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TECHNICAL INTERPRETATIONS OF THE DEPENDENCY BETWEEN THE HARDNESS OF IRON CAST ROLLS AND THE CHEMICAL COMPOSITIONS OF THE NODULAR IRONS

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ABSTRACT:
This paper suggest a mathematical interpretation of the influence of the main alloy elements over the mechanical characteristics (the hardness on the crust and on the necks of the rolls) of this nodular irons, resulting the average values and average square aberration of the variables HS, and the main alloying elements (Cr, Ni, Mo), the equations of the hyper surface in the four dimensional space. For the statistical and mathematical analysis, there were used 23 industrial cases. The resulted 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.
The paper presents the results of some researches regarding the chemical composition of the nodular irons destined for casting semihard rolls. It is presented, in graphical form, used the Matlab area, 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.
Keywords:
iron rolls, alloying elements, hardness, modelling, optimization, graphical addenda

1. INTRODUCTION

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. 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.

One of the parameters, which are determined the structure of the irons destined for rolls 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 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. 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 rolls cast in the simplex procedure, in combined forms (iron chill, for the crust and moulding sand, for the necks of the rolls). The research included rolls 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 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 semihard cast rolls, from nodular graphite irons (type FNS), hardness class 1 and 2, with the semihard crust of 40…150 mm depth. All these types of rolls have high strength, excellent thermal properties and resistance to accidents and there is very little hardness drops in the surface work layer.

2. TECHNICAL INTERPRETATION AND SIMULATION IN MATLAB AREA

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. [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 molding 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:

$$u = c_1 \cdot x^2 + c_2 \cdot y^2 + c_3 \cdot z^2 + c_4 \cdot x \cdot y + c_5 \cdot y \cdot z + c_6 \cdot z \cdot x + c_7 \cdot x + c_8 \cdot y + c_9 \cdot z + c_{10} \quad (0.1)$$

The optimal molding's form is given by the equations:

$$HB_{(body)} = -69.2668\,Ni^2 - 843.9321\,Cr^2 - 13082.6971\,Mo^2 + 258.4342\,Ni \cdot Cr - 3258.4415\,Cr \cdot Mo + 757.2487\,Mo \cdot Ni - 45.2572\,Ni + 1278.2053\,Cr + 6349.4428\,Mo - 739.6223 \quad (0.2)$$

$$HB_{(necks)} = -77.1259\,Ni^2 - 678.1307\,Cr^2 - 4915.8057\,Mo^2 + 384.4321\,Ni \cdot Cr - 1990.8226\,Cr \cdot Mo + 646.2006\,Mo \cdot Ni - 39.5771\,Ni + 471.3705\,Cr + 2131.6892\,Mo - 101.7176 \quad (0.3)$$

where the correlation coefficients are:

$$rf_{HB(body)\ =\ f(Ni,\ Cr,\ Mo)} = 0.77; \text{ and } rf_{HB(necks)\ =\ f(Ni,\ Cr,\ Mo)} = 0.76$$

and the aberrations from the regression surface are:

$$sf_{HB(body)\ =\ f(Ni,\ Cr,\ Mo)} = 13.96; \text{ and } sf_{HB(necks)\ =\ f(Ni,\ Cr,\ Mo)} = 8.73$$

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.

$$HB_{(body)}Ni_{med} = -843.9321\ Cr^2 - 13082.6971\ Mo^2 - 3258.4415\ Cr \cdot Mo + 1761.1402\ Cr + 7764.5101\ Mo - 1066.0756 \quad (0.4)$$

$$HB_{(body)}Cr_{med} = -13082.6971\ Mo^2 - 69.2668\ Ni^2 + 757.2487\ Mo \cdot Ni + 4630.9691\ Mo + 91.0387\ Ni - 300.2406 \quad (0.5)$$

$$HB_{(body)}Mo_{med} = -69.2668\ Ni^2 - 843.9321\ Cr^2 + 258.4342\ Ni \cdot Cr + 135.8241\ Ni + 499.0128\ Cr + 30.6111 \quad (0.6)$$

