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INVESTIGATIONS ON THE PHOSPHOROUS CAST IRON DESTINED FOR BRAKE SHOES MANUFACTURING

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Abstract:
The choice of friction material can have a direct influence on the wear life of the brake block or wheel, which is typically much more expensive to replace. The classical cast iron brake block is gradually replaced by organic composite or sintered composite brake blocks. Nowadays, attention is devoted to solving problems connected with using modern brake materials and their impact on thermal and mechanical loading of railway wheels. In this paper, the investigated subjects are the gray cast iron brake shoes, with lamellar graphite and with high content of phosphorus (0.8–1.1%), according to requirements for the brake shoes related materials.

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cast iron, brake block, phosphorus, brake shoes manufacturing

1. INTRODUCTORY NOTES

Train braking is a very complex process, specific for rail vehicles and of great importance to the essential contribution on the safety of the traffic. This complexity results from the fact that during braking numerous phenomena of different kinds occur – mechanical, thermal, pneumatic, electrical etc. The actions of these processes take place in various points of the vehicles and act on different parts of the train, with varying intensities[1–4]. The major problem is that all must favorably interact for the intended scope, to provide efficient, correct and safe braking actions [5–9]. The main factor that influences the selection of a friction material for railway applications is the performance criterion (friction and wear) [6–12].

On manufacturing brake shoes meant for the rolling stock, phosphorous cast irons are largely used [5–7]. Their friction coefficient is diminishing dramatically on braking at the relatively high speeds (up to 120–140 km/h), while their wear is encreasing when the temperature in the braking coupling rises [3,4]. Therefore, their use as cast irons is limited for railway vehicles running at speeds up to 120 km/h [1,3,4].

2. PHOSPHOROUS CAST IRONS FOR BRAKE SHOES MANUFACTURING

For brake shoes production, gray cast iron with lamellar graphite and nodular cast iron are used frequently, because of good thermal conductivity (necessary for the proper discharge of heat due to friction), good mechanical properties andgood wear resistance [13–15]. The main elements of its chemical composition are presented in Table 1 and mechanical properties fall within the intervals corresponding to the desired purpose [13–15]. Cast iron brake block has many advantages including hardness, impact strength and so on. It consists of two parts, the cast iron and the steel support. Both the surface and the core of the cast iron have the hardness within the range of 197<HB<225 [13–15].

It has been demonstrated that, in the railway breaking system, the shoe's iron graphite, respectively the wheels steel's chromium, are the most helpful structural elements in the materials intended for friction. As regards the graphite form it is still debatable which it the preferable one (globular or lamellar), but it is known that the carbon content must represent approx. 3.2 % in the final chemical composition of these irons [13–15].

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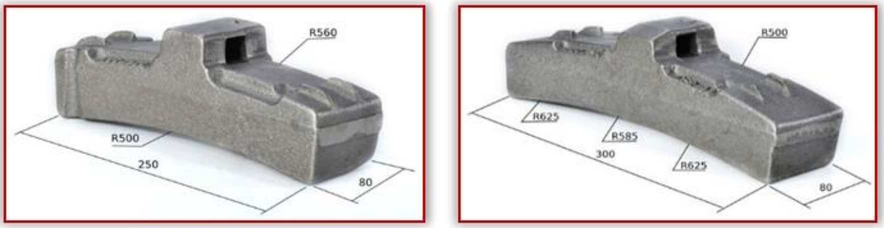

a) b)

Figure 1. a) Gray cast iron brake shoes for passenger trains; b) Gray cast iron brake shoes for freight wagons

Table 1. Chemical compositions of cast iron and steel support

Chemical compositions of cast iron		Chemical compositions of steel support	
Main components	Proportion, [%]	Components	Proportion, [%]
Carbon, [C]	3.0–3.5	Carbon, [C]	< 0.13
Phosphorus, [P]	1.3–1.5	Sulphur, [S]	< 0.062
Silicon, [Si]	1.5–2.0	Phosphorus, [P]	< 0.062
Sulphur, [S]	0.1–0.15		
Manganese, [Mn]	0.5–0.8		

A common characteristic constituent of gray iron microstructures is the phosphorus ternary eutectic known as steadite ($Fe_3C + Fe_3P + P$). The characteristic property of this system is a large area of the ternary phosphorous eutectic due to the strong tendency for phosphorus to segregate. The form of the phosphorus eutectic depends on the chemical composition of the gray iron (Fig. 2). In iron with an average tendency to graphitization and a phosphorus content of approximately 0.4%. The microstructure of each cast iron destined to the brake shoes is composed of steadite, cementite and flaky graphite distributed in pearlitic matrix. The high content of phosphorous improves the friction – wear behavior of such cast iron [13–15].

