ANNALS OF THE FACULTY OF ENGINEERING HUNEDOARA
2004, Tome II, Fascicole 3

OPTIMAL CORRELATION BETWEEN THE MECHANICAL PROPERTIES OF THE NODULAR CAST IRON ROLLS AND THE ALLOYED ELEMENTS

Imre KISS, Stefan MAKSAY

UNIVERSITATEA POLITEHNICA TIMISOARA,
FACULTATEA DE INGINERIE HUNEDOARA

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. This supposes us to know many technological factors, which lead to this deformation equipment.

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 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.

This article explains how the chemical composition, through the main alloying elements (Ni, Cr, Mo), influencing on a structure and the expected mechanical properties of the nodular cast irons, and presents also some graphical addenda.

KEY WORDS:
cast rolls, iron with nodular graphite's, alloying elements, nickel, chromium, molybdenum, mathematical correlations

1. INTRODUCTION

The nodular graphite cast iron is considered as one of the most versatile roll materials nowadays. A small proportion of magnesium added to the melt as nickel-magnesium or alternative alloy, or as pure magnesium produces it. In the nodular graphite's iron roll, the free carbon takes the shape of spheroids or nodules, thereby eliminating the notch effect of flake graphite and improving upon the mechanical properties of the cast iron.

The nodular cast iron rolls are characterised by the nodular shaped graphite in the microstructure. Through adjusting the alloy elements of nickel, chrome and molybdenum and heat treatment technique, the different type of rolls of popular nodular graphite cast iron. Large scale alloyed nodular graphite cast iron, pearlitic nodular graphite cast iron and acicular nodular graphite cast iron can be manufactured. All these types of rolls have high strength, excellent thermal properties and resistance to accidents and there is very little hardness drop in the surface work layer.

These type of material may be used to produce large scale rolls in double pouring process, the barrel of rolls has high hardness while the neck has high toughness, so these type of rolls exhibit the properties of high thermal stability and resistance to wear. As the characteristics of any casting are influenced by the microstruture 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. One of the parameters, which are determined the structure of the irons destined for rolls casting, is the chemical composition. 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.

2. RESULTS OF ANALYSES. TECHNICAL INTERPRETATION AND SIMULATION IN MATLAB AREA

In the case of the semihard cast iron rolls, the chrome has a less important influence than in the case of hard and extrahard rolls, as in their case the chrome proves to be the most efficient alloying element to regulate the crust depth. The semihard 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 FIGURE 1 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.

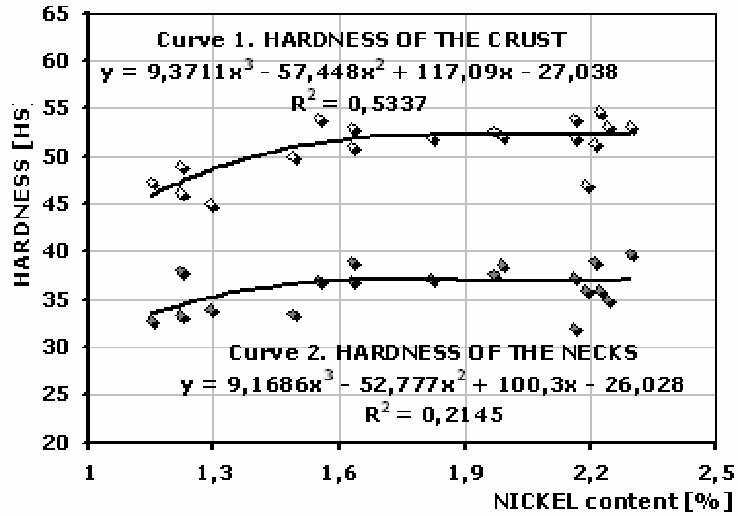
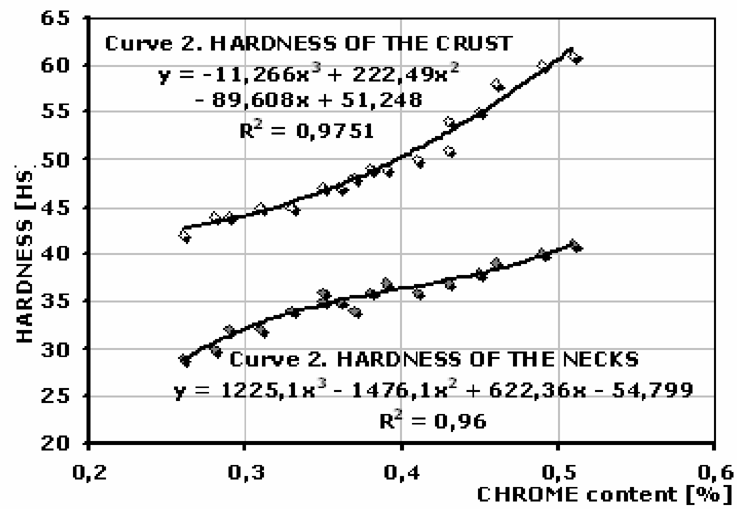


