REVISTA DE METALURGIA, 48 (2)
MARZO-ABRIL, 85-96, 2012
ISSN: 0034-8570
eISSN: 1988-4222
doi: 10.3989/revmetalm.1118

Investigations upon the indefinite rolls quality assurance in multiple regression analysis[(·)]

I. Kiss*

Resumen

The rolling rolls quality has been enhanced mainly due to the improvements of the chemical compositions of rolls materials. 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 a higher importance in this sense. This paper continues to present the scientifically results of our experimental research in the area of the rolling rolls. The basic research contains concrete elements of immediate practical utilities in the metallurgical enterprises, for the quality improvements of rolls, having in last as the aim the durability growth and the safety in exploitation. This paper presents an analysis of the chemical composition, the influences upon the mechanical properties of the indefinite cast iron rolls. We present some mathematical correlations and graphical interpretations between the hardness (on the working surface and on necks) and the chemical composition. Using the double and triple correlations which is really helpful in the foundry practice, as it allows us to determine variation boundaries for the chemical composition, in view the obtaining the optimal values of the hardness. We suggest a mathematical interpretation of the influence of the chemical composition over the hardness of these indefinite rolling rolls. In this sense we use the multiple regression analysis which can be an important statistical tool for the investigation of relationships between variables. The enunciation of some mathematically modeling results can be described through a number of multi-component equations determined for the spaces with 3 and 4 dimensions. Also, the regression surfaces, curves of levels and volumes of variations can be represented and interpreted by technologists considering these as correlation diagrams between the analyzed variables. In this sense, these researches results can be used in the engineers collectives of the foundries and the rolling mills sectors, for quality assurances of rolls as far back as phase of production, as well as in exploitation of these, what lead to, inevitably, to the quality assurance of produced laminates.

Palabras clave

Indefinite rolls; Optimal chemical composition; Regression analysis; Hardness; Mathematical correlations.

Investigaciones sobre el aseguramiento de la calidad de los cilindros de laminación indefinida mediante análisis de regresión múltiple

Abstract

Con este trabajo se ha logrado asegurar la calidad de los cilindros de laminación, debido fundamentalmente a la aportación de una determinada composición química a los materiales cilíndricos. Esta composición química mejorada, puede desarrollar de una forma efiicaz las propiedades de explotación, donde estos cilindros de laminación podrán ser fabricados, ofreciendo mejores resultados. El trabajo se presenta de una forma científica, aportando los resultados de una investigación experimental en el área de los cilindros de laminación. Dicha investigación contiene elementos suficientes y de inmediata utilidad práctica para las empresas metalúrgicas, y así de esta forma, mejorar la calidad de los cilindros de laminación. El objetivo principal es el aumento de la durabilidad y la seguridad en la explotación. En este proceso se presenta un análisis de la composición química y de la influencia sobre las propiedades mecánicas de los cilindros de laminación indefinida. Presentamos algunas correlaciones matemáticas añadiendo una interpretación gráfica entre la dureza (en la superficie de trabajo y el cuello) y la composición química. La determinación de las correlaciones dobles y triples, que son realmente útiles en la práctica de la fundición, nos permite determinar los límites de variación de la composición química, con vistas a obtener los valores óptimos de la dureza.Se podrá observar una interpretación matemática de la influencia de la composición química, sobre la dureza de estos cilindros de laminación. En este sentido, realizamos el análisis de regresión múltiple el cual puede aportar un importante instrumento estadístico para la investigación de las relaciones entre las variables. Los resultados matemáticamente modelados, pueden ser descritos mediante una serie de ecuaciones multicomponentes determinados por los espacios con dimensiones 3 y 4. Las superficies de regresión, curvas de niveles y volúmenes de variaciones, pueden ser representados e interpretados por técnicos , considerando estos como diagramas de correlación entre las variables analizadas. En este sentido, los resultados de estas investigaciones pueden ser utilizados por ingenieros de las fundiciones y sectores laminadores, ofreciendo garantías de calidad de los cilindros de laminación. en fase de producción, así como la explotación de estos, qué llevará, inevitablemente, el aseguramiento de una calidad de los laminados producidos.

Keywords

Cilindros; Composición química óptima; Análisis de regresión múltiple; Dureza; Relaciones matemáticas; Adiciones gráficas.

(·) Trabajo recibido el día 29 de marzo de 2011 y aceptado en su forma final el día 17 de febrero de 2012.
* University Politehnica Timisoara, Faculty of Engineering-Hunedoara, Department of Engineering & Management, Romania.

1. INTRODUCTORY NOTES

The definite chilled iron rolls have a high-hardness layer of white cast iron at the surface. The increased hardness is obtained by alloy additions-mainly nickel, chromium and molybdenum which modify the matrix structure to produce harder acicular phase. The core material can be either flake or nodular iron according to the requirement. The flake core display better thermal properties while the nodular iron achieves greater mechanical strength[1 and 2].

The indefinite chilled iron rolls consist of cast iron with fine interdendritic graphite evenly dispersed throughout the barrel of the roll. The size, shape and distribution of the graphite together with carbide content is controlled by the chilling effect and the alloy content. The additional of alloys such as manganese, nickel, chromium and molybdenum changes the matrix structure from pearlitic, bainite, to martensitic. Presence of these alloys produces rolls with restricted hardness drop along the cross sections. Inside chilling layer of rolls, there are tiny and disperse graphite, the quantity of which slowly and levelly increases from the outside to inside, the chilling depth, thereby, without obvious limits. Compared to the definite chilled iron roll where the chill-zone is graphite-free clear white, the indefinite roll is cast using such proportions of silicon, chromium, nickel and molybdenum that the working face is no longer completely white but contains a small amount of very finely divided graphite flakes gradually increasing from face to core with corresponding decrease in the amount of carbide. The rolls are to ensure minimum sacrifice of clear chill while achieving maximum functional depth. All these products are highly durable and performance oriented.