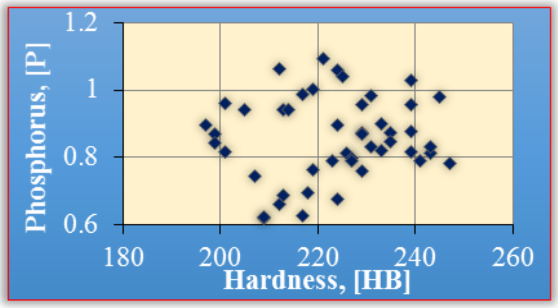

Figure 2. The usual phosphorus content variation in the analyzed cast irons destined for brake shoes manufacturing

The structural changes occurring under the action of the phosphorus content able to influence the properties of the cast irons are on the increase of the quantity of graphite and finishing it, the increase in the quantity of phosphorous eutectic and its distribution in the network form and obtaining the more quantity of perlite. Increasing the resistance is favored as long as the phosphorous eutectic is disposed in the form of isolated separation [13–15]. Also, due to the increase of the perlite's proportion and especially of the phosphorous eutectic, as high hardness constituent (500–600 HB), by the addition of phosphorus the general hardness is increased [13–15].

3. METHODS TO ACHIEVE THE CHEMICAL COMPOSITION BEHAVIOR

One of the main chapters of the statistics referring to the ability to predict. Although it is not find the perfect relations, by means of regression, can make statements of a variable, depending on the other values. The present researches are going to establish the influence of the chemical elements in the structure upon the mechanical properties (hardness) of the braking shoe material (gray phosphorous cast iron with lamellar graphite). The technological manufacturing process of the brake shoes, as well as the quality of material used in manufacturing them, can have a different influence upon the quality and the safety in the exploitation [13–15].

A major feature with huge impact on sustainability in the brake shoe is the hardness. At the brake shoes, hardness shall be determined in five points, two located at the ends of the shaker (on the same front side section) and three in the section of the shaker (diagonal cross–section)[13]. Our proposal approaches the issue of quality assurance of the brake shoes from the viewpoint of the quality of materials, which feature can cause duration and safety in exploitation. In order to achieve the chemical composition behavior upon the shoe's hardness 100 charges were analyzed. A few interpretations of the correlations between the cast irons chemical components – Carbon (C), Silicon (Si), Manganese (Mn), Phosphorus (P) and Sulfur (S) – and the obtained brake shoes hardness (HB) was enounced. We propose three kinds of correlations, using the Matlab area [13–15].

4. EXPERIMENTS

In the first experiment, we analyzed the equivalent carbon content value behavior on the hardness of cast iron brake shoes. As a result, several regression surfaces and correlation diagrams are revealed, presented in the Figs. 3–4.

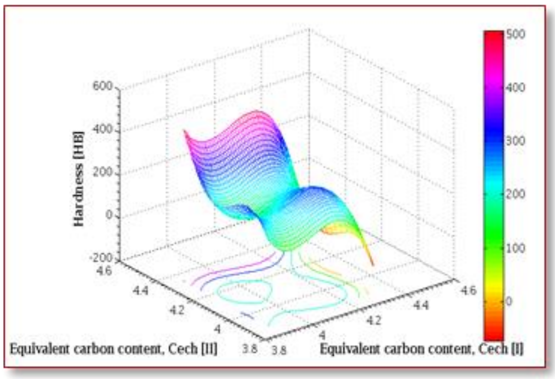

Figure 3. The regression surface, case of HB=f(Cech(I),Cech(II))

