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THE INFLUENCE OF THE ELEMENS C, Si, Mn UPON THE HARDNESS OF THE CAST ROLLING CYLINDERS

Ana Josan, Ştefan Maksay
University "Politehnica" of Timisoara, Faculty of Engineering Hunedoara
331128 Hunedoara, Revolutiei street, no.5, tel. +40254207532, e-mail: ana_j@fih.upt.ro
Romania

ABSTRACT
The paper introduces the results of statistical mathematical processing, by means of the MATLAB calculation program of the data related to the rolling cylinders cast at the metallurgical company, in view of determining the optimal chemical composition domain. For the cylinders under consideration we gave the chemical compositions and the hardnesses we registered. Once the domain of chemical composition has been restricted, important material economy can be obtained, which a direct impact on the manufacturing price of cylinders has cast of Adamit-type steel, thereby reducing the expenses of the company.
Keywords: hardness, Adamit steel, cylinders, chemical composition

1. INTRODUCTION
With respect to the rolling cylinders cast of Adamit-type hypereutectoid steel, the reference literature mentions the following [1,2,3,4]:

- **carbon content (C = 1,8…2,0%)** is the main element that determines the structure of the basic metallic mass, the amount of free cementite, the resistance and hardness of the surface of cast rolling cylinders;
- **silicon content (Si = 0,6…0,8%)** is to be found within the limits that grant a complete de-oxidizing of steel;
- **manganese** (0,70…0,90%) plays the role of deoxidizer, contributing to a certain increase of the resistance of cylinders, as a result of ferrite alloying.

2. THE VARIATION OF HARDNESS WITH RESPECT TO THE CONTENTS IN C, Mn AND Si, RESPECTIVELY HB=HB(C,Mn,Si) FOR THE CYLINDERS UNDER CONSIDERATION
In view of determining the optimal domain of chemical composition for the Adamit-type hypereutectoid steel meant for casting rolling cylinders, we studied 29 cylinders cast at S.C. Siderurgica S.A. Hunedoara, for which the chemical composition and the hardness are known. They are given in tab.1. By means of the data given in tab.1. and using the MATLAB calculation program, we carried out a statistical mathematical calculation meant to analyze the influence of the chemical composition upon the hardness of rolling cylinders, considering the effect upon exploitation reliability. The correlations we obtained after having run the program are given hereinafter, both in an analytical form and in a graphical one. In order to determine the dependency HB=HB(C,Mn,Si), the calculation program determines the mean values and the square mean deviations of the variables.
Further on, we give the results of multidimensional processing of the experimental data. With this aim, we looked for a modeling of dependent variable u with respect to the independent variables x, y, z having the form:

$$u = c1 \cdot x\hat{}2 + c2 \cdot y\hat{}2 + c3 \cdot z\hat{}2 + c4 \cdot x \cdot y + c5 \cdot y \cdot z + c6 \cdot z \cdot x + c7 \cdot x + c8 \cdot y + c9 \cdot z + c10 \quad (1)$$

Table 1. The chemical composition and the hardness values recorded for the rolls taken in the study.

No.	Chemical composition, [%]								Hardness [HB]*
	C	Mn	Si	S	P	Cr	Ni	Mo	
1	1,92	0,85	0,70	0,010	0,025	1,16	1,67	0,34	395
2	1,90	0,80	0,79	0,010	0,020	1,07	1,78	0,31	378
3	1,90	0,80	0,79	0,010	0,020	1,07	1,78	0,31	380
4	1,90	0,80	0,79	0,010	0,020	1,07	1,78	0,31	383
5	1,90	0,80	0,79	0,010	0,020	1,07	1,78	0,31	389
6	1,85	0,83	0,72	0,010	0,027	1,08	1,60	0,30	389
7	1,85	0,83	0,72	0,010	0,027	1,08	1,60	0,30	384
8	1,85	0,83	0,72	0,010	0,027	1,08	1,60	0,30	375
9	1,82	0,83	0,75	0,012	0,035	1,06	1,77	0,33	373
10	1,88	0,82	0,65	0,010	0,018	1,08	1,65	0,33	381
11	2,00	0,87	0,75	0,008	0,028	1,28	1,73	0,39	408
12	2,00	0,87	0,75	0,008	0,028	1,28	1,73	0,39	412
13	1,98	0,80	0,72	0,010	0,030	1,05	1,62	0,35	400
14	1,92	0,85	0,70	0,010	0,025	1,16	1,67	0,34	392
15	1,85	0,83	0,72	0,010	0,027	1,08	1,60	0,30	378
16	1,80	0,77	0,72	0,010	0,020	1,01	1,62	0,31	368
17	1,82	0,84	0,63	0,010	0,028	1,10	1,66	0,35	370
18	1,95	0,84	0,60	0,010	0,028	1,15	1,65	0,42	398
19	1,85	0,80	0,70	0,015	0,030	1,10	1,64	0,30	380
20	2,03	0,90	0,65	0,020	0,025	1,30	1,62	0,40	420
21	1,90	0,90	0,76	0,010	0,022	1,16	1,70	0,30	383
22	1,74	0,76	0,48	0,012	0,026	1,04	1,85	0,26	360
23	1,80	0,78	0,60	0,014	0,020	1,04	1,65	0,33	368
24	1,84	0,80	0,78	0,010	0,033	1,12	1,74	0,31	310
25	1,94	0,75	0,67	0,015	0,028	1,10	1,70	0,32	396
26	1,82	0,84	0,53	0,013	0,025	1,10	1,73	0,34	374
27	1,82	0,70	0,60	0,008	0,032	1,00	1,55	0,26	369
28	1,95	0,77	0,72	0,010	0,026	1,12	1,18	0,33	396
29	1,82	0,84	0,53	0,013	0,025	1,10	1,73	0,34	374