$$HB_{(necks)}Ni_{med} = -678.1307\ Cr^2 - 4915.8057\ Mo^2 - 1990.8226\ Cr \cdot Mo + 1189.7571\ Cr + 3339.2414\ Mo - 445.0005 \quad (0.7)$$

$$HB_{(necks)}Cr_{med} = -4915.8057\ Mo^2 - 77.1259\ Ni^2 + 646.2006\ Mo \cdot Ni + 1081.7467\ Mo + 163.1691\ Ni - 41.7373 \quad (0.8)$$

$$HB_{(necks)}Mo_{med} = -77.1259\ Ni^2 - 678.1307\ Cr^2 + 384.4321\ Ni \cdot Cr + 114.9492\ Ni - 4.6957\ Cr + 126.9318 \quad (0.9)$$

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.

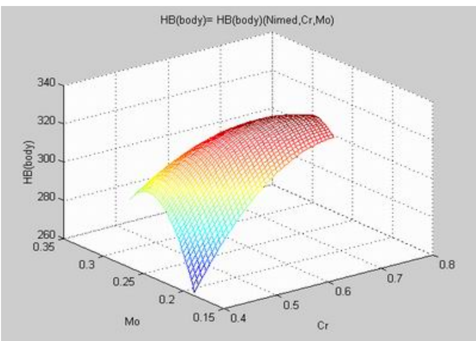

Figure 1. The Regression Surface
HB $_{(necks)}$ for Ni = Ni_{med}

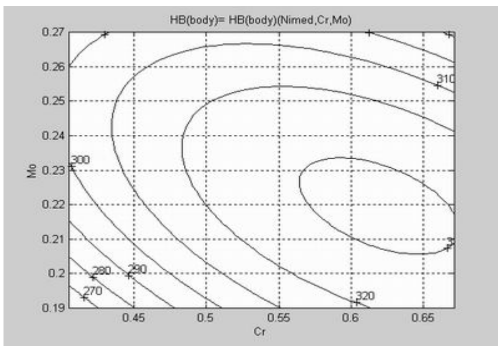

Figure 2. Level Curves
HB $_{(necks)}$ = f(Ni_{med}, Cr, Mo)

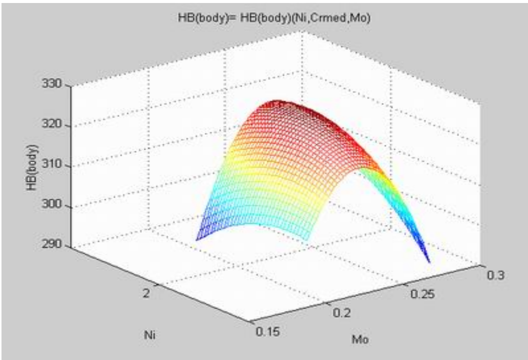

Figure 3. The Regression Surface
HB $_{(necks)}$ for Cr = Cr_{med}

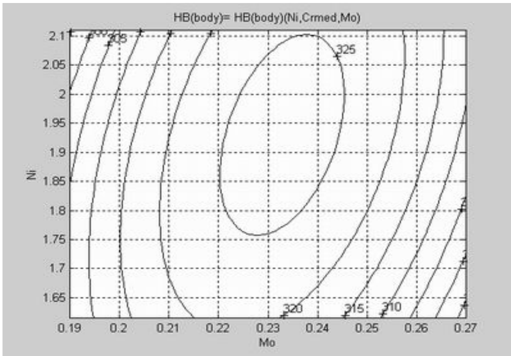

Figure 4. Level Curves
HB $_{(necks)}$ = f(Ni, Cr_{med}, Mo)