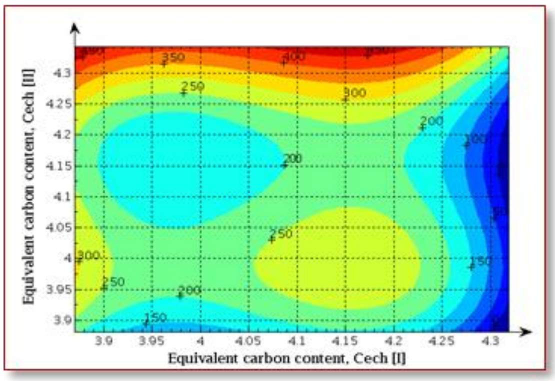

Figure 4. Correlation diagram, case of HB=f(Cech(I),Cech(II))

For gray iron destined to brake shoes casting the equivalent carbon content (CE) concept is used to understand how alloying elements affect the casting behavior. It is used as a predictor of strength in cast irons because it gives an approximate balance of austenite and graphite in the final structure. The carbon equivalent is invaluable in technological analysis and it is used in empirical formulas [13–15]. To determine the equivalent carbon content in cast irons the following formulas are used:

$$C_{ech}(I)=[C]+0.33[Si]+0.33[P]-0.027[Mn]+0.4[S] \quad (1)$$

$$C_{ech}(II)=[C]+0.33([Si]+[P]) \quad (2)$$

Thus, the total carbon equivalent of the cast iron consists of the carbon content and the carbon equivalents for each additional element. The carbon equivalents are usually determined experimentally.

The performed study had in view to obtain correlations between the hardness of the cast iron brake shoes and its chemical composition, defined by basic and the representative alloying element (phosphorous). The data revealed small variations of the hardness, which was due to variations in the narrow limits of the chemical composition. The values of the hardness are within the range 197–240 HB being in accordance with the international standards. The chemical and structural homogeneity of the shoes material lead to small variations of the values for the hardness (on both side surfaces and in the cross–section) what will find, finally, in the brake shoe's durability. There is a difference of hardness between the cross–section and the center section's measurement, which was explainable by the conditions of the solidification process, due to the cooling rate.

As the second statistical experiment, we analyzed the combined behavior of all chemical elements of gray phosphorus cast iron on the hardness of brake shoes, in several correlations. As a result, regression surfaces and correlation diagrams are revealed, presented in the Figs. 5–16.

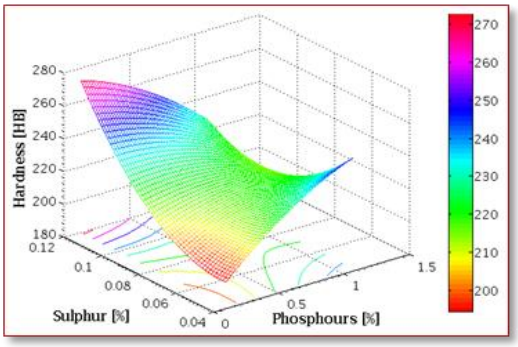

Figure 5. The regression surface, case of HB=f(S,P)

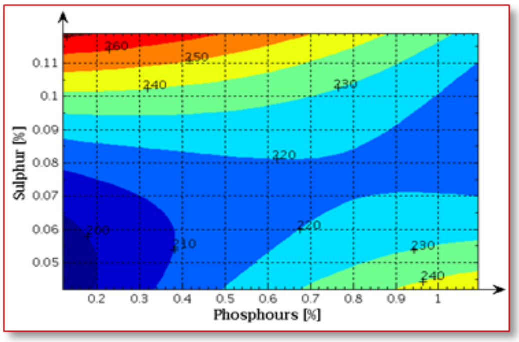

Figure 6. Correlation diagram, case of HB=f(S,P)

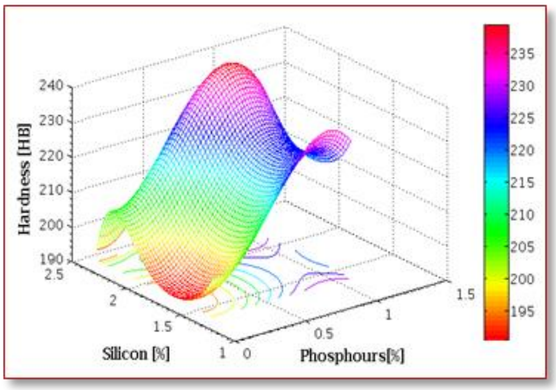

Figure 7. The regression surface, case of HB=f(Si,P)