* hardness, by necks, ranged for all the cylinders under consideration, in the interval 280…320HB

The modeling equation operated on a sample set of 29 cylinders is:

$$HB = -249{,}9905 \cdot C\text{^}2 - 968{,}5799 \cdot Si\text{^}2 + 1{,}2254 \cdot Mn\text{^}2 + 1310{,}0881 \cdot C \cdot Si - 305{,}8805 \cdot Si \cdot Mn + \\ + 69{,}9657 \cdot Mn \cdot C + 121{,}6014 \cdot C - 955{,}5616 \cdot Si - 58{,}6473 \cdot Mn + 420{,}7182 \quad (2)$$

the correlation coefficient having the value r_f = 0,83543104870423 and the deviation from the regression surface is s_f =10.72142591019631.

This surface in the four-dimensional space admits a saddle point with coordinates: **C_s = 1,2739; Si_s = 0,50898; Mn_s = 0,89127; HB_s = 281,127.**

The existence of this point within the technological domain has a particular importance because it grants stability to the process in the vicinity of this point, stability that is either desired, or to be avoided [5]. In this case, this point is to be avoided, as the carbon content is $C_ş$=1,2739%, value that does not belong to the standard composition range. The same situation is to be noticed for Mn as well as for Si, and hardness in this point $HB_ş$ is too low ($HB_ş$=281,127).

As this hyper surface cannot be represented in a 4-dimensional space, we resorted to successively replacing of one independent variable by its mean value. In this way we obtained the surfaces given in fig.1, 3, 5. For a more accurate analysis, we represented in fig. 2, 4, 6, the contour lines corresponding to the respective surfaces. They were obtained by the intersection of correlation surfaces with planes parallel to the horizontal (contour planes). Thus, the new surfaces we obtained, belonging to the 3-dimensional space can be represented and interpreted by technological engineers, as they have the following form:

$$HB_{C_{med}} = -968{,}5799 \cdot Si^2 + 1{,}2254 \cdot Mn^2 - 305{,}8805 \cdot Si \cdot Mn + 1511{,}018 \cdot Si + 261{,}3571 \cdot Mn - 236{,}4973 \quad (3)$$

$$HB_{Si_{med}} = 1{,}2254 \cdot Mn^2 - 249{,}9905 \cdot C^2 + 169{,}9657 \cdot Mn \cdot C - 269{,}9158 \cdot Mn + 1026{,}4656 \cdot C - 701{,}3415 \quad (4)$$

$$HB_{Mn_{med}} = -249{,}9905 \cdot C^2 - 968{,}5799 \cdot Si^2 + 1310{,}0881 \cdot C \cdot Si + 260{,}5044 \cdot C - 1205{,}5398 \cdot Si + 373{,}6075 \quad (5)$$

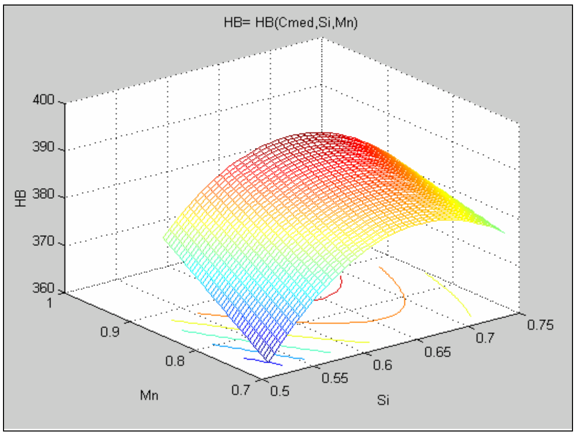

Figure 1. Surface HB = HB(C_{med}, Si, Mn)

