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THE BALANCE OF TITANIUM AND VANADIUM IN THE BLAST FURNACE WITH THE USE OF SINTER CONTAINING A TITANIUM-VANADIUM-MAGNETITE CONCENTRATE

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The investigation concerned the use of sinter containing a titanium-vanadium-magnetite concentrate for the production of pig iron. Sinter containing 0,46 to 0,51 % TiO_2 and 0,056 to 0,060 % vanadium was used for pig iron production in the blast furnace. Introducing 200 kg of this concentrate to the1 Mg sinter mix did not cause any deterioration of sinter quality.

Key words: *blast furnace, sinter, titanium-vanadium-magnetite concentrate*

Bilanca titana i vanadija u visokoj peći kod upotrebe sintera koji sadrži koncentrat titana-vanadija-magnetita. Istraživanje obuhvaća upotrebu sintera koji sadrži koncentrat titana-vanadija-magnetita za proizvodnju sirovog željeza. Sinter koji sadrži 0,46 do 0,51% TiO_2 i 0,056 do 0,060% vanadija upotrijebljen je za proizvodnju sirovog željeza u visokoj peći. Uvođenje 200 kg ovog koncentrata u mješavinu sintera nije izazvalo nikakvo pogoršanje kvalitete sintera.

Ključne riječi: *visoka peć, sinter, koncentrat titan-vanadij-magnetit*

INTRODUCTION

The problem of titanium and vanadium reduction in the blast furnace can be topical in conjunction with the prospective development of the documented titanium-vanadium-magnetite polymetallic ore deposits located in the north-eastern part of Poland. One of the proposed variants of processing of these ores involves obtaining two concentrates from them, namely: a titanium-vanadium-magnetite concentrate for the purposes of iron metallurgy and an ilmenite concentrate for the production of titanium white and metallic titanium.

A preliminary survey suggests that such a concentrate will contain 65 % of iron, up to 0,7 % of vanadium, 2,0 to 8,0 % of titanium dioxide and 0,4 to 2,0 % of silica. Vanadium, which does not form separate minerals in this particular ore, enters the crystallographic lattice of magnetite. Titanium remains in the ore partially in the crystallographic lattice of magnetite, mainly titanium-magnetite $(Fe, Ti)_3O_4$, as well as ilmenite, $FeOTiO_2$, and ulvite, $2FeO\text{-}TiO_2$. Vanadium contained in polymetallic ores constitutes a valuable component, and the recovery of this metal may determine the economic aspects of using such ores. In the Polish conditions, vanadium can be obtained from the titanium-vanadium-magnetite concentrate basically in the two following ways:

- by melting of concentrates in the form of sinters or pellets in the blast furnace, followed by the recovery of vanadium from the pig iron, while titanium dioxide from the slag;
- by means of the pyro-hydro-metallurgical treatment of the titanium-vanadium-magnetite concentrate, as a result of which vanadium is obtained by precipitating its compounds from the aqueous solution, while the component-concentrate remaining after vanadium removal may form a component of the charge for the production of iron sinter or pellets.

The both methods contain a possibility of applying the blast-furnace technology for the melting of the titanium-vanadium-magnetite concentrate suitably prepared in the form of sinter or pellets. Vanadium in the titanium-vanadium-magnetite concentrate does not prevent it from being directly used for the blast-furnace charge. Titanium, if introduced to the blast furnace in excessive amounts, may cause difficulties in the proper conducting of the process, mainly because of the thickening of the slag by TiO_2. So far, only a few countries use a batch for pig iron production, which contains a titanium-vanadium-magnetite concentrate, and only for isolated blast-furnace units. Such a concentrate is only used for the purpose of recovering vanadium contained in it. It should be emphasized that the use of a blast-furnace

R. Budzik, Faculty of Materials Processing Technology and Applied Physics Częstochowa University of Technology, Częstochowa, Poland

charge containing increased additions of titanium and vanadium has not been fully investigated.

Results of investigation undertaken on this subject might form part of the solutions to the problem of smelting pig iron with increased contents of titanium and vanadium. A possibility of using domestic titanium-vanadium-magnetite concentrate for pig iron production in Poland in the future should be taken into account. Therefore, several industrial tests on the application of similar titanium an vanadium- containing concentrates for the production of pig iron were undertaken.

