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Original scientific paper

CAST IRON ROLLS – AN OVERVIEW ON THE PROPER HARDNESS ASSURED BY THE MANUFACTURING PROCESS

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Abstract: The manufacturing process of the rolling rolls, as well as the quality of materials used in casting them, can have an important influence upon the quality and the safety of the exploitation. Our approaches to the issue of quality assurance of the rolling rolls, from the viewpoint of the quality of materials that are featured, can cause duration and safety in the rolling exploitation. This research is required because of the numerous flaws that cause rejection, since the phase of melting of these irons is intended to cast rolls. According to the industrial analysis in the cast iron rolls foundries, the results show that one of the main rejection categories is due to the inadequate hardness of the rolls. One of the parameters that will determine the cast iron's structure is the chemical composition, and this factor could assure the exploitation properties of each roll in all the stands of rolling mill. In this sense, the paper presents an overview of industrial and laboratory research regarding the assurance of the chemical composition of the irons (with nodular graphite) destined for the half–hard rolls casting, and tries to draw some remarks upon the proper correlations of these irons. This study analyses iron rolls cast in combined moulds (iron chill, for the barrel and moulding sand, for the necks of rolls) and includes charges of rolls from half–hard classes, with definite structure and nodular graphite, obtained in simplex cast processes. It presents, in graphical form, the influence of the chemical composition of these irons on the hardness, measured on the barrel. The proper solution is determined through some mathematical restrictions to the input data that the mathematical modelling is initiated with. It will be determined through regression equations, which describe the mathematical dependency between the hardness and the elements of chemical composition – the basic elements (Carbon [C], Manganese [Mn] and Silicon [Si]), the particulate elements (Sulphur [S], Phosphorus [P] and Magnesium [Mg]) and the main alloying elements (Nickel [Ni], Molybdenum [Mo] and Chrome [Cr]). The main results and the graphical addenda are presented.

Keywords: cast iron rolls; chemical composition; hardness; half-hard class; regression surfaces; modelling

1 INTRODUCTIVE NOTES

In the process of rolls casting, in spite of the most accurate guidance of the technological phases, the performance factor remains relatively low [1, 2]. The requirements, which are imposed to the cast iron rolls in service, are very different and often contradictory [1–6]. The rolls must have adequate mechanical resistance and high working temperature stability. Also, they must present a relative lower hardness in the core and on the necks, and a higher hardness on the roll's barrel (surface). [1, 2]

To assure these properties, in the core of rolls the structure of irons must contain graphite, whereas the barrel's hardness is guaranteed by the quantity of cementite [1, 2]. This peculiar structure will assure roll's good resistance at the thermal fatigue, the high wear resistance in dried friction conditions as well as the stability at unexpected temperature variations in the steels rolling process [1–10]. Overall, the rolls must present high service requirements, which are the peculiar hardness, the higher resistance in the various thermal and wear regimes, and stability at the high working temperature [1–6]. Also, the rolls must assure the steels clamping in the rolling process, as well as the high surface quality of the various rolled by–products [1–10].

In this sense, obtaining the various properties in different points of the same foundry product – i.e. cast iron rolls – meets difficult technological problems in manufacturing (in different process phases like iron melting, alloying, modification treatment of the graphite, moulding and mould's drying, casting, cooling and solidification in the combined moulds), which supposes to consider many technological factors [1, 2, 5, 6]. One of the main parameters that will determine the cast iron's peculiar structure is the chemical composition, which must assure the service requirements of each cast roll [1, 2].

First of all, the roll's barrel hardness achievement, fixed strictly by the requirements for each roll's type, is conditioned by the irons peculiar structure's achievement, which contains pearlite, cementite and nodular graphite. The macrostructure is not imposed by requirements (except for the nodular graphite irons, where a spherical shape of the graphite is strictly required), conditioned by the adequate quantities of cementite in the barrel, respectively the adequate quantities of graphite in core and on necks [1–6]. As a result of the spheroidal form of the graphite, the gradual fall in hardness is an added advantage of these types of rolls being much stronger than he clear–chill type rolls [1, 2]. They are used in conditions in which the first essential requirement is the toughness, rather than the resistance at wear, e.g. rolls for heavily loaded roughing stands. [1, 2, 10]

Overall, not respecting the chemical composition, the rolls will be rejected [1, 2]. An important group of defects, which lead to rolls rejection (approximately 9–10% of total rejection in foundries), consists of inadequate depths of the hard barrel. These technological defects may consist of insufficient or excessive thickness of the rolls barrel (i.e. on the rolling surface). [1, 2, 4]

The uneven thickness on the barrel's height leads to rejection, too [1, 2]. In other 5–6% of the situations, the rejection is caused by structural defects [1, 2]. Avoiding these in rolls casting is an extremely complex task, which requires an adequate consideration of manufacturing, especially the accurate guidance of rolls melting–alloying processes, close to the preparation of the combined chill for casting. [1, 2]

2 METHODOLOGY & TECHNICAL AREA

The iron rolls cast in the simplex procedure, in combined moulds (iron chill, for the barrel and moulding sand, for the necks of the rolls) are studied. [1, 2, 4]

The study included rolls from the half–hard classes (0, 1 and 2 classes), which required hardness between 33–59 Shore (219–347 Brinell) and 59–75 Shore (347–550 Brinell) for the hardest class [1, 2]. The required hardness is presented in Tab. 1. [1, 2, 4]

