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SOME MATHEMATICAL INTERPRETATIONS IN THE AREA OF CAST IRON CYLINDERS

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ABSTRACT

The technical conditions, which are imposed to the cast iron cylinders in the exploitation period, are very different and often contradictory. The obtaining of various physical and mechanical properties in the different points of the cylinders meets difficult technological problems in the industrial condition. This supposes us to know many technological factors, which lead to the exploitation of this deformation equipment.

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.

KEY WORDS:
cast iron rolls, alloying elements, hardness, technological parameters, mathematical interpretations, mathematical modeling

1. INTRODUCTION

The nodular graphite cast iron is considered as one of the most versatile roll materials nowadays. This 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 this type of rolls exhibits 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 cast 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 by the exploitation properties of the each roll in the stand of rolling mill, this leads to rejection. 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 raise the quality of rolls.

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.

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.

2. THE MATHEMATICAL INTERPRETATION

Having "*n*" experimental points, respectively $(x_1, y_1, u_1)_1$, $(x_1, y_1, u_1)_2$, ... $(x_1, y_1, u_1)_n$, we need to determine the real coefficients c_0, c_1 and c_2 in the equation of the plan. This is accomplished through the method of the smallest squares, which leads to finding them through the following system of three equations with three unknown variables (a_0, a_1, a_2):

$$\begin{cases} n \cdot c_0 + \left(\sum_{i=1}^{n}(x)_i\right) \cdot c_1 + \left(\sum_{i=1}^{n}(y)_i\right) \cdot c_2 = \sum_{i=1}^{n} u_i \\ \left(\sum_{i=1}^{n}(x)_i\right) \cdot a_0 + \left(\sum_{i=1}^{n}(x)_i^2\right) \cdot a_1 + \left(\sum_{i=1}^{n}(x)_i \cdot (y)_i\right) \cdot a_2 = \sum_{i=1}^{n}(x)_i \cdot u_i \\ \left(\sum_{i=1}^{n}(y)_i\right) \cdot a_0 + \left(\sum_{i=1}^{n}(x)_i \cdot (y)_i\right) \cdot a_1 + \left(\sum_{i=1}^{n}(y)_i^2\right) \cdot a_2 = \sum_{i=1}^{n}(y)_i^2 \cdot u_i \end{cases} \quad (1)$$

where the real coefficients (the sums from parentheses) are calculated tabularly. The solution of the system is done through the Cramer rule, using the determinants of the system.

Departing from the experimental results, in a first phase the stage are determined the mathematical models of dependencies for optimized parameters (the mechanical features the materials) with the technological parameters in the influences of the process, in the form of equation (2). In mathematical model it is reduced to complex mathematical processing of dependences in the features analyzed depending on two or three chemical elements, grouped depending on the influence upon them. Thus we can analyze dependences type (3).

$$\begin{gathered} HB_{(infneck)} = f(\text{basic chemical elements}) \\ HB_{(supneck)} = f(\text{basic chemical elements}) \\ HB_{(body)} = f(\text{basic chemical elements}); \\ HB_{(infneck)} = f(\text{alloying chemical elements}); \\ HB_{(supneck)} = f(\text{alloying chemical elements}); \\ HB_{(body)} = f(\text{alloying chemical elements}); \end{gathered} \qquad (2)$$

$$\begin{gathered} HB_{(infneck)} = f(C, Si, Mn); \\ HB_{(infneck)} = f(Ni, Cr, Mo); \\ HB_{(supneck)} = f(C, Si, Mn); \\ HB_{(supneck)} = f(Ni, Cr, Mo); \\ HB_{(body)} = f(C, Si, Mn); \\ HB_{(body)} = f(Ni, Cr, Mo); \end{gathered} \qquad (3)$$

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. As parameters for optimization we selected:

- the Brinell hardness, measured on the body of rolls, $HB_{(body)}$;
- the Brinell hardness, measured on the necks of rolls, $HB_{(infnecks)}$ and $HB_{(supnecks)}$.

