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RESEARCH ON THE FACTORS INFLUENCING THE QUALITY OF PHOSPHOROUS CAST IRONS

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Abstract: This paper focuses on the influence of chemical composition upon the hardness mechanical characteristics of phosphorous cast irons. The casting of the parts is done by meeting specific chemical and mechanical parameters. Data collected from a cast iron foundry has been used for analysis, resulting in a series of graphic and analytical correlations created with the Matlab application. The resulting regression areas and level curves allow the identification of the optimal areas of variation in chemical composition of the cast irons with the purpose of obtaining an optimal hardness degree.
Keywords: phosphorous cast iron, hardness, brake block, quality

INTRODUCTION

When manufacturing brake blocks intended for rolling stock, phosphorous cast irons P10 are most widely used. These brake blocks have limited usage as their friction coefficient decreases notably when braking at high speed, and the wear caused by the tendency to jam increases as the temperature in the friction coupler rises [1,2].

The size of the eutectic particles and the distribution of the phosphide network in the structure, the shape, size and distribution of the graphite network, as well as the quantity of graphite expelled during graphical crystallization, all play an important part in the resulting quality of the cast iron used for producing brake blocks.

The chemical elements found in the structure of the cast iron from which brake blocks are made have a different influence on crystallization. The rise in manganese content favours cementitious crystallization. Manganese neutralises the harmful influence of sulphur by forming manganese sulphide, which leads to increased hardness and tear resistance. On the other hand, as the manganese content increases, the fluidity of the cast iron and its casting capacity decreases. A rise in silicon content favourises the graphical crystallization. By modifying the silicon content, the relation between carbon, bound as cementite (Fe_3C), and the free carbon found as graphite, changes. In industrial practice, the sum (C+Si) is taken into account, but it depends on the cast iron structure required and the thickness of the part shell. The silicon enhances cast iron fluidity, thus improving its casting properties [3,4].

The sulphur and the iron form iron sulphide (FeS) which, upon solidification, forms with the iron an easily fusible eutectic (Fe–FeS) that melts at 950^0 C. This eutectic has a delayed solidification, thus favouring the production of intercrystalline segregations which lead to decreased mechanical properties of cast irons. This effect is a consequence of the redistribution of alloying elements in between the liquid and solid phases during the primary structure formation. The micro–segregation occurs as a consequence of mass shift by short distance diffusion [5,6]. The sulphur also prevents graphitization, favouring the formation of cementite, leading to increased hardness and fragility, increased contraction, decreased fluidity and a higher tendency to form cracks in the cast iron.

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].

Types of brake blocks for engines and freight/ passenger wagons (figure 1) [8]:

- S_1 – brake blocks size 1 for freight/ passenger wagons;
- S_2 – brake blocks size 2 for freight wagons;
- LDH – brake blocks for 1250 HP Diesel hydraulic engines;
- LDE – brake blocks for 2100 HP Diesel electric engines;
- LE – brake blocks for 5100 kW and 3400 kW electric engines.

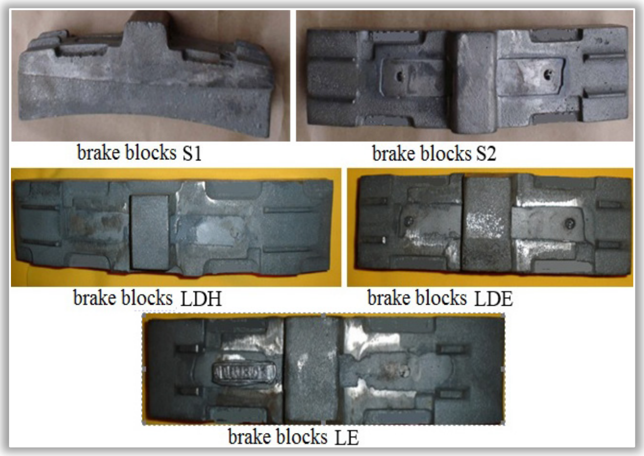


Figure 1. Types of brake blocks for engines and freight/ passenger wagons [8]

Phosphorous cast irons are frequently used in manufacturing brake blocks for rolling stock [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].

DESCRIPTION OF MANUFACTURING AND CONTROL PROCESSES

— Manufacturing Brake Blocks

In order to analyse 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 analysed 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 a 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, as shown in figure 2.

Figure 2. Manual brake blocks casting line [4]

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 analysed.