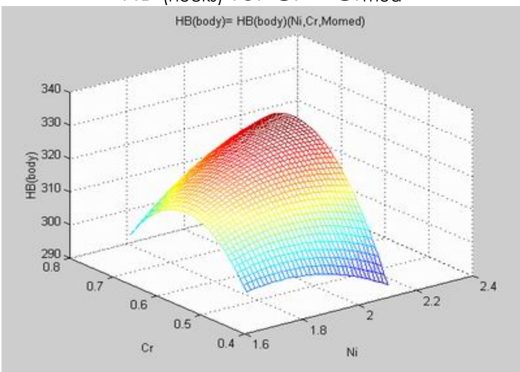

Figure 5. The Regression Surface
HB $_{(necks)}$ for Mo = Mo_{med}

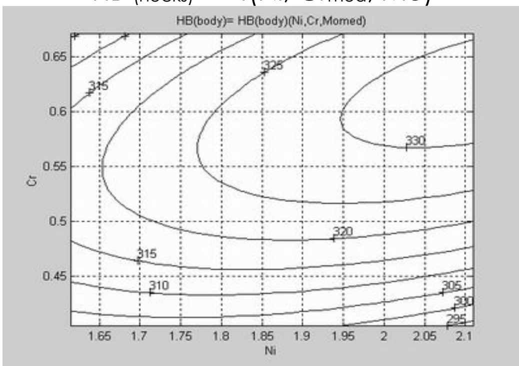

Figure 6. Level Curves
HB $_{(necks)}$ = f(Ni, Cr, Mo_{med})

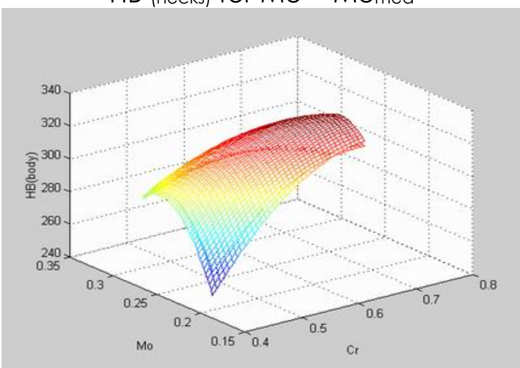

Figure 7. The Volume Variation of the Regression Surface HB $_{(necks)}$ for Ni = Ni_{med}

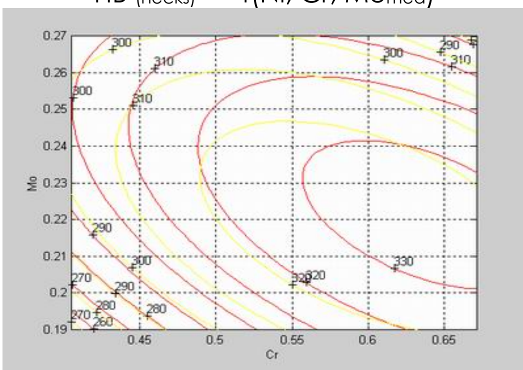

Figure 8. Level Curves for the Volume Variation of the Regression Surface HB $_{(necks)}$ for Ni= Ni_{med}

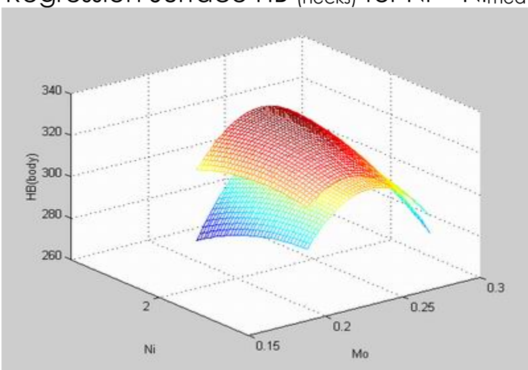

Figure 9. The Volume Variation of the Regression Surface HB $_{(necks)}$ for Cr = Cr_{med}

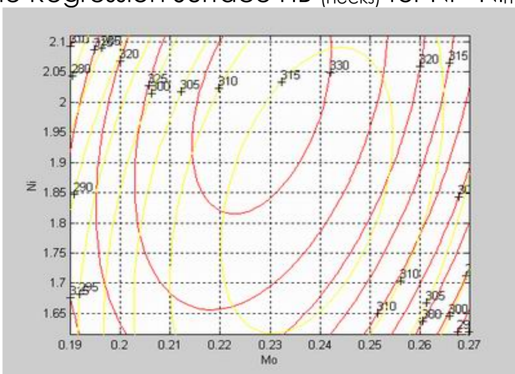

Figure 10. Level Curves for the Volume Variation of the Regression Surface HB $_{(necks)}$ for Cr = Cr_{med}

