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THE CHEMICAL COMPOSITION OF PHOSPHOROUS CAST IRONS BEHAVIOR IN THE MANUFACTURING OF BRAKE SHOES MEANT FOR THE ROLLING STOCK

[1.] University Politehnica Timisoara, Faculty of Engineering Hunedoara, Hunedoara, Romania

Abstract: Friction products are safety–critical items, which must be carefully designed and selected to ensure several performance criteria. The design or formulation selected is a compromise between several conflicting priorities and the trade–offs can be tailored according to the wide range of different customer requirements that exist in the market. Brake blocks, also called "shoes", are made of cast iron, respecting the principle of having a different hardness (and resulting wear) from the other elements of the friction pair, i.e. the wheel (made of steel). Cast iron blocks have specific features, like a rather high weight, limited cost, easy supply and a peculiar friction coefficient dependency on the sliding (vehicle) speed. For making brake shoes are used frequently gray cast iron with lamellar graphite and nodular cast iron, which have a good thermal conductivity (necessary for the proper discharge of heat due to friction), good mechanical properties, good wear resistance. Our research 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 this work the investigated subjects are the gray cast iron brake shoes, with lamellar graphite and with a high content of phosphorus (0.8-1.1%), according to requirements for the brake shoes related materials. In order to achieve the chemical composition behavior upon the phosphorous gray cast iron shoe's hardness 100 charges were analyzed.
Keywords: phosphorous gray cast iron, brake blocks (shoes), hardness, Matlab area

INTRODUCTORY NOTES

To encourage train transport, the tendencies of trains do not focus just on delivering the right comfort for passengers, but also on increasing traffic speed, together with the high level of safety, less costs and increased availability. These are the main challenges as regards braking systems. The technological development has permitted these elements, although they are the most exposed equipments of a rail vehicle, to optimize the transport safety level and to act rapidly and efficiently in case of emergencies. The braking system is one of the most important and complex subsystems of railway vehicles, especially when it comes for safety. [3,4,13]

Of all the known braking systems, mechanical braking system, based on tribological principles, is the oldest and the only one able to stop a vehicle or a train of railway vehicles within an area of deceleration and braking space required.[5]

A major problem is the friction between wheel and brake shoes, which leads to severe thermal regimes and special thermal fatigue nature efforts, requiring specific constructive and operating standards. It is still to notice that, regarding the classical systems used for railway vehicles, there are also several major challenges that may affect the braking capacity. These aspects must be very well known and understood. [3,4] Braking capacity of the brake shoe depends on the quality, material properties and friction torque components and in particular by friction lining material.

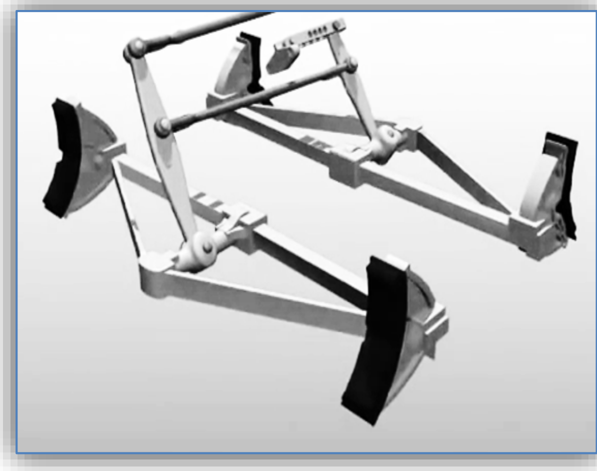

Figure 1. The brake beam mechanism

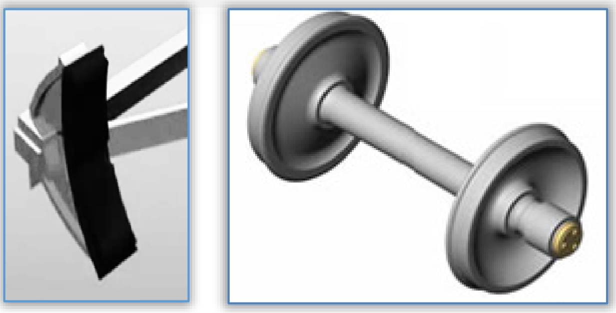

Figure 2. The friction pair (brake shoe – wheel)

