RESEARCH ON THE INFLUENCE OF CHEMICAL COMPOSITION ON THE HARDNESS OF CAST IRON

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The paper presents the research and its following results regarding the influence of chemical composition on the hardness of the cast iron used for manufacturing brake blocks for rolling stock. After processing the experimental data, the results have shown correlations between the elements found in the chemical composition and the main quality parameter for brake blocks, namely hardness. The resulting regression areas and level curves allow the identification of the optimal areas of variation in chemical composition of the cast iron for its technological range of hardness.

Keywords: phosphorous cast iron, hardness, brake block, quality.

1. Introduction

Cast iron properties are determined both by the nature of the metallic mass and by the quantity, shape and size of graphite segregation elements. The hardness and plasticity properties increase when the quantity and dimensions of the graphite segregation elements diminish and when their compactness grows [1].

An increase of the carbon and silicon content leads to a larger quantity of graphite, respectively a higher degree of cast iron graphitization. When carbon and silicon content grow, the traction strength and the hardness decrease, because the quantity of graphite and ferrite in the cast iron grows.

The growth of manganese content determines an increase of the traction strength, due to its action of pearlite formation, respectively an increase of hardness, its values being higher as the carbon saturation degree is lower.

A higher content of sulphur increases the hardness of the cast iron. Phosphorus reduces the solubility of carbon in the cast iron, which favors the graphitization process. Phosphorus is slightly soluble in the solidified cast iron, reason for which it is found almost entirely as phosphorous eutectic [2]. The

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amount of phosphorous eutectic is directly depending on the content of phosphorus. Phosphorous eutectic is distributed as isolated segregations, slightly elongated at one end or distributed in a continuous or discontinuous lattice at the limit of the primary structure grains. Phosphorus influences the mechanical properties of the cast iron by the structural modifications; it produces: graphite grain size reduction, the increase of the perlite ratio and the formation of the phosphorous eutectic. Phosphorous eutectic is hard (500-600HB) and brittle, with a significant influence upon the properties of the cast iron. The hardness is directly proportional to the content of phosphorus.

Brake blocks are made of phosphorous cast iron that is cast according to specifications approved by AFER [3]. Phosphorous cast iron is the grey pearlitic one with an increased concentration of phosphorus (0.25-1.5%), which grants the formation of the ternary phosphorous eutectic – the steadite - Fe_3C + Fe_3P + Fe-C-P, hard eutectic (650HB), brittle, having a low melting temperature (953°C). The structure resulting from perlite, graphite, ferrite and the phosphorous eutectic determines the wear resistance of the semi-finished part [4]. While braking, the superficial layer of the brake block can reach temperatures of 800 – 900^0C, temperatures at which some structural constituents can melt. On cooling down, structural modifications may arise, alongside with an increase of hardness [5]. By increasing the content of phosphorus in the cast iron, phosphorous eutectic is formed inside its structure.

This eutectic melts at the high temperatures resulted from braking and occupies the space created at the limit of austenite grains, which favors a better contact wheel – shoe and a higher friction coefficient, which increases the efficiency of braking. Brake blocks are made by the casting of second-fusion cast iron. The process of obtaining cast iron is performed according to the requirements provided by the supplier of brake blocks for motor and towed rolling stock, and also needs to follow the tender specifications no. 1/SFMR/SDT/2000 [7].

Phosphorous cast irons are frequently used in manufacturing brake blocks for rolling stock [8, 9]. It is required to determine the influence of different chemical elements found in the structure upon the hardness of the cast iron in order to avoid obtaining a phosphorous cast iron which would be too hard and which would prematurely wear the wheel dressing of the train. However, a too soft phosphorous cast iron would lead to increased consumption of brake blocks due to premature wear [9, 10].