FIGURE 1.
THE HARDNESS
DEPENDENCE
BY THE NICKEL CONTENT
AT THE SEMIHARD
IRON ROLLS

FIGURE 2.
THE HARDNESS
DEPENDENCE
BY THE CHROME CONTENT
AT THE SEMIHARD
IRON ROLLS



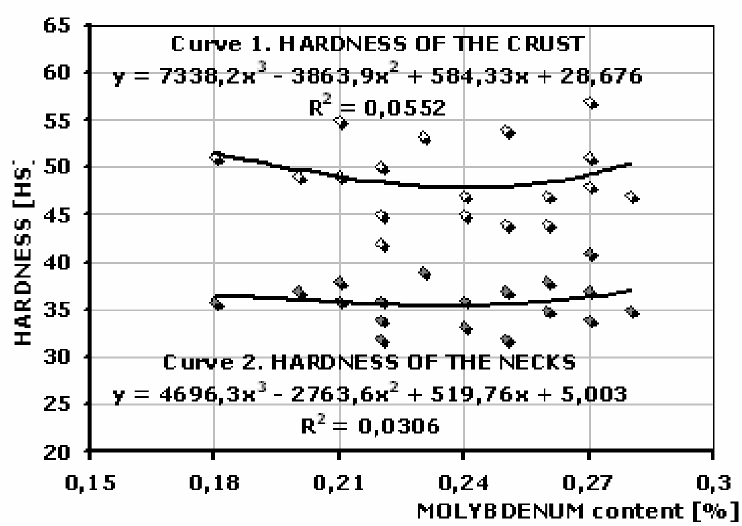


FIGURE 3.
THE HARDNESS
DEPENDENCE
BY THE MOLYBDENUM
CONTENT
AT THE SEMIHARD
IRON ROLLS

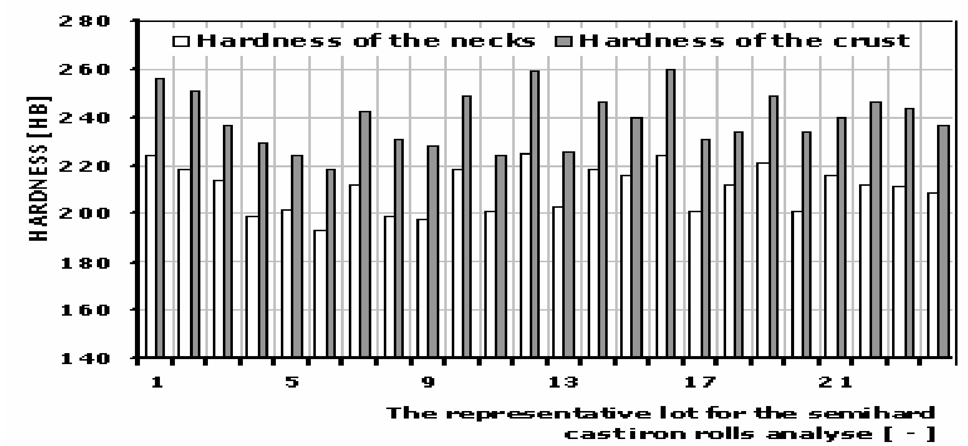


FIGURE 4. THE REPRESENTATIVE LOT
FOR THE SEMIHARD CAST IRON ROLLS ANALYSE

The nickel addition leads to the improvement of the mechanical properties (resistance at wear, resistance at thermal shock, hardness and upon the workability of the cast rolls). If we do not allow this element to increase the graphitisation degrees and the white solidification in the peripherical area of the rolling surface, this content will be considerably reduced. Accordingly, the silicon content of the irons is modified, as this element replaces nickel.

Also, the nickel content is in close accordance with the chrome content of the irons, to favour 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 graphitising effect of the nickel. The proportion between the nickel and the chrome is situated between 2…4. FIGURE 2 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.

The molybdenum is a carburigenous element, but this effect is relevant only at percentage above 0.6%. Below this value, fine structures are obtained on the entire section, also an increase of the wear resistance and to high temperature stabilities, as well as a considerable mechanical resistance. 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.

In the case of semihard rolls, the content of phosphorus does not pass this limit, and is imposed by standards to 0.1…0.3%. The analysed nodular graphite irons present a molybdenum content, which varies between 0.18…0.28 %. To illustrate this composition interval and for the measured hardness on the rolls' area, the graphic of FIGURE 3 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.

