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THE HARDNESS OF THE CAST IRON CYLINDERS IN SOME MATHEMATICAL INTERPRETATIONS

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ABSTRACT
The irons destined to these cast rolls belong to the class of low-alloyed irons, with reduced content of chrome, nickel and molybdenum. The technological instructions firmly state the elements required raising the quality of rolls, but the limits can be extensive or limited. Depending on the number of the technological parameters, it was chosen the analysis of multiple regressions studying the influence of the chemical composition upon the hardness, through the mathematical modeling.
We suggest a mathematical interpretation of the influence of the main alloy elements over the mechanical characteristics (the hardness on the crust of the cylinders) of this nodular irons.

KEYWORDS
mathematical interpretation, main alloy elements, chrome, nickel and molybdenum
cast iron cylinders, hardness, graphical addenda

1. INTRODUCTION

All FNS type cylinders are alloyed especially with chrome, nickel and molybdenum, in different percentages. The irons destined to these cast cylinders belong to the class of low-alloyed irons, with reduced content of these elements. The technological instructions firmly state the elements required to raise the quality of cylinders.

The statistical methods of the analysis do not solve a whole series of appearances regarding to the decisions model to establish the management of the process. For this reason, in parallel with the statistical methods, was developed the methods of optimization.

As part as the basic experiment, through the regression analysis, it was aimed the determination of the mathematical functions form which connect the dependent variables u of the technological process with the free variables (the technological parameters) x, y, z,..., meaning u = f(x, y, z,...), on the strength of some experimental determinations, this after it accomplished a dispersion analysis of these correlation data. The determination of what real coefficients enter into the expression u = f (x, y, z,...) is done, in the vast majority of the cases, through the method of the smallest squares.

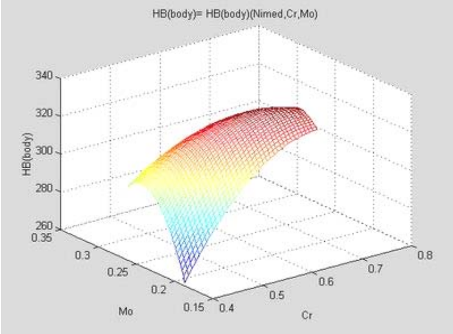

Figure 1. The Regression Surface
HB $_{(necks)}$ for Ni = Ni_{med}

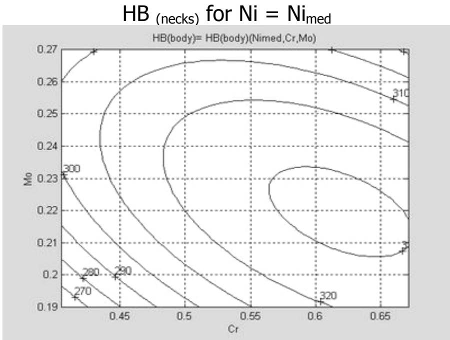

Figure 2. Level Curves
HB $_{(necks)}$ = f(Ni_{med}, Cr, Mo)

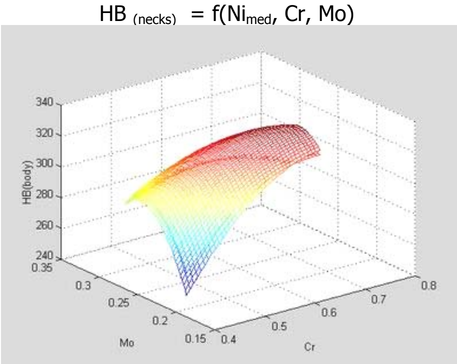

Figure 3. The Volume Variation of the Regression Surface HB $_{(necks)}$ for Ni = Ni_{med}

