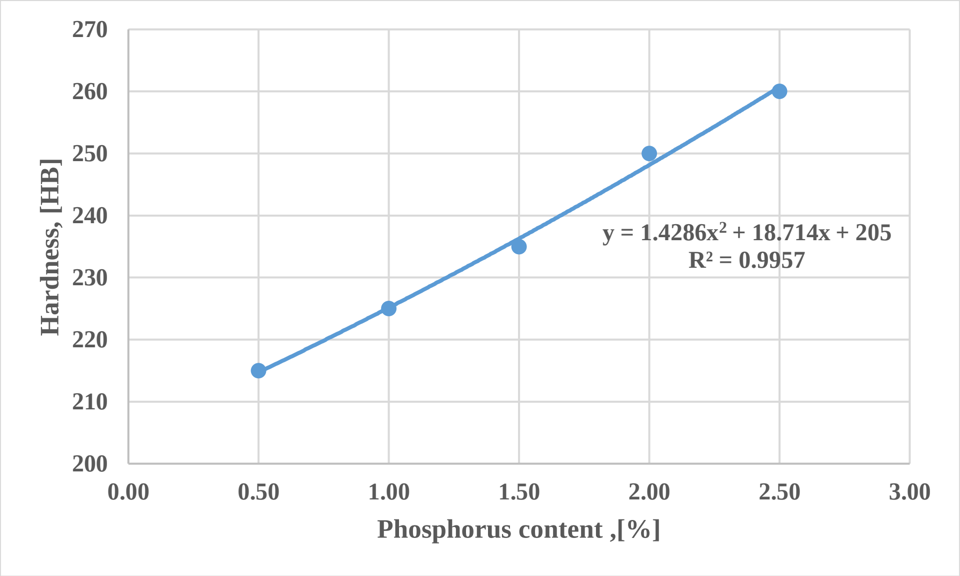

Figure 2/1.10. The influence of phosphorus on cast iron hardness

The chemical elements existing in the composition of the shoe material influence the crystallization differently, for example, the increase of the manganese content favors the cementic crystallization, and the increase of the silicon content on the graphite one.
Font is the most used molded metal in shapes and the phases of cast iron graphite develop together with the metal matrix during solidification and the understanding and control of the structure, its density and morphology is essential for the properties of cast iron.

CHAPTER 2
TECHNICAL QUALITY CONDITIONS OF BRAKE SHOES MADE OF PHOSPHORED FONT

The manufacture of phosphorus cast iron clogs are carried out at FOREVA Simeria, part of REVA Simeria.

The casting section of SC FOREVA SRL Simeria produces semi-finished products cast in gray cast iron and poorly alloyed, with a mass between 1 kg – 5000 kg, destined for [10/22]:

a) brake shoes;

b) spare parts for general industrial use;

The technological flow from SC FOREVA SRL Simeria has [10/22]:

- three induction electric ovens;
- automatic air-pressing format machine;
- mixer with EIRICH pallets, capacity 640kg;
- HAMMERS mixer;
- training mixture preparation station;
- debauchery with eccentric mass, capacity 7.5t;
- a semi-automatic line for pouring brake shoes;
- sandblasting chamber with WHEELABRATOR SMARTLINE turbines;
- sandblasting chamber with tape alice;
- an automated Omega SO8172 designing-cast line.

Shoe brakes are usually equipped with phosphor cast iron or composite clogs. Phosphorus cast iron clogs are generally used for rolling stock with a maximum speed not exceeding

140km/h. Composite brake shoes are used to replace conventional cast iron clogs, which are considered an important source of noise.

When making brake shoes for rolling stock, the most widely used are P10 phosphorus cast iron [1/3.2/6.11/23].

Brake shoes, size S1, S2, S3, LDE, LDH and LE are obtained by casting from phosphorus cast iron and are intended for motor and towed rolling stock.

Specifications No.1/SFMR/SDT/2000 [2/6] regulates the conditions to be met by P10 cast iron brake shoes, clogs for rolling stock. Table 1/2.1 shows the chemical composition of phosphorous cast iron clogs type [1/3, 6/5, 2/6].

Tabele 1/2.1. Chemical composition of phosphorus cast iron shoes

Compoziţia chimică, %			
Total Carbon (C_t)	**Si**	**P**	**Mn**
2,90% – 3,30%	1,20% – 2,00%	0,80% – 1,10%	(1,72% S + 0,30%) - 1%; S-sulful din fontă

Physical and mechanical characteristics of cast iron brake shoes:

- Brinell hardness;
- Shock resistance of clogs and reinforcement strength.

The shoe must have on the side surface, as in the section, a Brinell hardness between 197 – 255HB [6/5, 2/6, 12/29].