Table 1 The Required Hardness of the Half–Hard Cast Iron Rolls

Roll's Type	Class of Hardness	Required Rolls Hardness			
		on Barrel (Surface)		in Core / on Neck's	
		[Shore Hardness]	[Brinell Hardness]	[Shore Hardness]	[Brinell Hardness]
FNS	0	33–42	218–286	30–40	195–271
FNS	1	43–59	294–347	30–40	195–271
FS	2	59–68	420–491	35–45	218–309
FNS	2	69–75	499–550	35–45	218–309

Table 2 The Required Chemical Composition of the Half–Hard Cast Iron Rolls

Roll's Type	The Chemical Composition, (%)								
	C	Si	Mn	P	S	Ni	Cr	Mo	Mg
FS	2.9–3.6	0.3–1.2	max 0.6	max 0.15	max 0.1	max 0.6	max 0,5	0.3–0.5	–
FNS	3.0–3.5	1.2–2.5	0.1–0.7	max 0.15	max 0.02	1.5–2.5	max 0.8	0.3–0.5	0.02–0.04

The recommended chemical compositions for the half–hard class rolls, cast from lamellar graphite iron (type FS) and nodular graphite iron (type FNS) in Tab. 2 are presented. [1, 2] The rolls' chemical composition includes the basic elements ([C], [Si], [Mn], [S] and [P]), the alloying elements ([Cr], [Ni] and [Mo]), as well as the Magnesium [Mg] content (in the case of nodular irons). [1, 2, 4] In special cases, these irons can contain up to 0.15–0.2% Vanadium [V] [1, 2]. Also, in the case of irons with nodular graphite, destined to casting rolls (type FNS), is accepted a higher content of Phosphorus [P], because this participates at the roll's surface hardening [1,2].

The research includes half–hard cast rolls from nodular graphite irons (type FNS), hardness class 1 and 2, with the half–hard barrel of 40–150 mm depth [1, 2]. The lot of analysed rolls is representative for the half–hard category as the chemical composition and the measured hardness of that is presented in Tab. 3 [1,2]. The hardness checking (on the two necks, respectively on barrel), is done in equidistant points, according to the standard stipulation.

The value of the equivalent Carbon [C_{ech}], calculated by the formula (I), is recommended to be maximum 4.3%, for cast iron rolls. Also, for this value's calculation, the formula (II) is accepted, too. [1, 2]

$$[C]_{ech} = [C] + 0.3\left([Si] + [P]\right) - 0,03[Mn] + + 0.4[S] + 0.07[Ni] + 0.05[Cr]\ (\%) \quad (I)$$

$$[C]_{ech} = [C] + 0.33[Si] + 0.1[Ni]\ (\%) \quad (II)$$

Table 3 The Chemical Composition and the Measured Hardness of the Half–Hard Cast Iron Rolls

Chemical Composition, (%)	
Carbon [C]	3.22–3.42
Silicon [Si]	1.72–2.19
Manganese [Mn]	0.62–0.79
Phosphorus [P]	0.130–0.165
Sulphur [S]	0.011–0.024
Nickel [Ni]	1.49–2.22
Chrome [Cr]	0.36–0.72
Molybdenum [Mo]	0.18–0.28
Magnesium [Mg]	0.021–0.029
Equivalent Carbon value, (%)	
Equivalent Carbon [C_{ech}]	3.952–4.219
Hardness, [Brinell units]	
on the Necks	219–276
on the Barrel	282–352

We applied the mathematical modelling [1, 2, 7] taking into consideration the industrial data obtained from the rolls industry, as well as the cast iron roll's requirements. Using the mathematical correlations (double and triple) is really helpful in the rolls manufacturing. Basically, it allows us to determine the chemical composition variation boundaries, in view the obtaining a proper rolls hardness [1–6, 9].

Therefore, we suggest a mathematical approach on influence of the basic elements (Carbon [C], Manganese [Mn] and Silicon [Si]), the particulate elements (Sulphur [S], Phosphorus [P] and Magnesium [Mg]) and the main alloy elements (Nickel [Ni], Molybdenum [Mo] and Chrome [Cr]) over the hardness on the rolls rolling surface.

Finally, we determine mathematically the equations of the hyper surfaces in the 3 and 4 dimensional space, the average values and average square aberrations (presented in Tabs. 4–6). [1, 2]

Table 4 The variable's limits of variation, the average values and the variable's deviation from the average values. Case of the Carbon [C], Silicon [Si] and Manganese [Mn] contents

The variables	Limits of variation	Average values	Variable's deviation
Carbon [C], (%)	3.14–3.52	3.2861	0.0852
Silicon [Si], (%)	1.48–1.92	1.7191	0.1303
Manganese [Mn], (%)	0.42–0.73	0.5683	0.0755
Hardness on barrel, $[HB]_{barrel}$	355–486	421.2211	36.8652

Table 5 The variable's limits of variation, the average values and the variable's deviation from the average values. Case of the Phosphorus [P], Sulphur [S] and Magnesium [Mg] contents

The variables	Limits of variation	Average values	Variable's deviation
Phosphorus [P], (%)	0.106–0.141	0.1199	0.0075
Sulphur [S], (%)	0.008–0.032	0.0191	0.0063
Magnesium [Mg], (%)	0.021–0.031	0.0255	0.0029
Hardness on barrel, $[HB]_{barrel}$	355–486	421.2211	36.8652