Brake shoes work in special service conditions: the materials for them should possess great strength to avoid cracking and low hardness to protect the vehicle wheel from too much wear. [1,3,13] These properties are easily satisfied by the adjustment of the material's microstructure. On the other hand, the tribological properties are even more important, in that the brake shoes must possess not only better wear resistance, but also a high friction coefficient to stop the train in the shortest distance whenever emergency occurs.

To achieve ideal brake friction material's characteristics, such as constant coefficient of friction under various operating conditions, resistance to heat, water and oil fade, low wear rate, possess durability, heat stability, exhibits low noise, and not to damage brake shoes, some requirements have to be compromised in order to achieve some other requirements. [2,4] Consequently, the braking system producers must guarantee:

≡ stable and reliable coefficients of friction;
≡ control of the brake fading effect (coefficient of friction reduction);
≡ braking efficiency and uniform dissipation of heat developed when applying the brakes;
≡ great match performance–use;
≡ reduction of noise, in all the operating conditions, thanks to the perfect balance of the chemical/physical properties of the compound components.

However, it is practically impossible to have all these desired properties.[3,4,10,13] Railroad brake shoes are supposed to be light, corrosion-resistant, in line with performance characteristics, as well as having to have a stable friction coefficient, a low wear rate, a low noise, a long use life, and a reasonable cost. Designers have extensive freedom in dimensioning brakes for new vehicles and it is not always necessary to reproduce the friction coefficient of the cast iron brake shoe. The only essential requirement is that equivalent speeds produce equivalent stopping distances. [1,7,8,13] Therefore, some requirements have to be compromised in order to achieve some other requirements. In general, each formulation of friction material has its own unique frictional behaviors and wear–resistance characteristics.

Current trends in the development of railway vehicles (high speed, low weight, high capacity etc.) leads to decrease even at suppressing the use of the wheel (running surface) for the braking function. [5,9] The main directions of future research and investigations in rail vehicle braking are:

≡ advanced research on the classical brake friction material's characteristics and behaviour;
≡ finding materials whose coefficient of friction is independent of speed and weather conditions (rain, ice etc.);
≡ replacement of a standard and well known material (cast iron) with a completely different one (composite blocks) for reducing and possible elimination of the rolling noise emissions of wagons;
≡ find and research new materials for friction materials in terms of their density, to reduce unsuspended vehicle weight;
≡ devoted attention to solving problems connected with using modern brake materials and its impact on thermal and mechanical loading of railway wheels.

Brake shoes are made in a variety of materials (cast iron brake shoe, as solid one-piece casting, composite brake shoe, as high friction and low friction brake shoe, and powder metallurgy brake shoe, as sintered), all of which have their own drawbacks (hard on the wheels, friction coefficient, cost). From the standpoint of predictable performance and reliability, the superior friction material applied to a railroad car wheel is the cast iron, particularly where the service requirements are severe. In the modern railway transport, the classical cast iron brake shoes, still widely used on freight wagons, are gradually replaced by the organic composite or sintered composite brake shoes.

Traditionally, freight wagons were fitted with brake systems using cast iron blocks. Passenger wagons still resist and are nowadays equipped with the original solution of cast iron brake blocks.

PHOSPHOROUS CAST IRONS FOR BRAKE SHOES MANUFACTURING

Iron is a friction material used to manufacture brake shoes, because it is easily prepared and put into shape, very inexpensive and has no harmful influence on the wheel-running surface. On manufacturing brake shoes meant for the rolling stock, phosphorous cast irons are largely used.[2,5-8,13,14] Their friction coefficient diminishing dramatically on braking at the relative high speeds (up to 120–140 km/h), while their wear is growing when the temperature in the braking coupling goes up. Therefore, their use as simply cast irons is limited for railway vehicles running at speeds of up to 120 km/h.