For the casting of brake shoes, intended for the motor and towed rolling stock, it was analyzed creation flow, the moulding and designing at the FOREVA Casting within REVA SA Simeria, this being a traditional organization in repairing railway wagons and producing brake shoes. FOREVA Simeria Foundry holds authorizations for casting phosphorus cast iron brake shoes for motor and towed rolling stock and issues certificates of railway approval and examination as well as a certificate of approval Quality Management System (issued by ONFR-AFER).

Part II
OWN RESEARCH AND EXPERIMENTATIONS REGARDING SUPERIOR QUALITY FONT USED IN ROLLING MATERIAL BRAKING SYSTEMS

CHAPTER 3
INDUSTRIAL EXPERIMENTAL RESEARCH FOR CASTING FOSFOROUS BRAKE SHOES

The technological process of obtaining brake shoes includes:

• technological flow of cast iron development;
• the technological flow of preparation of training and shape-making mixtures;
• technological flow of liquid cast iron casting;
• the technological flow of debate and cleaning of brake shoes.

Brake shoes for motor and towed rolling stock are approved parts, and their supply activities are authorized by the Romanian Railway Authority [2/6].

For industrial research, high quality cast iron brake shoes – P10 phosphor cast iron were analyzed. The foundry management system implies the existence of procedures and working instructions that establish the methods for checking and testing the quality of brake shoes cast from phosphorus cast iron throughout the technological process.

During the industrial experiments, 70 P10 cast iron rods were developed, from which series of shoes were cast, of different types (S1, S2, S3, LDH, LDE and LE).

For the elaboration of experimental fonts, the load was structured as follows:

- 40-65% steel waste (scrap);
- 10-30% cast iron waste (phosphorous cast iron clog waste ;
- 20-50% alloy cast iron waste (recycled material);
- 20-30% alloy steel waste (recirculated material).

Depending on the availability of ferrous raw materials, the batches consisted of: steel waste (scrap), cast iron waste (phosphor cast iron clog waste) and recirculated material (cast iron / steel).

Brinell hardness test is performed according to SR EN ISO 6506-1: 2006 (figure 3/3.7) and with the instructions in the specification [1/3, 2/6, 13/38, 14/39], as follows:

- at one point at each end of the shoe, on its face, after removing 2mm of material, by polishing or grinding;
- at three points located diagonally, on the surface of a sample obtained by cross-sectioning the broken clogs when the shock test.

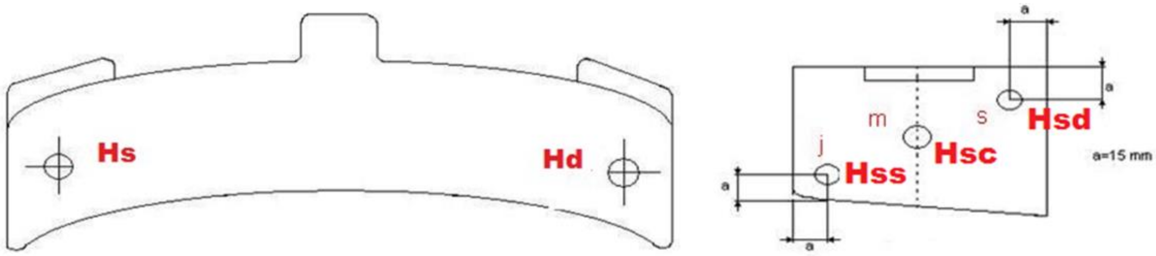

Figure 3/3.7. Hardness measuring points [13/38]

The processing of experimental data was performed in the Excel and Matlab calculation programs.

For industrial batches the metallographic examination of the shoe cast iron was performed according to SR EN ISO 945-1: 2009 and the UIC 832 sheet and consisted of the analysis of four samples / batch, namely [1 /3, 6/5, 15/30]:

- a sample (without chemical attack and with a thickness G of 100x) to identify the form of graphite separations and their character and the length of the lamellar graphite separations;
- a sample (nital attack and a G thickness of at least 200x) to determine the perlite configuration;
- two samples (with nital attack and a thickness G of 25x and 50x) for base metal mass and phosphorus eutectic.

To highlight the influence of graphite on the properties of cast iron, two samples were taken from experimental shoes and studied (type S1), the analysis being performed within the Timișoara Research and Renewable Energy Institute.

After the processing procedure, the samples were analyzed using the Olympus BX51M optical microscope to obtain the microstructures at the 100x, 200x, 300x and 500x magnifications for both samples. From the point of view of the graphite-occupied surface, the classification in the G6 type structure is highlighted, both for the P1 sample and for the P2 sample.