The transition from chill to graphite being smoother, the gradual change in hardness associated with the indefinite-chill structure allows deeper grooving[1 and 2].Thus indefinite chill rolls are superior in biting performance and have enough strength and resistance against thermal shock occurring at the time of accident in the rolling operation compared to clear chill rolls. Rolls of this type have hardness up to about 70 degrees Shore *C* can be grooved for use in roughing and finishing stands, for processing sections such as T-bars and U-sections, and for roughing and intermediate rolling rolls of wire and rod mills[1, 2, 3 and 4].

From point of view of the application, these rolls are used on finishing stands of continuous hot rolling strip mills and continuous bar mills, pre-finishing stands of high-speed wire mills, intermediate and finishing stands of light section mills. The indefinite chill rolls are used on roughing and intermediate stands of various types of continuous rolling mills and finishing stands of bar mill. The nodular indefinite chill rolls are used as the secondary finishing and back-up rolls in section mill and hot rolling strip mill. Also, the nodular indefinite chill rolls are suitable for use on stainless-steel hot rolling strip mills[1, 2, 3 and 4]. This study analyses indefinite chill rolls cast in the simplex procedure, in combined forms (iron chill, for the crust and molding sand, for the necks of the rolls). The research included indefinite chill rolls with the hardness of these rolls ranging from 45 degrees to 55 degrees shore *C* (roughing stand rolls, diameter 300 mm to 600 mm and length from 600 mm to 1200 mm), 60 degrees to 65 degrees shore C (intermediate stand rolls, 250 mm to 360 mm in diameter and length from 500 mm to 600 mm) and rolls ranging from 70 degrees to 75 degrees shore *C* (finishing stand rolls, 250 mm to 360 mm in diameter and length from 500 mm to 600 mm).

This study analyses indefinite chill rolls cast in the simplex procedure, in combined forms (iron chill, for the crust and molding sand, for the necks of the rolls). The recommended hardness of the indefinite cast-iron rolls in table I is presented.

Table I. Recommended hardness of the indefinite cast-iron rolls

Tabla I. Dureza recomendada de los cilindros de laminación indefinida

Analyzed roll types	Hardness Class	Recommended hardness of rolls, [degrees shore C hardness]	
		on the working surface, $HS_{(rolling\ surface)}$	on the core and the necks, $HS_{(necks)}$
Indefinite chilled iron rolls-hard class	1	59-68	45-60
Indefinite chilled iron rolls-hard class	2	69-75	45-65

Rev. metal. 48 (2), MARZO-ABRIL, 85-96, 2012, ISSN: 0034-8570, eISSN: 1988-4222, doi: 10.3989/revmetalm.1118

2. ABOUT THE ROLLS QUALITY ASSURANCE

The entire operations from selection of materials to dispatch of finished products go through a series of quality control checks conducted by a team of metallurgists. The products are tested for surface hardness by the conventional hardness testing equipment along with sample checks in the laboratory to confirm to specification defined by the customers. The metallographic and mechanical tests are carried out to ensure the over all internal soundness, in particular, the quality of bound between the rolling surface and the core.

One of the most important requirements imposed on both work and backup rolls in hot rolling mills is a high hardness of the roll-rolling surface and a sufficient quenched-layer (working-layer) depth[1, 2, 3 and 4]. These requirements are caused by the fact that the strength of the deformed material increases during rolling; as a result, the possibility of reduction decreases. The uniform hardness of rolls should ensure a high-quality sheet surface, increase the wear resistance of the working layer in the roll, and decrease the degree of its damage[1 and 2].

Depicted, developed, specified process and methods have been institutionalized for achieving the quality requirements of products of various grades. Synchronization between all activities and sub process are maintained to build desired properties in products.

The roll quality has been enhanced mainly due to the improvement of the chemical compositions of rolls materials. Increasing the resistance of rolls requires the proper distribution of residual stresses over the cross section of the roll rolling surface[1 and 2].

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. From this point of view is applied the mathematical modeling, witch is achieved starting from the differentiation on rolls component parts, taking into consideration the industrial data obtained from the rolls hardness, as well as the national standards requirements, which recommends the hardness, for different chemical compositions[1, 2, 5-10].

Specific requirements are made for each hot rolled strip, not only regarding width, thickness and length, but also with regard to metallurgic properties. To achieve this, we use mathematical models developed in ©Matlab area[11-13].

3. ABOUT THE MULTIPLE REGRESSION ANALYSIS

Therefore, we suggest a mathematical interpretation of the influence of the chemical composition over the hardness (on the necks and on the rolling surface) of these indefinite rolls. In this sense we use the regression analysis which can be an important statistical tool for the investigation of relationships between variables. We seeks to ascertain the causal effect of one variable upon another-the effect of a irons chemical composition increase upon hardness of the indefinite cast-iron rolls, in our case.

The multiple is a technique that allows additional factors to enter the analysis separately so that the effect of each can be estimated[11, 15 and 16]. It is valuable for quantifying the impact of various simultaneous influences upon a single dependent variable. Further, because of omitted variables dues to the simple regression (like a simple ©Excel representation), the multiple regression is often essential even when the investigator is only interested in the effects of one of the independent variables[1, 2, 14-16].

In statistics, regression analysis includes any techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps us understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed[2, 5-10]. Multiple regression analysis is in fact capable of dealing with an arbitrarily large number of explanatory variables. For the multidimensional processing of experimental data, is searched for a method of modeling the hardness (dependent variables) depending on the chemical components (independent variables)[1 and 2]. With n explanatory variables, multiple regression analysis will estimate the equation of a hyper surface in n-space such that the sum of squared errors has been minimized[1, 2 and 10]. In our case we use eight variables and (according to the table II) these are: carbon (C), silicon (Si), manganese (Mn), nickel (Ni), chromium (Cr), molybdenum (Mo), phosphorus (P) and sulfur (S). As dependent variables we used $HS_{(rolling\ surface)}$, respectively $HS_{(necks)}$[1 and 2].