Various kinds of casting iron brake shoes are mainly grouped according to the composition of phosphorus as followings:

- ≡ grey cast iron brake shoe
- ≡ medium phosphorus cast iron brake shoe
- ≡ high phosphorus cast iron brake shoe
- ≡ alloy cast iron brake shoe

The difference lies in the content of the phosphorus. The phosphorus content in normal type is 0.7-1.0%, while in high phosphorous cast iron brake shoes, the phosphorus content is above 10%. In the rolling stock, a brake shoe of phosphoric cast iron had a wear resistance and a higher friction coefficient, therefore, phosphorus was a very important element for the performance improvement of brake shoe.

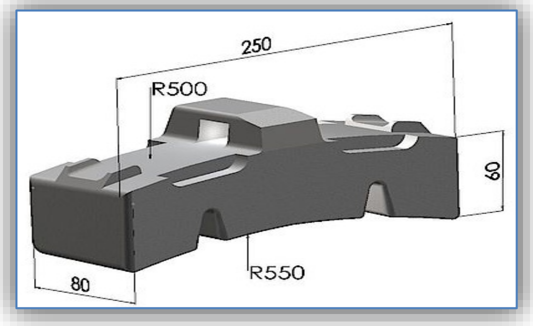

Figure 3. Gray cast iron brake shoes for passenger trains

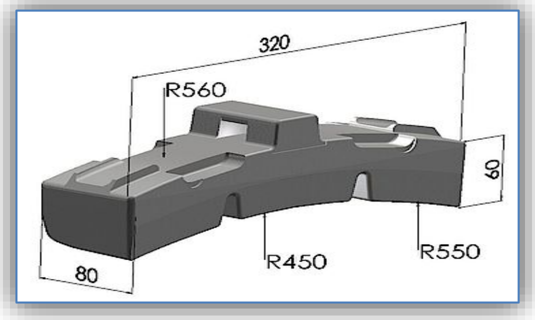

Figure 4. Gray cast iron brake shoes for freight wagons

For making brake shoes are used frequently gray cast iron with lamellar graphite and nodular cast iron, which have a good thermal conductivity (necessary for the proper discharge of heat due to friction), good mechanical properties, good wear resistance. Cast iron brake block enjoys 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 core of the cast iron have the hardness within the range of 197<HB<225. [9,13,14]

The main elements of its chemical composition in Table 1 and Table 2 are presented and mechanical properties fall within the intervals corresponding to the desired purpose.

Table 1. Chemical compositions of cast iron

Main components	Proportion, [%]
Carbon, [C]	3.0–3.5
Phosphorus, [P]	1.3–1.5
Silicon, [Si]	1.5–2.0
Sulphur, [S]	0.1–0.15
Manganese, [Mn]	0.5–0.8

Table 2. Chemical compositions of steel support

Components	Proportion, [%]
Carbon, [C]	< 0.13
Sulphur, [S]	< 0.062
Phosphorus, [P]	< 0.062

Typically, the alloy has a composition corresponding to conventional grey cast iron, except for the high phosphorus content. Preferably, the phosphorus is added to cast iron in the form of ferro-phosphorus, which may be incorporated into cast iron in the proportions necessary to provide an alloy with the desired phosphorus content.

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. In irons 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 was 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. [13,14]

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. 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.

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 to friction. As regards the graphite form are talking yet whether it is preferable (globular or lamellar), but it is known that the carbon content must represent approximately 3.2% in the final chemical composition of these irons.

SEVERAL STATISTICAL EXPERIMENTS

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.

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 section of the shaker (diagonal cross–section). [13,14]

Our research 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 (4) kinds of correlations, using the Matlab area.

In the first experiment, the general behavior of Carbon (C) content in relation with the Silicon (Si) and Manganese (Mn) contents, which have influence on the hardness of brake shoes, in several Matlab graphic area representations are analyzed. As result, several regression surfaces and correlation diagrams are revealed, presented above, in the Figures 5–10.