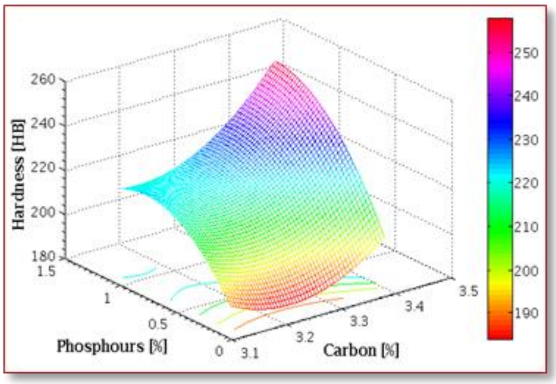

Figure 11. The regression surface, case of HB=f(C,P)

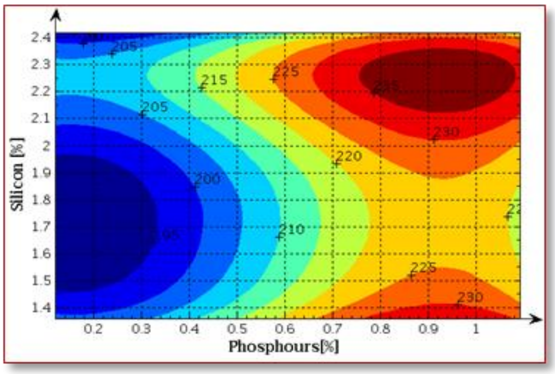

Figure 8. Correlation diagram, case of HB=f(Si,P)

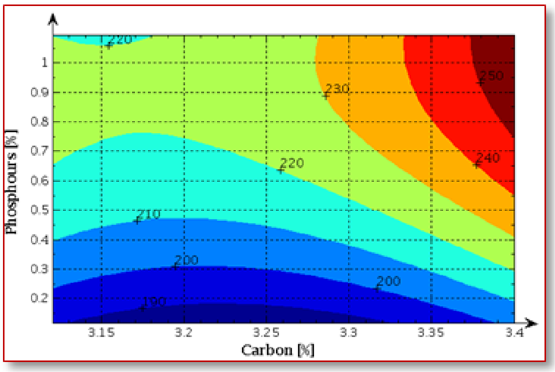

Figure 12. Correlation diagram, case of HB=f(C,P)

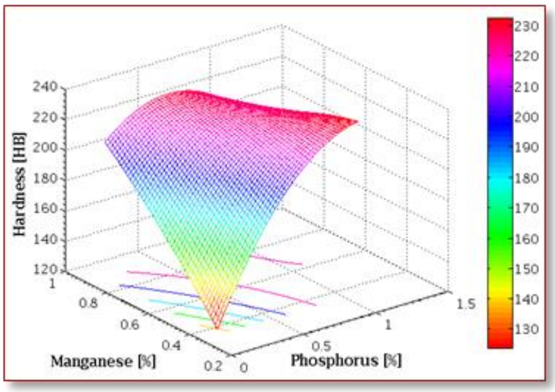

Figure 9. The regression surface, case of HB=f(Mn,P)

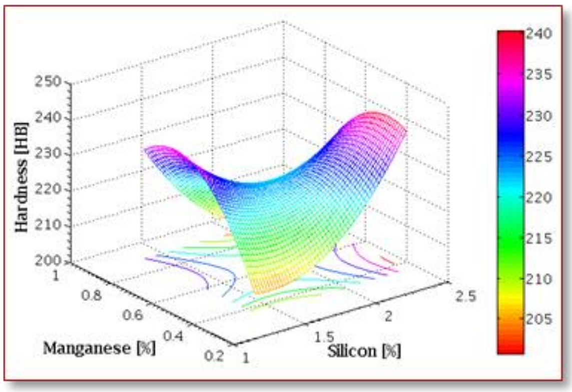

Figure 13. The regression surface, case of HB=f(Mn,Si)

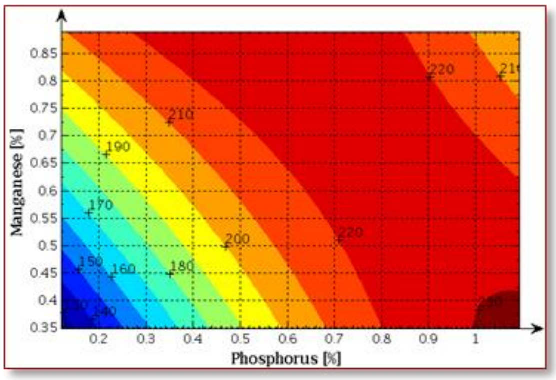

Figure 10. Correlation diagram, case of HB=f(Mn,P)