Table 6 The variable's limits of variation, the average values and the variable's deviation from the average values. Case of the Chrome [Cr], Nickel [Ni] and Molybdenum [Mo] contents

The variables	Limits of variation	Average values	Variable's deviation
Chrome [Cr], (%)	0.30–0.97	0.4978	0.1314
Nickel [Ni], (%)	0.81–2.68	1.3535	0.4779
Molybdenum [Mo], (%)	0.18–0.71	0.3722	0.1502
Hardness on barrel, $[HB]_{barrel}$	355–486	421.2211	36.8652

By processing the data obtained in foundry practice, we obtained equations of correlation between the chemical composition of the rolling rolls iron and the hardness distribution on the roll's barrel [1, 2, 7]. The main results and the graphical addenda are presented below, in synthesis.

3 RESULTS & GRAPHICAL ADDENDA

3.1 Correlation between the Basic Elements

The main basic element of the iron composition is Carbon [C]. In the case of the half–hard iron rolls, this varies between 3.0–3.5% that assures the recommended 220–420 Brinell hardness (on the barrel) and 220–300 Brinell hardness (in core and on the necks) [1,2]. After the melting period, the Carbon [C] content fits in the established values (3.22–3.42%), while the hardness, measured on the different points of roll's barrel, is between 222–352 Brinell [1,2].

The Silicon [Si] has influence upon the refinement of graphite, being one of the elements that have graphitising effect and favours the presence of graphite in the core. The Silicon [Si] percentage is in close dependence with the content of Carbon [C]. Their action is similar, but the separate effect of each of them is stronger when one of the elements is in a smaller or a larger proportion accordingly. With the growth of Silicon [Si] and Carbon [C] content, it will increase the graphite's quantity, and therefore the half–hard barrel's thickness is narrowed.

The analyses showed that the Silicon [Si] varied between 1.64–2.19%, which is technically accepted (1.2–2.5% being the limits stipulated by these rolls requirements). Following the data, we can remark the hardness diminution with the growth of Silicon [Si] content, the general variation being similar to a Carbon [C] variation.

At a lower limit of Manganese [Mn] content, this element has a strong anti–graphitising effect. Above the 0.7% Manganese [Mn] content, carbides are stabilised and the hardness is increasing. We also know, above 1.0% Manganese [Mn] content, this element acts like an alloying element, stabilises the cementite, and implicitly hardens the irons [1, 2].

$$\begin{aligned}[HB]_{(barrel)} &= 638.14[C]^2 - 241.48[Si]^2 + 1975.15[Mn]^2 - \\ &- 687.68[C]\cdot[Si] + 310.44[Si]\cdot[Mn] + 142.35[Mn]\cdot[C] + \\ &+ 3363.00 - 2995.15[C] + 3009.10[Si] - 3135.56[Mn]\end{aligned} \quad (1)$$

The correlation coefficient of Eq. (1) is $rf = 0.7667$ and the deviation from the regression surface is $sf = 32.5612$.

3.2 Correlation between the Particulate Elements

Having an unfavourable effect upon the mechanical properties, the Sulphur [S] content is recommended to be in minimal quantities. The hardness as well as the strength decrease while the Sulphur [S] content grows. Also, the Sulphur [S] affects the graphite nodularity, so there is a need to reduce it to the minimum, strictly restricted to be at maximum 0.02%. Above this value, the Sulphur [S] has a negative value upon the mechanical properties.

In the case of half–hard rolls, the Phosphorus [P] content is limited to a maximum of 0.2–0.3% [1, 2]. Since this chemical element shapes tough compounds, which are needed in the rolling surface, Phosphorus [P] does not have an effect, if limited in this interval. The increase of hardness can be observed, together with growth of the Phosphorus [P] percentage.

Magnesium [Mg] plays a special part, as it is the element with which the ladle inoculation has been made. The graphite's nodularity assures the higher mechanical properties, by eliminating several inconveniences found at the rolls cast from irons with lamellar graphite. [1, 2]

$$\begin{aligned}[HB]_{(barrel)} &= -331.55[S]^2 + 883.11[P]^2 + 188.87[Mg]^2 + \\ &+ 469.14[S]\cdot[P] - 793.68[P]\cdot[Mg] - 774.06[Mg]\cdot[S] - \\ &- 236.72[S] - 10470.29[P] + 173.81[Mg] + 1028.50\end{aligned} \quad (2)$$

The correlation coefficient of Eq. (2) is $rf = 0.7471$ and the deviation from the regression surface is $sf = 24.5054$.

3.3 Correlation between the Alloying Elements

The irons intended for these cast rolls are alloyed especially with Nickel [Ni], Molybdenum [Mo] and Chrome [Cr], in reduced contents, being low alloyed irons [1,2].

The requirements firmly state the elements required to rise the rolls quality, the contents of these elements being between large limits. Also, the contents of these alloying elements can be reduced due to the strong effect of the Magnesium [Mg] from the nodulising agent, upon the structure and the graphite's form.

The Nickel [Ni] addition leads to the improvement of the mechanical properties. If we do not allow this element to increase the graphitisation degrees and the white solidification in the barrel, this content can be considerably reduced. Accordingly, the Silicon [Si] content can be varied, as this element replaces Nickel [Ni].