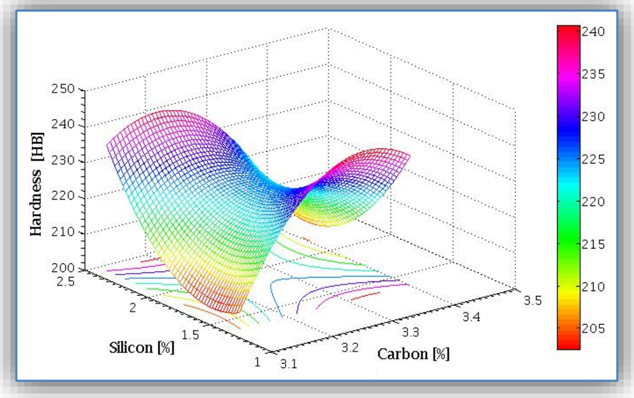

Figure 5. The regression surface, case of HB=f(C,Si)

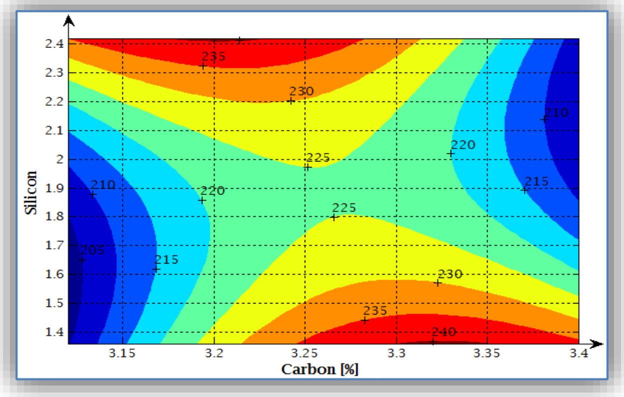

Figure 6. Correlation diagram, case of HB=f(C,Si)

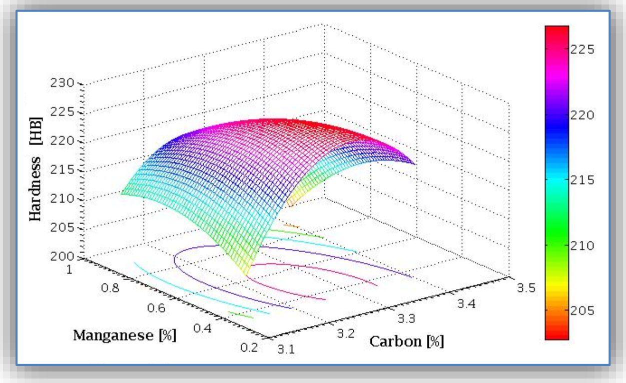

Figure 7. The regression surface, case of HB=f(C,Mn)

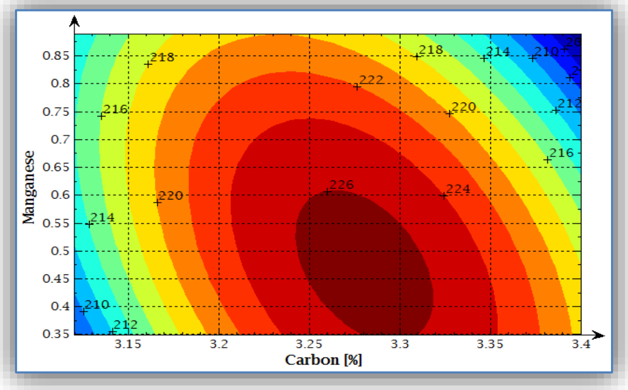

Figure 8. Correlation diagram, case of HB=f(C,Mn)

