C. KOLMASIAK, I. NOWODZIŃSKA-BUDZIK, R. BUDZIK

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MANAGEMENT OF THE PIG IRON Si AND SLAG CaO/SiO_2 TECHNOLOGICAL INDICATORS IN ORDER TO PRODUCE PIG IRON WITH A TITANIUM CONTENT BELOW 0,02 %Ti

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The article present the developed method for production of pig iron with a very low titanium content of Ti < 0,02 %, while taking into account specific charge conditions. A two-week preliminary pig iron production test carried out determined the direction in managing two technological indicators, namely pig iron [Si] content and slag (CaO/SiO_2) basicity, to obtain pig iron with a [Ti] content below 0,02 %. Based on the data from the preliminary test, proper tests were carried out with a pig iron Si content in the range from 1,0 % to 1,6 % and a slag CaO/SiO_2 basicity in the range from 0,96 to 1,10. Data obtained from those tests enabled a statistical model to be established in the form of regression planes of two independent variables, [Si] and (CaO/SiO_2). The regression equation of the first degree, [Ti] = f[(Si), (CaO/SiO_2)], defined the plane that gave the process engineer the answer to the question of how to manage the [Si] and (CaO/SiO_2) indicators so as to obtain pig iron with the desired [Ti] content below 0,02 %.

Key words: titanium, steel, pig iron, iron metallurgy, metallurgical processes

INTRODUCTION

Pig iron production in Poland relies almost exclusively on ores imported from abroad. The blast-furnace charge components, in addition to iron oxides, always contain many other compounds, including titanium compounds [1].

This article describes a method for the production of pig iron with the following chemical composition required by the contracting party: 1,60 % to 2,20 % Si; 0,51 % to 0,80 % Mn; 0,1 to 0,3 % P; to 0,05 % S and to 0,02 % Ti, that is a pig iron with a very low titanium content.

The required chemical composition, except for titanium, corresponds to that of the pig iron conforming to the Polish Standard PN-93/1-01010/02 „Definition and classification of pig irons", mark Pig-P6Si, with chemical composition: 1,5÷3,5 % Si, 0,4 ÷ 1,5 % Mn, 0,12 ÷ 0,5 % P max up to 0,06 % S.

Iron-bearing components used in Polish metallurgy always contain more than 0,2 % titanium [2, 3], which means that the content of titanium introduced with the iron-bearing charge exceeds the pig iron titanium content required by the contractor, on average, by a minimum of ten times. Because of the contractor's requirement, the process engineers were faced with the problem of how to run the blast-furnace technological process so as to obtain a low-titanium pig iron with a titanium content below 0,2 %. It was no problem to obtain the pig iron of the required Si, Mn, P and S contents, but instead, a great challenge was to develop a new technology for production of the pig iron with a titanium content below 0,02 %. To produce the pig iron with a pig iron titanium content below 0,02 %, a number of preliminary tests were carried out under industrial conditions, which enabled the authors to determine the method of management of certain indicators of technology to provide the objective pursued.

THE METHOD OF CONDUCTING TESTS

The first stage of testing was started with the analysis of the initial two-week period of producing a pig iron with a silicon content from 1,60 % to 2,20 %.

In the initial period, the charge consisted of 8 200 kg iron-bearing pellets, 1 400 kg sinter and the appropriate amounts of dolomite, limestone, iron-manganese slag and coke. The charge introduced 8,20 kg Ti, which, related to 6 500 kg Fe contained in the charge (for simplification, it was assumed that this corresponded to the amount of pig iron in the charge), amounted to 0,126 %.

In the Ironworks' conditions, with this charge, the amount of slag was, on average, 500 kg/ton of pig iron. This means that 1,260 kg Ti would pass to 1 ton of pig iron and 0,5 ton of slag. On the assumption that the pig iron may not contain more than 0,02 % titanium, the coefficient of partition between the metal and the slag ([Ti]/([Ti]+(Ti)) should not exceed 0,02/0,126, so the yield of titanium in the pig iron should be smaller than 15,87 %.