2. Manufacturing Brake Blocks

In order to analyze the influence of chemical composition on the hardness quality characteristics of brake blocks, a number of 70 charges of cast iron have been observed in the industrial practice, which were produced by a company that manufactures cast iron parts. The brake blocks manufacturing process involves obtaining phosphorous cast iron and then casting it. Scrap, cast iron waste and worn brake blocks are used to obtain cast iron. The load at the charging points that were analyzed was: 10-20% first-fusion cast iron; 30-60% cast iron waste (worn brake blocks); 20-30% steel waste. The cutting-to-dimension of the load plays an important role in its production in induction furnaces, which means that the load needs to be cut according to the size and melting capacity of the furnace. The recharging of the furnace is done periodically, usually by bucket, ensuring a continuous melting process, with minimum energy consumption. When using small waste metal parts (chips, splinters), these are briquetted (pressed) or minced and a continuous line load is ensured. The cast iron thus obtained is poured into casts on the manual casting line [11].

The research has been done in order to determine the influence of the chemical composition of the cast iron on the hardness of brake blocks. The chemical composition, as well as the physical and mechanical characteristics have been analyzed. The quality control for brake blocks is done according to the tender specifications no.1/SFMR/SDT/2000 [3]. Hardness checking [3] is done at both ends and through the cross section, in three points, as shown in Fig. 1.

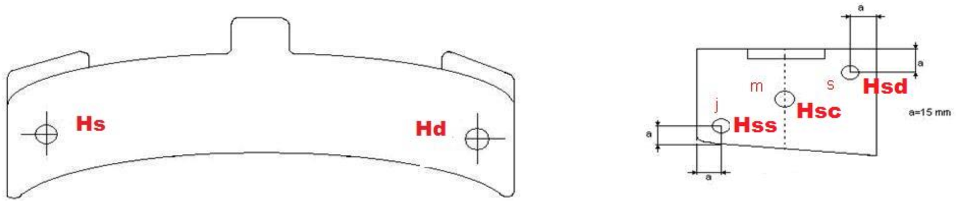


Fig. 1. Areas of brake blocks hardness sampling [3].

Also, for each charge, a mechanical shock resistance test is performed, and the metallographic structure is checked.

The resulting experimental data showing the influence of chemical composition on hardness has been processed in Matlab and the results are given both in analytical and graphical form. The processed data resulted in 2nd degree correlation equations between hardness (H_s, H_d, H_{ss}, H_{sc}, H_{sd} respectively the average for the block surface $(H_s+H_d)/2$ and for its cross section $(H_{ss}+H_{sc}+H_{sd})/3$ – dependent parameters) and the elements present in the chemical composition (P, Mn and Si – independent parameters) shown in Figs. 2 - 5.

3. Results

The resulting correlations are given in a graphical form only for the average obtained for the surface of the brake block and along its cross section.