In the case of the half–hard cast iron rolls, the Chrome [Cr] has a less important influence than in the case of hard and extra–hard rolls, as in their case the Chrome [Cr] proves to be the most efficient alloying element to regulate the crust depth. The half–hard rolls have Chrome [Cr] content, which is preserved at low limits (a maximum of 0.6%), although this content still assures the necessary hardness on the barrel. An increase of the hardness is to notice, together with a growth of the Chrome [Cr] content.

Also, Chrome [Cr] content is in close accordance with the Nickel [Ni] content, to favour the formation of the perlitical structure, without the massive and rough carbides. Both are added simultaneously, because the addition of Chrome [Cr] compensates the graphitising effect of the Nickel [Ni]. The proportion between Nickel [Ni] and Chrome [Cr] is situated in a 2–4 value of ratio.

Molybdenum [Mo] is a carburigenous element, but this effect is relevant only at percentage above 0.6%. Below this value, fine structures are obtained, also an increase of the mechanical properties (especially the high temperature stabilities). In these irons, contents beyond a percentage of 0.15 % Molybdenum [Mo], are not recommended, because a part of Molybdenum [Mo] is lost through the combination with Phosphorus [P], therefore Molybdenum [Mo] losing a part of its alloying behaviour.

In the case of half–hard rolls, the content of Molybdenum [Mo] does not pass this limit, and is imposed to 0.1–0.3%. The analyses showed that the Molybdenum [Mo] content varies between 0.18–0.28%. Although the marks seem dispersed, it is easy to notice the growth of hardness as the content of Molybdenum [Mo] increases in this interval.

$$\begin{aligned}[HB]_{(barrel)} &= 63.55[Ni]^2 + 660.05[Mo]^2 - 449.63[Cr]^2 - \\ &- 84.71[Ni]\cdot[Mo] + 177.74[Mo]\cdot[Cr] - 253.52[Cr]\cdot[Ni] - \\ &- 13.60[Ni] - 291.23[Mo] + 817.36[Cr] + 260.62\end{aligned} \quad (3)$$

The correlation coefficient of Eq. (2) is $rf = 0.7066$ and the deviation from the regression surface is $sf = 26.0834$.

3.4 Drawing the Correlation Diagrams

Since the surfaces (described by equation 1–3) cannot be represented in a 3–dimensional space, the independent variables were successively replaced with their average values (Tabs. 4–6) and by mathematical restrictions to the input values, the proper solution is determined. Is searched to constraint average values, inclusively to dependent variables, desired to achieve through the proper chemical composition.

Starting from the Eq. (1) and the average values from Tab. 4, we obtain the following double correlations:

$$\begin{aligned}[HB]_{(barrel)}[C]_{med} &= -241.49[Si]^2 + 1975.15[Mn]^2 + \\ &+ 310.44[Si]\cdot[Mn] + 749.31[Si] - 2667.77[Mn] + 411.57\end{aligned} \quad (4a)$$

$$\begin{aligned}[HB]_{(barrel)}[Si]_{med} &= 1975.15[Mn]^2 + 638.14[C]^2 + \\ &+ 142.35[Mn]\cdot[C] - 2601.87[Mn] - 4177.37[C] + 7822.34\end{aligned} \quad (4b)$$

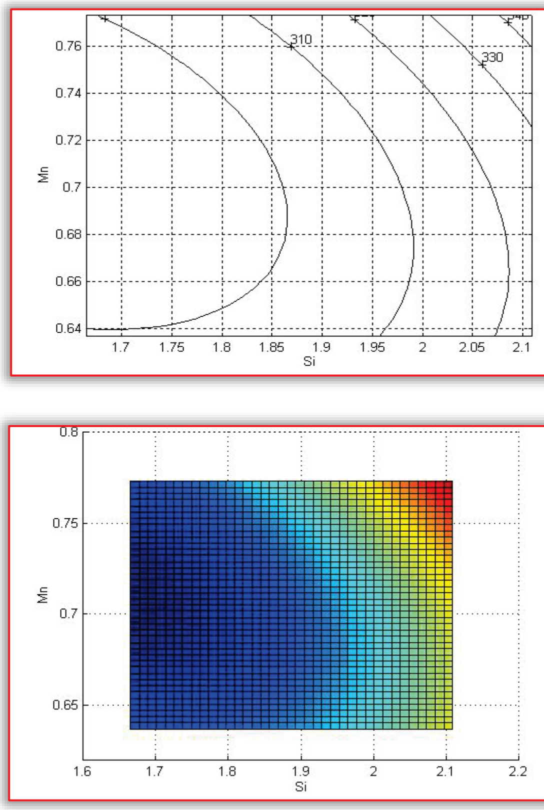
$$\begin{aligned}[HB]_{(barrel)}[Mn]_{med} &= 638.14[C]^2 - 241.48[Si]^2 - \\ &- 687.68[C]\cdot[Si] - 2914.25[C] - 3185.51[Si] - 2219.00\end{aligned} \quad (4c)$$

