SOME APPROACHES REGARDING THE QUALITY ASSURANCE IN THE CAST-IRON ROLLS MANUFACTURING

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Abstract
The technical conditions, which are imposed to the cast-iron rolls in the exploitation period, are very different and often contradictory. The obtaining of various physical and mechanical properties in the different points of the same foundry product meets difficult technological problems in the industrial condition. One of the parameters, which determine the structure of the irons destined for rolls casting, is the chemical composition. If we not respect this composition, which guaranties the exploitation properties of the each roll in the stand of rolling mill, it will lead to rejection. Alloying elements have in principle the same influence on structure and properties. It is presented, in graphical form, the influence of the main alloying elements upon the hardness, and measured on the necks and the core of the rolls, respectively on the working surface (body) of these very important rolling mill components The realization of an optimal chemical composition can constitute a technical efficient mode to assure the exploitation properties, the material from which the rolling mills rolls are manufactured having an important role in this sense.

Keywords: cast-iron, rolls, alloying, hardness, casting, technology

1 Introduction

Engineering is concerned with the design of a solution to a practical problem. A scientist may ask why a problem arises, and proceed to research the answer to the question or actually solve the problem in his first try, perhaps creating a mathematical model of his observations. By contrast, engineers want to know how to solve a problem, and how to implement that solution. In other words, scientists attempt to explain phenomena, whereas engineers use any available knowledge, including that produced by science, to construct solutions to problems. [1-5,14-15]
Engineering is the application of scientific and mathematical principles to develop economical solutions to technical problems, creating products, facilities, and structures that are useful to people. Engineers use their judgment, and reasoning to apply science, technology, mathematics, and practical experience. The result is the production and the optimal operation of the cast processes in this field. Often when engineers analyze a system to be controlled or optimized, they use a mathematical model. In analysis, engineers can build a descriptive model of the system as a hypothesis of how the system could work, or try to estimate how an unforeseeable event could affect the processes. As with all modern scientific and technological endeavors, computers and software play an increasingly important role. Numerical methods and simulations

can help predict design performance more accurately than previous approximations. A mathematical model usually describes the processes by a set of variables and a set of equations that establish relationships between the variables. In this sense, this research had in view to obtain correlations between the hardness of cast-iron rolls and its chemical composition, defined by the representative alloying elements. [6-15]

The nodular graphite cast-iron is considered as one of the most versatile roll materials nowadays. Large scale alloyed nodular graphite cast-iron, pearlitic nodular graphite cast-iron and acicular nodular graphite cast-iron can be manufactured.

The nodular graphite cast-iron rolls are so superior in wear resistance to that of cast steel rolls that they are specially adapted for roughing and intermediate plate mills and rod or bar mill roughers. [1,3,14-15] As a result of the nodular form of the graphite, nodular graphite cast-iron rolls are much stronger than rolls of the clear-chill type and the gradual fall in hardness is an added advantage. As such, these rolls are particularly suitable for strip mills, also bar billet mills, and are being increasingly used for other applications. The pearlitic rolls are specifically good for small section and flat rolling. There is also some use of pearlitic nodular graphite cast-iron rolls in conditions in which the first essential is toughness, rather than wear-resistance, e.g. rolls for heavily loaded roughing stands. [1,3,14-15]

This type of material may be used to produce large scale rolls in double pouring process. The body of rolls has high hardness while the neck has high toughness, so these types of rolls exhibit the properties of high thermal stability and resistance to wear. As the characteristics of any casting are influenced by the microstructure that is formed during the solidification in the casting form, and under the influence of the cooling speed, the main criteria, which determines the mechanical properties of the rolls is the structure. All structural components can be found in cast-iron rolls, each of the components having its own well-determined hardness. [1,14-15]

One of the parameters, which are determined the structure of the cast-irons destined for rolls, is the chemical composition. [1,14-15] If we do not respect this composition, which are guarantied the exploitation properties of the each roll in the stand of rolling mill, leads to rejection of this.