Using the multiple regression we determinate some correlations between the hardness and the components of the irons chemical composition. Using the double and triple correlations (co-variations of two or three variables which have influence upon the dependent variables) is really helpful in the foundry practice, as it allows us to

Table II. Recommended chemical composition of the indefinite cast-iron rolls

Tabla II. Composición química recomendada del cilindro de laminación indefinida

Rolls Types	Chemical Composition, [%]							
	C	Si	Mn	P	S	Ni	Cr	Mo
Indefinite chilled iron rolls – hard class 1	3.2 3.4	1.1 1.5	0.3 0.6	0.15	0.05	2.2 3.5	0.7 1.0	0.3 0.5
Indefinite chilled iron rolls – hard class 2	3.1 3.4	0.8 1.2	0.5 0.8	0.15	0.05	2.8 3.2	0.8 1.2	0.3 0.5

determine variation boundaries for the chemical composition, in view the obtaining the desired and optimal values of the hardness on the necks and on the rolls rolling surface.

4. MATHEMATICAL INTERPRETATION AND GRAPHICAL ADDENDA

To determine the hardness variation (measured in degrees shore *C*) on the rolls rolling surface and on the necks, determined by the basic elements, respectively by the alloying elements content, the calculus program shall determine the average values, which are presented in table III.

Next we present the results of the multidimensional processing of the experimental data. In the experiments destined to the hardness variation on the rolling surface the optimal forms for the simulation are given by the regression hyper-surface equations (1-3). The optimal forms of modeling, studied on a sample of the cases, differentiated for the two technological zones of the rolls (necks and rolling surfaces), are given by these equations.

$$HS_{(rolling\ surface)} = 250.5611\ C^2 - 13.2732\ Si^2 - 43.7058\ Mn^2 - 74.0716\ C\ Si - 107.3683\ Si\ Mn - 380.0182\ Mn\ C - 1342.6039\ C + 318.8083\ Si + 1361.0911\ Mn + 1724.7641 \quad (1)$$

$$HS_{(rolling\ surface)} = 51.4723\ Cr^2 - 1.7318\ Ni^2 - 132.3277\ Mo^2 - 13.2882\ Cr\ Ni + 39.1779\ Ni\ Mo - 21.6965\ Mo\ Cr - 64.083\ Cr + 16.7549\ Ni - 8.6636\ Mo + 74.0582 \quad (2)$$

$$HS_{(rolling\ surface)} = 116.0963\ C^2 - 2238.3377\ S^2 + 19.0403\ P^2 - 1337.8405\ C\ S - 925.4455\ S\ P + 441.0629\ P\ C - \quad (3)$$

Table III. Average value

Tabla III. Valor medio de durezas

	Average value [%]		Average value [%]
C	3.22	Cr	1.12
Si	1.03	Ni	3.02
Mn	0.51	Mo	0.35
S	0.04	P	0.24
Hardness on rolling surface [HS]	70	Hardness on necks [HS]	68

Rev. metal. 48 (2), MARZO-ABRIL, 85-96, 2012, ISSN: 0034-8570, eISSN: 1988-4222, doi: 10.3989/revmetalm.1118

$$- 783.4358\ C + 4792.4738\ S - 1365.4297\ P + 1367.8144$$

In the experiments destined to the hardness variation on the necks (and, also, in the core) the optimal forms for the simulation are given by the regression hyper-surface equations (4-6).

$$HS_{(necks)} = 120.3068\ C^2 - 13.2135\ Si^2 + 33.4065\ Mn^2 - 111.1691\ C\ Si - 126.0437\ Si\ Mn - 146.1125\ Mn\ C - 581.6597\ C + 448.8427\ Si + 552.0267\ Mn + 629.7934 \quad (4)$$

$$HS_{(necks)} = 26.0559\ Cr^2 - 1.7433\ Ni^2 - 155.3718\ Mo^2 - 13.0093\ Cr\ Ni + 31.1541\ Ni\ Mo - 46.9943\ Mo\ Cr - 1.594\ Cr + 18.0408\ Ni + 64.7345\ Mo + 24.537 \quad (5)$$

$$HS_{(necks)} = 21.0352\ C^2 - 1818.1936\ S^2 + 63.3272\ P^2 - 1075.8714\ C\ S - 1006.7249\ S\ P + 378.5439\ P\ C - 167.2904C + 3912.2531\ S - 1184.1818\ P + 370.9232 \quad (6)$$

The regression hyper-surfaces behavior in the vicinity of the point where the three independent variables have average value can only be studied, by attributing the three independent variables values on spheres concentric to the studied point. Since this surface cannot be represented in the four-dimensional space, each independent variable was replaced successively with its average value. Thus, the equivalent equations which correspond to the analyses of the hardness variation on the rolling surface in formula pack (7-15) are presented. Similarly, the equivalent equations which correspond to the analyses of the hardness variation on the necks in the formula pack (16-24) are presented.

$$HS_{(rolling\ surface)}\ C_{med} = - 13.2732\ Si^2 - 43.7058\ Mn^2 - 107.3683\ Si\ Mn + 79.8461\ Si + 135.1145\ Mn + 1.1596 \quad (7)$$

$$HS_{(rolling\ surface)}\ Si_{med} = - 43.7058\ Mn^2 + 250.5611\ C^2 - 380.0182\ Mn\ C + 1250.0293\ Mn - 1419.2236\ C + 2040.3373 \quad (8)$$

$$HS_{(rolling\ surface)}\ Mn_{med} = 250.5611\ C^2 - 13.2732\ Si^2 - 74.0716\ C\ Si - 1536.5272\ C + 264.0182\ Si + 2407.9476 \quad (9)$$

$$HS_{(rolling\ surface)}\ Cr_{med} = - 1.7318\ Ni^2 - 132.3277\ Mo^2 + 39.1779\ Ni\ Mo + 1.7605\ Ni - 33.1459\ Mo + 67.2859 \quad (10)$$

$$HS_{(rolling\ surface)}\ Ni_{med} = - 132.3277\ Mo^2 + 51.4723\ Cr^2 - 21.6965\ Mo\ Cr + 109.7909\ Mo -104.2599\ Cr + 108.8857 \quad (11)$$

$$HS_{(rolling\ surface)}\ Mo_{med} = 51.4723\ Cr^2 + 1.7318\ Ni^2 -13.2882\ Cr\ Ni - 71.718\ Cr + 30.5417\ Ni + 54.6229 \quad (12)$$