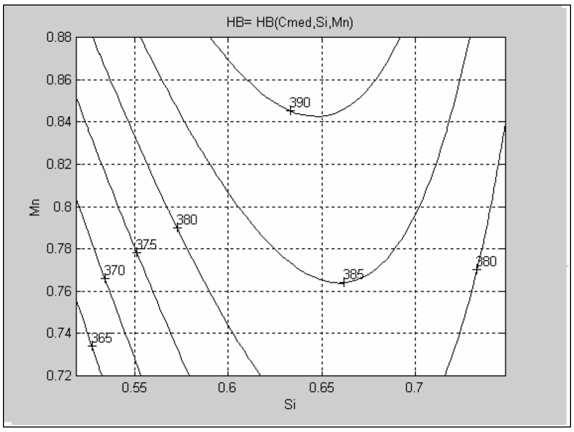

Figure 2.The contour lines of variation HB=HB(C_{med},Si Mn)

Considering the influence of elements like C, Mn, Si on the hardness of steel cast cylinders and, after the analysis of fig.1, 2, one can mention that for a mean value of carbon and an optimal value of silicon, considered to be ranging within Si_{optim} = 0,62…0,67%, the hardness will be maximal (390HB) for a content in manganese, ranging within Mn_{optim} = 0,842 and 0,864%. If we analyze the representations given in fig. 3,4 we can say that, for the same content in silicon, the increase of carbon and manganese lead to an increase of hardness.

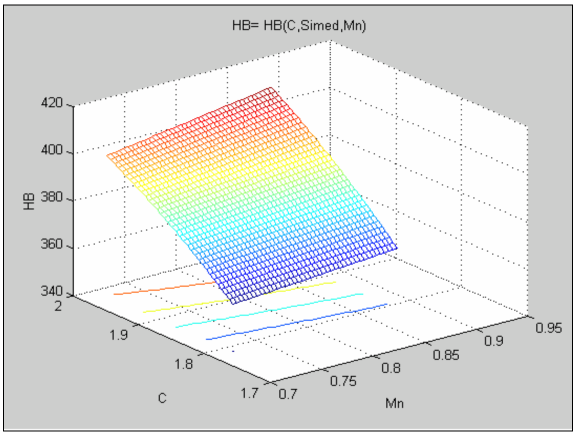

Figure 3. Surface HB = HB(C, Si_{med}, Mn)

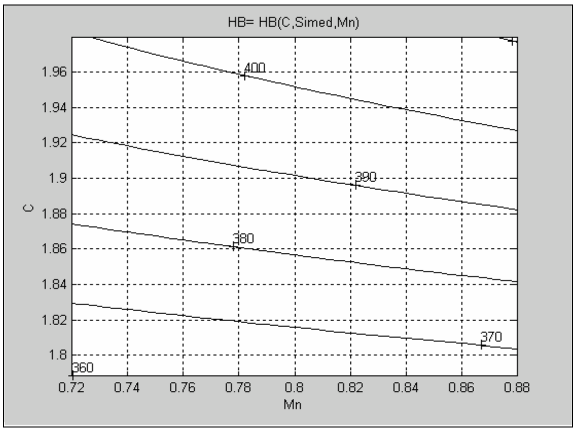

Figure 4.The contour lines of variation HB = HB(C, Si_{med}, Mn)

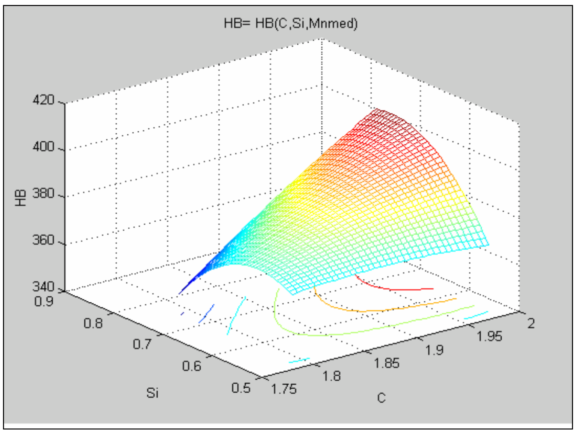

Figure 5. Surface HB = HB(C, Si, Mn_{med})