Table 1. **Chemical composition and the strength indices of the sinter**
Tablica 1. **Podaci o kemijskom sastavu i čvrstoći sintera**

Sinter composition	Content / %	Sinter strength / %
Fe	50,30 to 51,60	
FeO	8,51 to 12,01	Drum test
SiO_2	10,80 to 11,90	for strength: 56 to 58,1;
CaO	11,40 to 12,80	for abrasion: 5,3 to 5,7
MgO	1,44 to 1,87	
TiO_2	0,46 to 0,51	
V	0,056 to 0,058	

PURPOSE AND SCOPE OF INVESTIGATION

The main objective of the investigation was to explore the behaviour of titanium and vanadium in the blast-furnace process, and chiefly:

- the effect of the silicon content of pig iron on its content of titanium,
- the effect of slag basicity on the coefficient of partition of titanium and vanadium between the slag and the pig iron, and
- the determination of the coefficient of partition of vanadium and titanium between the pig iron, the slag and the blast-furnace dust.

Table 2. **Average chemical composition of blast-furnace charge components**
Tablica 2. **Prosječni kemijski sastav komponenti kojima se puni visoka peć**

Component	Chemical composition / %						
	Fe	SiO_2	CaO	MgO	Al_2O_3	TiO_2	V
Sinter	50,30 to 51,60	10,80 to 11,90	11,40 to 12,80	1,44 to 1,87	1,08 to 1,10	0,46 to 0,51	0,056 to 0,060
Limestone	1,56	1,60	53,6	0,30	0,12	traces	traces
Phosphorite	0,93	7,09	23,3	3,24	0,75	traces	traces
Coke	1,03	4,17	0,91	0,27	0.31	traces*	traces

*Traces - a content below 0,001 %

The scope of investigation for the determination of the balance of titanium and vanadium covered:

- establishing the recipe in such a manner that the amount of TiO_2 in the sinter does not exceed 10 kg per tonne of pig iron produced,
- production of a titanium-vanadium-bearing sinter of proper strength,
- applying the produced sinter as the charge for the production of pig iron,
- determination of chemical compositions in the pig iron, slag, dust and sludge, and
- drawing up vanadium and titanium balances.

Table 3. **Chemical compositions of pig iron and slag for 16 tops**
Tablica 3. **Kemijski sastavi sirovog željeza i troske za 16 talina**

Number tops	Chemical compositions of pig iron / %				Chemical compositions of slag / %			
	Si	Mn	Ti	V	CaO	SiO_2	Ti	V
1	2,32	0,68	0,14	0,062	46,0	38,0	0,23	0,220
2	2,29	0,71	0,15	0,065	45,6	37,5	0,30	0,023
3	2,27	0,64	0,19	0,067	45,9	38,3	0,36	0,016
4	2,74	0,55	0,23	0,105	45,5	38,6	0,45	0,018
5	3,11	0,60	0,29	0,078	44,6	37,2	0,46	0,021
6	2,80	0,57	0,28	0,072	44,2	36,5	0,51	0,020
7	2,43	0,57	0,22	0,102	41,2	39,0	0,55	0,019
8	2,57	0,56	0,19	0,104	43,8	40,0	0,64	0,020
9	2,35	0,55	0,16	0,067	43,2	41,2	0,65	0,018
10	2,25	0,49	0,16	0,063	41,2	40,4	0,74	0,021
11	2,04	0,42	0,17	0,093	41,2	41, 0	0,73	0,022
12	2,35	0,64	0,19	0,060	42,0	41,4	0,82	0,017
13	2,38	0,72	0,19	0,081	41,2	41,2	0,84	0,018
14	2,74	0,86	0,28	0,106	43,5	38,5	0,63	0,021
15	2,35	0,73	0,16	0,074	41,4	38,2	0,47	0,023
16	2,21	0,60	0,15	0,062	42,3	38,1	0,45	0,021

THE METHOD OF CARRYING OUT THE INDUSTRIAL TEST

For carrying out the industrial test, a sinter containing a titanium-vanadium-magnetite concentrate with a TiO_2 content of approx. 5,0 kg per tonne of pig iron was produced.

The sinter mix composition included the titanium-vanadium-magnetite concentrate in the amount of 200 kg, grainy hematite ore 580,2 kg, mill scale 80,5 kg, limestone 104,4 kg, dolomite 27 kg and coke breeze 65 kg per tonne of sinter. Chemical composition and the strength indices of the obtained sinter are given in Table 1.