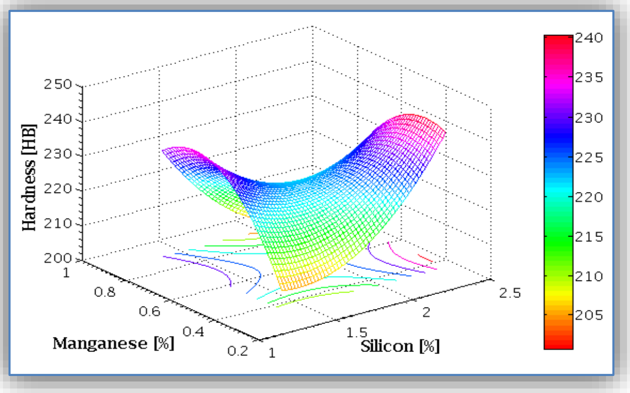

Figure 9. The regression surface, case of HB=f(Mn,Si)

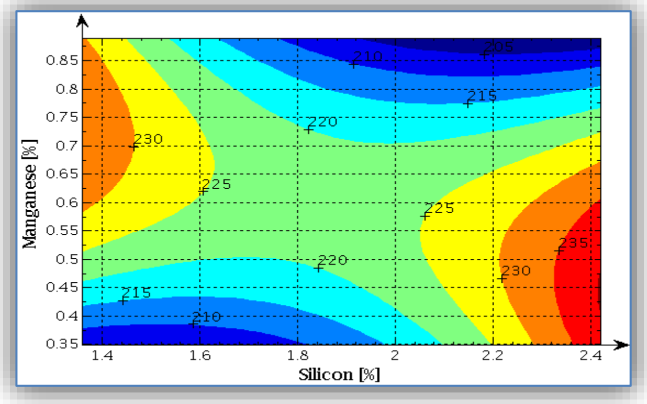

Figure 10. Correlation diagram, case of HB=f(Mn,Si)

As second statistical experiment, followed by the Matlab graphic area representations, the combined behavior of Carbon (C) content in relation with the Sulphur (S) and Phosphorus (P) contents of gray phosphorus cast irons on the hardness of brake shoes, in several correlations are analyzed. As result, several regression surfaces and correlation diagrams are revealed, presented above, in the Figures 11–16.

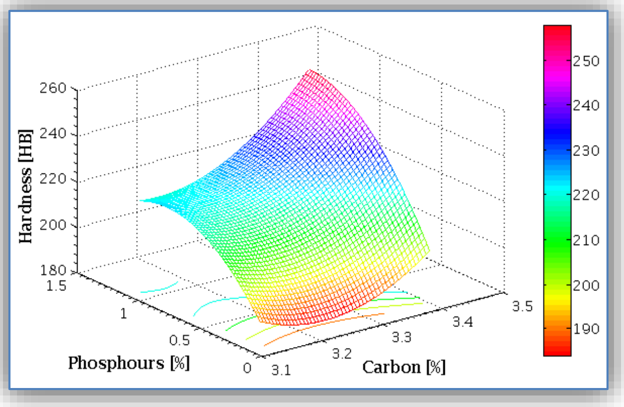

Figure 11. The regression surface, case of HB=f(C,P)

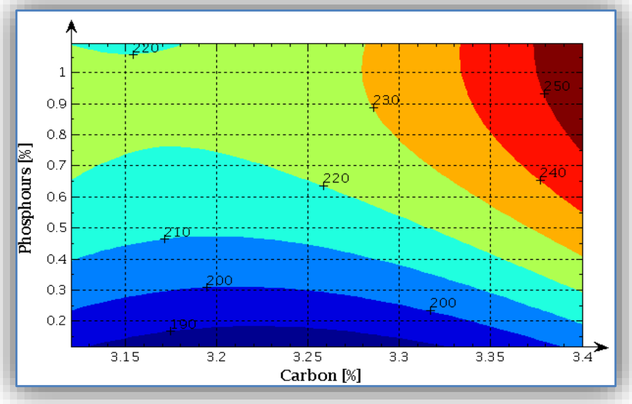

Figure 12. Correlation diagram, case of HB=f(C,P)