CHAPTER 4
CHEMICAL COMPOSITION OPTIMIZATION TO OBTAIN HIGH QUALITY BRAKE SHOES USING EXCEL AND MATLAB PROGRAMS

The industrial research aimed to establish correlations between the elements in the chemical composition of brake shoes (independent parameters) and hardness - the main qualitative parameter for brake shoes (dependent parameter). Data on the chemical composition of the brake shoes of the industrial experimental batch and their hardness at the measured points were processed in the EXCEL and MATLAB programs.

To establish the correlation equations, the following parameters were analyzed: independent parameters: elements of the chemical composition of the brake shoes (C, Mn, Si, S, P); dependent parameters: the hardness measured at the five points of the shoe (Hs, Hd, Hss, Hsc and Hsd), the average hardness on the surface of the shoe (Hm) and the average hardness in the shoe section (Hsm). For example, figures 4/ 4.9 - 10/4.15 show regression surfaces and level curves for cast iron hardness (Hs, Hd, Hss, Hsc, Hsd, (Hs + Hd)/2, (Hss + Hsc + Hsd /3)) depending on the chemical composition C, Mn [16 /40-18/44]. Also, the correlation coefficient and the coordinates of the inflection points were determined for each correlation.

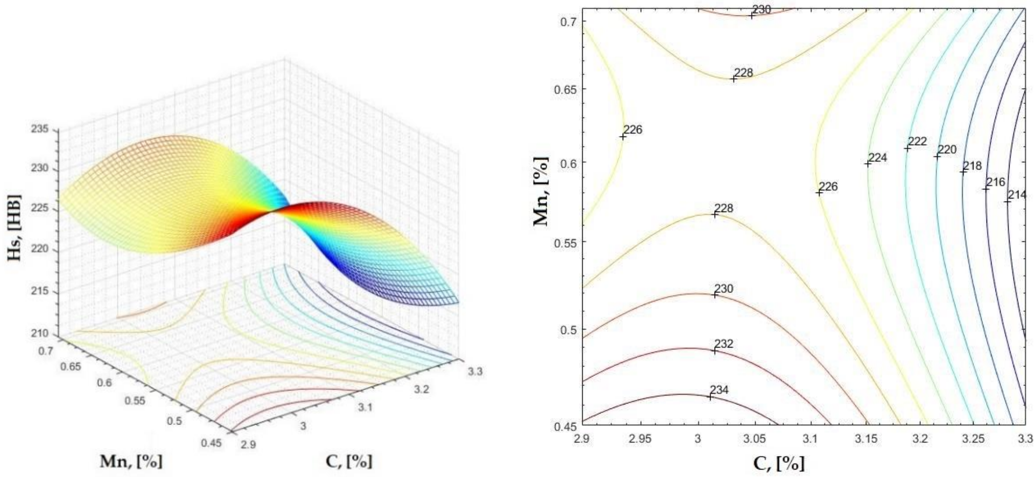

Figure 4/4.9. Regression surface and level curves for Hs = f (C, Mn)

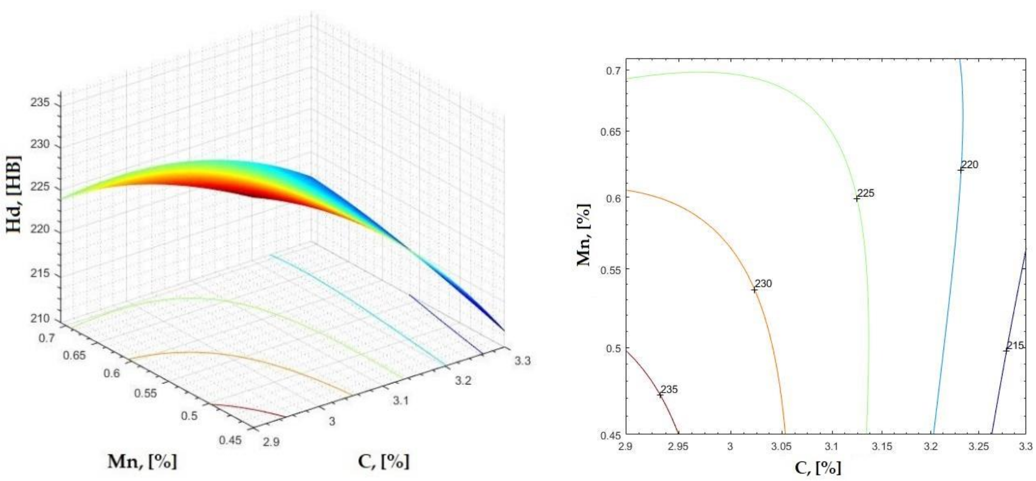

Figure 5/4.10. Regression surface and level curves for Hd = f (C, Mn)