$$HS_{(rolling\ surface)}\ C_{med} = - 2238.3377\ S^2 + 19.0403\ P^2 - 925.4455\ S\ P + 476.4667\ S + 57.4833\ P + 48.6704 \quad (13)$$

$$HS_{(rolling\ surface)}\ S_{med} = 19.0403\ P^2 + 116.0963\ C^2 + 441.0629\ P\ C - 1409.6382\ P - 847.3444\ C + 1591.6431 \quad (14)$$

$$HS_{(rolling\ surface)}\ P_{med} = 116.0963\ C^2 - 2238.3377\ S^2 - 1337.8405\ C\ S - 677.5631\ C + 4570.3299\ S + 1041.1537 \quad (15)$$

$$HS_{(necks)}\ C_{med} = - 13.2135\ Si^2 + 33.4065\ Mn^2 - 126.0437\ Si\ Mn + 90.2111\ Si + 80.6533\ Mn + 5.4205 \quad (16)$$

$$HS_{(necks)}\, Si_{med} = 33.4065\, Mn^2 + 120.3068\, C^2 - 146.1125\, Mn\, C + 421.6471\, Mn - 696.6531\, C + 1079.9381 \quad (17)$$

$$HS_{(necks)}\, Mn_{med} = 120.3068\, C^2 - 13.2135\, Si^2 - 111.1691\, C\, Si - 656.2209\, C + 384.5226\, Si + 920.1918 \quad (18)$$

$$HS_{(necks)}\, Cr_{med} = - 1.7433\, Ni^2 - 155.3718\, Mo^2 + 31.1541\, Ni\, Mo + 3.3611\, Ni + 11.7061\, Mo + 55.9149 \quad (19)$$

$$HS_{(necks)}\, Ni_{med} = - 155.3718\, Mo^2 + 26.0559\, Cr^2 - 46.9943\, Mo\, Cr + 158.9289\, Mo - 40.9278\, Cr + 63.1471 \quad (20)$$

$$HS_{(necks)}\, Mo_{med} = 26.0559\, Cr^2 - 1.7433\, Ni^2 - 13.0093\, Cr\, Ni - 18.1313\, Cr + 29.0039\, Ni + 28.0768 \quad (21)$$

$$HS_{(necks)}\, C_{med} = - 1818.1936\, S^2 + 63.3272\, P^2 - 1006.7249\, S\, P + 441.3842\, S + 37.0385\, P + 50.1543 \quad (22)$$

$$HS_{(necks)}\, S_{med} = 63.3272\, P^2 + 21.0352\, C^2 + 378.5439\, P\, C - 1232.2731\, P - 218.6848\, C + 553.6622 \quad (23)$$

$$HS_{(necks)}\, P_{med} = 21.0352\, C^2 - 1818.1936\, S^2 - 1075.8714\, C\, S - 76.4247\, C + 3670.5989\, S + 90.3208 \quad (24)$$

The obtained surface regression and the contour lines are shown in figures 1-6 (in the case of the rolling surface), respectively in figures 7-12 (in the case of the rolls necks).

The regression surfaces are rendered in figures 1, 3 and 5, in the case of the rolling surface. By sectioning these surfaces with level planes (Figs. 2, 4 and 6), a more correct quantitative interpretation regarding the fair determining of the indefinite rolls rolling surface hardness value shall be obtained by establishing the optimal variation field of the chemical composition.

In the case of the necks, the regression surfaces obtained using the multiple regression analysis in figures 7, 9 and 11 are rendered. The level curves which present the optimal domains of the chemical elements in the figures 8, 10 and 12 are presented.

Taking into consideration the obtained equations we can drawing the multiple linear regression forms which describes the influences of the all chemical elements. Therefore, we can conclude about the forms of equations enounced below (equations 25 and 26), which describe the regression hyper-planes.

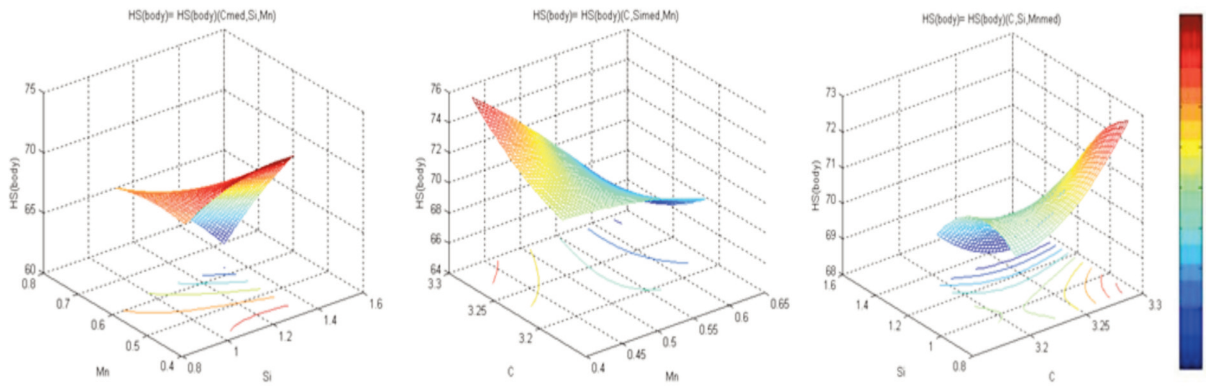

Figure 1. Regression surfaces $HS_{(rolling\ surface)}$ for middle value of silicon, manganese and carbide (case of the surface).

Figura 1. Superficies de regresión $HS_{(rolling\ surface)}$ para el valor medio del silicio, manganeso y carbono (caso de la superficie).