In order to reduce the experiments number and to simplify the optimization calculi, among the parameters of influence, we chose the chemical composition of the cast irons with nodular graphite. These hypotheses lead the optimization model through the prism of the multi-component correlations in formula (II)

The industrial data are modeled in the form of equation (4). We consider the variations limits of the variables (x, y, z), as well as the variation limits of the analyzed features. Also, in the limits of graphical representation ($lim\ x_{inf}$, $lim\ x_{sup}$, $lim\ y_{inf}$, $lim\ y_{sup}$, $lim\ z_{inf}$, $lim\ z_{sup}$), as well as the average values of the variables and of the analyzed features (x_{med}, y_{med}, z_{med}, u_{med}) are stated.

$$\begin{aligned} u\,(x, y, z) = {} & C_1 x^2 + C_2 y^2 + C_3 z^2 + C_4 y z + C_5 x z \\ & + C_6 y x + C_7 x + C_8 y + C_9 z + C_{10} \end{aligned} \qquad (4)$$

At that rate, the equations of the regression hyper-surfaces are in equation (3), for which there is a correlation coefficient (*rf*) and a deviation from the regression surface (*sf*).

3. THE PRESENTATION OF GRAPHICAL INTERFACES USING THE ELECTRONIC CALCULATION PROGRAM

Fig.1 presents the screen which generates the regression surfaces of the variable ($HB_{(body)}$, $HB_{(infnecks)}$, $HB_{(supnecks)}$) for the cases $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$, waves x, y, z represent combination of chemical elements depending on the mathematical model under study.

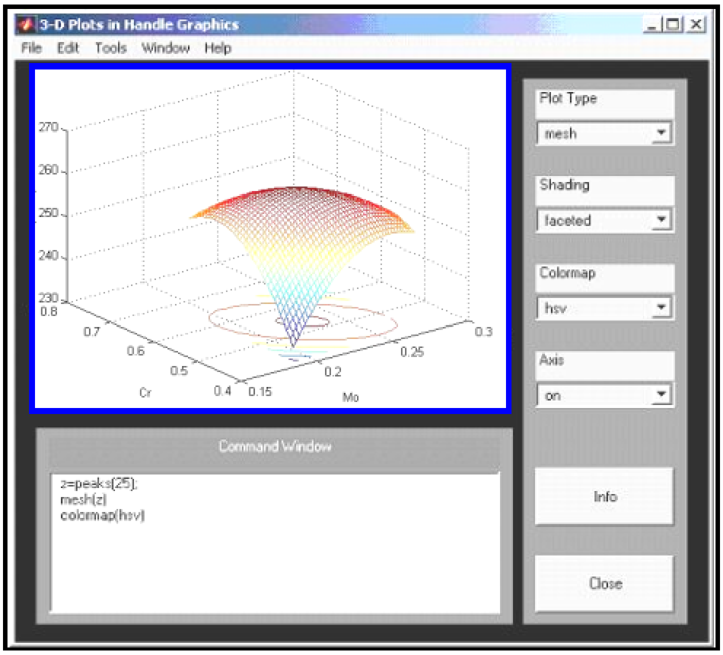

Fig.1. Regression surface of the variabile u ($HB_{(body)}$, $HB_{(infnecks)}$, $HB_{(supnecks)}$) for the cases $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$