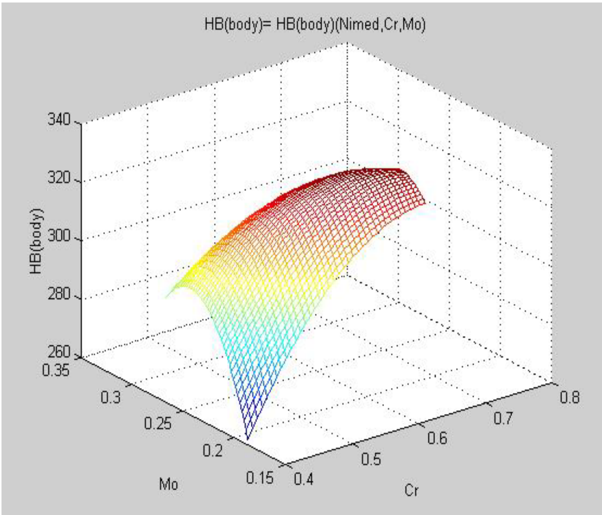


FIGURE 5. THE REGRESSION SURFACE
$HB_{(body)}$ FOR $Ni = Ni_{med}$

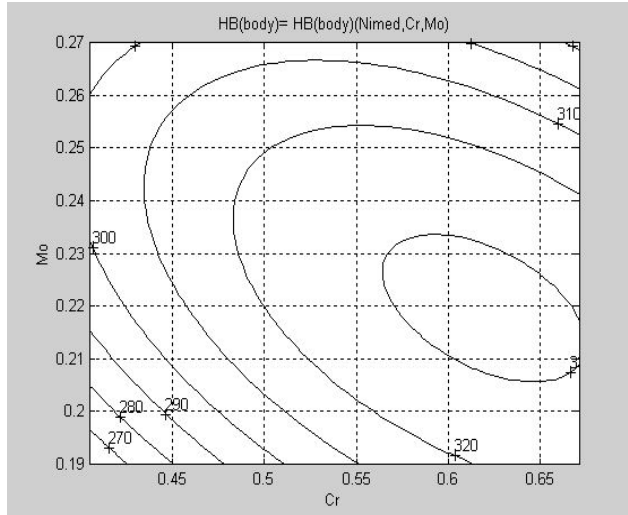


FIGURE 6. LEVEL CURVES
$HB_{(tăblie)} = f(Ni_{med}, Cr, Mo)$

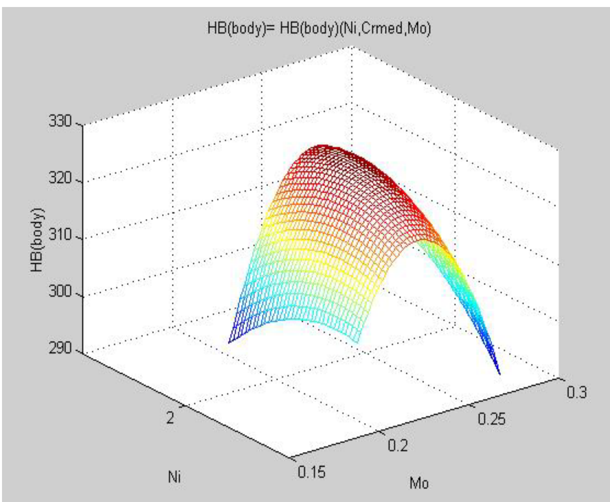


FIGURE 7. THE REGRESSION SURFACE
$HB_{(body)}$ FOR $Cr = Cr_{med}$

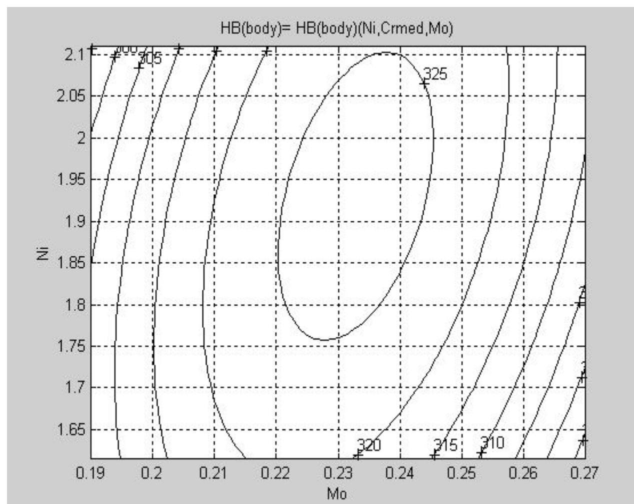


FIGURE 8. LEVEL CURVES
$HB_{(tăblie)} = f(Ni, Cr_{med}, Mo)$

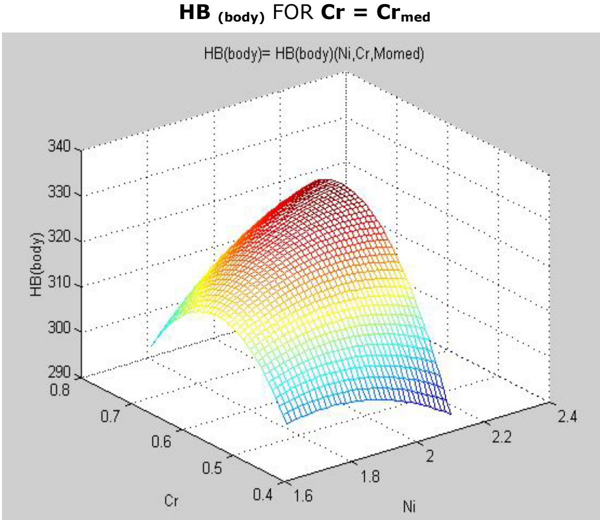


FIGURE 9. THE REGRESSION SURFACE
$HB_{(body)}$ FOR $Mo = Mo_{med}$

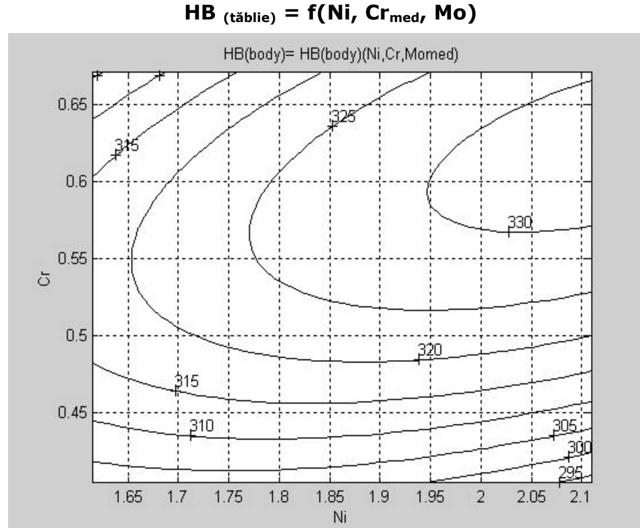


FIGURE 10. LEVEL CURVES