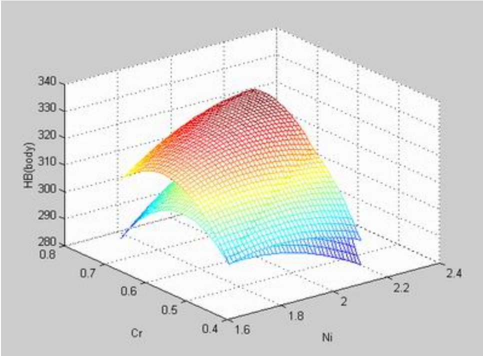

Figure 11. The Volume Variation of the Regression Surface HB (necks) for Mo = Mo_{med}

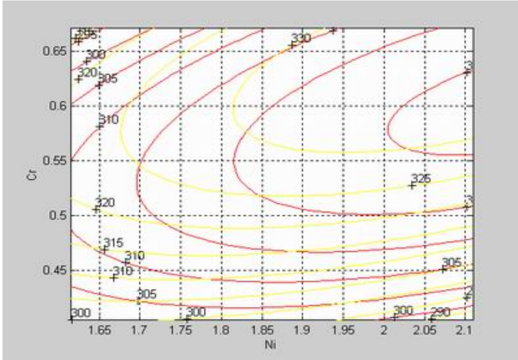

Figure 12. Level Curves for the Volume Variation of the Regression Surface HB (necks) for Mo= Mo_{med}

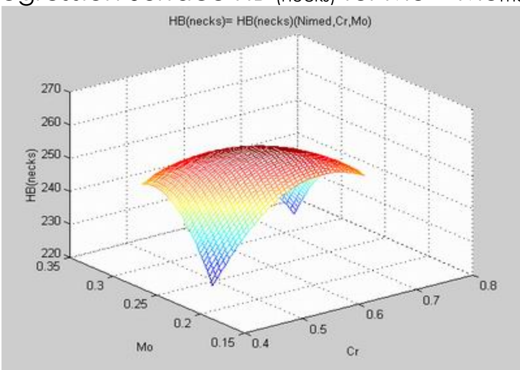

Figure 13. The Regression Surface HB (body) for Ni = Ni_{med}

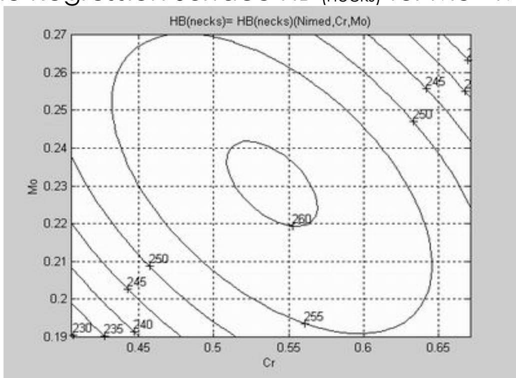

Figure 14. Level Curves HB (body) = f(Ni_{med}, Cr, Mo)