Starting from the Eq. (2) and the average values from Tab. 5, we obtain the following double correlations:

$$\begin{aligned}[HB]_{(barrel)}[S]_{med} &= 883.11[P]^2 + 188.87[Mg]^2 - \\ &- 793.69[P]\cdot[Mg] - 1529.54[P] + 2648.74[Mg] + 458.36\end{aligned} \quad (5a)$$

$$\begin{aligned}[HB]_{(barrel)}[P]_{med} &= 188.87[Mg]^2 - 331.55[S]^2 - \\ &- 774.06[Mg]\cdot[S] - 777.41[Mg] + 326.38[S] + 1042.66\end{aligned} \quad (5b)$$

$$\begin{aligned}[HB]_{(barrel)}[Mg]_{med} &= -331.55[S]^2 + 883.11[P]^2 + \\ &+ 469.14[S]\cdot[P] - 434.77[S] - 307.22[P] + 2707.26\end{aligned} \quad (5c)$$



a)

b)

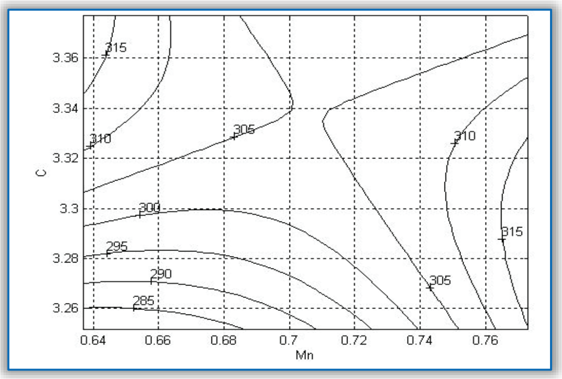
Figure 1 The Hardness [HB] dependence with the Carbon [C], Silicon [Si] and Manganese [Mn] contents at the Half–hard Cast Iron Rolls. Case of Carbon [C] at the calculated average value: $[HB]_{barrel}(C_{med}, Si, Mn)$

Starting from the Eq. (3) and the average values from Tab. 6, we obtain the following double correlations:

$$\begin{aligned}[HB]_{(barrel)}[Ni]_{med} &= -449.63[Cr]^2 + 660.05[Mo]^2 + \\ &+ 177.74[Mo]\cdot[Cr] + 474.22[Cr] - 541.23[Mo] + 358.69\end{aligned} \quad (6a)$$

$$\begin{aligned}[HB]_{(barrel)}[Cr]_{med} &= 660.05[Mo]^2 + 63.55[Ni]^2 - \\ &- 184.71[Ni]\cdot[Mo] - 202.75[Mo] - 139.81[Ni] + 556.09\end{aligned} \quad (6b)$$

$$\begin{aligned}[HB]_{(barrel)}[Mo]_{med} &= 63.55[Ni]^2 - 449.63[Cr]^2 - \\ &- 253.52[Cr]\cdot[Ni] - 82.34[Ni] + 883.51[Cr] + 243.66\end{aligned} \quad (6c)$$



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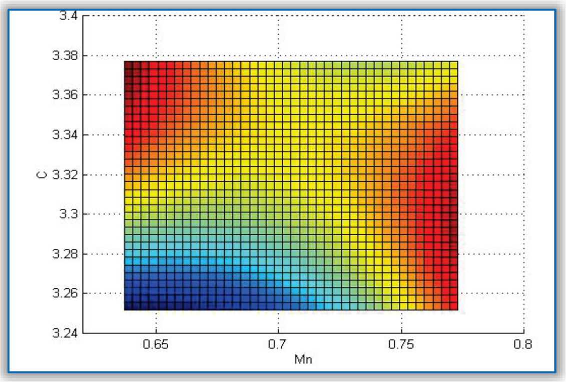

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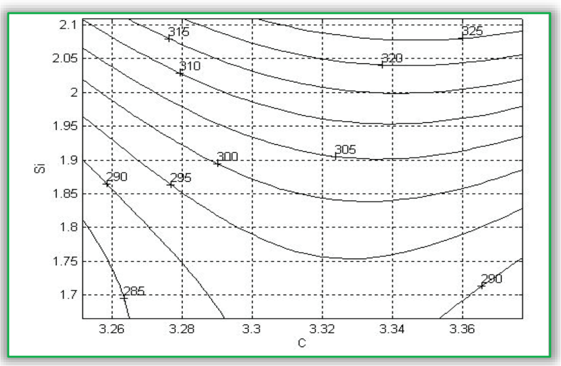
Figure 2. The Hardness [HB] dependence with the Carbon [C], Silicon [Si] and Manganese [Mn] contents at the Half–hard Cast Iron Rolls. Case of Silicon [Si] at the calculated average value: $[HB]_{barrel}(C, Si_{med}, Mn)$



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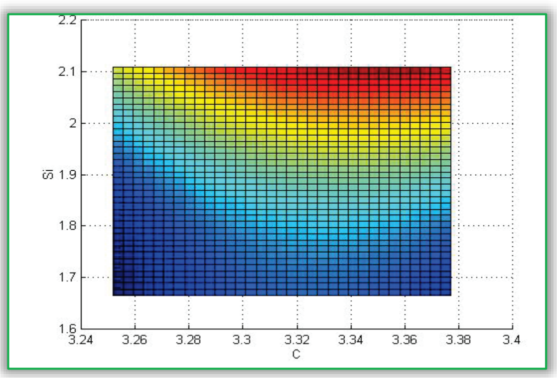