$HB_{(tăblie)} = f(Ni, Cr, Mo_{med})$

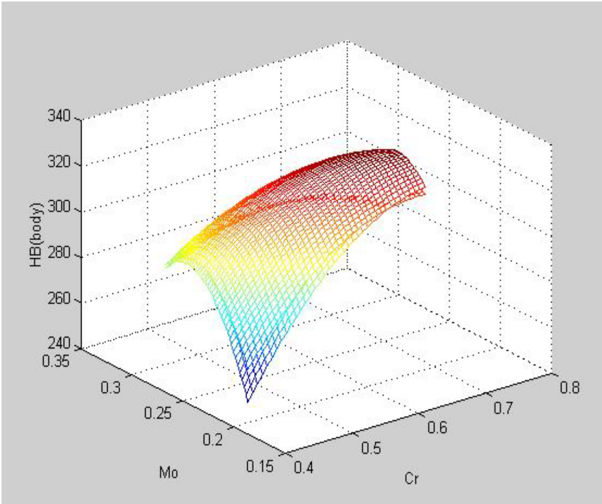


FIGURE 11. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Ni = Ni$_{med}$**

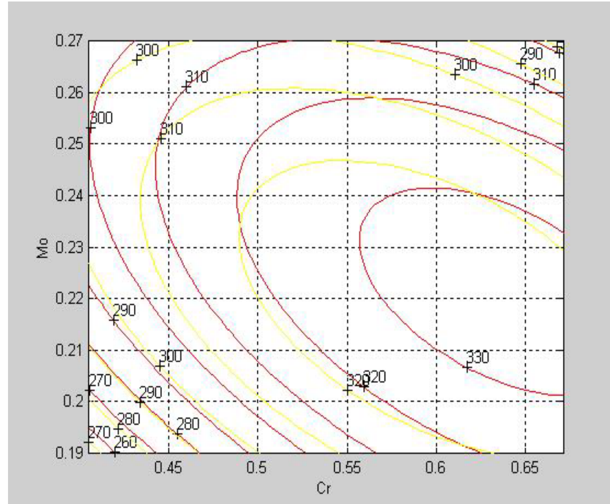


FIGURE 12. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Ni = Ni$_{med}$**

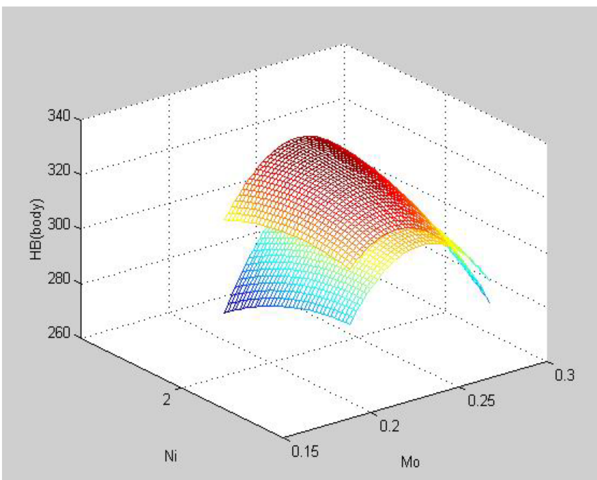


FIGURE 13. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Cr = Cr$_{med}$**

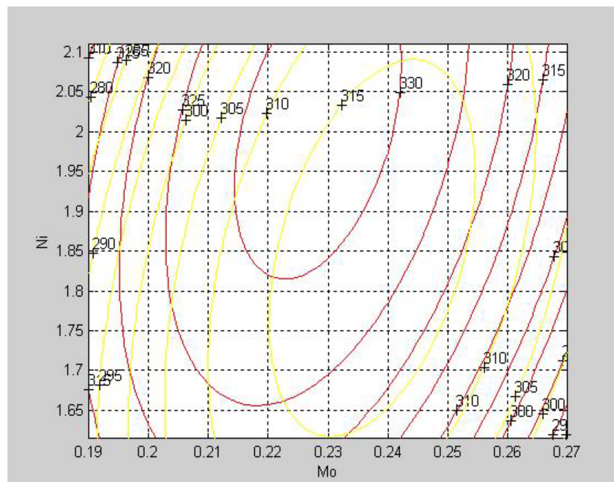


FIGURE 14. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Mn= Mn$_{med}$**

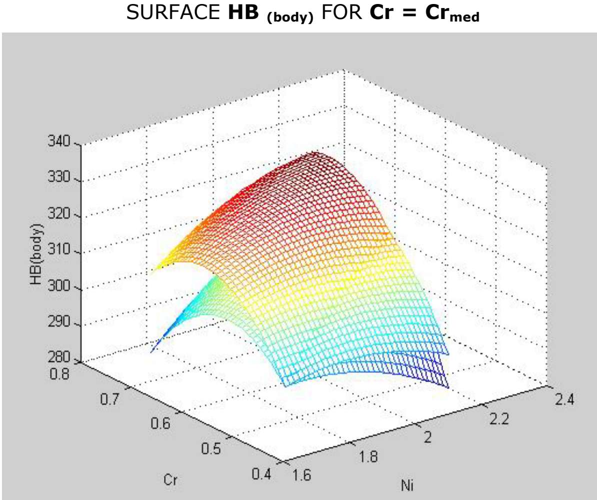


FIGURE 15. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Mo = Mo$_{med}$**