2 Discussion

The quality of rolls is determined through hardness and through wear resistance, last index having a special importance for all modern rolling mills with a growth production. Of major importance for the rolls exploitation is not merely growth resistance, but also the ability to oppose to different types of wear. Thus, rolling mill rolls considerable influence the specific production and the qualitative level of laminates, reason for which they are given a special attention, in manufacturing, as well as in usage. These requirements cannot be completely fulfilled, compelling to the granting of priorities depending on the type of laminates, therefore to compromises. At large, the problem is reduced to the correct material choice, eased by the rich available experience in the current conditions of manufactured and burdened, in the same time, by the large diversity of material used. Although the manufacture of rolls is in continuously perfecting, the requirements for superior quality rolls are not yet completely satisfied, in many cases, the absence of quality rolls preventing the realization of quality laminates or the realization of productivities of which rolling mills are capable**.** [1,14-15]

To the selection of materials is considered the type of rolling mill, the sizes of rolls (in specially this diameter), the speeds of lamination, the stands from the train of lamination for which is achieved rolls, the working temperature in the lamination process, the module of cooling during work, the size caliber, the pressure on rolls, the rolled material hardness etc. [1,14-15]

The choice of material for rolls is the operation which takes into consideration the own solicitations of the lamination process afferent to the type of laminates (half-products or finite laminates), and the features of different materials considerate optimum in the fabrication of different typo-dimensions of rolls.

3 Presentation of the Rolls

The rolls must present high hardness at the crust of rolls and lower hardness in the core and on the necks, adequate with the mechanical resistance and in the high work temperatures. [1,14-15] If in the crust the hardness is assured by the quantities of cementite from the structure of the irons, the core of the rolls must contain graphite to assure these properties. In **Fig. 1** the technological scheme of the cast-iron rolls manufacturing process is presented.

IRON MELTING PROCESS
in induction furnace, 12.5 tone
CHARGES
70…80% iron + 20…30% first fusion iron
addition (FeSi, FeMn, SiCa, SiMn, FeCr, FeMo, Ni, electrode dust)
MELTING
$T_{melting}$ = 1410…1430^{0}C
OUTSIDE TREATMENTS
laddle treatment, plunging procedure, with FeSiNiMg (12…15%Mg),
$T_{treatment}$ = 1370…1390^{0}C
CASTING PROCESS
$T_{casting}$ = 1290…1310^{0}C, casting time: 15 min.
$V_{casting}$ = 0.8…1.0 t/min., small rolls; $V_{casting}$ = 1.5 ÷ 2.0 t/min., bigger rolls;
CLEANING
after minimum 48 hours at the cast

Fig.1 The technological scheme of the cast-iron rolls manufacturing process

This study is required because of the numerous defects, which cause rejection, since the phase of elaboration of these irons, destined to cast rolls. According to the previous presentation, it results that one of the most important reject categories is due to the inadequate hardness of the rolls. The research includes half-hard cast rolls, from nodular graphite irons (type FNS), hardness class 1 and 2, with the half-hard crust of 40-150 mm depth. All these types of rolls have high strength, excellent thermal properties and resistance to accidents. In **Fig. 2** the casting equipment profile, the casting process and the solidification front, with section in the combined casting equipment (sand for the necks, chill for the body of rolls), are presented.

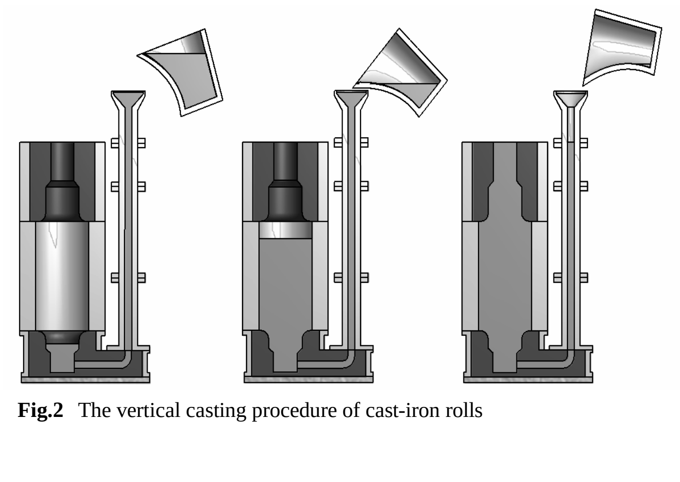

Fig.2 The vertical casting procedure of cast-iron rolls

In **Table 1** the hardness of the half-hard nodular graphite cast-iron rolls are presented, according to the Romanian's standards. **Table 2** presents the general chemical compositions, recommended for the half-hard nodular graphite cast-iron rolls.