Rev. metal. 48 (2), MARZO-ABRIL, 85-96, 2012, ISSN: 0034-8570, eISSN: 1988-4222, doi: 10.3989/revmetalm.1118

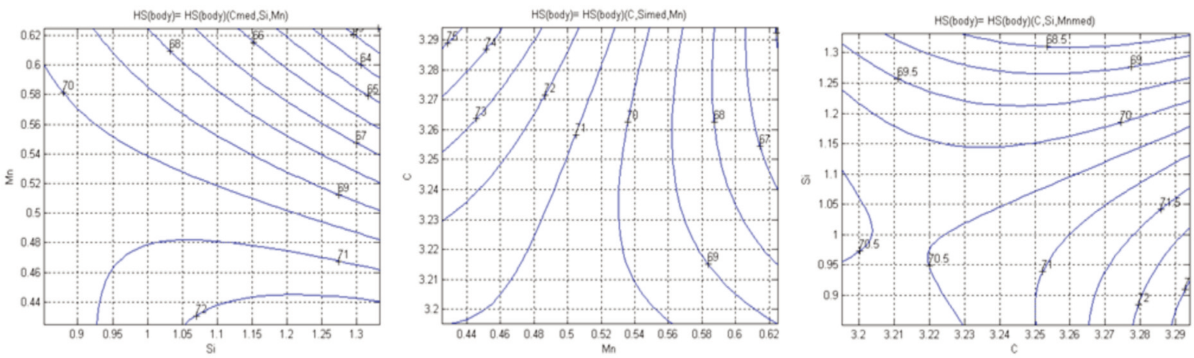

Figure 2. Level curves for the middle value of the silicon, manganese and carbide (case of the surface).

Figura 2. Curvas de nivel para el valor medio del silicio, manganeso y carbono (caso de la superficie).

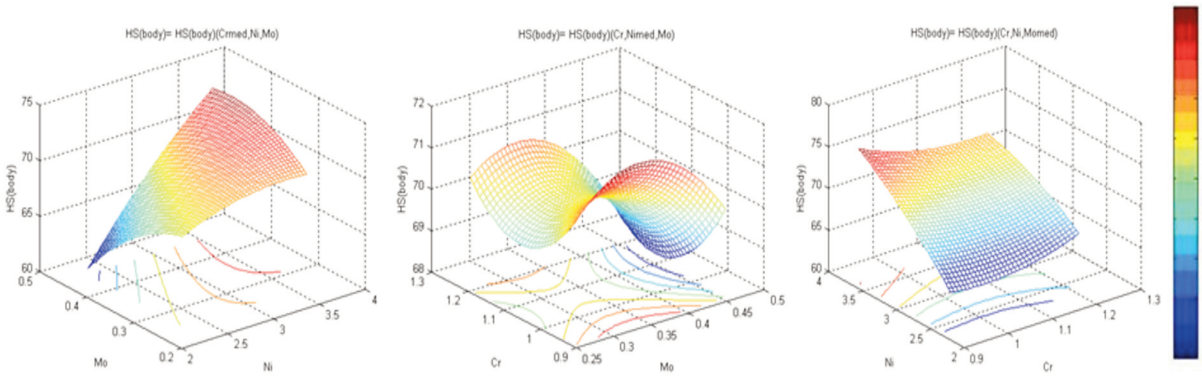

Figure 3. Regression surfaces $HS_{(rolling\ surface)}$ for middle value of nickel, molybdenum and chromium (case of the surface).

Figura 3. Superficies de regresión $HS_{(rolling\ surface)}$ para el valor medio del níquel, molibdeno y cromo (caso de la superficie).

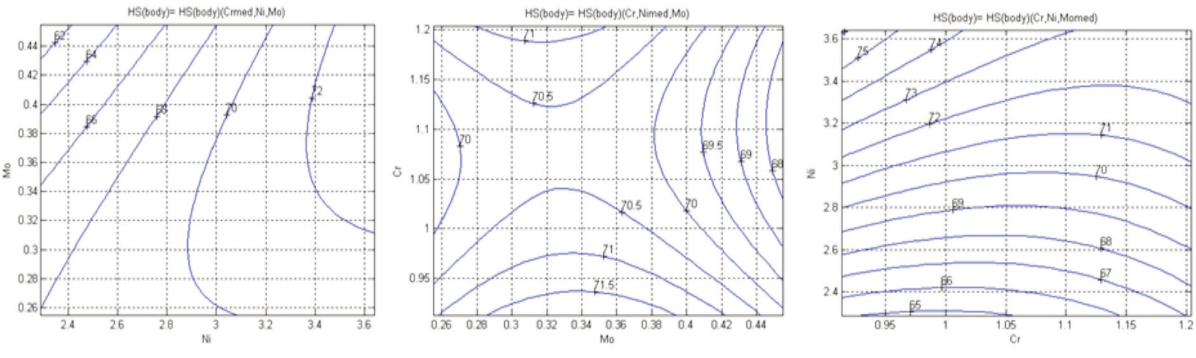

Figure 4. Level curves for the middle value of the nickel, molibdenum and chromium (case of the surface).

Figura 4. Curvas de nivel para el valor medio del níquel, molibdeno y cromo (caso de la superficie).

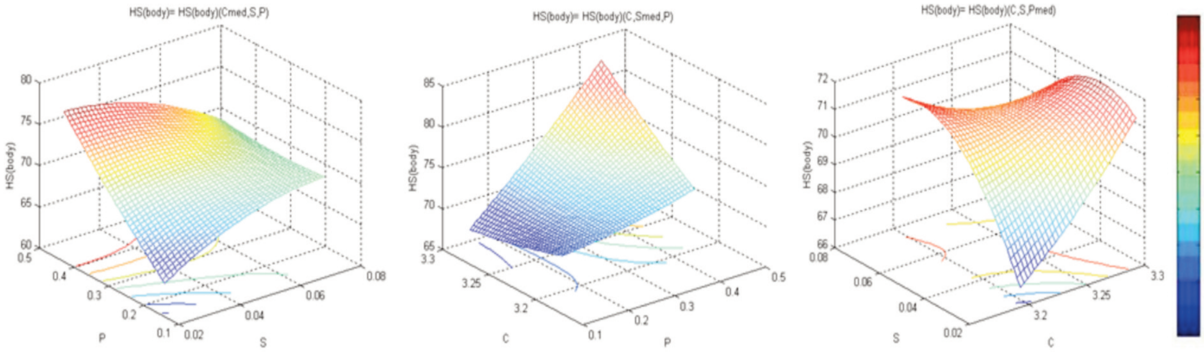

Figure 5. Regression surfaces $HS_{(rolling\ surface)}$ for middle value of sulfur, phosphorus and carbide (case of the surface).