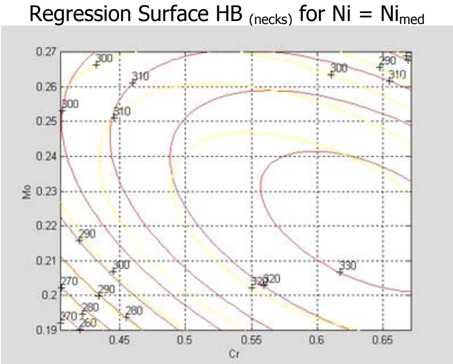

Figure 4. Level Curves for the Volume Variation of the Regression Surface
HB $_{(necks)}$ for Ni= Ni_{med}

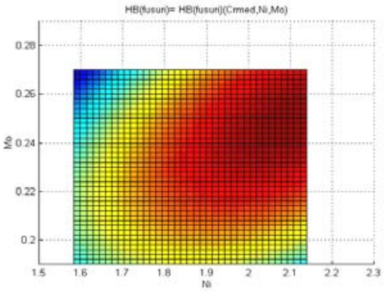

Figure 5. The Volume Variation of the Regression Surfaces for Ni = Nio_{med}

The cylinders must present high hardness at the crust of cylinders and lower hardness in the core and on the necks, adequate with the mechanical resistance and in the high work temperatures. If in the crust the hardness is assured by the quantities of cementite from the structure of the irons, the core of the cylinders must contain graphite to assure these properties.

One of the parameters, which are determined the structure of the irons destined for cylinders casting, is the chemical composition. [4, 5, 9, 10, 11, 12, 13, 14] 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. All these type of cylinders are alloyed especially with chrome, nickel and molybdenum, in different percentages. 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.

This study analyses iron cylinders cast in the simplex procedure, in combined forms (iron chill, for the crust and moulding sand, for the necks of the cylinders). The research included cylinders from the semihard class, with hardness, between 33…59 Shore units (219…347 Brinell units) for the 0 and 1 hardness class, measured on the crust, respectively 59…75 Shore units (347…550 Brinell units), for the class 2 of hardness.

This study is required because of the numerous defects, which cause rejection, since the phase of elaboration of these irons, destined to cast cylinders. According to the previous presentation, it results that one of the most important reject categories is due to the inadequate hardness of the cylinders. The research includes semihard cast cylinders, from nodular graphite irons (type FNS), hardness class 1 and 2, with the semihard crust of 40…150 mm depth. All these types of cylinders have high strength, excellent thermal properties and resistance to accidents and there is very little hardness drops in the surface work layer.

2. THE MATHEMATICAL INTERPRETATION

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 cylinders) of this nodular irons.

By the way, 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. [2, 6, 7, 8] For the statistical and mathematical analysis, there were used 23 industrial cases.

The variables variation limits are: Ni = 1.49…2.24; Cr = 0.36…0.72; Mo = 0.18…0.28, and the hardness variation limits are $HB_{(necks)}$ = 219…276 and $HB_{(body)}$ = 282…352. Therefore, the graphical representation limits, for this molding case, are:

$$\lim Ni_{inf} = 1.61;\ \lim Ni_{sup} = 2.11;$$
$$\lim Cr_{inf} = 0.40;\ \lim Cr_{sup} = 0.67;$$
$$\lim Mo_{inf} = 0.19;\ \lim Mo_{sup} = 0.27.$$

The middle values for the three variables (Ni, Cr, Mo) and the hardness (HB), necessary for the calculation of the optimal form of modelling are:

$$Ni_{med} = 1.86;\ Cr_{med} = 0.52;\ Mo_{med} = 0.23;$$
and
$$HB_{(necks)med} = 251.52;\ HB_{(body)med} = 308.32;$$

Next, there are shown the results of the multidimensional processing of experimental data. For that purpose, we searched for a method of molding the dependent variables u depending on the independent variables x, y, z:

$$u = c_1 \cdot x^2 + c_2 \cdot y^2 + c_3 \cdot z^2 + c_4 \cdot x \cdot y + c_5 \cdot y \cdot z + c_6 \cdot z \cdot x + c_7 \cdot x + c_8 \cdot y + c_9 \cdot z + c_{10} \quad (1)$$