Table 1 Hardness of the half-hard nodular graphite cast-iron rolls

Rolls type	Hardness class	Hardness on the working surface		Hardness in core and on the necks	
		[HS]	[HB]	[HS]	[HB]
FNS	0	33-42	218-286	30-40	195-271
FNS	1	43-59	294-347	30-40	195-271
FNS	2	69-75	499-550	35-45	218-309

Table 2 Chemical composition of the half-hard nodular graphite cast-iron rolls

Rolls type	Chemical composition, [%]								
	C	Si	Mn	P max	S max	Ni	Cr max	Mo	Mg
FNS	3.0-3.5	1.2-2.5	0.1-0.7	0.15	0.02	1.5-2.5	0.8	0.3-0.5	0.02-0.04

We presents some considerations upon the mechanical properties, especially the hardness of the iron rolls, assured by the chemical composition and tries to draw some conclusions upon the optimal composition of this irons destined for rolls casting.

Also, we presents the results of some researches regarding the chemical composition of the irons (with nodular and lamellar graphite) destined for casting half-hard rolls. It is presented, in graphical form, the influence of each alloying elements from the composition of these irons on the hardness, measured on the crust and the necks. The rolls must present high hardness at the crust of rolls and lower in the care and the necks, adequate with mechanical resistance and in the high work temperature. If in the crust, the hardness is guarantied by the quantities of cementite in the structure of irons, the core of rolls must be content graphite, to assure this property.

Starting from the principle of molding process, used as necessary basic instrument, both in phase of conception, as well as in the industrial technologies analysis, is determined the optimum regimes of the cast rolls, from the view from chemical composition, as one as the most important parameters of disturbance of the manufacturing process.

4 Analyzes and Interpretations

All FNS type rolls are alloyed especially with Chrome, Nickel and Molybdenum, in different percentages. The irons destined to these cast rolls belong to the class of low alloyed irons, with reduced content of these elements. The technological instructions firmly state the elements required to rise the quality of rolls. [1,14-15]

In this case the contents of these elements stand between large limits. Also, the contents of these alloying elements can be reduced due to the strong effect of the magnesium from the nodulising agent, upon the structure and the form of the graphite. Nodular graphite cast-iron rolls grades alloyed with Chromium to achieve a deep penetration of carbides. These grades have a lower hardness drop and good wear resistance properties and are recommended for rolls with deep grooves. Nodular graphite cast-iron rolls grades alloyed with Molybdenum and Nickel subjected to high temperature heat treatment have an excellent resistance to fire cracking properties along with high strength.

In our foundries, specialized in the cast-iron rolls, in spite of trying the most accurate guidance of the iron melting processes, the outside treatments melting aggregate, the modeling and drying of moulds (the so-called casting process), the cooling and the directional solidification of irons in the moulds, as well as of the rapping, cleaning and the subsequent processing of the rolls, the performance factor remains relatively low. [1,14-15]

The optimal values of the alloying elements in these irons (Chrome, Nickel and Molybdenum) are to be found on the diagrams of **Fig. 3, Fig. 4** and **Fig. 5**. Thus the optimal additions can be determined in these elements to assure the proper hardness.

The half-hard rolls have Chrome content, which is preserved at low limits (a maximum of 0.6%), although this content still assures the necessary hardness on the rolling surface and in the core the rolls. According to the practical values, the graphic from **Fig. 3** has been made, presenting the hardness variation with the Chrome content of these irons. An increase of the hardness is to notice, together with a growth of the Chrome content.