It should be noted that previously, in another ironworks, an industrial trial was carried out, where charge

C. Kolmasiak, I. Nowodzińska-Budzik, R. Budzik, Czestochowa University of Technology, Czestochowa, Poland

introducing about 10 kg Ti per ton of pig iron was used. That trial demonstrated that the yield of Ti in pig iron with an Si content from 2,0 to 3,2 % and a slag basicity from 1,02 to 1,24 amounted to, on average, 36 %, always exceeding 30 %. The trial found that with the decrease in silicon content in the range from 3,2 to 2,0 % and in basicity from 1,24 to 1,0, the yield of titanium in pig iron decreased. Despite the difference in charge conditions and in chemical composition of the pig iron, the trial described above indicated the direction for developing a new technology for production of pig iron with the composition as defined in the introduction to this article. Therefore, it was assumed that within an initial period (two weeks) pig iron with a silicon content ranging from 1,75 to 2,25 % would be produced. The data obtained from that initial period are given in Table 1.

Table 1 **Chemical composition of selected pig iron casts at the initial testing stage / wt %**

No.						basicity of slag
	Si	Mn	P	S	Ti	CaO/SiO_2
1	1,67	0,72	0,014	0,041	0,026	1,04
2	1,78	0,73	0,022	0,032	0,031	1,10
3	2,05	0,66	0,014	0,029	0,037	1,14
4	2,10	0,80	0,014	0,023	0,039	1,13
5	2,18	0,80	0,015	0,050	0,041	1,14
6	1,65	0,61	0,014	0,056	0,028	1,09
7	2,21	0,61	0,013	0,042	0,037	1,11
8	2,04	0,49	0,015	0,047	0,034	1,08
9	2,25	0,58	0,015	0,020	0,041	1,10
10	1,65	0,48	0,015	0,056	0,027	1,08
11	2,08	0,74	0,016	0,029	0,034	1,07
12	1,61	0,72	0,014	0,031	0,026	1,07
13	1,62	0,69	0,015	0,035	0,026	1,03
14	1,62	0,72	0,014	0,034	0,025	1,05
15	1,65	0,68	0,015	0,042	0,027	1,05

The data show that, with the assumed charge conditions, pig irons of a titanium content from 1,61 to 2,25 % always contained more than 0,020 Ti. The lowest titanium contents were 0,025 % and 0,026 % Ti with a pig iron Si content of 1,61 % and 1,67 %, respectively, and with respective slag basicities from 1,04 to 1,07. The analysis of the results from the initial period found that:

- with the desired pig iron Si content and the available charge, the required titanium content could not be achieved;
- with the decrease in pig iron silicon content from 2,25 to 1,61 and in slag basicity from 1., tent decreased from 0,041 to 0,026.

The above relationships enabled the authors to draw the following conclusions concerning the subsequent stage of pig iron smelting tests:

- the sinter (which contained approx. 25 % Ti) should be replaced with less titanium containing pellets, which would reduce the amount of the charge-introduced titanium from 8,20 kg to 7,1 kg; reducing the charge titanium content did not provide the certainty that a pig iron titanium content below 0,02 % would be obtained, anyway.

Therefore, it was decided to:

- maintain the slag basicity at the lowest possible level, but above 0,95 %;
- reduce the silicon content below the required value down to the range from 1,6 to 1,0 %, and to supplement the missing silicon amount with ground ferrosilicon out of the blast furnace;
- reduce any increase in pig iron sulphur content above the required value, resulting from decreasing the slag basicity, by the addition of soda to the ladle.

With so defined conditions, pig iron production was run for several weeks. Selected 46 pig iron casts provided a basis for statistical analysis. The lowest pig iron titanium content of 0,014,% was obtained with a pig iron silicon content of 0,97,% and a slag basicity of 0,97, while the highest titanium content of 0.030% with a silicon content of 1,75 % and a basicity of 1,10.

The data obtained during this period were used to establish a mathematical model for the existing charge conditions, in the form of the multiple regression of the relationship between the independent variables: slag basicity (CaO/SiO_2) and pig iron silicon content [Si], and the dependent variable, which was the percentage pig iron titanium content [Ti]. This model, which has the form of a multiple regression equation of the first degree, is as follows:

$$[Ti] = -0{,}01+0{,}01(Si)+0.016(CaO)/(SiO_2)$$

The large correlation coefficient of 0,84 with the significance level of 0,05 indicates almost the full agreement of the results calculated from the equation with the results obtained from the testing period.