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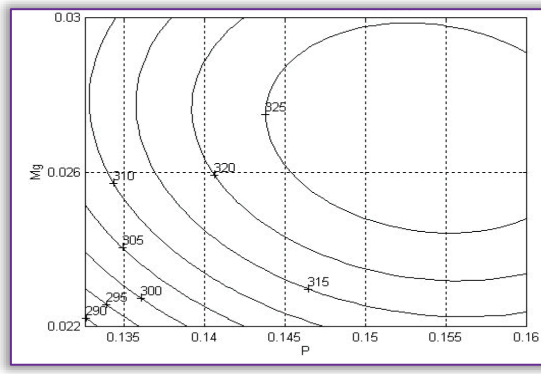
Figure 3. The Hardness [HB] dependence with the Carbon [C], Silicon [Si] and Manganese [Mn] contents at the Half–hard Cast Iron Rolls. Case of Manganese [Mn] at the calculated average value: $[HB]_{barrel}(C, Si, Mn_{med})$



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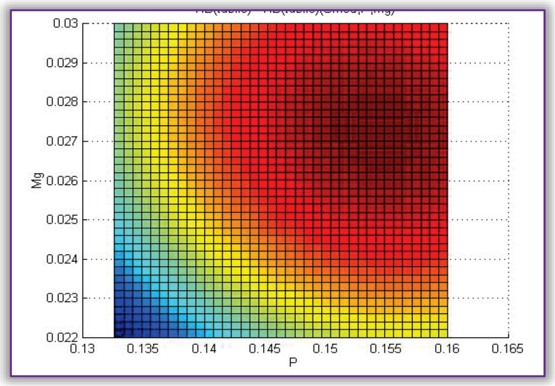

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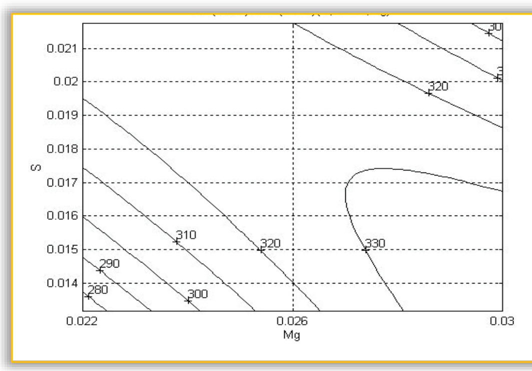
Figure 4. The Hardness [HB] dependence with the Phosphorus [P], Sulphur [S] and Magnesium [Mg] contents at the Half–hard Cast Iron Rolls. Case of Phosphorus [P] at the calculated average value: $[HB]_{barrel}(P_{med}, S, Mg)$



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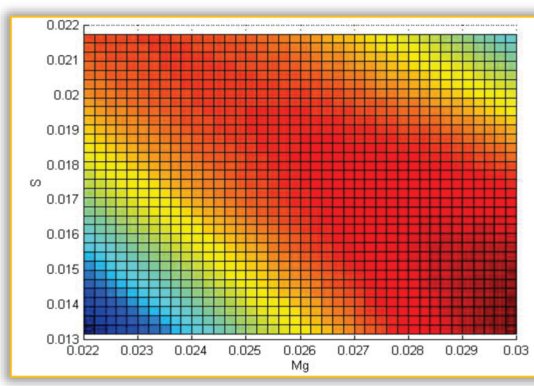

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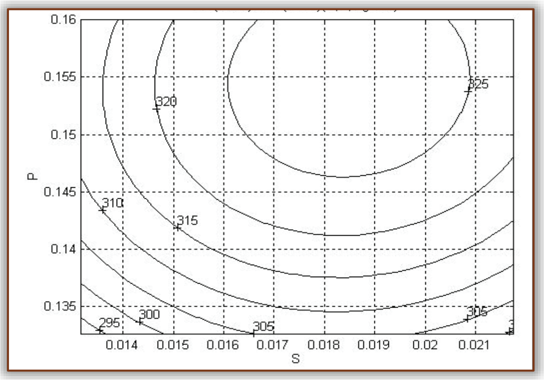
Figure 5. The Hardness [HB] dependence with the Phosphorus [P], Sulphur [S] and Magnesium [Mg] contents at the Half–hard Cast Iron Rolls. Case of Sulphur [S] at the calculated average value: $[HB]_{barrel}(P, S_{med}, Mg)$



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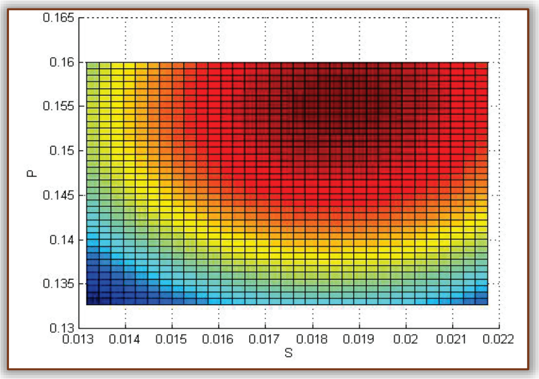