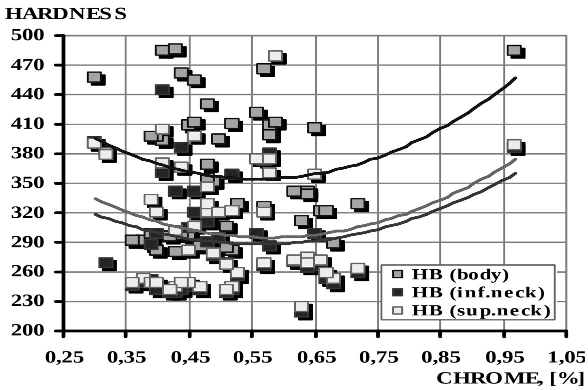

Fig.3 The hardness dependence with the Chrome content at the half-hard iron rolls

$$HB_{(body)} = 1703.92\ Cr^3 - 2607.02\ Cr^2 + 1216.81\ Cr + 193.06$$
$rs = 0.3805$; $rd = 14.48\ \%$ (1)

$$HB_{(sup.neck)} = 72.62\ Cr^3 + 377.67\ Cr^2 - 512.68\ Cr + 450.95$$
$rs = 0.5534$; $rd = 30.62\ \%$ (2)

$$HB_{(inf.neck)} = 1468.22\ Cr^3 - 2337.32\ Cr^2 + 1146.87\ Cr + 122.49$$
$rs = 0.5534$; $rd = 20.74\ \%$ (3)

$$HB_{(body)}/HB_{(sup.neck)} = 3.74\ Cr^3 - 7.38\ Cr^2 + 4.66\ Cr + 0.28$$
$rs = 0.3872$; $rd = 14.99\%$ (4)

$$HB_{(body)}/HB_{(inf.neck)} = -0.52\ Cr^3 + 1.15\ Cr^2 - 0.75\ Cr + 1.38$$
$rs = 0.2822$; $rd = 7.96\%$ (5)

$$HB_{(body)} = 168.62\ Ni^3 - 703.71\ Ni^2 + 814.89\ Ni + 145.67$$
$rs = 0.5594$; $rd = 31.29\ \%$ (6)

$$HB_{(sup.neck)} = 84.29\ Ni^3 - 306.75\ Ni^2 + 251.27\ Ni + 320.53$$
$rs = 0.3305$; $rd = 10.92\ \%$ (7)

The Nickel content is in close accordance with the Chrome content of the irons, to favor the formation of the perlitical structure, without the massive and rough carbides. These two elements are added simultaneously, because the addition of Chrome compensates the graphitizing effect of the Nickel. The proportion between the Nickel and the Chrome is situated between 2.0-4.0%.

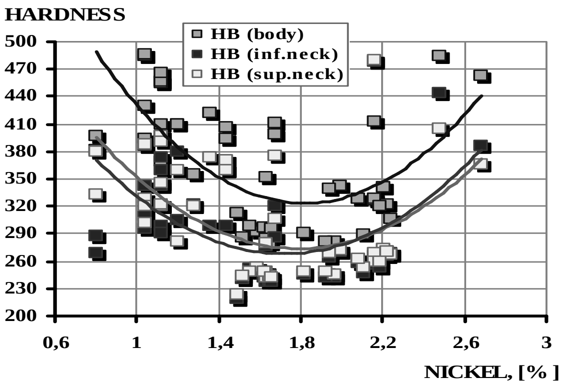

Fig.4 The hardness dependence by the Nickel content at the half-hard iron rolls

$HB_{(inf.neck)} = 158.57\ Ni^3 – 688.43\ Ni^2 + 889.41\ Ni - 33.27$
rs = 0.3501; rd = 12.25 % (8)

$HB_{(body)}/HB_{(sup.neck)} = 0.1922\ Ni^3 – 0.99\ Ni^2 + 1.59\ Ni + 0.41$
rs = 0.4362; rd = 19.02% (9)

$HB_{(body)}/HB_{(inf.neck)} = – 0.09\ Ni^3 + 0.51\ Ni^2 – 0.98\ Ni + 1.86$
rs = 0.1769; rd = 7.11% (10)

Fig. 4 presents the optimal value of the hardness both on the crust and in the core of rolls, for the obtained contents of Nickel. The variation is almost linear, maximum hardness being obtained at a higher limit of the recommended Nickel.