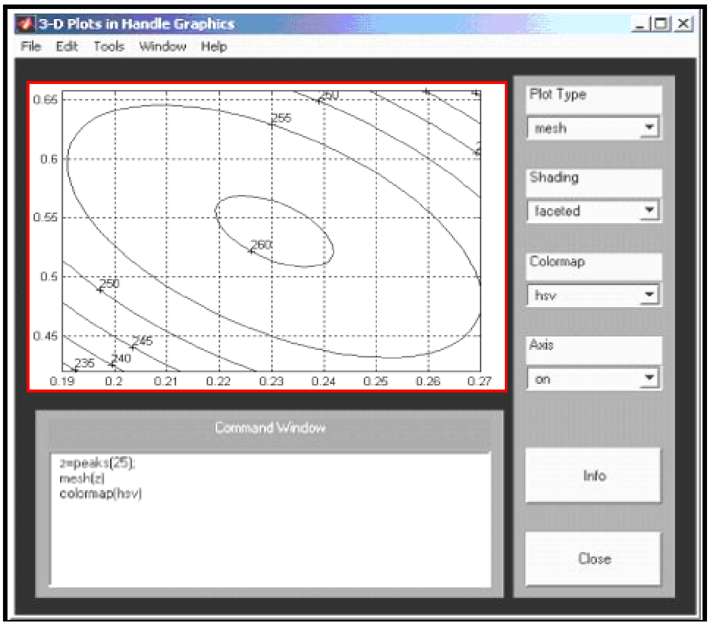

Fig.2. The level curves generation for the dependences $u = f(x, y, z)$, formally $u = f(x_{med}, y, z)$, $u = f(x, y_{med}, z)$ and $u = f(x, y, z_{med})$

Fig.2 presents the program screen capture which generates the level curves of the dependence $u = f(x, y, z)$, formally $u = f(x_{med}, y, z)$, $u = f(x, y_{med}, z)$ and $u = f(x, y, z_{med})$ for the cases $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$. This level curves represents the projection in the two-dimensional plan of the regression surfaces presented in the Fig.1.

Fig.3 presents the screen which generates the variation domain of the characteristics $u = f(x, y, z)$, formally $u = f(x_{med}, y, z)$, $u = f(x, y_{med}, z)$ and $u = f(x, y, z_{med})$ for the cases $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$. This geometrical areas represents level curves variations in the two-dimensional plan.

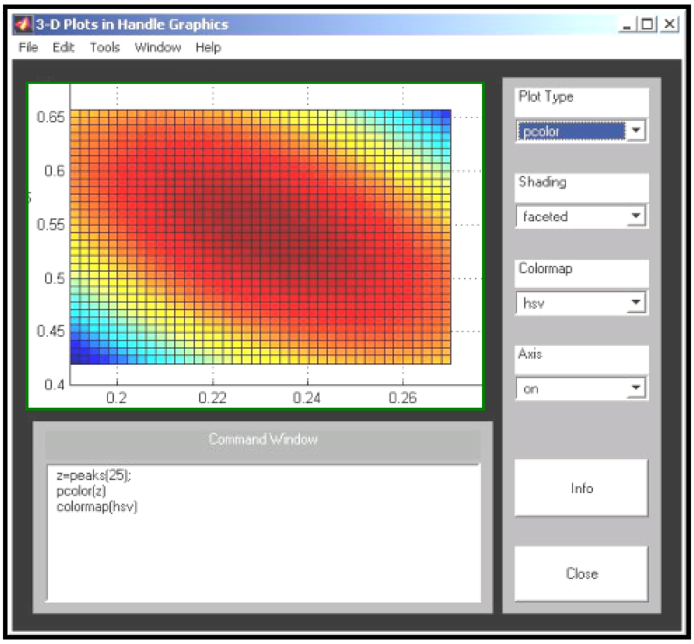

Fig.3. Screen for the variation domain generation of the dependences $u = f(x, y, z)$, formally $u = f(x_{med}, y, z)$, $u = f(x, y_{med}, z)$ and $u = f(x, y, z_{med})$