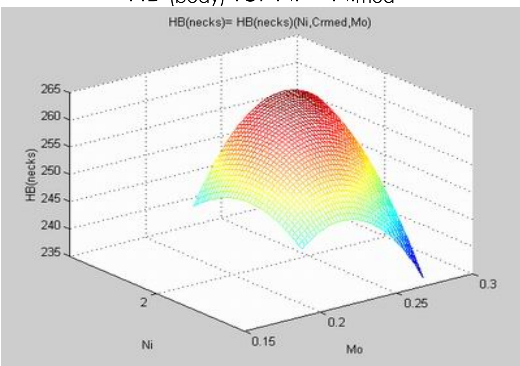

Figure 15. The Regression Surface HB (body) for Cr = Cr_{med}

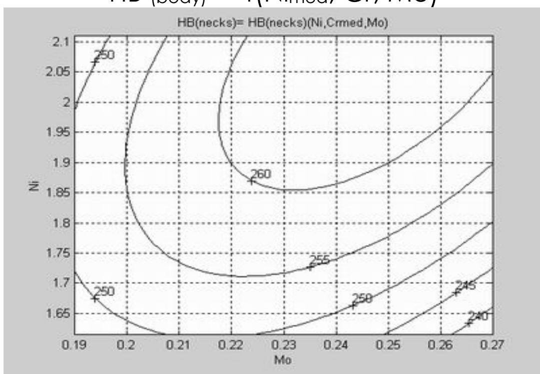

Figure 16. Level Curves HB (body) = f(Ni, Cr_{med}, Mo)

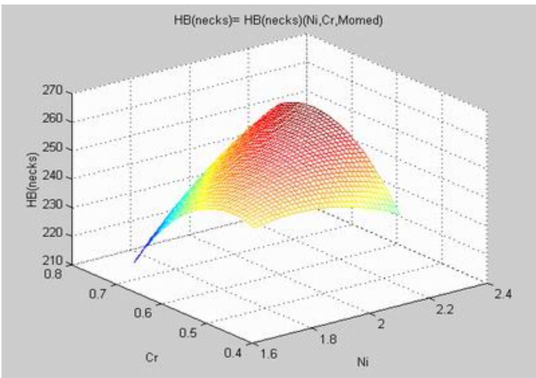

Figure 17. The Regression Surface HB (body) for Mo = Mo_{med}

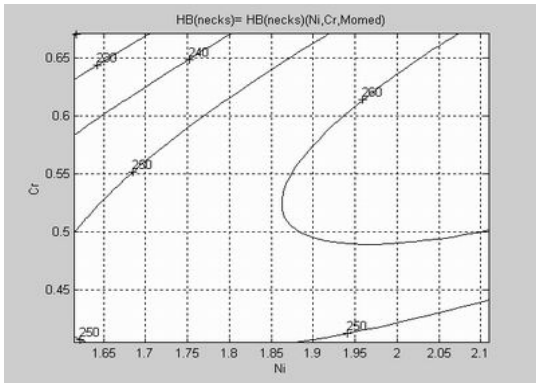

Figure 18. Level Curves HB (body) = f(Ni, Cr, Mo_{med})

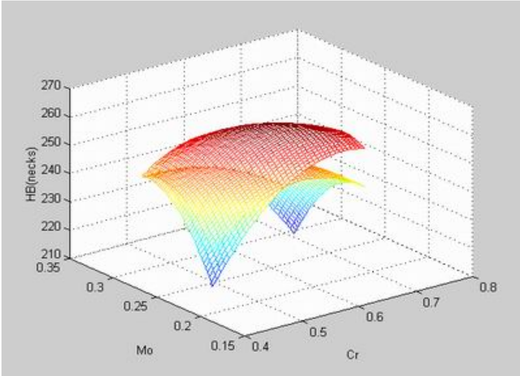

Figure 19. The Volume Variation of the Regression Surface HB $_{(body)}$ for Ni = Ni_{med}

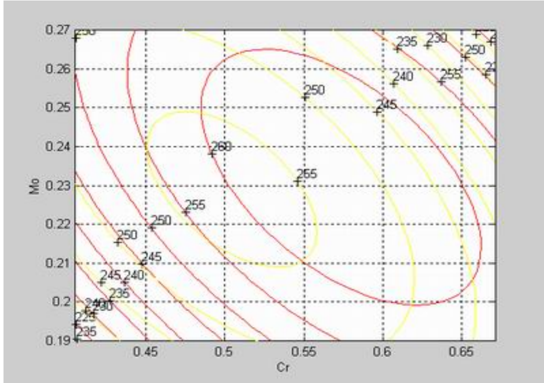

Figure 20. Level Curves for the Volume Variation of the Regression Surface HB $_{(body)}$ for Ni = Ni_{med}