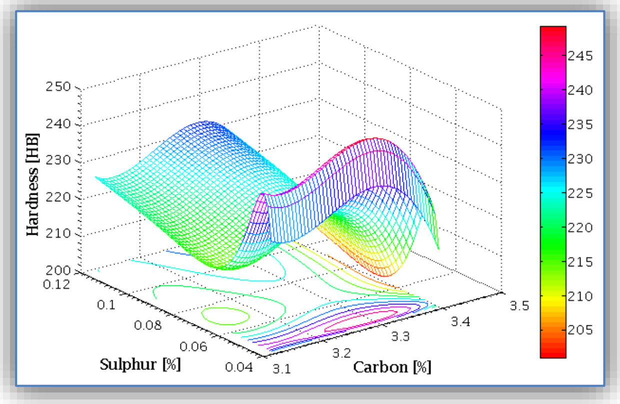

Figure 13. The regression surface, case of HB=f(C,S)

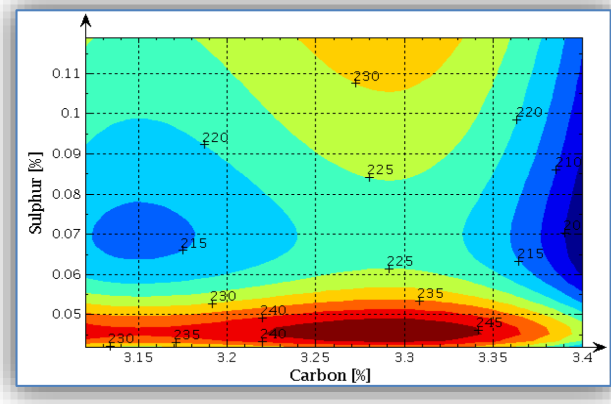

Figure 14. Correlation diagram, case of HB=f(C,S)

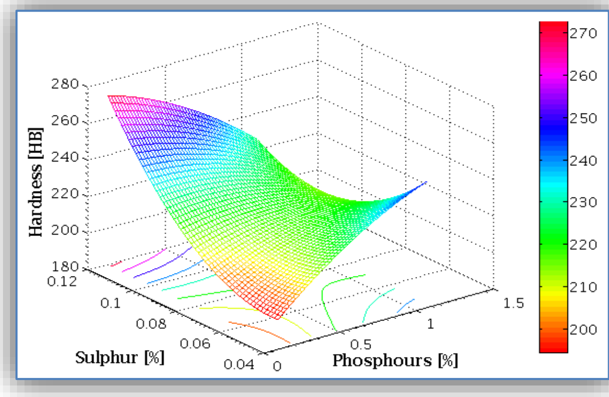

Figure 15. The regression surface, case of HB=f(P,S)

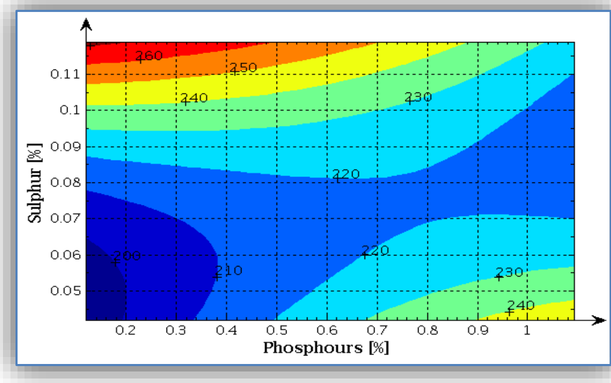

Figure 16. Correlation diagram, case of HB=f(P,S)

As third statistical experiment, followed by the Matlab graphic area representations, we analyzed the combined behavior of Carbon (C) content in relation with the Sulphur (S) and Phosphorus (P) contents of gray phosphorus cast irons on the hardness of brake shoes, in several correlations. As result, regression surfaces and correlation diagrams are revealed, presented in the Figures 15–24, correlated with Figures 9-10.