The optimal form of the modelling is given by the equations:

$$HB_{(body)} = -69.2668\,Ni^2 - 843.9321\,Cr^2 - 13082.6971\,Mo^2 + 258.4342\,Ni \cdot Cr - 3258.4415\,Cr \cdot Mo + 757.2487\,Mo \cdot Ni - 45.2572\,Ni + 1278.2053\,Cr + 6349.4428\,Mo - 739.6223 \quad (2)$$

$$HB_{(necks)} = -77.1259\,Ni^2 - 678.1307\,Cr^2 - 4915.8057\,Mo^2 + 384.4321\,Ni \cdot Cr - 1990.8226\,Cr \cdot Mo + 646.2006\,Mo \cdot Ni - 39.5771\,Ni + 471.3705\,Cr + 2131.6892\,Mo - 101.7176 \quad (3)$$

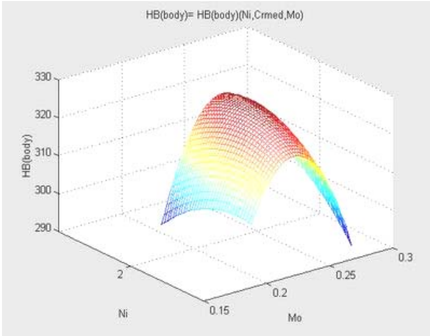

Figure 6. The Regression Surface $HB_{(necks)}$ for $Cr = Cr_{med}$

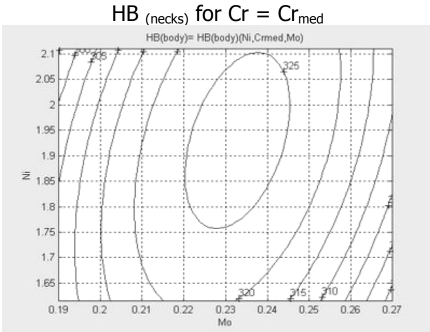

Figure 7. Level Curves $HB_{(necks)} = f(Ni, Cr_{med}, Mo)$

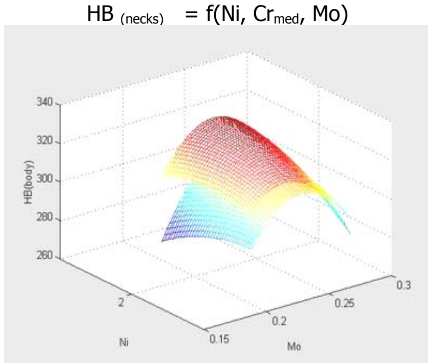

Figure 8. The Volume Variation of the Regression Surface $HB_{(necks)}$ for $Cr = Cr_{med}$

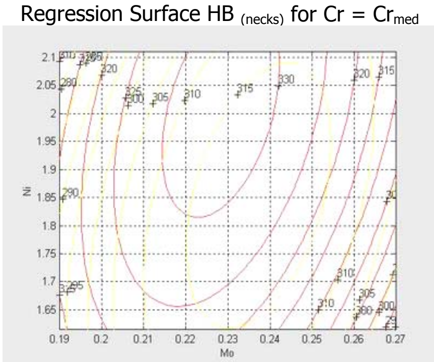

Figure 9. Level Curves for the Volume Variation of the Regression Surface $HB_{(necks)}$ for $Cr = Cr_{med}$