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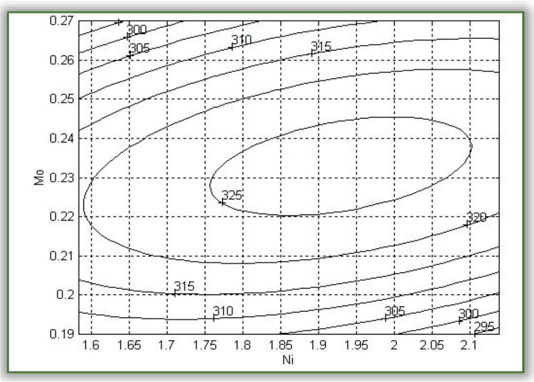
Figure 6 The Hardness [HB] dependence with the Phosphorus [P], Sulphur [S] and Magnesium [Mg] contents at the Half–hard Cast Iron Rolls. Case of Magnesium [Mg] at the calculated average value: $[HB]_{barrel}(P, S, Mg_{med})$



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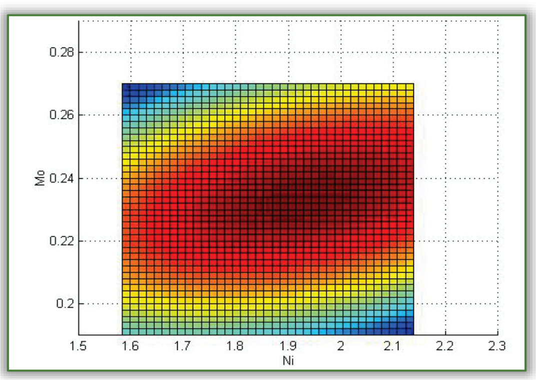

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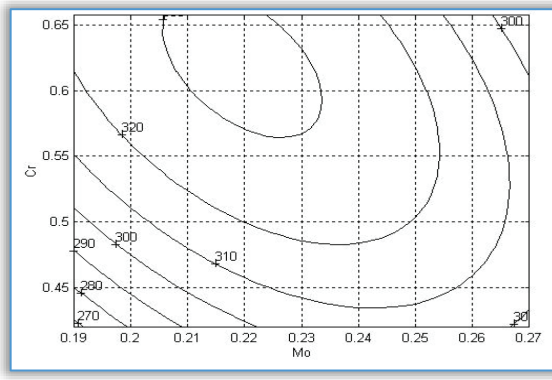
Figure 7 The Hardness [HB] dependence with the Chrome [Cr], Nickel [Ni] and Molybdenum [Mo] contents at the Half–hard Cast Iron Rolls. Case of Chrome [Cr] at the calculated average value: $[HB]_{barrel}(Cr_{med}, Ni, Mo)$



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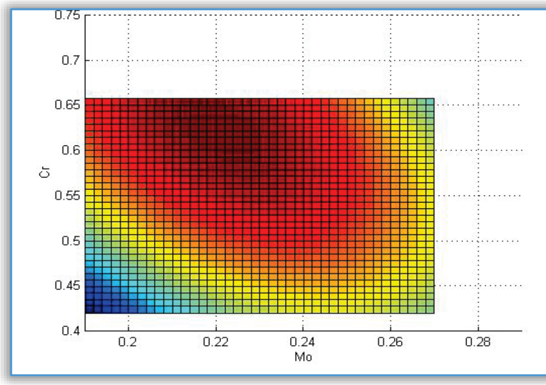

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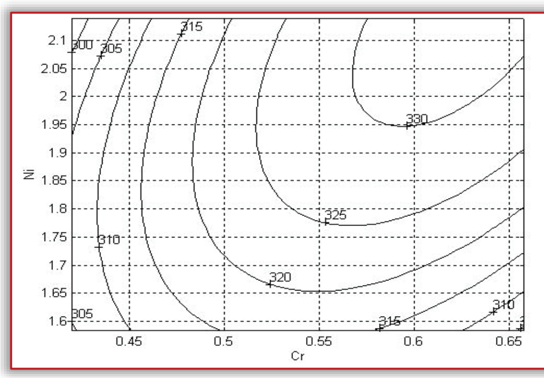
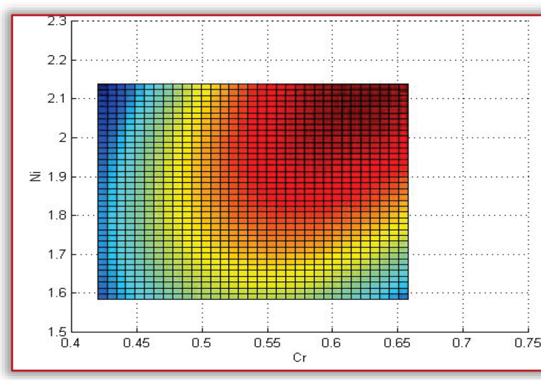
Figure 8 The Hardness [HB] dependence with the Chrome [Cr], Nickel [Ni] and Molybdenum [Mo] contents at the Half–hard Cast Iron Rolls. Case of Nickel [Ni] at the calculated average value: $[HB]_{barrel}(Cr, Ni_{med}, Mo)$



a)



b)

Figure 9 The Hardness [HB] dependence with the Chrome [Cr], Nickel [Ni] and Molybdenum [Mo] contents at the Half–hard Cast Iron Rolls. Case of Molybdenum [Mo] at the calculated average value: $[HB]_{barrel}(Cr, Ni, Mo_{med})$

Therefore, the Eqs. (4)a–c, (5)a–c and (6)a–c were obtained, which describe the correlations between the elements, belonging to the 3–dimensional space.