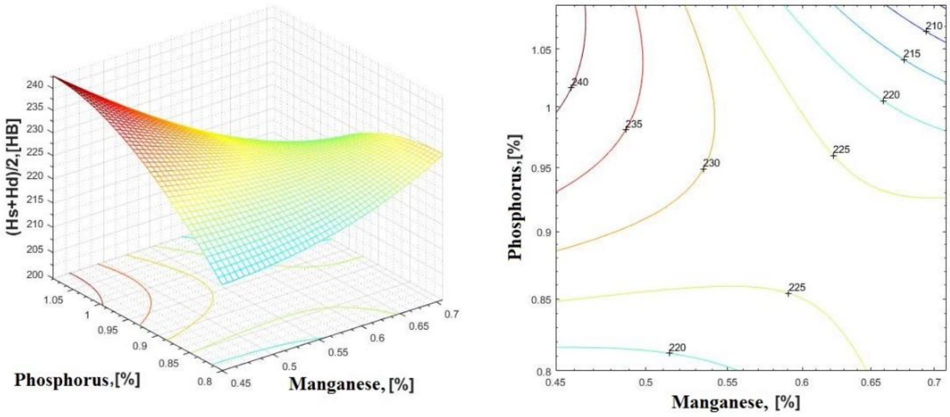


Fig. 2. $(H_s+H_d)/2 = f\ (Mn, P)$

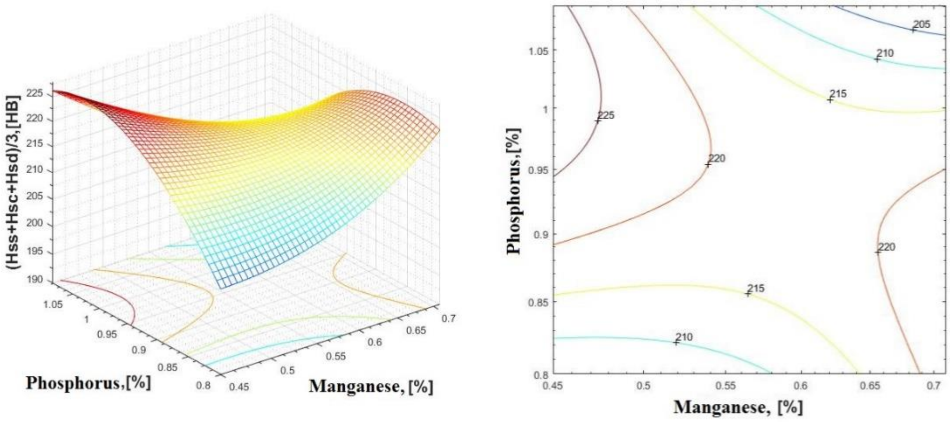


Fig. 3. $(H_{ss}+H_{sc}+H_{sd})/3 = f\ (Mn, P)$

Correlation equations for hardness variation depending on the content of manganese and phosphorus are:

$$\frac{H_s+H_d}{2} = 152.22 \cdot Mn^2 - 289.59 \cdot P^2 - 680.07 \cdot Mn \cdot P + 416.37 \cdot Mn + 958.78 \cdot P - 332.04 \quad (1)$$

Correlation coefficient: $R^2 = 0.50$.

Inflection point: $Mn = 0.62\%$; $P = 0.89\%$, $(HB_s+HB_d)/2 = 226.17$ HB.

$$\frac{H_{ss}+H_{sc}+H_{sd}}{3} = 0.24 \cdot Mn^2 - 0.44 \cdot P^2 - 0.57 \cdot Mn \cdot P + 0.25 \cdot Mn + 1.16 \cdot P - 0.39 \quad (2)$$

Correlation coefficient: $R^2 = 0.78$.

Inflection point: $Mn = 0.59\%$; $P = 0.92\%$, $(H_{ss}+H_{sc}+H_{sd})/3 = 218.57$ HB.