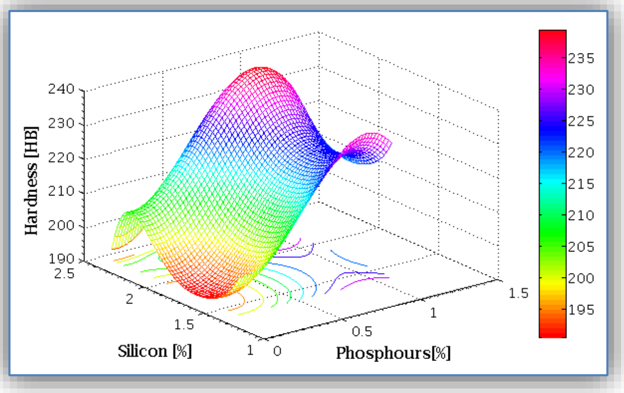

Figure 17. The regression surface, case of HB=f(Si,P)

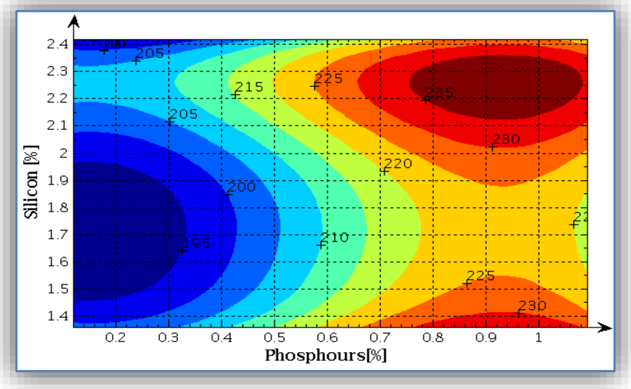

Figure 18. Correlation diagram, case of HB=f(Si,P)

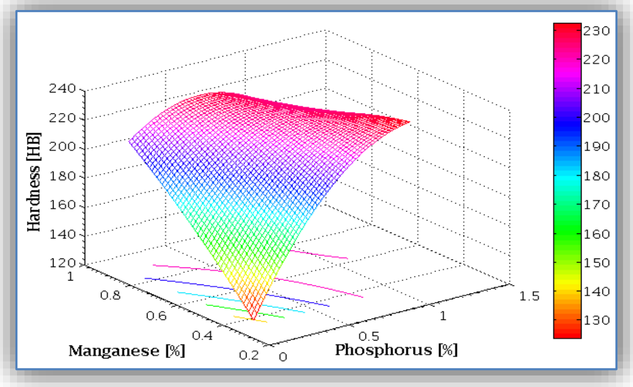

Figure 19. The regression surface, case of HB=f(Mn,P)

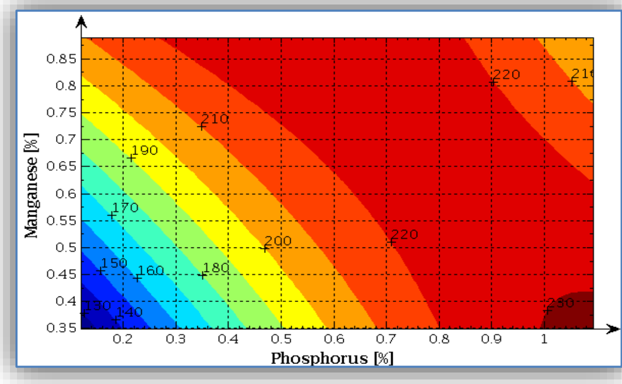

Figure 20. Correlation diagram, case of HB=f(Mn,P)

As final experiment, the equivalent carbon content value behavior on the hardness of cast iron brake shoes is analyzed. As result, several regression surfaces and correlation diagrams are revealed, presented in the Figures 21–22.