These regression surfaces, described by the Eqs. (4)a–c, (5)a–c and (6)a–c can be represented as correlation diagrams (Figs. 1–9) and, therefore, can be interpreted by the manufacturers. Using these diagrams is really helpful in the foundry practice, as it allows us to determine variation boundaries for the chemical composition, in view of obtaining the proper hardness.

5 DISCUSSIONS & TECHNOLOGICAL REMARKS

Particularly, the following comments can be made:

- the relation between the variables can be illustrated graphically, too (Figs. 1–9). These variation domains, described by the Eqs. (4)–(6)a–c, which governed on the roll's barrel, belonging to the 3–dimensional space can be reproduced and therefore interpreted by manufacturers.
- knowing the level curves (isolines, presented in Figs. 1a–9a) which determine the technological domains for the half–hard rolls barrel (presented in Figs. 1b–9b), allows the proper addition of basic, particulate and alloying elements. Therefore, we can obtain a desired hardness within the required limits.
- the proper values of the chemical composition in the main elements of this irons destined to the cast of the half–hard rolls (Carbon [C], Manganese [Mn] and Silicon [Si]) are to be found on the diagrams on Figures 1–3, in a double correlation. According to them the proper addition of each main element can be noticed, which will assure the proper hardness on the barrel.
- a proper proportion between the Silicon [Si] and the Manganese [Mn] contents is needed both from the basic metallic charges and from the ferro–alloy addition (Fe–Si, Fe–Mn, Si–Mn);
  - ≡ for a narrower half–hard barrel, a supplementary addition of Fe–Si is made, which released the Silicon [Si] content, thus segregating supplementary quantities of graphite in the barrel area and narrowing the barrel;
  - ≡ for increased depth of barrels, a supplementary addition of carbides is made to heighten the quantity of the tough formation cementite;
- additionally, the content of the nodulising agent (Magnesium [Mg]) will be correlated with the [S] and [P] content, found on the correlation diagrams on Figs. 4–6, in a triple correlation; in the triple dependency of Phosphorus [P], Sulphur [S] and Magnesium [Mg], besides an proper ratio of Silicon [Si] and Carbon [C] contents. A special importance is needed to be given to the Sulphur [S], as it can affect the graphite's nodularity;
- the proper values of the chemical composition in the alloying elements (Molybdenum [Mo], Nickel [Ni] and Chrome [Cr]) are to be found in the double correlation graphs, on Figs. 7–9. According to them, the proper content of each main element can be noticed, values that can assure the adequate hardness. Thus, the proper additions of alloying elements can be used in practice in order to assure the proper hardness.
- a proper proportion between the Chrome [Cr], Nickel [Ni] and Molybdenum [Mo] contents is needed both from the metallic charges and from the ferro–alloy used for alloying (Fe–Cr, Fe–Ni, Fe–Mo);
- the main chemical composition must be correlated with further addition of alloying elements, respecting the adequate proportions between Silicon [Si] and Nickel [Ni] or between Manganese [Mn] and Chrome [Cr], besides a proper ratio of Carbon [C] and Silicon [Si];
- the smooth decrease of hardness and its maintaining on the depth is performed through the proper and exactly determined proportions between all the elements (basic, particulate and alloying).

6 CONCLUSIONS

As general conclusion, it can be noted that in the melting phase of the irons, the proper hardness can be obtained through the qualities of metallic charge and addition materials (nodulising agent – Magnesium [Mg] and ferro–alloys – Fe–Si, Fe–Mn, Si–Mn, Fe–Cr, Fe–Ni and Fe–Mo). as well as through a proper guidance of melting, alloying and nodulising processes.

In the cast–iron rolls, all the structural constituents are to be found, each of them having its own hardness, well determined. One of the basic factors that determine the structure is the chemical composition, basic Carbon [C], Manganese [Mn] and Silicon [Si]), particulate (Phosphorus [P], Sulphur [S] and Magnesium [Mg]) and the alloying (Molybdenum [Mo], Nickel [Ni] and Chrome [Cr]), too. The non–compliance of each sort of rolls chemical composition will lead to rejection of them.

Based on the experiments, on the results obtained from the manufacturing data processing, we concluded that realization of the proper chemical compositions of the cast–iron can constitute a technically efficient way to assure the exploitation properties, the roll's material having an important role in this sense.

Mathematical modelling establishes a methodology for determination of process parameter's of rolls manufacturing, for which a mechanical feature is the proper values. Because it has the actual data, the model optimization is carried out on industrial data, collected on cast rolls.

The investigations are described in the context of recovery from a technical point of view of the manufacturing and exploitation of the cast iron rolls, for which there is concern the casting sectors (cast iron rolls foundries) and the rolling mill stands, aimed at determining the quality's assurance and increase the durability in service.

This research opens the way of irons chemical compositions analyses, intended for all cast iron rolls. Implementation of these results in the industrial practice also provides guarantees on quality assurance of the cast rolls.

Acknowledgement

At the fundament of this study are several scientific works in which the author is involved, through his experience gained as an engineer in a well–known factory for its iron rolling mills rolls production. The research includes the own studies and analyses, experiments and research, regarding the quality improvement of the iron rolls [1–6, 9].

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