Figura 5. Superficies de regresión $HS_{(rolling\ surface)}$ para el valor medio del azufre, fósforo y carbono (caso de la superficie).

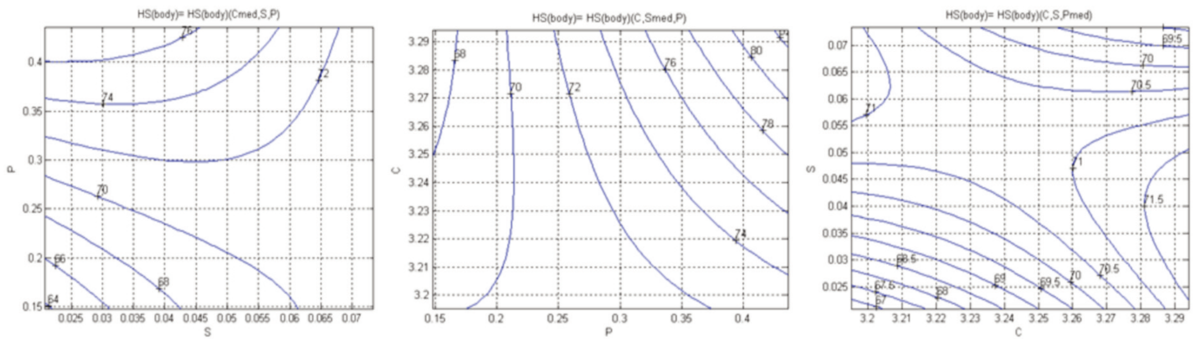

Figure 6. Level curves for middle value of sulfur, phosphorus and carbide (case of the surface).

Figura 6. Curvas del nivel para el valor medio del azufre, fósforo y carbono (caso de la superficie).

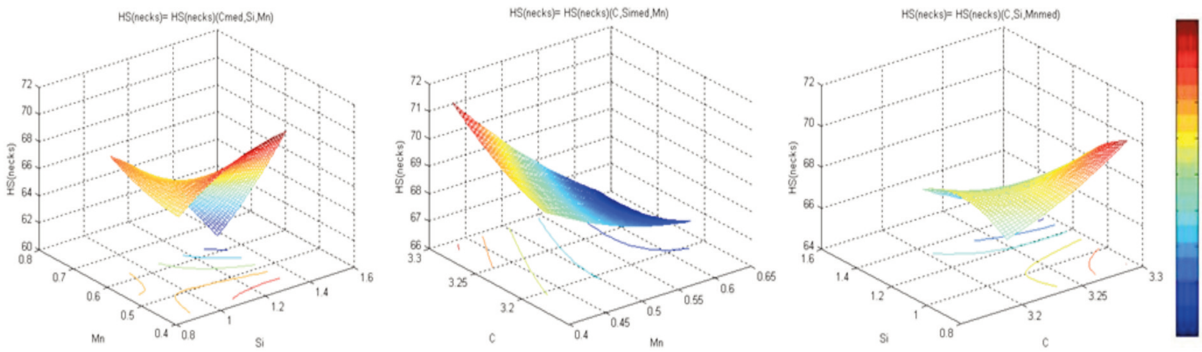

Figure 7. Regression surfaces $HS_{(necks)}$ for the middle value of the silicon, manganese and carbide (case of the necks).

Figura 7. Superficies de regresión $HS_{(necks)}$ para el valor medio del silicio, manganeso y carbono (caso de los cuellos).

Rev. metal. 48 (2), MARZO-ABRIL, 85-96, 2012, ISSN: 0034-8570, eISSN: 1988-4222, doi: 10.3989/revmetalm.1118

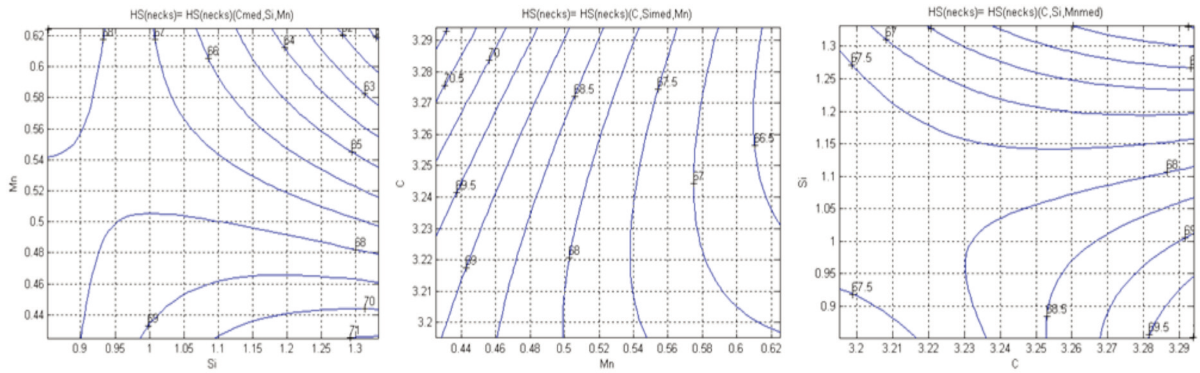

Figure 8. Level curves $HS_{(necks)}$ for the middle value of the silicon, manganese and carbide (case of the necks).

Figura 8. Curvas de nivel para el valor medio del silicio, manganeso y carbono (caso de los cuellos).