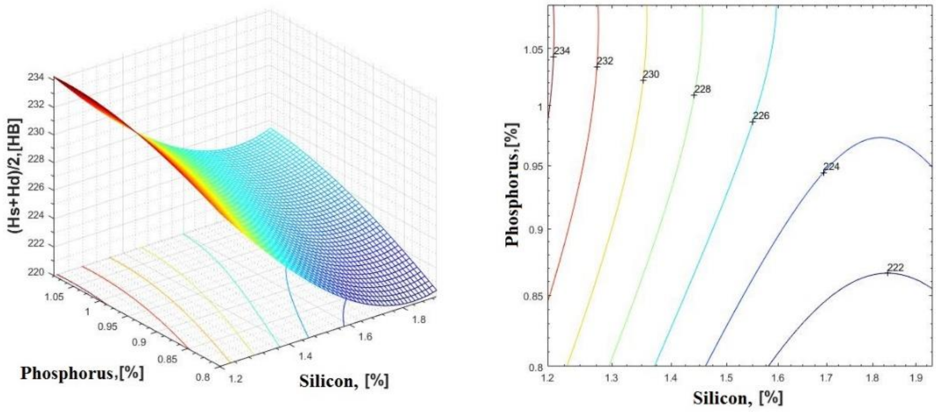


Fig. 4. $(H_s+H_d)/2 = f\ (Si, P)$

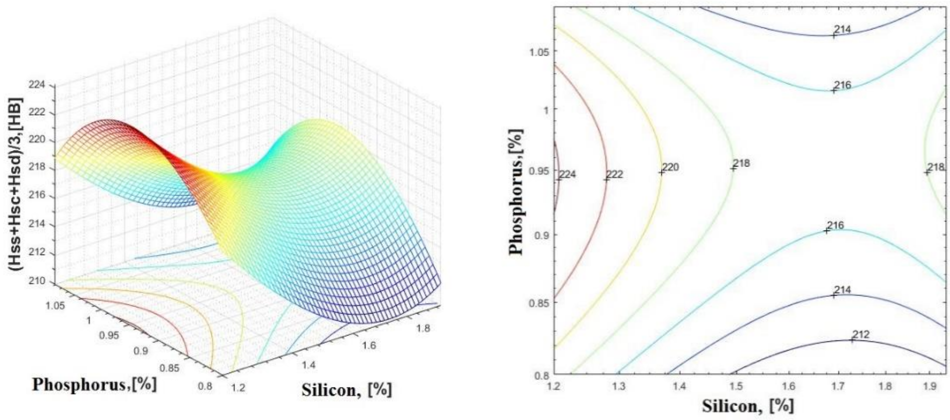


Fig. 5. $(H_{ss}+H_{sc}+H_{sd})/3 = f\ (Si, P)$

Correlation equations for hardness variation depending on the content of silicon and phosphorus are:

$$\frac{H_s+H_d}{2} = 25.96 \cdot Si^2 - 47.80 \cdot P^2 + 7.84 \cdot Si \cdot P - 102.01 \cdot Si + 92.38 \cdot P + 265.14 \qquad (3)$$

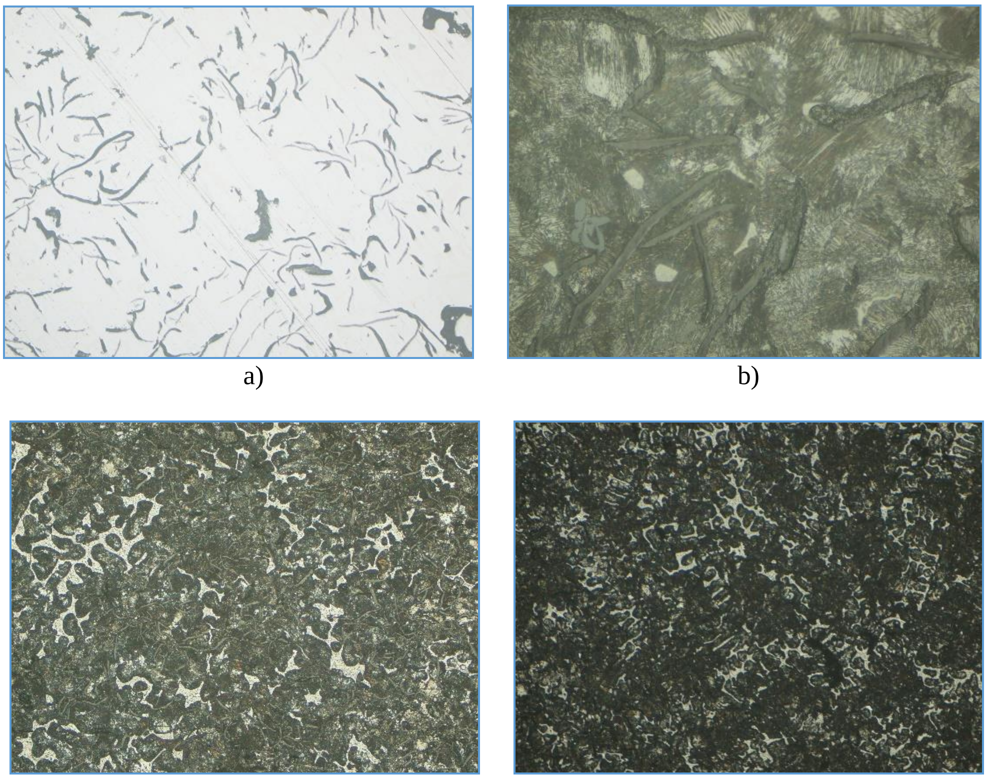
Correlation coefficient: $R^2 = 0.59$.
Inflection point: $Si = 1.79\%$; $P = 1.11\%$, $(HB_s+HB_d)/2 = 224.95$ HB.

$$\frac{H_{ss}+H_{sc}+H_{sd}}{3} = 30.49 \cdot Si^2 - 258.15 \cdot P^2 + 14.64 \cdot Si \cdot P - 117.23 \cdot Si + 470.61 \cdot P + 90.20 \qquad (4)$$

Correlation coefficient: $R^2 = 0.87$.
Inflection point: $Si = 1.69\%$; $P = 0.95\%$, $(H_{ss}+H_{sc}+H_{sd})/3 = 216.81$ HB.