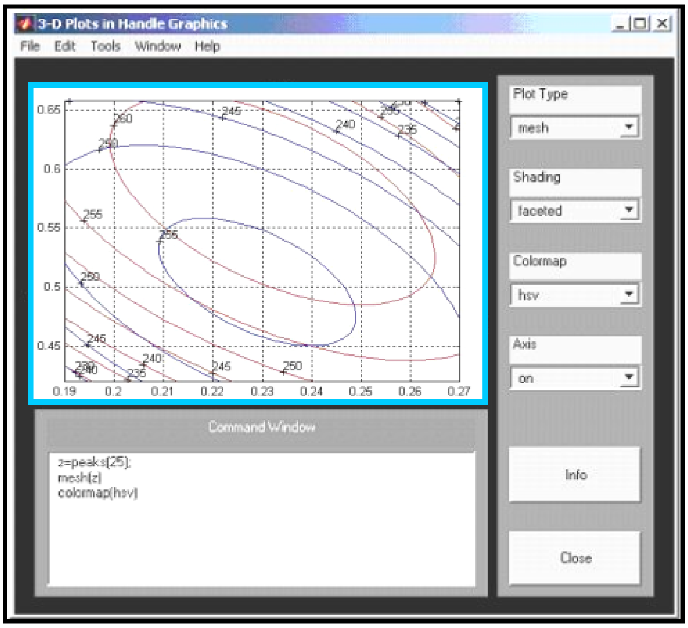

Fig.4. Screen for the adjusting diagrams generation built for the average values ale parameters (x_{med}, y_{med}, z_{med})

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 (Fig. 4), with which we can completely controlled the process.

Fig.5 presents the screen, which generates the correlation surfaces, meaning the projection in the two-dimensional plan of the variation volumes of the regression surfaces. These are obtained through superposing of the $u = f(x_{med}, y_{med}, z_{med})$ and one of surfaces corresponding for the average values $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$, meaning $u = f(x_{med}, y, z)$, $u = f(x, y_{med}, z)$ and $u = f(x, y, z_{med})$.

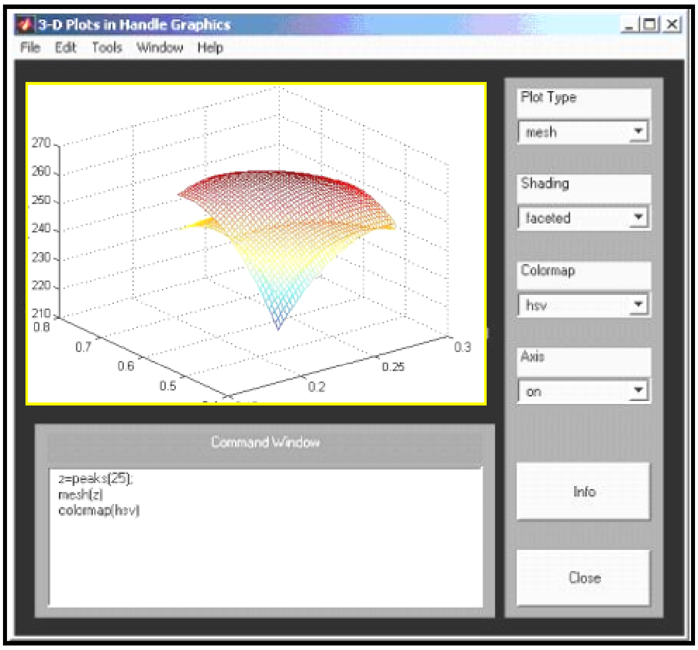

Fig.5. Screen for the regression surface volume variation generation for the average values $x = x_{med}$, $y = y_{med}$ and $z = z_{med}$

4. CONCLUSIONS

- the performed study had in view to obtain correlations between the hardness of the cast iron rolls (on the necks and on the working surface) and its chemical composition, defined by basic and the representative alloying elements.
- the values processed were made using Matlab calculation program. Using this calculation program we determine some mathematical correlation, correlation coefficient and the deviation from the regression surface. This surface in the four-dimensional space (described by the equation) admits a saddle point to which the corresponding value of hardness is an optimal value of 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 behavior 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 average 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 concentric 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), 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 a viscosity within the required limits.

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