The portion of titanium-vanadium-magnetite concentrate of 200 kg in the sinter mix allowed a sinter of a TiO_2 content from 0,46 to 0,51 % and a V content from 0,056 to 0,058 % to be obtained.

The blast-furnace charge for the production of pig iron containing increased contents of titanium and vanadium was composed of sinter, limestone, phosphorite and coke (Table 2.). The average chemical composition of blast-furnace charge components is given in Table 2.

Immediately after each pig iron tapping, a sample of pig iron, slag, dust and sludge, each, was taken to determine its respective chemical composition. Recording of the mass of charge materials, pig iron, slag, dust and sludge and the results of chemical analyses in the blast-furnace operation period under testing enabled the calculation of shortened balances of iron, titanium and vanadium. Chemical compositions of pig iron and slag 16 tops are presented in Table 3. The consolidated balance of iron, titanium and vanadium for the period under testing is given in Table 4.

Table 4. **Material balance of iron, titanium and vanadium for the pig iron production period under testing**

Tablica 4. **Bilanca materijala željeza, titana i vanadija za period proizvodnje sirovog željeza u kojemu se provodi testiranje**

Input							
Component	Mass / Mg	Fe		Ti		V	
		%	T	%	Mg	%	Mg
Sinter	3887	51,4	1972	0,48 traces	11,13	0,058	2,254
Phosphor.	107	0,93	1,0	traces	-	traces	-
Limesto.	96	1,56		traces	-	traces	-
Coke	1500	1,03	15,5	traces	-	traces	-
Total	5540		1990		11,3		2,25
Output							
Component	Mass / Mg	Fe		Ti		V	
		%	T	%	Mg	%	Mg
Pig iron	2029,0	92,8	1882,9	0,210	4,260	0,007	1,968
Slag	1295,0	0,9	11,6	0,505	6,539	0,020	0,186
Dust	39,0	22,9	8,9	0,210	0,082	traces	-
Sludge	20,0	34,5	6,9	0,180	0,036	traces	-
Skull	99,0	81,1	79,7	0,215	0,213	0,097	0,096
Total	3482	-	1990,0	-	11,13		2,25

On the basis of Table 4., the yield in the pig iron of input iron, titanium and vanadium can be presented. Table 5. shows the percentage fractions of the above elements passing from the charge to the pig iron, slag, dust and skulls, respectively.

The shortened material balance shows that under the specific industrial conditions in the production of pig iron with a silicon content from 2,0 to 3,2 % and with a slag basicity from 1,1 to 1,2 the yield of titanium in pig iron has amounted averagely to 38,27 %, while 58,75 % of titanium have passed to the slag.

Table 5. **Percentage fractions of iron, titanium and vanadium in the blast furnace products**

Tablica 5. **Postotni udjeli željeza, titana i vanadija u proizvodima visoke peći**

Component	Fraction / %		
	Fe	Ti	V
Pig iron	94,62	38,27	87,47
Slag	0,57	58,75	8,26
Dust	0,47	0,74	Traces
Sludge	0,34	0,32	Traces
Skulls	4,00	1,92	4,27
Total	100 %	100 %	100 %

It is interesting to note that almost all vanadium passes to the pig iron; in the case of a specific industrial test, the yield of vanadium in pig iron has reached 87,47 %, while only 8,26 % of the overall amount of vanadium input to the blast furnace with the charge have passed to the slag.

CONCLUSIONS

From the performed test on the production of pig iron with increased contents of titanium and vanadium, the following observations have been made and conclusions drawn:

1. In the smelting of pig irons with a silicon content from 2,0 to 3,0 % and with an average slag basicity of 1,15, 94,62 % of iron, 30,2 % of titanium and 87,47 % of vanadium, on average, pass to the pig iron.
2. Introducing 200 kg of the titanium-vanadium-magnetite concentrate per tonne of sinter to the sinter mix did not cause any reduction in the quality of the sinter obtained.
3. Introducing an increased amount of titanium with the charge, as compared to the charge containing no titanium-vanadium-magnetite concentrates, did not cause any side effects in the pig iron production technology.
4. There is a possibility of producing pig irons from a charge containing titanium in the amount of up to 5,0 kg TiO_2.

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