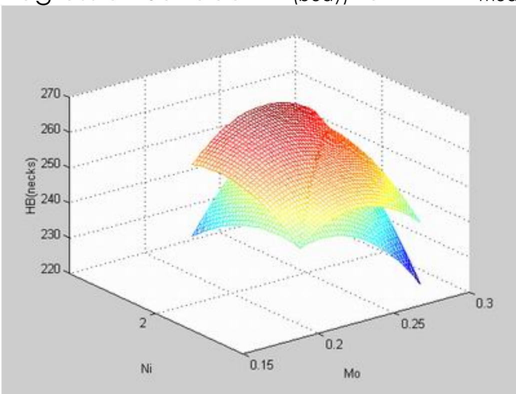

Figure 21. The Volume Variation of the Regression Surface HB $_{(body)}$ for Cr = Cr_{med}

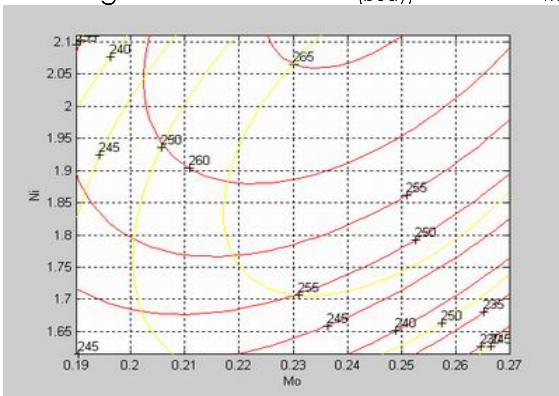

Figure 22. Level Curves for the Volume Variation of the Regression Surface HB $_{(body)}$ for Mn= Mn_{med}

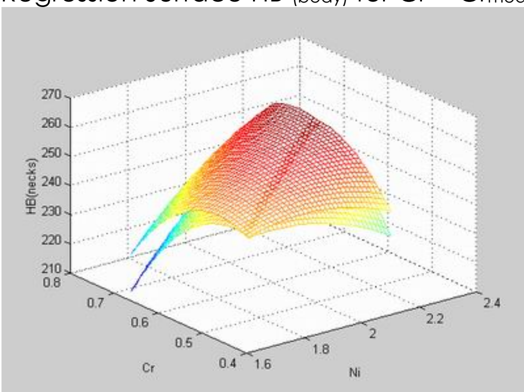

Figure 23. The Volume Variation of the Regression Surface HB $_{(body)}$ for Mo = Mo_{med}

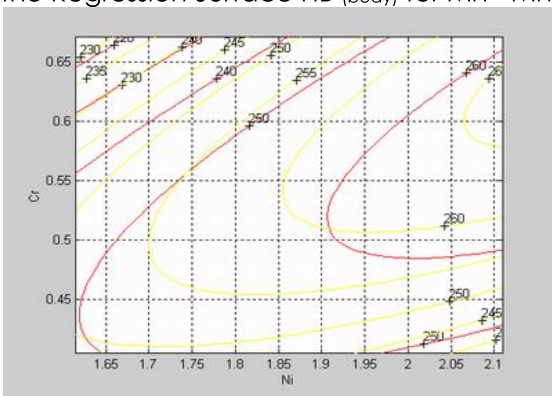

Figure 24. Level Curves for the Volume Variation of the Regression Surface HB $_{(body)}$ for Mo= Mo_{med}

5. CONCLUSIONS

- 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 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 0.1, and particular equations 0.2 and 0.3) 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 0.4…0.9), belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers (Figures 1, 3, 5, respectively Figures 13, 15, 17). Knowing these level curves (Figures 2, 4, 6, respectively Figures 14, 16, 18) allows the correlation of the values of the two independent variables so that we can obtain the hardness within the required limits.
- The Figures 7, 9, 11, respectively Figures 19, 21, 23 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 8, 10, 12, respectively Figures 20, 22, 24, the level curves for the volume variation of the regression surfaces $HB_{(necks)}$ and $HB_{(body)}$, for the Ni_{med}, Cr_{med} and Mo_{med}, are presented in the graphical addenda;
- 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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