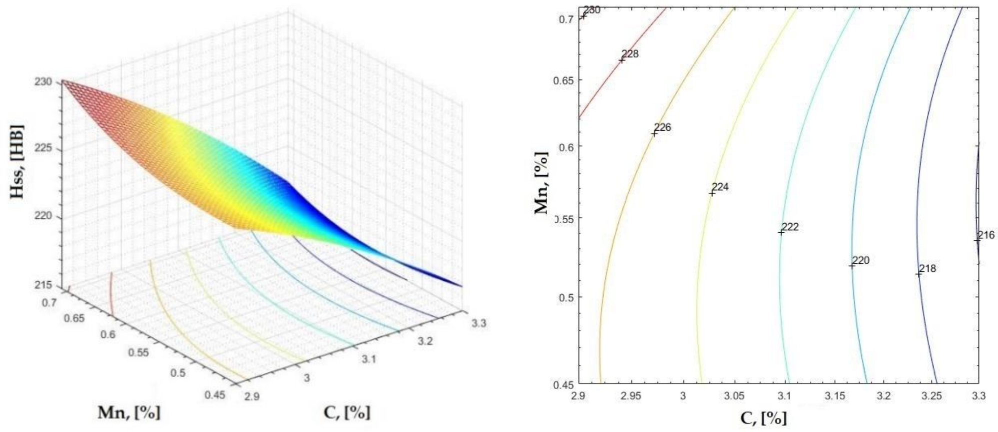

Figure 6/4.11. Regression surface and level curves for Hss = f(C, Mn)

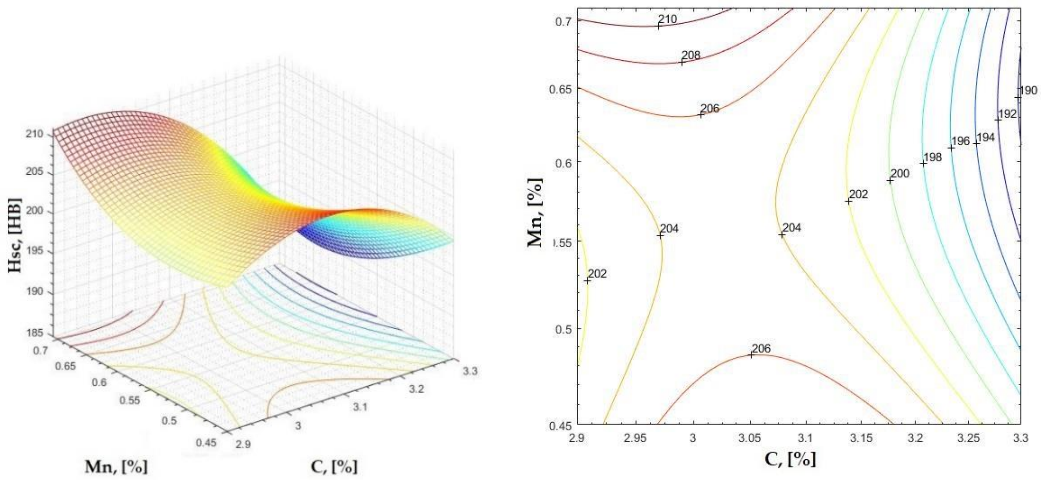

Figure 7/4.12. Regression surface and level curves for Hsc = f(C, Mn)

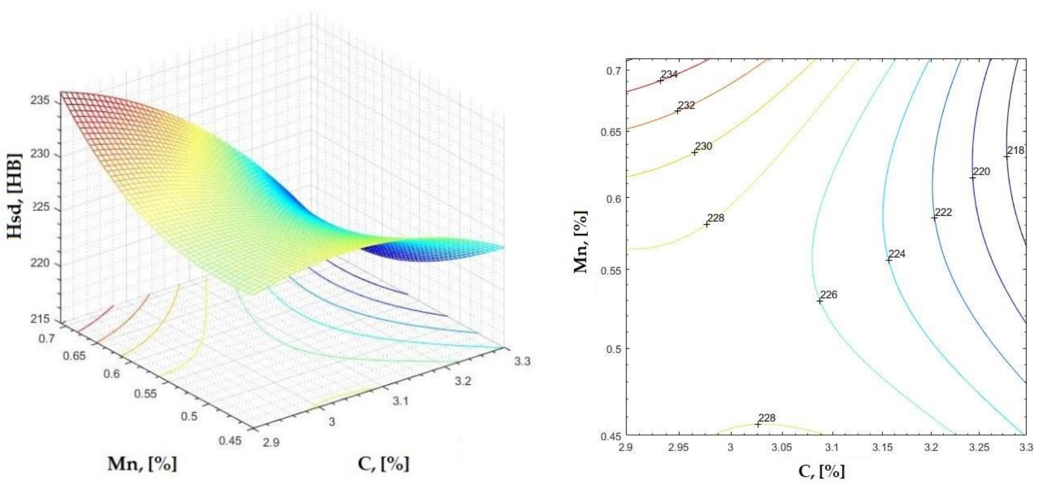

Figure 8/4.13. Regression surface and level curves for Hsd = f(C, Mn)