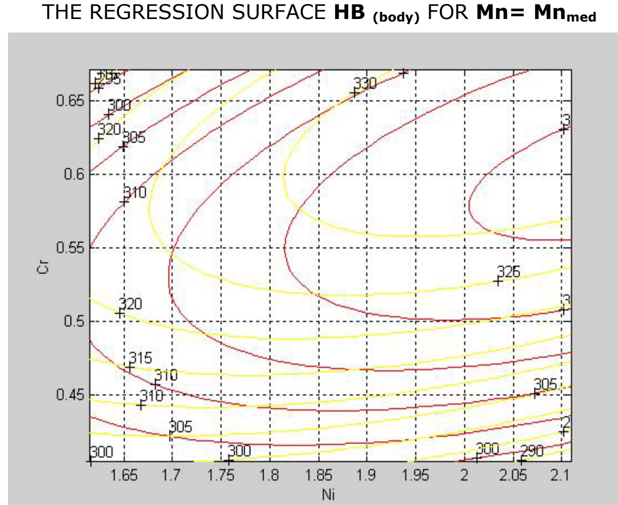


FIGURE 16. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\mathbf{(body)}}$ FOR **Mo= Mo$_{med}$**

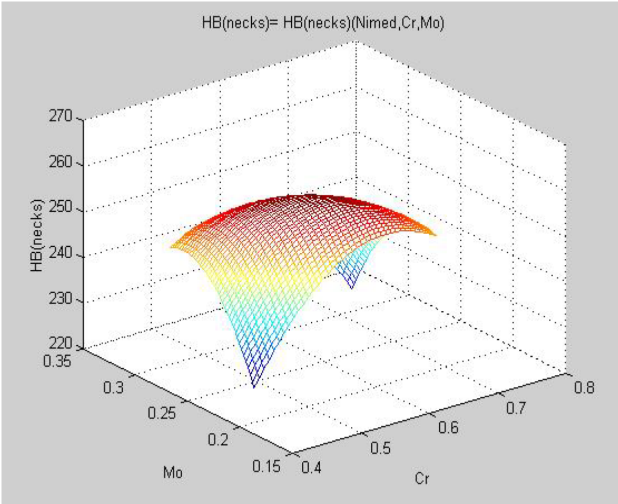


FIGURE 17. THE REGRESSION SURFACE
HB $_{(necks)}$ FOR **Ni = Ni$_{med}$**

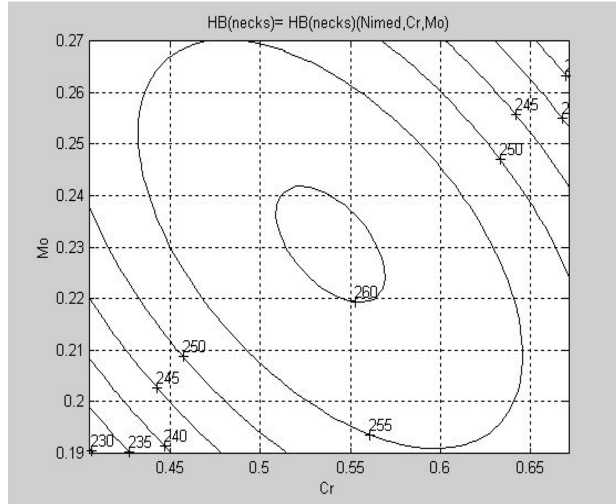


FIGURE 18. LEVEL CURVES
HB $_{(fusuri)}$ = f(Ni$_{med}$, Cr, Mo)

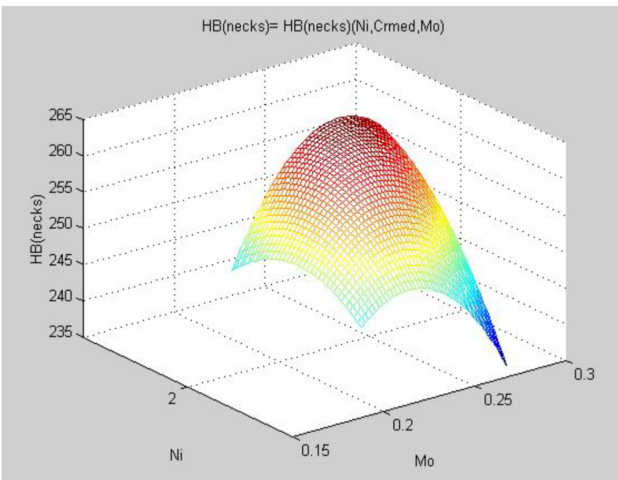


FIGURE 19. THE REGRESSION SURFACE
HB $_{(necks)}$ FOR **Cr = Cr$_{med}$**

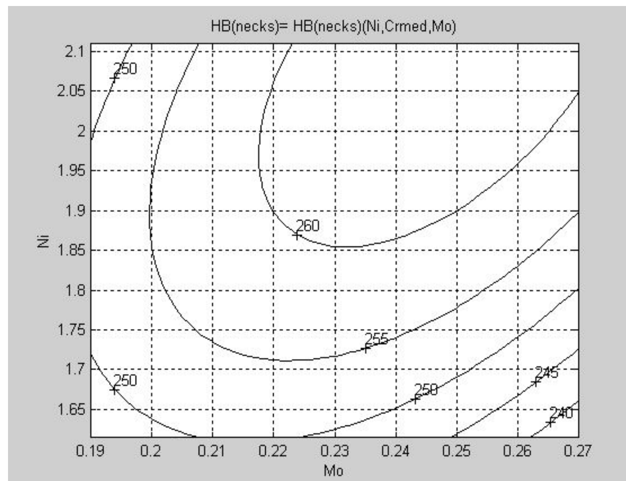


FIGURE 20. LEVEL CURVES
HB $_{(fusuri)}$ = f(Ni, Cr$_{med}$, Mo)