— Brake Blocks Control

The quality control for brake blocks is done according to the tender specifications no.1/SFMR/SDT/2000 [3]. The first parameters checked are the percentages of chemical elements found in the cast iron. For this check, samples from the melting pot are taken and checked with a spectrometer (figure 3).

Figure 3: Determining the chemical composition of analysed samples [4]

Hardness checking [3] is done at both ends and through the cross section, in three points, as shown in figure 4.

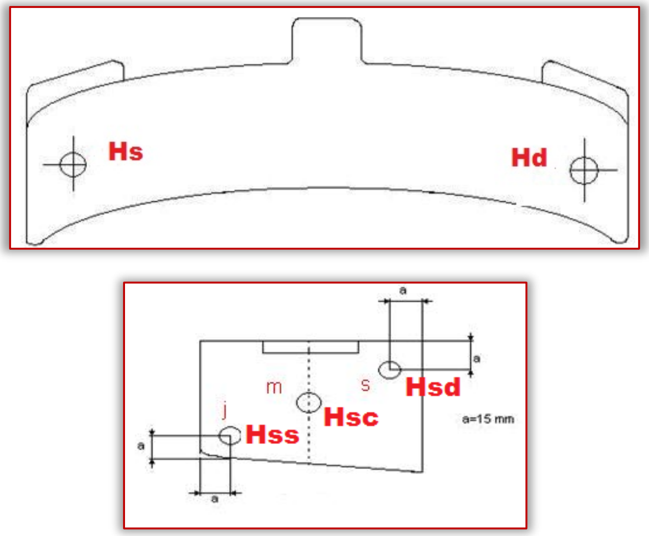


Figure 4. Areas of brake blocks hardness sampling [3].

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

SOLUTIONS AND APPROACHES

The data obtained from industrial practice has been processed through Matlab and Excel software. Charts of variation in hardness by carbon, manganese, phosphorus and silicon have been created for all points in which hardness was measured. By calculating an average, charts of variation in average hardness for the outside and cross section of the part have been created. These charts have been done using Microsoft Excel and have been represented using second degree polynomial functions. Then, using Matlab and a second degree equation, three–dimensional charts with regression areas and level curves for hardness variation by combination of two chemical elements have been created for analysis, for all the points. The equation is as follows:

$$z = a(1)\cdot x^2 + a(2)\cdot y^2 + a(3)\cdot xy + a(4)\cdot x + a(5)\cdot y + a(6) \quad (1)$$

RESULTS

The following correlations obtained for the average hardness in the cross section of the brake block are presented here as example – $H_{sm} = (H_{ss}+H_{sc}+H_{sd})/3$.

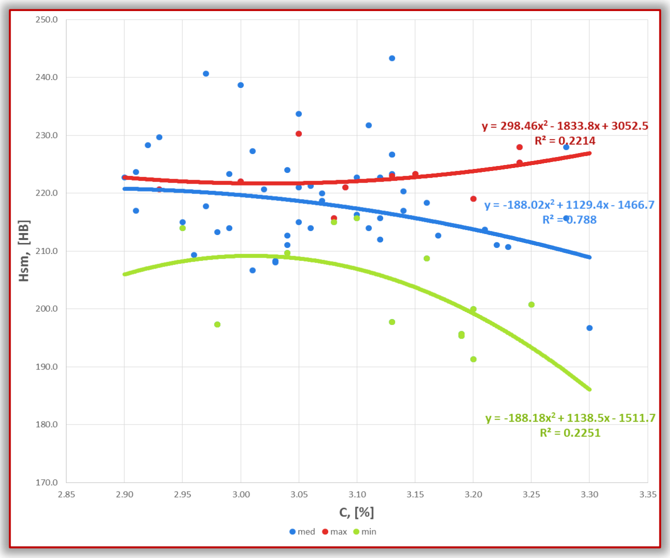


Figure 5. The variation of average hardness in the cross section by carbon percentage

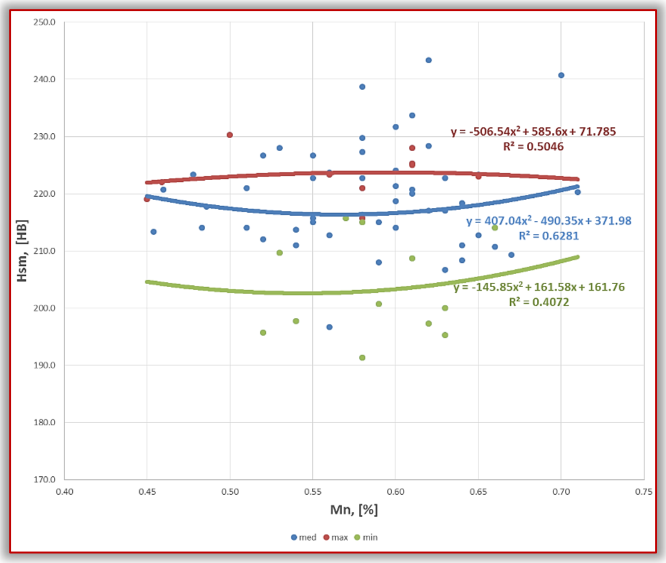


Figure 6: The variation of average hardness in the cross section by manganese percentage