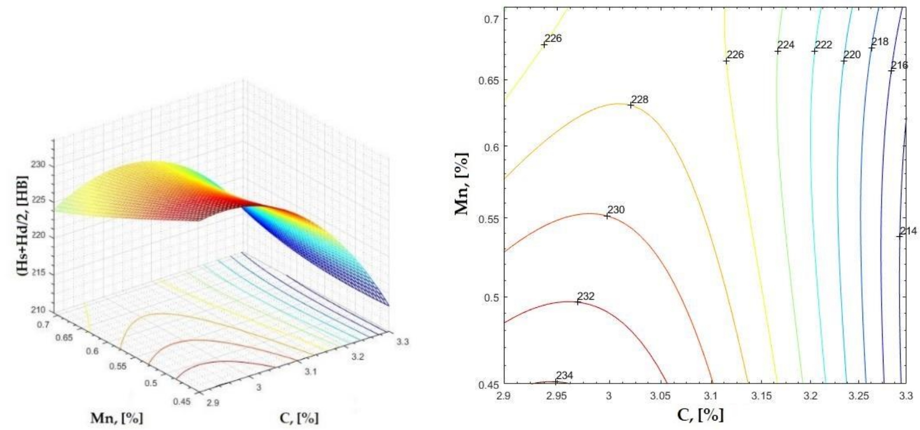

Figure 9/4.14 Regression surface and level curves for (Hs+Hd)/2 = f(C, Mn)

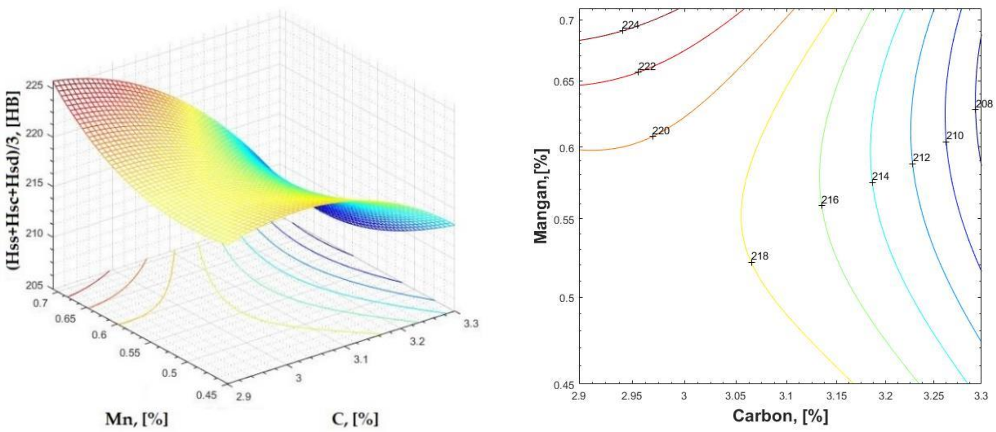

Figure 10/4.15. Regression surface and level curves for (Hss+Hsc+Hsd)/3 = f(C, Mn)

For values of the hardness parameter between 197-255HB, the analysis of the correlations in the MATLAB program results in the optimal fields of variation: C = 2.90-3.1%, Mn = 0.45-0.6%, Si = 1.20-1.70%, S = 0.07-0.09%; P = 0.80-1.10%.

CHAPTER 5
SIMULATION OF THE BRAKE SHOES PROCESS FOR CARTING AND SOLIDIFICATION, USING SPECIALIZED PROGRAMS

In order to simulate the process of casting and solidifying the S1 type brake shoes, cast from phosphorus cast iron, the model of the pieces was made. SolidWorks software CAD module was used for modeling. Following the modeling of the shoe, the two components are obtained: the shoe itself (made of cast iron) and the reinforcement rail (made of steel). Subsequently, through the same software, Solidworks, the assembly of the reinforcement rail is made. Following the realization of the 3D model of the S1 type shoe, the casting and solidification process takes place, with the help of the Altair-InspireCast software. In this way, a finite element analysis of the casting and solidification process is performed. For the S1 type shoe, the casting form comprises a battery of 8 clogs, together with the casting network. Reinforcement rails are located before casting the liquid alloy into form. In this context, for obtaining the set of raw castings, the model was made with the help of SolidWorks software (figure 11/5.6). To simulate the casting and solidification process, the 3D model was made, using the finite element method. The obtained model illustrates the phenomenon that takes place in industrial practice, respectively the casting through a battery of 8 brake shoes.