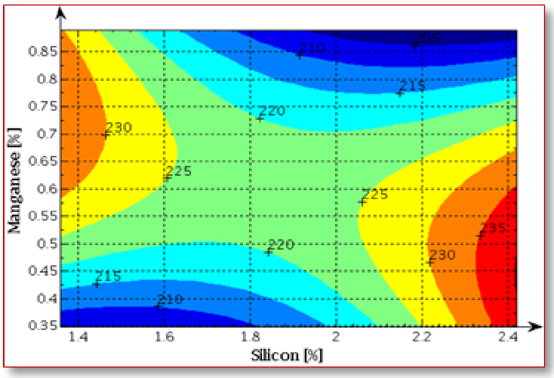

Figure 14. Correlation diagram, case of HB=f(Mn,Si)

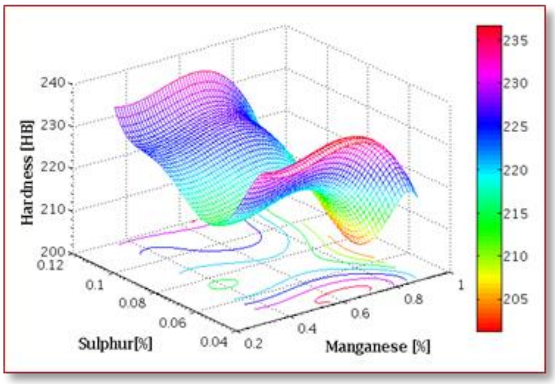

Figure 15. The regression surface, case of HB=f(Mn,S)

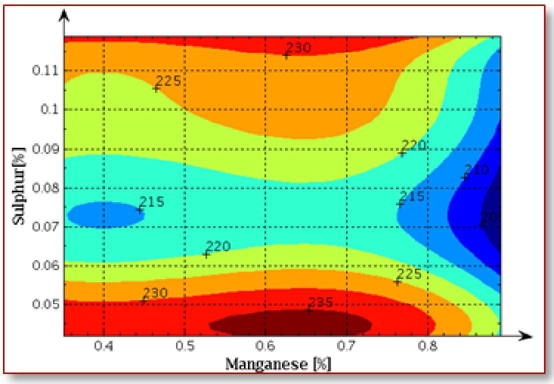

Figure 16. Correlation diagram, case of HB=f(Mn,S)

5. DISCUSSIONS

The values processed were made using Matlab calculation program. Technological engineers and brake shoe's manufacturers can interpret these regression surfaces, belonging to the three–dimensional space, and the correlation diagrams, belonging to the bi–dimensional space, presented in Figures 5–16. Analysing the results of the experimental research upon a number of 100 charges of phosphorous cast iron brake shoes , the following may be concluded:

» the chemical composition of iron used in the manufacturing of the brake shoes ensures their hardness within the limits set by the standards.

» the correlation diagrams clearly results the influence of the content of Carbon, Manganese and Silicon on the hardness of the brake shoes;

» the level curves, obtained into the correlation diagrams allow us to choose the independent parameters (Carbon, Manganese and Phosphorous) in such a way as to obtain thedesired value of hardness.

6. CONCLUDING REMARKS

This paper reviews key aspects of brake shoes material and presents an analysis of the influences of chemical composition upon their hardness. Using the double correlations variation boundaries for the chemical composition, in view the obtaining the optimal values of the hardness of brake shoes, are obtained. The partial results and evidence obtained by the actual experiments are presented.

The materials used in the railway breaking components manufacturing may constitute one of the main research directions. In the case of the wheels, the monobloc alloy steel wheel solution was reached , with limited content of carbon and manganese, treated to a depth in ranging between 30–50 mm from the contact surface, which can lead to the increased sustainability. But in the case of the brake shoes related investigations, they could give no solutions concerning the character of the generalization, due to the heavy working regime (which involves environmental factor, temperature regimes, vibration and impact, etc.), but also due to the complexity of the concomitant wear phenomenon in the brake shoe–wheel system.