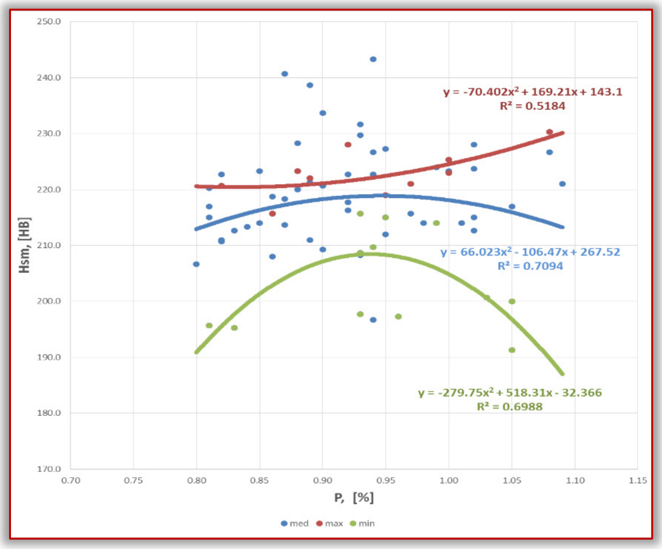


Figure 7: The variation of average hardness in the cross section by phosphorus percentage

Figures 5–7 show the variation in average hardness calculated for the three cross section measurements by carbon, manganese and phosphorus percentages.

Figures 8–9 show the regression areas and level curves for average hardness variation in the cross section by carbon, manganese and phosphorus content.

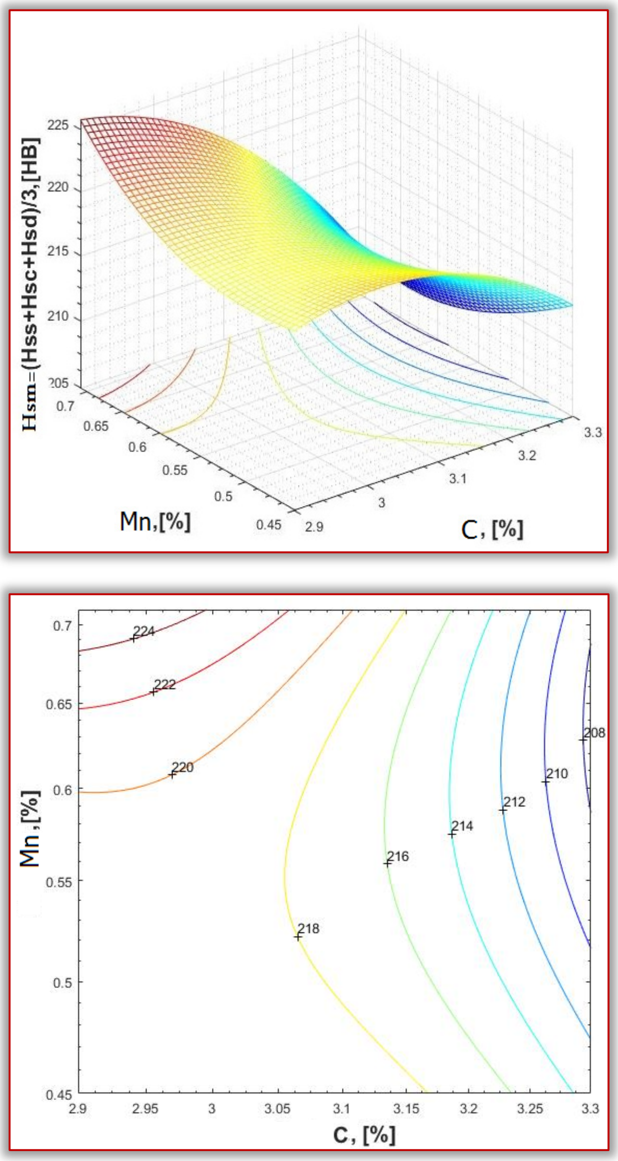


Figure 8: $H_{sm} = f(C, Mn)$

In case of the average hardness variation in the cross section by carbon and manganese content, the equation becomes:

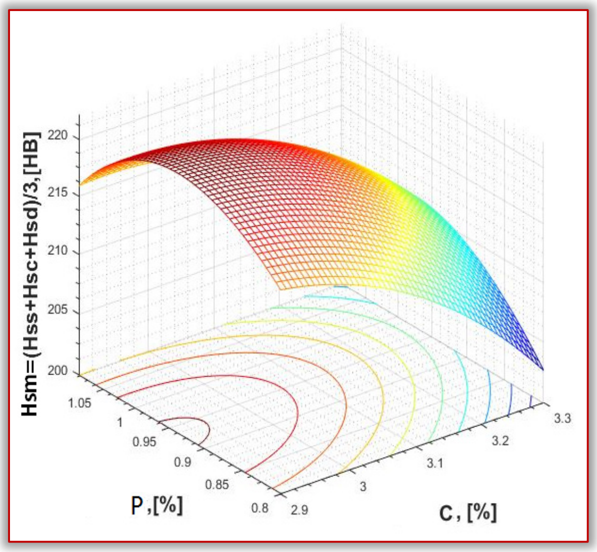
$$H_{sm} = -80.75 \cdot C^2 + 165.42 \cdot Mn^2 - 115.06 \cdot C \cdot Mn + 539.02 \cdot C + 168.92 \cdot Mn - 624.68 \qquad (2)$$

The correlation coefficient is R^2=0.2912 and the coordinates of the inflection point are: H_{sm} = 218.7914 HB; C = 2.9663%; Mn = 0.5210%.

In case of the average hardness variation in the cross section by carbon and phosphorus content, the equation becomes:

$$H_{sm} = -67.20 \cdot C^2 - 267.72 \cdot P^2 + 52.48 \cdot C \cdot P + 338.15 \cdot C + 349.21 \cdot P - 427.99 \qquad (3)$$

The correlation coefficient is R^2 = 0.3294 and the calculation reveals a point of local maximum for the following values: H_{sm} = 222.2430; C = 2.8807%; P = 0.9345%.



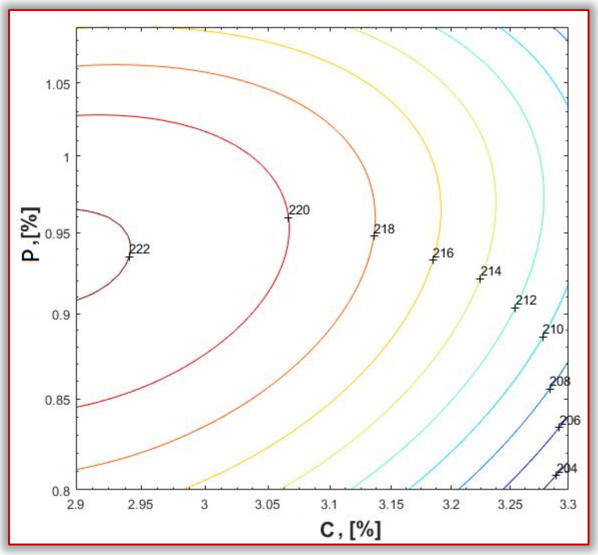


Figure 9: $H_{sm} = f(C, P)$

CONCLUSIONS

The rise in carbon concentration leads to negative outcomes due to graphitization increase and a decrease in tear resistance. The increase in hardness with manganese content addition is translated using a second degree polynomial equation. As the manganese content rises, so do the complex carbides proportions, and a dissolution of iron in the solid solution takes place (ferrite).

The phosphorus contributes to the formation of a phosphorous eutectic. The increase in phosphorus content leads to increased hardness, both at the surface and in the cross section of the brake block.

After analysing the results of the experimental research performed on a number of 70 phosphorous cast iron charges produced in a brake block foundry, the following conclusions can be drawn:

- the chemical composition of the cast iron used in manufacturing brake blocks ensures the necessary hardness to comply with standards;
- the correlations presented above reveal a clear influence of carbon and manganese content upon hardness;
- there is a difference in hardness between the brake block cross section extremities and its cross section centre, due to solidifying conditions;
- the level curves presented in the charts allow choosing independent parameters (C, Mn and P) so as to obtain a desired hardness value.

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