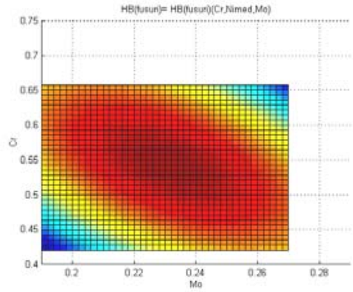

Figure 10. The Volume Variation of the Regression Surfaces for $Cr = Cr_{med}$

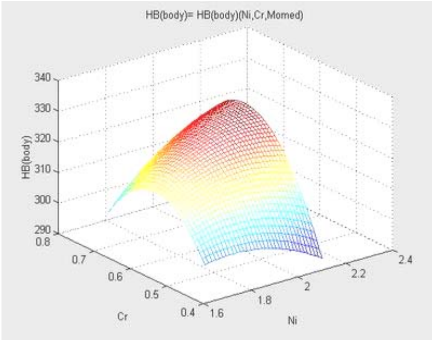

Figure 11. The Regression Surface HB $_{(necks)}$ for Mo = Mo_{med}

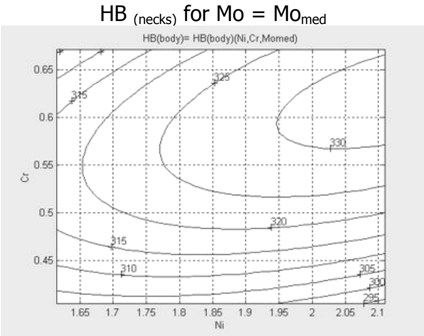

Figure 12. Level Curves HB $_{(necks)}$ = f(Ni, Cr, Mo_{med})

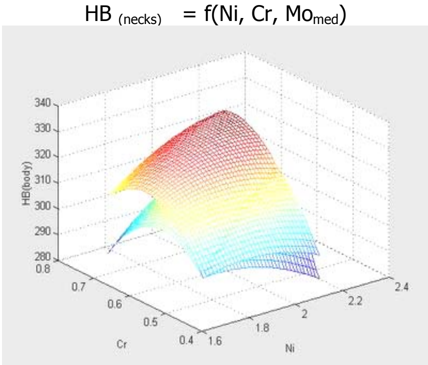

Figure 13. The Volume Variation of the Regression Surface HB $_{(necks)}$ for Mo = Mo_{med}

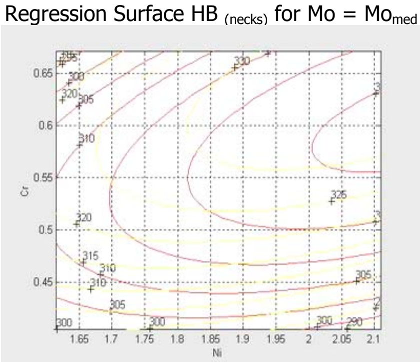

Figure 14. Level Curves for the Volume Variation of the Regression Surface HB $_{(necks)}$ for Mo= Mo_{med}

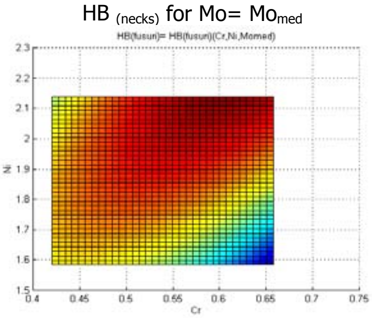

Figure 15. The Volume Variation of the Regression Surfaces for Mo = Mo_{med}

where the correlation coefficients are:

$$rf_{HB(body) = f(Ni, Cr, Mo)} = 0.77;$$

and

$$rf_{HB(necks) = f(Ni, Cr, Mo)} = 0.76$$

and the aberrations from the regression surface are:

$$sf_{HB(body) = f(Ni, Cr, Mo)} = 13.96;$$

and

$$sf_{HB(necks) = f(Ni, Cr, Mo)} = 8.73$$

3. PRESENTATION THE RESULTS OBTAINED IN MATLAB AREA

In the technological field, the behaviour of these hyper surfaces in the vicinity of the saddle point, or of the point where three independent variables take their average value, can be studied only tabular, which means that the independent variables are attributed values on spheres concentric to the studied point.