To analyze the metallurgical processes is used, mainly, the statistical fundamental methods that permit to draw conclusions, from the observed values, about the repartition of the frequencies of various parameters, about their interaction, about verification validity of certain premises, and about the research of the dependencies among different parameters. In this sense, the realization of optimum chemical compositions of the cast–iron can constitute a technical efficient way to assure the exploitation properties, the material from which the brake shoes are manufactured having an important role in this sense. Therefore, the realization of an optimal chemical composition can constitute a technical efficient mode to assure the exploitation properties, the material from which the shoes are manufactured having an important role in this sense. From this point of view the mathematical analysis is applied, taking into consideration the collected industrial data. Moreover, durability in exploitation is extremely current, both for immediate practice, and for the scientific research attributed to the cast–iron used in brake shoes manufacturing.

Thus, have been searched as shoe's material, irons and alloys, which present a higher friction coefficient, constantly with the railway speed and, at the same time, a reduced wear speed for the breaking components. Moreover, obviously, all at the possible lowest cost. In these conditions, the research has shown that the irons remain a preferential material for the brake shoes, as demonstrated on both and freight wagons. Along with the gray irons (with the lamellar or nodular graphite), with high levels of phosphorus (above 0.8–1.1%), have given good results in exploitation, increasing resistance to wear and reducing the braking path without increasing the wheels wear. These favorable tribological effects by the difference of the smoother structure and with more overlapping of eutectic phosphorous network are explained., The superiority of the irons with high phosphorus content has been demonstrated too, the operating conditions confirming these allegations.

REFERENCES

[1] F. Lacôte, Evolution of Railway Technology – 50 Years of Progress in Railway Technology, Japan Railway & Transport Review, (27), 2001: 25–31.
[2] T. Hodges, A life–cycle approach to braking costs, International Railway Journal, 2012.
[3] C. Cruceanu, Brakes for railway vehicles, Matrix Rom Publishing House, Bucharest, 2007.
[4] C. Cruceanu, Train Braking, Reliability and Safety in Railway, Intech, 2012.
[5] L.I. Dungan, M.A. Dungan, Materials used in couplings mechanical friction braking system of high speed railway vehicles, Buletinul AGIR, (2–3), 2010: 121–126.
[6] Y. Zhang, Y. Chen, R. He, B. Shen, Investigation of tribological properties of brake shoe materials – phosphorous cast irons with different graphite morphologies, Wear, 166 (2), 1993: 179–186.
[7] T. Tsujimura, Improved performances of cast iron brake shoe, Railway Technical Research Institute, Quarterly Reports. 35 (4), 1994: 215–217.
[8] T. Tsujimura, H. Arai, N. Fujiwara, Development of high performance special cast iron brake shoes, Railway Technical Research Institute, Quarterly Reports, 31 (4), 1990: 218–224.
[9] A.B. Boghani, Characterizing the performance of cast–iron, high–phosphorus cast–iron, and composition freight car brake shoes under simulated drag braking conditions, Federal Railroad Administration, 1981, pp.54–61.
[10] A. Akkus, M. Yeğin, Research on wear rate and mechanical properties of brake sabots (shoes) used in railway rolling stocks, International Journal of Applied Science and Technology, 4 (7), 2014: 76–84.
[11] F. Shang, H.X. Zhou, B. Qiao, H.Q. Li, Y.Q. He, Application of metal powder metallurgy technology in preparation of friction materials of the railway vehicles, Advanced Materials Research, 287–290, 2011: 2987–2990.
[12] H. Paukert, ERRI tests two types of synthetic brake shoe, International Railway Journal, 2003.
[13] L.V. Pascu, Cercetări privind îmbunătăţirea calităţii saboţilor de frână destinaţi materialului rulant, University Politehnica Timisoara, Doctoral thesis, 2015.
[14] I. Kiss, V. Cioata, V. Alexa, S. Ratiu, Investigations on the selection of friction materials destined to railway vehicles applications, International Conference on Applied Sciences – ICAS 2016, Hunedoara, Romania, 2016.
[15] I. Kiss, The chemical composition of phosphorous cast irons behavior in the manufacturing of brake shoes meant for the rolling stock, Acta Technica Corviniensis – Bulletin of Engineering, 9 (3), 2016: 78–84.