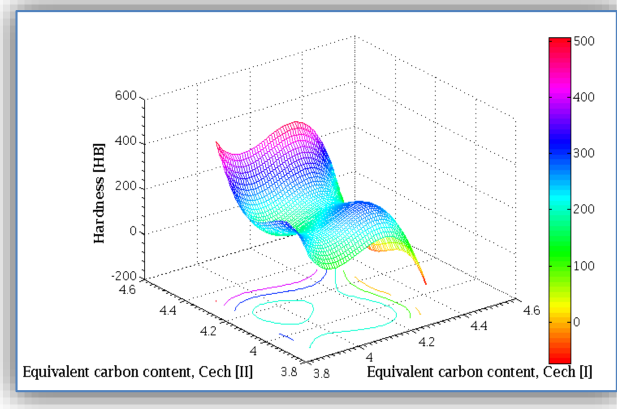

Figure 21. The regression surface, case of HB=f($C_{ech(I)}$,$C_{ech(II)}$)

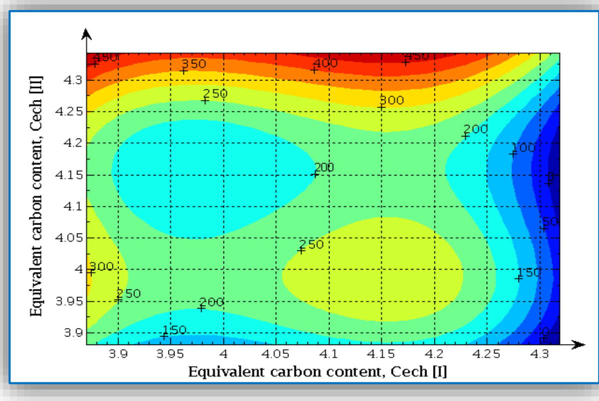

Figure 22. Correlation diagram, case of HB=f($C_{ech(I)}$,$C_{ech(II)}$)

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 final structure. The carbon equivalent is invaluable in technological analysis and it is used in empirical formulas. To determine the equivalent carbon content in the 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.

DISCUSSIONS

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 is 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.

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 5–22. By analyze of the results of the experimental research upon a number of 100 charges of phosphorous cast iron brake shoes may be concluded the following:

≡ the chemical composition of iron used in the manufacture of the brake shoes ensure their hardness within the limits set by the standards.
≡ the correlation diagrams clearly results the influence of the content of Carbon (C), Manganese (Mn), Silicon (Si), Sulphur (S) and Phosphorous (P) on the hardness of the brake shoes;
≡ the level curves, obtained into the correlation diagrams allow us to choose the independent parameters (Carbon, Manganese, Silicon, Sulphur and Phosphorous) in such a way as to obtain a desired value of hardness.

For cast iron brake used in high speed train, we can improve the performance by increase the content of phosphorus as alloy element. Typically the alloy has a composition corresponding to conventional grey cast iron, except for the high phosphorus content.

CONCLUDING REMARKS

In cooperation with railway operators and brake system suppliers, the rail vehicle manufacturers develops on optimized friction surface combinations for cast iron shoes and steel wheels, while taking into consideration customer technical specifications, suitable for passenger trains and freight wagon applications.

Most railway companies have agreed that the procurement and operation of freight wagons with composite shoes is practically not more expensive than the procurement and operation of "traditional" wagons with cast iron shoes. The lifetime of composite shoes is much longer than the lifetime of cast iron brake shoes. However, the results of the first few years of operation show that not all problems have been solved yet. Further improvements and new patterns of maintenance seem to be necessary.

But,

While the composition and characteristics of all cast iron brake shoes are similar, the same is not true for composite brake shoes. Due to different compositions and processing methods adopted by different manufacturers, the composite brake shoes exhibit diverse friction characteristics (L-type which exhibit "low" friction coefficients and K-type which exhibit relatively "high" friction coefficients). In this sense, on manufacturing brake shoes meant for the rolling stock, the "traditional" phosphorous cast iron are largely used, due to the main advantages of cast iron brake shoes:

≡ a small friction coefficient affected by the environment and more stable, so it is „all-weather" operational;
≡ good thermal conductivity, low thermal damage to the wheels;
≡ durable, low prices.

So ordinary cast iron brake shoes are generally used for low-speed operation of passenger trains. For cast iron brake used in high speed train, we can improve the performance by increase the content of phosphorus or add some alloy element.

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