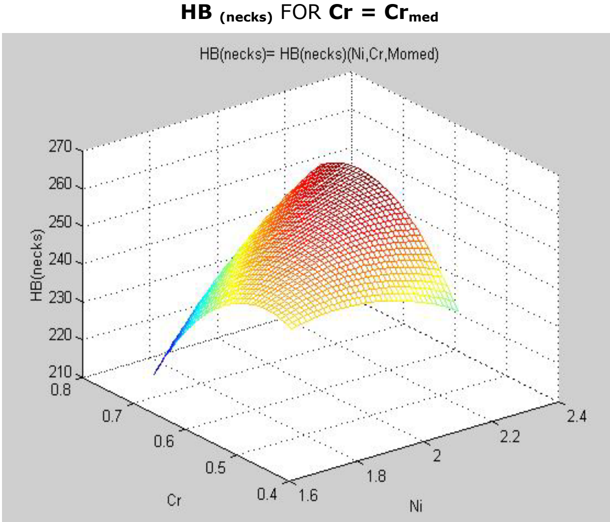


FIGURE 21. THE REGRESSION SURFACE
HB $_{(necks)}$ FOR **Mo = Mo$_{med}$**

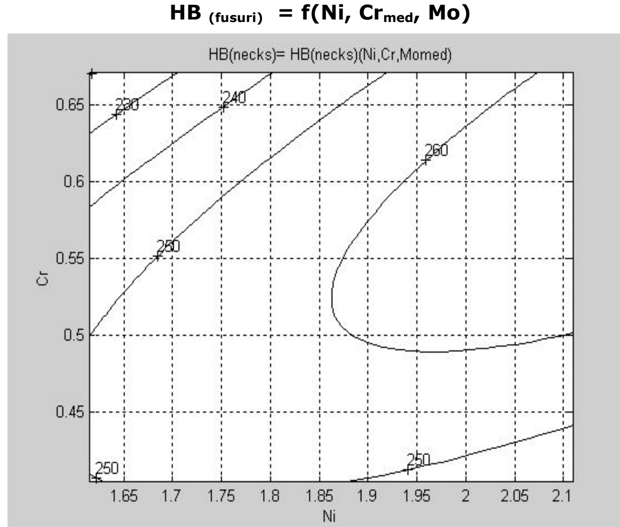


FIGURE 22. LEVEL CURVES
HB $_{(fusuri)}$ = f(Ni, Cr, Mo$_{med}$)

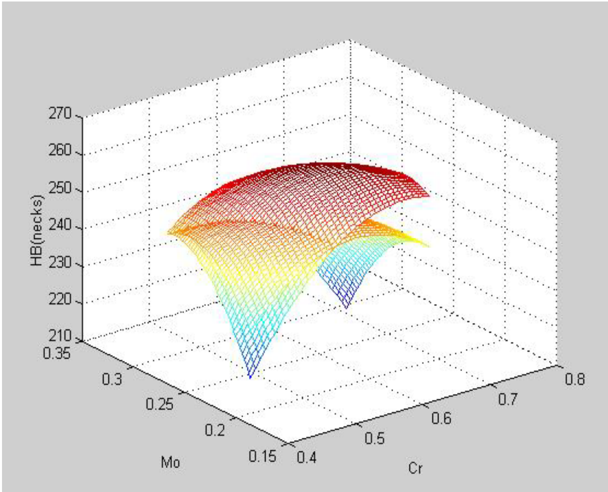


FIGURE 23. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Ni = Ni**$_{\text{med}}$

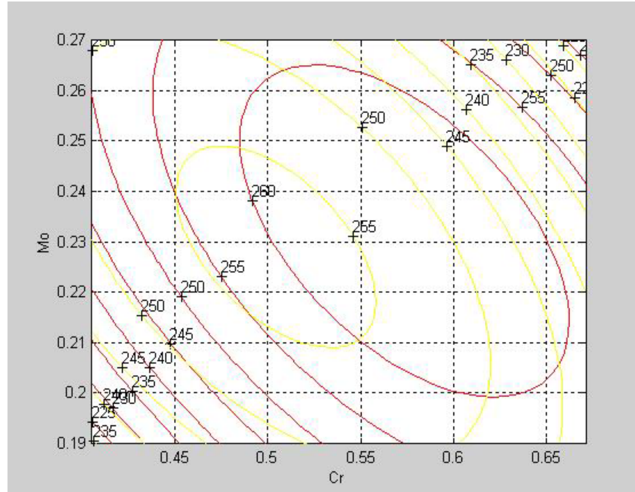


FIGURE 24. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Ni= Ni**$_{\text{med}}$