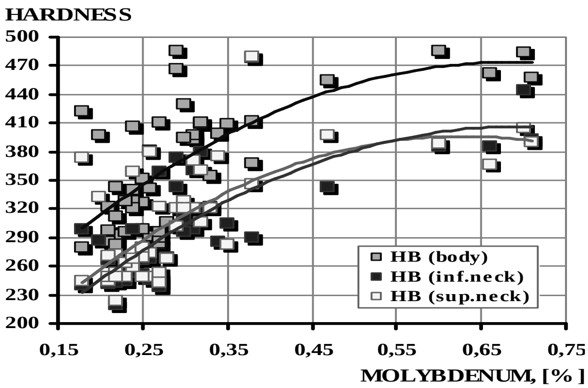

Fig.5 The hardness dependence by the Molybdenum content at the half-hard iron rolls

$HB_{(body)} = – 2846.62\ Mo^3 + 2886.71\ Mo^2 – 401.64\ Mo + 307.12$
rs = 0.4834; rd = 23.36 % (11)

$HB_{(sup.neck)} = – 4439.21\ Mo^3 + 4817.11\ Mo^2 – 1136.82\ Mo + 335.96$
rs = 0.4736; rd = 22.89 % (12)

$HB_{(inf.neck)} = – 481.92\ Mo^3 – 47.84\ Mo^2 + 682.82\ Mo + 115.52$
rs = 0.5682; rd = 32.28 % (13)

$HB_{(body)}/HB_{(sup.neck)} = 8.18\ Mo^3 – 9.96\ Mo^2 + 3.52\ Mo + 0.84$
rs = 0.2271; rd = 5.15% (14)

$HB_{(body)}/HB_{(inf.neck)} = – 5.19\ Mo^3 + 6.29\ Mo^2 – 2.41\ Mo + 1.52$
rs = 0.2487; rd = 6.18% (15)

The Molybdenum addition in the irons composition increases both the resistance at the thermal shock and the fatigue resistance. In the Molybdenum alloyed irons, contents beyond a percentage of 0.15%, are not recommended, because a portion of the Molybdenum is lost through the combination with the phosphorus, and the Molybdenum loses a part of its alloying element function.

The analyzed nodular graphite irons present a Molybdenum content, which varies between 0.18-0.28%. In the case of half-hard rolls, the content of Molybdenum does not pass this limit, and is imposed by standards to 0.1-0.3%.

To illustrate this composition interval and for the measured hardness on the rolls' area, the graphic of **Figure 5** has been made. Although the marks seem dispersed, it is easy to notice the growth of hardness as the content of Molybdenum increases in this interval.

5. Conclusions

One of the parameters, which determine the structure of the irons destined for the rolls casting, is the chemical composition. If we not respect this composition, which guaranties the exploitation properties of the each roll in the stand of rolling mill, it will lead to rejection.

The two-dimensional representations don't present only that than of tendencies of influences, through his diminution or the enlargement of the feature characteristics, and the polynomial functions just appreciate, on ensemble, the influence of the chemical elements upon hardness in different in points of rolls, indicating just the limits of variation. For this reason is enforced an analysis of the cumulated influences of elements upon the hardness in different in parts of rolls, which study will be the study of the further researches.

Therefore, we suggest a mathematical interpretation of the influence of the main alloy elements over the mechanical characteristics (the hardness on the crust of the rolls) of this nodular irons, resulting the average values and average square aberration of the variables HB, and the main alloying elements (Cr, Ni, Mo), the equations of the hyper surface in the four dimensional space.

The performed research had in view to obtain correlations between the hardness of the cast iron rolls (on the necks and on the body) and the representative alloying elements (Ni, Cr, Mo). The values processing were made using Matlab calculation program. Using this area we can determinate some mathematical correlations, correlation coefficients and the deviations from the regression surface. This surfaces in the four-dimensional space (described by the adequate equations) admit a saddle point to which the corresponding value of hardness is an optimal value of the chemical elements. The existence of a saddle point inside the technological domain has a particular importance as it ensures stability to the process in the vicinity of this point, stability

which can be either preferable or avoidable. These surfaces, belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers. Knowing these level curves allows the correlation of the values of the two independent variables so that we can obtain the hardness within the required limits.
In this mode, the usage of the Matlab area, can also be extended to the study of influences other chemical components (C, Si, Mn, S, P, Mg), and this influences upon the necks and the body of the rolling mills.

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