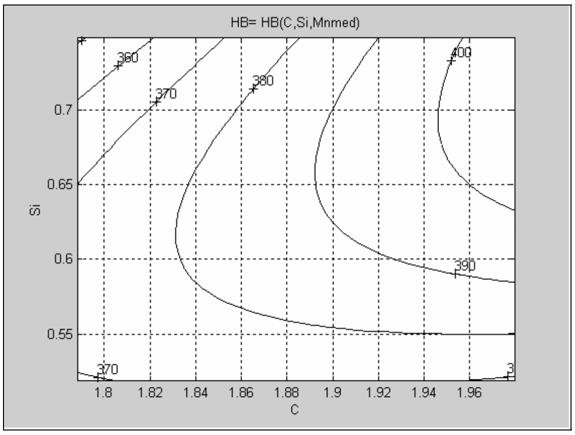

Figure 6.The contour lines of variation HB = HB(C, Si, Mn_{med})

Thus, according to the graphs, the result is:

- for a minimal limit of manganese (Mn = 0,7%) maximal hardness can be obtained (of 400HB), for a 2% content of carbon;
- for the minimal limit of carbon (C = 1,8%) the maximal hardness of 370HB is reached for a content of manganese of aprox.0,89%.

Under these circumstances one can say that the percentage of carbon should be towards its top limit and the manganese percentage towards the lower one.

Fig. 5,6 shows that, for 1,96%C, maximal hardness is obtained for approx. 0,65%Si or, in other words, for fix contents of manganese (constants) silicon being maintained between 0,60…0,67% grants a maximum of hardness for any carbon content

3. CONCLUSIONS

After having statistically and mathematically processed the data registered in industrial practice, by means of the MATLAB package, we managed to determine the optimal chemical composition leading to the hardness required by the hot rolling process, so that the exploitation reliability of rolling cylinders be as high as possible. The graphs given in fig.7 suggestively illustrate the optimal domain of the chemical composition for the rolling cylinders cast of Adamit-type hypereutectoid steel so that hardness should range within the limits requested by the standards in force.

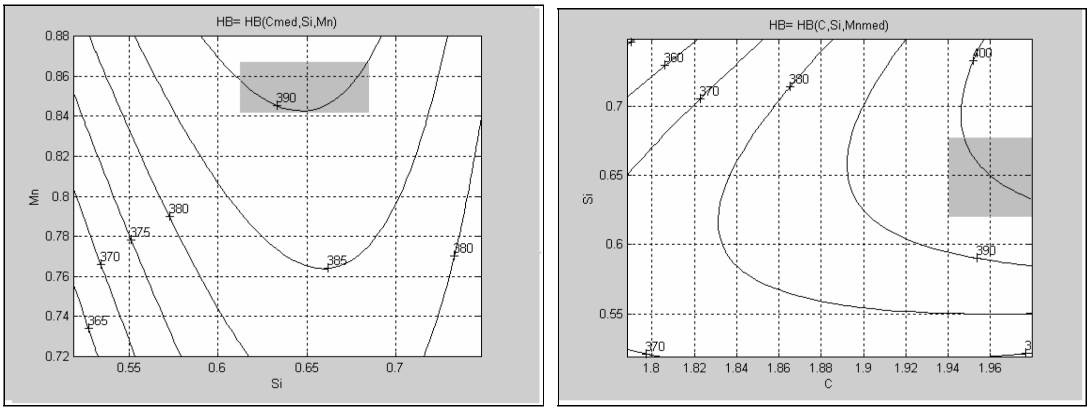

Figure 7. Restricted domains for the contents of C, Mn, Si.

The analysis of the graphs leads to the following conclusions:

- variation ration $\frac{\Delta C}{\Delta Mn} = \frac{1,927 - 1,882}{0,89 - 0,72} = \frac{0,045}{0,17} \cong 0,3 = \frac{1}{3}$, leads to $3 \cdot \Delta C = 1 \cdot \Delta Mn$, i.e. 0,1%C which can be replaced by 0,3%Mn for a constant hardness;
- for 1,96%C, maximal hardness can be obtained for approx. 0,65%Si or, in other words, for fix contents of manganese (constant) silicon beiong maintained between Si_{optim}=0,60…0,67% which ensures maximal hardness for any content of carbon;
- Mn_{optim} = 0,842…0,864%

A restriction of the field of chemical composition has a direct impact on the manufacturing costs for rolling cylinders cast of Adamit-type steel.

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