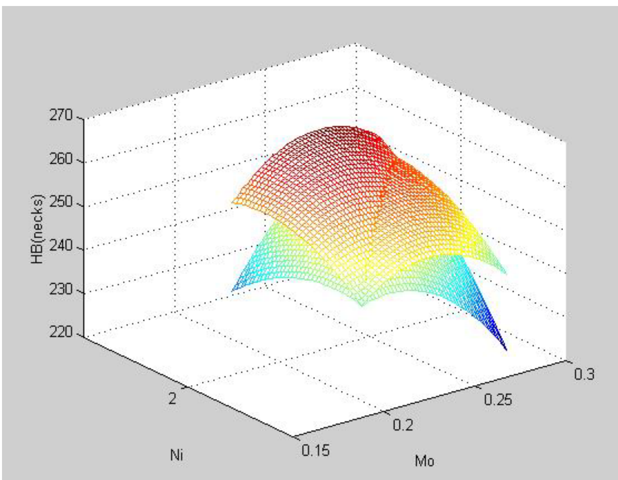


FIGURE 25. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Cr = Cr**$_{\text{med}}$

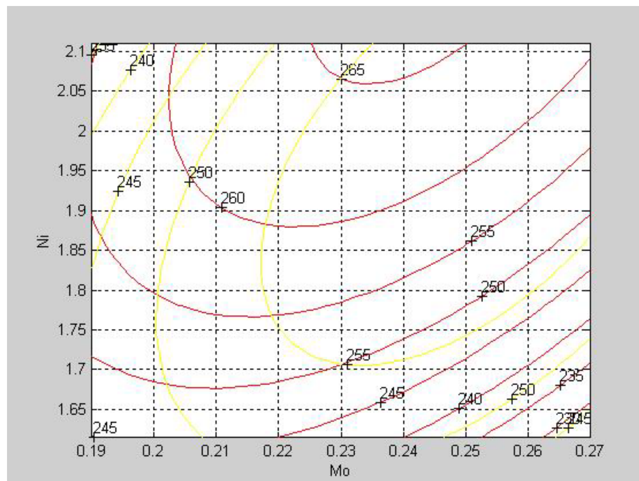


FIGURE 26. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Cr = Cr**$_{\text{med}}$

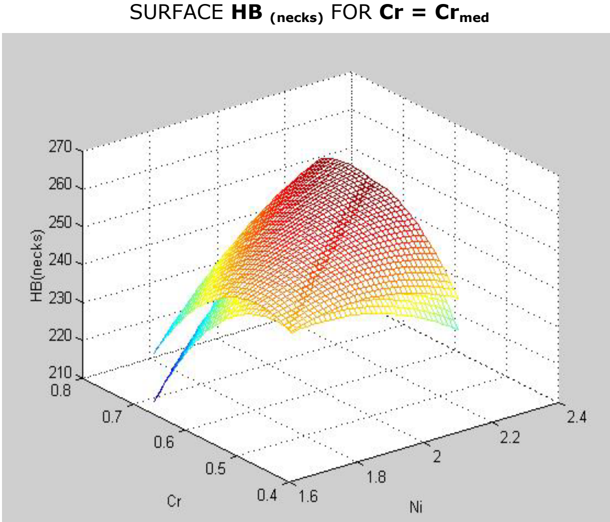


FIGURE 27. THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Mo = Mo**$_{\text{med}}$

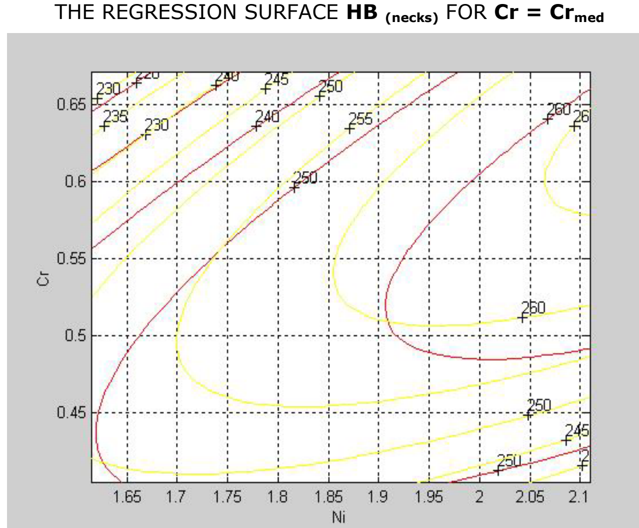


FIGURE 28. LEVEL CURVES FOR THE VOLUME VARIATION OF THE REGRESSION SURFACE **HB** $_{\text{(necks)}}$ FOR **Mo= Mo**$_{\text{med}}$

$$HB_{(body)} = -69.2668\,Ni^2 - 843.9321\,Cr^2 - 13082.6971\,Mo^2 + 258.4342\,Ni{\cdot}Cr - 3258.4415\,Cr{\cdot}Mo + 757.2487\,Mo{\cdot}Ni - 45.2572\,Ni + 1278.2053\,Cr + 6349.4428\,Mo - 739.6223 \quad (1)$$