The multiple regression equation allows the boundary conditions of the response surface of interest to be calculated, which are shown in Table 2.

This table indicates the existence of respective pairs of independent variables that satisfy the condition for the maximum titanium content below 0,02 %:

- [Si] = 1,0 % - 1,40 %; CaO/SiO_2 = 0,95, Ti = 0,0162 % - 0,0192 %
- [Si] = 1,0 % - 1,40 %; CaO/SiO_2 = 1,0, Ti = 0,016 % - 0,020 %
- [Si] = 1,0 % - 1,30 %; CaO/SiO_2 = 1,05, Ti = 0,0168 % - 0,0198 %
- [Si] = 1,0 % - 1,20 %; CaO/SiO_2 = 1,1, Ti = 0,0178 % - 0,0196 %

Thus, pig iron with the required titanium content may be produced within the pig iron silicon content and slag basicity ranges resulting from the pairs of variables shown above. Having a mathematical model in the form of multiple regression at his disposal, a process engineer is able to manage within the region of independent variables (technological parameters) in the pig iron silicon content range from 1,0 to 1,40 and in the slag basicity range from 0,95 to 1,10 to select the economically and technologically optimal variant of production of the required low-titanium pig iron. Having relevant pairs of variables available, a two-week trial of production of

Table 2 **[Ti] = -0,01+0,01 (Si)+0,016 (CaO)/(SiO_2)**

x_1 = Si / %	1,0	1,10	1,20	1,30	1,40	1,50	1,10	1,70
x_2 = CaO/SiO_2	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95
y = Ti / %	0,0152	0,0162	0,0172	0,0182	0,0192	0,0202	0,0212	0,0222

cd tab. 2.

x_1 = Si / %	1,00	1,10	1,10	1,30	1,40	1,50	1,60	1,70
x_2 = CaO/SiO_2	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
y = Ti / %	0,016	0,017	0,018	0,019	0,020	0,021	0,022	0,023

cd tab. 2

x_1 = Si / %	1,00	1,10	1,10	1,30	1,40	1,50	1,60	1,70
x_2 = CaO/SiO_2	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
y = Ti / %	0,0168	0,0178	0,0180	0,0198	0,0218	0,018	0,0228	0,0238

cd tab. 2

x_1 = Si / %	1,00	1,10	1,10	1,30	1,40	1,50	1,60	1,70
x_2 = CaO/SiO_2	1,10	1,10	1,10	1,10	1,10	1,10	1,10	1,10
y = Ti / %	0,0176	0,0186	0,0186	0,0206	0,0216	0,0225	0,0236	0,0246

pig iron with a titanium content below 0,02 % Ti was carried out with the following independent variables: Si = 1,0 % – 1,40 % and CaO/SiO_2 = 1,0 – 1,1. With these parameters of technological indicators, more that 10 K Mg of pig iron containing less than 0,02 % Ti was produced, which was the aim of the investigation undertaken.

FINDINGS AND CONCLUSIONS

- Production of pig iron with a very low titanium content should be based on charge components that will introduce the lowest possible amount of titanium.
- The tests carried out have confirmed the advantageous effect of reducing the pig iron silicon content and reducing the slag basicity on the reduction of the titanium yield.
- Production of pig iron with a titanium content below 0,020 % at given charge conditions will require the operation to be conducted with the following independent variables:

  Si = 1,0 % – 1,40 %, (CaO/SiO_2) = 0,95 – 1,0

  Si = 1,0 % – 1,20 %, (CaO/SiO_2) = 1,0 – 1,10
- For special pig irons not covered by the standards, preliminary trials should be carried out for given charge conditions in order to determine, using statistical calculus, the optimal range of independent variables that can be managed under the blast-furnace conditions to produce pig iron of the appropriate chemical composition.

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Note: The person responsible for the English translation in Poland is Czesław Grochowina, Studio Tekst, Czestochowa, Poland