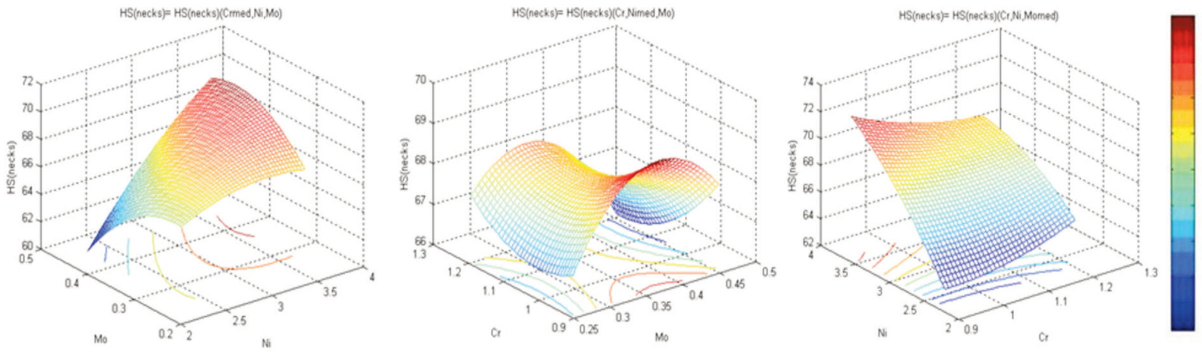

Figure 9. Regression surfaces $HS_{(necks)}$ for middle value of nickel, molibdenum and chromium (case of the necks).

Figura 9. Superficies de regresión $HS_{(necks)}$ para el valor medio del níquel, molibdeno y cromo (caso de los cuellos).

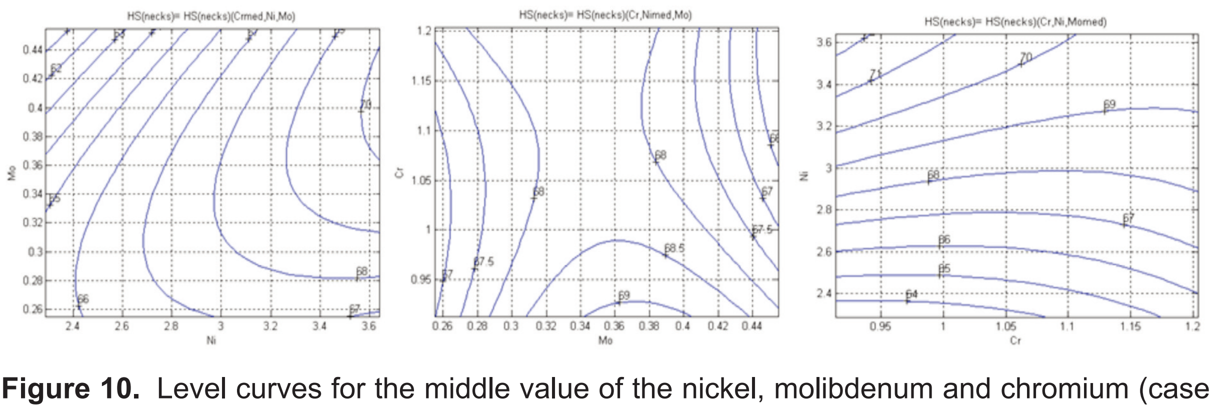

Figure 10. Level curves for the middle value of the nickel, molibdenum and chromium (case of the necks).

Figura 10. Curvas de nivel para el valor medio del níquel, molibdeno y cromo (caso de los cuellos).

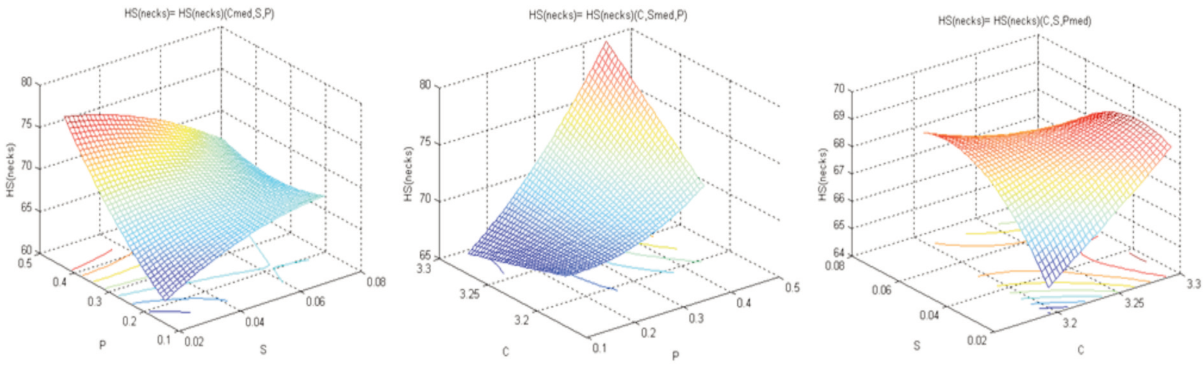

Figure 11. Regression surfaces $HS_{(necks)}$ for middle value of sulfur, phosphorus and carbide (case of the necks).

Figura 11. Superficies de regresión $HS_{(necks)}$ para el valor medio del azufre, fósforo y carbono (caso de los cuellos).

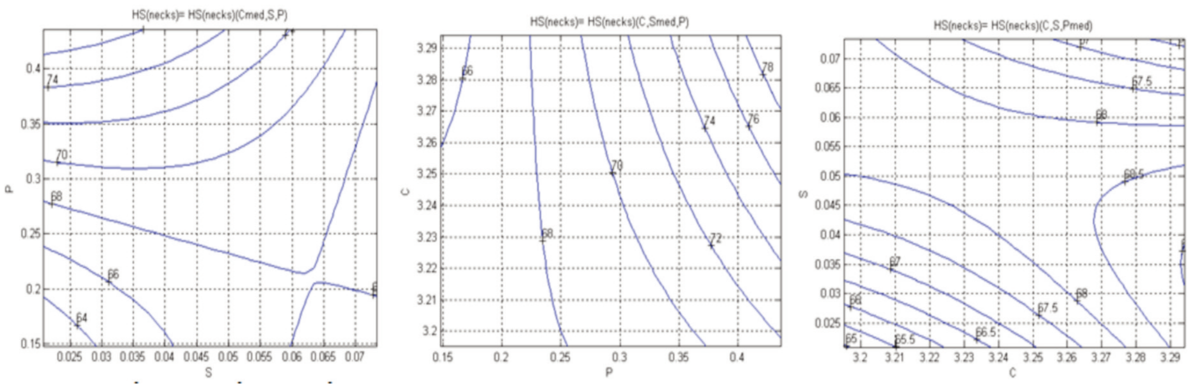

Figure 12. Level curves for the middle value of the sulfur, phosphorus and carbide (case of the necks).