Because these surfaces cannot be represented in the three-dimensional space, the independent variables were successively replaced with their average values. This is how the following equations were obtained.

$$HB_{(body)}Ni_{med} = -843.9321\,Cr^2 - 13082.6971\,Mo^2 - 3258.4415\,Cr\cdot Mo + 1761.1402\,Cr + 7764.5101\,Mo - 1066.0756 \quad (4)$$

$$HB_{(body)}Cr_{med} = -13082.6971\,Mo^2 - 69.2668\,Ni^2 + 757.2487\,Mo\cdot Ni + 4630.9691\,Mo + 91.0387\,Ni - 300.2406 \quad (5)$$

$$HB_{(body)}Mo_{med} = -69.2668\,Ni^2 - 843.9321\,Cr^2 + 258.4342\,Ni\cdot Cr + 135.8241\,Ni + 499.0128\,Cr + 30.6111 \quad (6)$$

$$HB_{(necks)}Ni_{med} = -678.1307\,Cr^2 - 4915.8057\,Mo^2 - 1990.8226\,Cr\cdot Mo + 1189.7571\,Cr + 3339.2414\,Mo - 445.0005 \quad (7)$$

$$HB_{(necks)}Cr_{med} = -4915.8057\,Mo^2 - 77.1259\,Ni^2 + 646.2006\,Mo\cdot Ni + 1081.7467\,Mo + 163.1691\,Ni - 41.7373 \quad (8)$$

$$HB_{(necks)}Mo_{med} = -77.1259\,Ni^2 - 678.1307\,Cr^2 + 384.4321\,Ni\cdot Cr + 114.9492\,Ni - 4.6957\,Cr + 126.9318 \quad (9)$$

4. PRESENTATION THE GRAPHICAL ADDENDA

These surfaces, belonging to the three-dimensional space, can be represented and, therefore, interpreted by technologists. Knowing these level curves allows the correlation of the values of the twos independent variables so that the hardness can be obtained in between the requested limits. This surface in the Figures 1...15 are presented.

5. CONCLUSIONS

- the performed research had in view to obtain correlations between the hardness of the cast iron cylinders (on the necks) and the representative alloying elements (Ni, Cr, Mo).
- 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;
- the presented values processing were made using Matlab calculation program. Using this area we determinate some mathematical correlation, correlation coefficient and the deviation from the regression surface. This surface in the four-dimensional space (described by the general equation 1, and particular equations 2 and 3) admits a saddle point to which the corresponding value of hardness is an optimal alloying 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 of avoidable.
- the behaviour of this hyper surface in the vicinity of the stationary point (when this point belongs to the technological domain) or in the vicinity of the point where the three independent variables have their respective mean value, or in a point where the dependent function reaches its extreme value in the technological domain (but not being a saddle point) can be rendered only as a table, namely, assigning values to the independent variables on spheres which are concentrically to the point under study.
- as these surfaces cannot be represented in the three-dimensional space, we resorted to replacing successively one independent variable by its mean value. These surfaces (described by the equation 4...9), belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers (Figures 1, 6 and 11). Knowing these level curves (Figures 2, 7 and 12) allows the correlation of the values of the two independent variables so that we can obtain the hardness within the required limits.
- the Figures 3, 8 and 13 presented the volume variation of the regression surfaces $HB_{(necks)}$ and $HB_{(body)}$ for one of the middle value of the variables Ni, Cr, Mo.
- in the Figures 4, 9 and 14 the level curves for the volume variation of the regression surfaces $HB_{(necks)}$, for the Ni_{med}, Cr_{med} and Mo_{med}, are presented in the graphical addenda;
- in the Figures 5, 10 and 15 the volume variation of the regression surfaces are presented.
- depending on the number of free variables (the technological parameters) that we consider, it was chosen the analysis of multiple regressions studying the influence of free variables x, y, z,... upon the dependent variable u. In this sense, it was aimed to establish calculus methodologies of values for the technological parameters in the manufacturing process of the semihard rolling mill cylinders, obtained through the simplex classical cast of the iron with nodular graphite, for which the mechanical features of rolling mill cylinders have the required values.

- following the experiments we determine the mechanical features according to the technological parameters of influences in the process. Because we dispose of real data, afterwards it is required to present the model of optimization on industrial data, sampled from rolling mills cylinders.
- these diagrams are built for the average values of the parameters (x_{med}, y_{med}, z_{med}), only that through the representation of the diagrams for parameters values contained in the variations limits we can obtain adjusting diagrams, with which we can completely controlled the process.

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