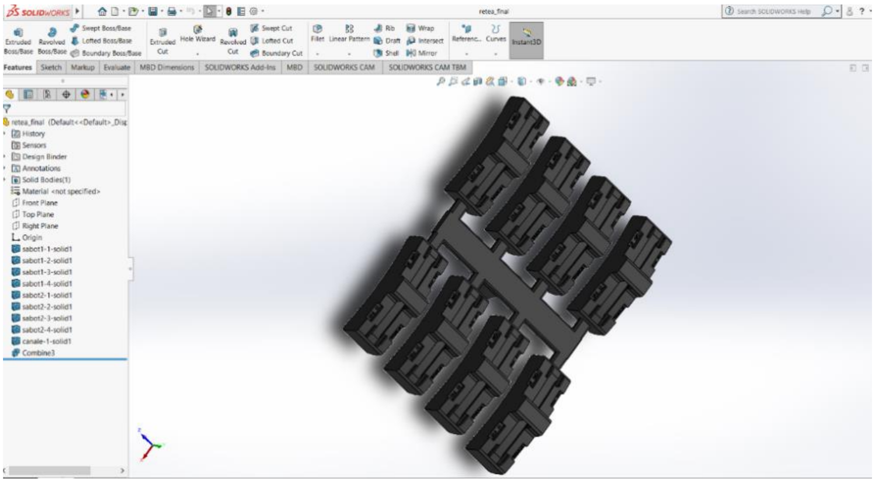

Figure 11/5.6. Assemble of raw castings

The module for the study of the liquid alloy solidification process indicates, at the first moment, the maximum temperature (1273.15°C), after which a visible decrease of the recorded temperatures takes place. The results of the simulation show that after about 5 minutes, the temperature dropped by about 190°C. The end of the solidification process, indicated by the process simulation, is identified at 16381.81s (approximately 4.55 hours), presented in figure 12/5.16.

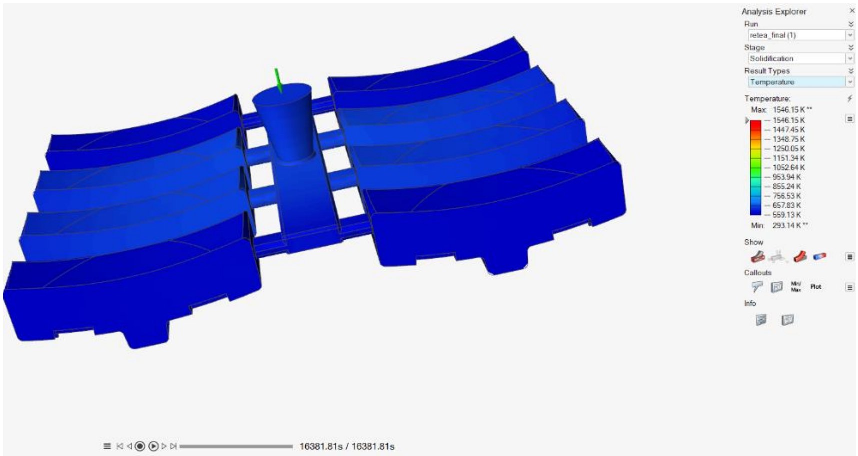

Figure 12/5.16. End of solidification process

Following the simulation of the process of casting and solidification of the liquid alloy, the following results:

• Possibility to anticipate the behavior of the metal alloy during technological processes;

• Optimizing process parameters according to the dimensions of different cast landmarks;

• Obtaining optimal areas of variation of parameters, with influence on mechanical and resistance characteristics;

• Based on the simulation results, the optimal technological variants for casting, solidification can be selected, taking into account the real conditions in the industrial environment;

•The data resulting from the simulation are similar to the data recorded in industrial practice.

CHAPTER 6
INDUSTRIAL VERIFICATION OF EXPERIMENTAL RESULTS

The research carried out to verify the results obtained was done on the same technological flow, on the semi-automatic line of formation-casting of cast iron clogs. Industrial experiments were performed for 2 batches pouring S1 type cast iron brake shoes – type P10 – phosphorus cast iron.