Figura 12. Curvas de nivel para el valor medio del azufre, fósforo y carbono (caso de los cuellos).

$$HS_{(rolling\ surface)} = 6.7337\ C - 0.0188\ Si - 16.3039\ Mn + 2.6893\ Cr + 4.6469\ Ni - 9.5035\ Mo + 16.4113\ P + 6.0779\ S + 39.0356 \quad (25)$$

$$HS_{(necks)} = 5.8727\ C + 0.0779\ Si - 14.1715\ Mn + 1.5534\ Cr + 3.6614\ Ni - 5.1136\ Mo + 17.3414\ P - 9.9792\ S + 41.3754 \quad (26)$$

Multiple regression fits data to a model that defines $HS_{(rolling\ surface)}$ and $HS_{(necks)}$ as a function of all independent variables. The term *multiple regression* is usually used to mean fitting data to a linear equation with all variables included in our research.

Based on the obtained results we can recommend the optimal average value of the chemical composition for obtain the optimal hardness. These recommendations in the table IV and V are presented.

5. CONCLUSIONS

— We have obtained excellent results in our research and we applied these results in the production departments of the rolling mills. In addition, it also assures the fundaments for obtain the correct mechanical properties of the iron destined for the cast rolls. Based on the specialized engineers opinions, these problems can be solved by adaptation of the casting process of the rolls and by the correct manage of the irons elaboration.
— The regression analysis can be used for prediction in the iron rolls manufacturing. Regression analysis

 Rev. metal. 48 (2), MARZO-ABRIL, 85-96, 2012, ISSN: 0034-8570, eISSN: 1988-4222, doi: 10.3989/revmetalm.1118

Table IV. Chemical composition - statistically recommended

Tabla IV. Composición química estadísticamente recomendada

Rolls Types	Chemical Composition - Statistically recommended, [%]							
	C	Si	Mn	P	S	Ni	Cr	Mo
Indefinite chilled iron rolls – hard class 2	3.22	1.03	0.51	0.24	0.04	3.02	1.12	0.35

Table V. Statistically recommended hardness

Tabla V. Dureza estadísticamente recomendada

Analyzed roll types	Hardnes s Class	Recommended hardness of rolls, [degrees shore C hardness]	
		on the working surface, $HS_{(rolling\ surface)}$	on the core and the necks, $HS_{(necks)}$
Indefinite chilled iron rolls-hard class	2	70	67

is also used to understand which among the various independent variables of the technological foundry processes are related to the dependent variable, and to explore the forms of these relationships. The researcher can use the estimated standard errors to create confidence intervals (optimal domains) and conduct hypothesis about the further iron elaboration and casting processes. Analyzing the correlations, we could establish the optimum domains for the chemical composition, in order to obtain adequate values of hardness in case of the indefinite cast-iron rolls. The 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.

— Based on the obtained results we will be able to establish an optimal chemical composition. Moreover, we will also have in view the establishing of the dependence relations for the components of the chemical components and the hardness, in the case of the necks and/or rolling surface. Further research shall be performed in order to establish certain complex dependence relations, namely the data will be processed by analyzing the influence of the chemical composition upon the rolls hardness.

REFERENCES

[1] I. Kiss, *The quality of rolling mills rolls cast by iron with nodular graphite*, Mirton Publishing House, Timisoara, Romania, 2005, pp. 19-28.

[2] I. Kiss, *Cast-iron rolls, Approaches of the quality in the multidisciplinary research*, Mirton Publishing House, Timisoara, Romania, 2008, pp. 9-42.

[3] K.H. Schröder, *A basic understanding of the mechanics of rolling mill rolls*, Eisenwerk Sulzau-Werfen, ESW-Handbook, 2003, pp. 54-56.

[4] K.H. Schröder, *Questions, answers, more questions, Twenty-five years of experience in discussing rolls and rolling technology*, 42nd Mechanical Working and Steel Processing Conference Proceedings, Toronto, Canada, 2000, pp. 1-12.

[5] I. Kiss and St. Maksay, *Ann. Fac. Eng. Hunedoara, Int. J. Engineering*, 4 (2006) 77-82.

[6] I. Kiss, V.G. Cioata and V. Alexa, *Ann. Fac. Eng. Hunedoara, Int. J. Engineering*, 2 (2003) 145-150.

[7] I. Kiss and St., Maksay, *Metalurgia International,* 2 (2008) 22-28.

[8] I. Kiss, *Rev. Metal. Madrid,* 4 (2008) 335-342.

[9] I. Kiss and St. Maksay, *Tehnicki Vjesnik-Technical Gazette,* 1 (2008) 33-37.
[10] I. Kiss, V.G. Cioata and V. Alexa, *Acta Tech. Corviniensis*, *Bull. of Eng.*, 2 (2010) 31-36.
[11] St. Maksay, *Special Mathematics*, vol. I & II, Politehnica Publishing House, Timisoara, 2001, pp. 88-96.
[12] D.C. Hanselman and B. Littlefield, *Mastering MATLAB 5, A comprehensive tutorial and reference*, New Jersey, USA, 1998 pp. 38-42.
[13] S.E. Lyshevski, *Engineering and Scientific Computations Using MATLAB*, John Wiley & Sons, Inc. New York, USA, 2003, pp. 99-124.
[14] D.G. Kleinbaum, L. L. Kupper and K. E. Muller, *Applied regression analysis and other multivariable methods*, PWS Publishing Co. Boston, USA, 1988, pp. 112-118.
[15] J. Cohen, P. Cohen, S.G. West and L.S. Aiken, *Applied multiple regression/correlation analysis,* Lawrence Erlbaum Associates, New Jersey, USA, 3rd ed., 2003, pp. 13-14.
[16] L.S. Aiken, S.G. West and R.R. Reno, *Multiple regression: testing and interpreting interactions*, Sage Publications, Inc. Thousand Oaks, CA, USA, 1991, pp. 35-36.