After performing the analysis, the influence of different chemical elements found in the structure upon the cast iron hardness was determined, so as not to obtain a too hard phosphorous cast iron, which would prematurely wear the train wheel dressing. On the other hand, a too soft phosphorous cast iron would lead to increased consumption of brake blocks due to premature wear. The regression areas and level curves analyzed give the optimal variation levels for the elements found in the chemical composition of the cast iron, so that the hardness will only vary within technological ranges.

Samples were taken from each charge and submitted to spectral analysis in order to determine the chemical composition. The metallographic examination of the brake block cast iron is done according to specification SR EN ISO 945-1:2009 and chart UIC 832 and consists in analyzing four samples as follows: one sample (without chemical attack and a G magnification of 100x) for identifying the form of graphite segregations respectively their nature and the length of lamellar graphite segregations, one sample (with nital attack and a G magnification of at least 200x) for determining the perlite configuration, and two samples (with nital attack and a G magnification of 25x and 50x) for the base metallic mass and the phosphorous eutectic. Fig. 6 presents the microstructures of the analyzed samples.



a) b)

c) d)

Fig. 6. Microstructures of samples:
a) – graphite, no attack, 100X; b) – lamellar perlite, nital attack, 500X;
c) – base metallic mass, nital attack, 100X, d) – phosphorous eutectic, nital attack, 50X

The analysis of the microstructures reveals the existence of a lamellar graphite, while graphite segregations are isolated and uniformly distributed. The proportion of ferrite in the form of isolated clumps is under 5% of the sample's surface. The eutectic lattice is uniformly distributed.

The high phosphorus content improves the wear resistance of these cast irons, as steadite is formed in their structure. The structure made of perlite, graphite and phosphorous eutectic (steadite) determines a high wear resistance and fluidity. The properties of cast irons are given both by their metallic mass nature and by the quantity, shape and size of graphite segregations. Resistance and plasticity properties increase as the quantity and size of graphite segregations decrease and become compacted.

4. Conclusions

After the analysis of equations of double correlation, presented in analytical and graphical form, a number of conclusions can be drawn:

- the variation of independent parameters within technological limits determines a variation for the dependent parameter, also within technological limits, with the latter being situated on a regression area or next to it, taking into account dispersion, deviation and error;
- the graphical representations for second degree polynomial functions are surfaces that have as stationary point either an extreme point (of maximum or minimum), or an inflection point, their coordinates being found within technological limits of variation for independent parameters (chemical composition), respectively within the limits provided by the tender specifications for the dependent parameter (hardness);
- by intersecting the correlation areas with level planes (parallel to the horizontal plane) level curves were obtained, thus allowing setting the variation limits for the independent parameters in order to obtain a certain value for the dependent parameter. It was observed that there are higher variation limits for the independent parameters found near the stationary point when an inflection point exists;
- for each graphical representation, sub-domains can be identified, where it may be necessary to find the values for the dependent parameter, which determines, in fact, the variation limits for the independent parameters;
- as dependent parameter, hardness was taken into account (determined in two points on the brake block surface, and in three points in its cross section, respectively its average on both the surface and the cross section of the block), and as independent parameters, the chemical composition of the phosphorous cast iron from which the brake blocks are made, thus obtaining equations of double correlation;

- for all the obtained correlations, the R^2 coefficient has values of over 0.5, which indicates that these correlations are significant and represent well the connection between hardness and chemical composition;
- the correlations presented analytically and graphically show extreme points (points of minimum, points of maximum, respectively inflection points);
- for values of the hardness parameter found between 197 and 255 HB, the variation limits for the independent parameters are determined as follows: 0,6-0.75%Mn, 1.45-1.90%Si, 0.06-0.09%S, 0.80-0.95% P, and residual elements preferably under 0.2%.

Cast iron hardness increases with the rise in manganese content, which leads to reduced segregation of carbon, and prevents the action of sulfur, thus improving hardness and tear resistance. The rise in manganese content increases contraction, due to decreased graphitization, and also reduces the cast iron fluidity and its casting capacity. Consequently, the manganese content must be limited at values between 0.5-0.8%

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