Starting from the results obtained after optimizing the technological parameters, namely: from the correlations obtained between the elements in the chemical composition of the brake shoes and the hardness (the main qualitative parameter for the brake shoes), a load calculation was performed in order to determine an optimal structure for the metal load of the experimental batches.

Starting from the resulting optimal areas of variation, of the elements in the chemical composition, namely C = 2.90-3.10%, Mn = 0.45-0.60%, Si = 1.20-1.70%, S = 0.07-0.09%; P = 0.80-1.10% results in a structure of the load of the experimental batches presented in table 6.1. Depending on the availability of waste and the correlations obtained, the following load structure was determined for the experimental batches: steel waste (scrap); cast iron waste (phosphorous cast iron clog waste); recirculated material (alloy cast iron or alloy steel waste of internal origin).

In order to highlight the influence of the microstructure on the mechanical and technological characteristics of the brake shoes, the morphological characterization of the experimental samples was chosen using the electron microscopy with scanning (electronic microscope with scanning Quanta FEG 250) [19/68].

The determinations were made within the Research Institute for Renewable Energy at the Polytechnic University of Timișoara.

Samples were taken for microstructural analysis for the two experimental P10 phosphorus cast iron batches for the manufacture of S1 type brake shoes.

Microscopic analysis was performed by determinations performed with and without reagent attack of samples. Thus, it can be said that:

- *graphite highlighting* for both samples (form of graphite separations, graphite distribution, length of graphite separations and surface occupied by it) was obtained on unattacked samples;
- the *highlighting of the basic metal mass, perlite and phosphorus eutectic* was obtained by determinations on the attacked samples with a nital 5%.

CHAPTER 7
FINAL CONCLUSIONS. ORIGINAL CONTRIBUTIONS
FUTURE RESEARCH DIRECTIONS

Analyzing the literature, simulating the casting and solidification of brake shoes from quality cast iron and the results of experimental industrial research results in the following final conclusions.

Font is the most used molded metal in shapes and the phases of cast iron graphite develop together with the metal matrix during solidification and the understanding and control of the structure, its density and morphology is essential for the properties of cast iron. The chemical elements existing in the composition of the shoe material influence the crystallization differently, for example, the increase of the manganese content favors the cementic crystallization, and the increase of the silicon content on the graphite one.

The influence of the phosphorus content of the cast iron from which the shoe is made is important, but the influence of the other components of the metallographic structure on the braking coefficient and wear must not be ignored.

The P10 phosphor cast iron, from which brake shoes are made, has a number of superior characteristics. In phosphorous cast iron brake shoes, the coefficient of friction decreases with increasing speed, the density of the material is 7.2 kg/dm^3 and the maximum permissible speed of the rolling stock is up to 140 km/h.

For the casting of the brake shoes intended for for the motor and towed rolling stock the design flow, cating and their creation were analyzed at the FOREVA Foundry within REVA SA Simeria, this being a traditional organization in repairing railway wagons and producing brake shoes. FOREVA Simeria Foundry holds authorizations for casting phosphorus cast iron brake shoes for motor and towed rolling stock and issues certificates of railway approval and examination as well as a certificate of approval Quality Management System (issued by ONFR-AFER).

The foundry management system presupposes the existence of procedures and working instructions that establish the methods for checking and testing the quality of brake shoes cast from phosphorus cast iron, throughout the technological process.

Industrial research for casting phosphorus cast iron brake shoes was carried out at the FOREVA foundry, which produces brake shoes on a semi-automatic line of cast iron parts formation. Brake shoes for motor and towed rolling stock are approved parts, and the activities of supplying railway products at the FOREVA foundry are authorized by the Romanian Railway Authority.

Experimental data came from 70 high quality cast iron batches – P10 type phosphorus cast iron – from which S1/S2/S3/LDH/LDE/LE brake shoes were cast. Experimental research and industrial data processing have focused on the technological flow of elaboration, training and casting of S1 and S2 type brake shoes.

In experimental batches the load structure had the following composition: 40-65% steel waste (scrap), 10-30% cast iron waste (phosphor cast iron clog waste), 20-50% alloy cast iron waste (recycled material), 20-30% alloy steel waste (recirculated material). Regarding the chemical composition, from the analysis of experimental industrial data is observed a classification of it in the product standard.

In order to obtain the optimal variation intervals for the chemical composition according to the hardness values determined on the brake shoes, the industrial experimental data were processed in the EXCEL and MATLAB calculation programs.

The analysis of equations and graphic correlations resulting from the EXCEL program, in order to obtain values of the hardness parameter between 197-255HB results in optimal areas of variation: C = 2.90-3.20%, Mn = 0.40-0.70%, Si = 1.20-1.90%, S = 0.08-0.09%, P = 0.80-1.05%.