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

$$HB_{(body)}Cr_{med} = -13082.6971\,Mo^2 - 69.2668\,Ni^2 + 757.2487\,Mo{\cdot}Ni + 4630.9691\,Mo + 91.0387\,Ni - 300.2406 \quad (3)$$

$$HB_{(body)}Mo_{med} = -69.2668\,Ni^2 - 843.9321\,Cr^2 + 258.4342\,Ni{\cdot}Cr + 135.8241\,Ni + 499.0128\,Cr + 30.6111 \quad (4)$$

$$HB_{(fusuri)} = -77.1259\,Ni^2 - 678.1307\,Cr^2 - 4915.8057\,Mo^2 + 384.4321\,Ni{\cdot}Cr - 1990.8226\,Cr{\cdot}Mo + 646.2006\,Mo{\cdot}Ni - 39.5771\,Ni + 471.3705\,Cr + 2131.6892\,Mo - 101.7176 \quad (5)$$

$$HB_{(necks)}\,Ni_{med} = -678.1307\,Cr^2 - 4915.8057\,Mo^2 - 1990.8226\,Cr{\cdot}Mo + 1189.7571\,Cr + 3339.2414\,Mo - 445.0005 \quad (6)$$

$$HB_{(necks)}\,Cr_{med} = -4915.8057\,Mo^2 - 77.1259\,Ni^2 + 646.2006\,Mo{\cdot}Ni + 1081.7467\,Mo + 163.1691\,Ni - 41.7373 \quad (7)$$

$$HB_{(necks)}\,Mo_{med} = -77.1259\,Ni^2 - 678.1307\,Cr^2 + 384.4321\,Ni{\cdot}Cr + 114.9492\,Ni - 4.6957\,Cr + 126.9318 \quad (8)$$

3. CONCLUSIONS

- the performed research had in view to obtain correlations between the hardness of the cast iron rolls (on the necks and on the working crust) and its chemical composition, defined by the representative alloying elements.
- the values processing were made using MATLAB calculation program. Using this calculation program we determinate some mathematical correlation, correlation coefficient and the deviation from the regression surface. This surface in the four-dimensional space (described by the equation 1 and 5) 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 this surface 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 2…4 and 6…8), belonging to the three-dimensional space can be reproduced and

therefore interpreted by technological engineers (FIGURES 5, 7, 9, 17, 19, 21). Knowing these level curves (FIGURES 6, 8, 10, 18, 20, 22) allows the correlation of the values of the two independent variables so that we can obtain a viscosity within the required limits.

- the optimal values of the alloying elements in this irons (chrome, nickel and molybdenum) are to be found on the diagrams of FIGURES 1…3. Thus the optimal additions can be determined in these elements to assure the proper hardnesses;
- the non-uniformity of the crust can be technologically imposed, just as in the case of the passing area;

4. BIBLIOGRAPHY / REFERENCES

[1] BUDAGHIANŢ, N.A., KARSSKI, V.E.: Cast Iron Rolls, Editura Tehnică, Bucureşti, 1984.

[2] SOFRONI, L., RIPOŞAN, I.: Iron Casting, Editura Tehnică, Bucureşti, 1985

[3] SOFRONI, L., STEFANESCU, D.M.: Special Irons, Editura Tehnică, Bucureşti, 1974

[4] SOFRONI, L., STEFANESCU, D.M.: Inoculate Irons with High Properties, Editura Tehnică, Bucureşti, 1971

[5] SOFRONI, L., STEFANESCU, D.M.: Irons with Nodular Graphite, Editura Tehnică, Bucureşti, 1974

[6] RIPOŞAN, I.: Nodular Graphite Iron for the Cast Iron Rolls, in: Buletin of University Politehnica Bucureşti, 1980/3

[7] SOFRONI, L., RIPOŞAN, I.: Contribution for the Improvement of the Cast Iron Rolls Quality, in: Metalurgia, 1983/10

[8] KISS, I.: Considerations Upon the Reject Forms of the Cast Iron Rolls, at Scientific Conference, Bucureşti, 2000

[9] KISS, I.: The Hardness of Cast Iron Rolls with Indefinite Structure, in: Symposium, Petroşani, 2001

[10] KISS, I., HEPUŢ, T.: Mechanical Properties of the Cast Iron Rolls, Assured by the Chemical Composition, Buletinul Ştiinţific al Universităţii Politehnica Timişoara, 2002

[11] KISS, I., HEPUŢ, T.: The Hardness of the Cast Iron Rolls, Assured by the Alloy Elements and the Modification Treatment of the Graphite Nodularity, Buletinul Ştiinţific al Universităţii Politehnica Timişoara, 2002

[12] KISS I., RATIU S., VILCEANU, L, ALEXA, V.: Particularităţi ale proprietăţilor mecanice la cilindri de laminor turnaţi din fonte cu grafit nodular, Simpozion International Universitaria ROPET, Petroşani, 2002

[13] KISS, I.; RAŢIU, S.; NICA, Gh.: Some Considerations Regarding the Mechanical Properties of the Cast Iron Rolls, Assured by the Chemical Composition and the Modification Treatment of the Graphite Nodularity (I), Scientific Conference Research and Development of Mechanical Elements and Systems Jahorina – IRMES, Sarajevo, Bosnia & Herzegovina, 2002

[14] KISS, I., HEPUŢ, T., RAŢIU, S.: The Hardness Of The Cast Iron Rolls, Assured by the Alloyed Elements and the Modification Treatment of the Graphite Nodularity, in: "MASINSTVO" – Journal of Mechanical Engineering, No.1 / 2003, Zenica, Bosnia & Herzegovina

[15] KISS, I.: The Mechanical Properties of the Semihard Cast Iron Rolls Assured by the Basic Elements, in: "MASINSTVO" – Journal of Mechanical Engineering, No.4 / 2003, Zenica, Bosnia & Herzegovina