Data processing in the MATLAB calculation program has led to the acquisition of regression surfaces and level curves as well as specific correlation equations that describe these dependencies. Then individually analyzing each surface – with specific influence of two elements of the chemical composition on the hardness, optimal variation intervals of these elements were identified. For values of the hardness parameter between 197-255HB, the analysis of the correlations in the MATLAB program results in the optimal fields of variation: C = 2.90-3.1%, Mn = 0.45-0.6%, and = 1.20-1.70%, S = 0.07-0.09%; P = 0.80-1.10%.

In order to obtain high quality brake shoes, their hardness must be within the upper range specified in the product standard.

Correlations obtained in graphic and analytical form have applicability in industrial practice. Starting from the optimal resulting intervals, of the chemical composition of the cast iron, the structure of the metal load for the elaboration unit is determined, thus resulting in a high quality cast iron, respectively an improvement in the quality of the brake shoes.

Correlations also allow, in industrial practice, that in order to obtain clogs with a predetermined hardness, the structure of the load is very easily determined based on the optimal areas of variation of the chemical composition of the cast iron.

Simulating the process of solidifying castings is of technological importance, as it combines a series of process parameters, respectively heat transfer, phase transformations, diffusion processes, volume variations, flow processes, local supply processes. The solidification process influences the quality of the castings, namely the micro and macrostructure of the parts, their compactness, their mechanical strength, dimensional accuracy, surface quality.

Also, a special influence on solidification are the constructive factors of the cast (geometry, dimensions, alloy nature) and technological factors (casting temperature, shape nature, massage system supply system etc.), which leads to the need to simulate the process and compare the results obtained with the industrial practice.

The use of software to simulate solidification at the industrial level became possible with the development of the calculation technique and led to the obtaining of concrete studies aimed at optimizing the training and casting technologies.

Following the simulation of the process of casting and solidification of the liquid alloy, the following results:

• Possibility to anticipate the behavior of the metal alloy during technological processes;

• Optimizing process parameters according to the dimensions of different cast landmarks;

• Obtaining optimal areas of variation of parameters, with influence on mechanical and resistance characteristics;

• Based on the simulation results, the optimal technological variants for casting, solidification can be selected, taking into account the real conditions in the industrial environment;

• The data resulting from the simulation are similar to the data recorded in industrial practice.

The solidification process influences the quality of the castings, namely the micro and macrostructure of the parts, their compactness, their mechanical strength, dimensional accuracy, surface quality. Also, a special influence on solidification are the constructive factors of the cast (geometry, dimensions, alloy nature) and technological factors (casting temperature, shape nature, massage system supply mode, etc.), which leads to the need to simulate the process and compare the results obtained with the industrial practice.

Analyzing the results obtained in industrial research and experimentation, the following original contributions result:

1. Analysis and synthesis of technology for developing and casting phosphorus cast iron brake shoes;
2. Determination of the quality characteristics of phosphorus cast iron brake shoes;
3. Establishing the modalities for experimental testing on brake shoes performed during the doctoral thesis;
4. Analysis of the technological flow of elaboration, formation and casting of brake shoes at FOREVA Simeria;
5. Macro and microstructural characterization of samples resulting from industrial experimental research;
6. Obtaining correlation equations in graphic and analytical form resulting from the processing of industrial experimental data in the EXCEL and MATLAB calculation programs;

7. Obtaining the regression surfaces and the level curves of the dependence of the hardness of the brake shoe according to the chemical elements in the composition of the phosphorus cast iron;
8. Determining the optimal areas of variation of the analyzed technological parameters;
9. Making the 3D model of the brake shoe, type S1, cast in cast iron, using SolidWorks software;
10. Realization of the 3D model of the casting shoe assembly, using SolidWorks software;
11. The actual realization of the simulation of the process of casting and solidification of the clogs, using the Altair-InspireCast software;
12. The data resulting from the simulation are similar to the data recorded in industrial practice.
13. Selection of optimal technological variants for casting and solidifying brake shoes taking into account the results obtained by simulation and the real conditions in the industrial environment;
14. Industrial verification of the results obtained;
15. Morphological and compositional characterization of experimental samples of phosphorus cast iron taken from industrial practice.

Research continuation directions:

- Increasing the degree of preparation of the metal load intended for the elaboration of the phosphorus cast iron;
- Reduction of specific metal and energy consumption on the technological flow of manufacture of brake shoes;
- Increasing the service life of brake shoes;
- Extension of research on the production of composite brake shoes, taking into account European regulations on noise reduction by rail.

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