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SINTERING OF ORE MIXES CONTAINING IRON CONCENTRATES OF A LOW SiO_2 CONCENTRATION OF BELOW 1,0 %

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The investigation concerned the production of ore sinter from sinter mixes containing a concentrate of a very small grain size of below 0,1 mm and a low silicon content of below 1,0 % with an addition of 0,69 %, 8,5 % and 16 % of calcium (CaO) and 11,5 %, 16 % and 21 % of coke, respectively. The obtained sinter of a low Si content of below 1,0 % is partially metallised and may be used as an iron ore substitute for the steelmaking process.

Key words: *sintering, concentrates, low SiO_2*

Sinteriranje mješavina rude koje sadrže koncentrate željeza s niskom koncentracijom SiO_2 ispod 1,0 %. Istraživanje je vezano uz proizvodnju rudnog sintera od mješavina sintera koje sadrže koncentrat vrlo male veličine zrna od ispod 0,1 mm i niski udio silicija ispod 1,0 % s dodatkom od 0,69 %, 8,5 % i 16 % kalcija (CaO) i 11,5 %, 16 % i 21 % koksa, respektivno. Dobiveni sinter s niskim udjelom Si ispod 1,0 % je djelomično metaliziran i može se upotrijebiti kao zamjena za željeznu rudu za postupak proizvodnje čelika.

Ključne riječi: *sinteriranje, koncentrati, niski SiO_2*

INTRODUCTION

At present, the production of pig iron worldwide is based on the use of prepared sintered material or iron pellets. Both the sinter and the pellets are produced on various types of equipment, mostly on special belts. Sinter is formed from mixes containing iron ore of grain sizes of up to 6,0 mm, coke breeze of a grain size of up to 3,0 mm and other additives. The additives in sinter mixes are limestone, lime and iron-bearing waste. In the production of sinter, there is a trend toward an increasingly frequent replacement of grainy ore with iron-bearing concentrates of grain sizes below 1,0 mm [1, 2]. In the majority of the world's blast furnaces, sinter is a basic charge material for pig iron production. Many steel mills are producing presently, in addition to the sinter for pig iron production, also a sinter which is an ore substitute in the steelmaking process [3, 4]. This paper present the results of laboratory tests on the production of a partially metallised sinter intended for the steelmaking process.

LABORATORY TESTING

Sintering of a partially metallised, so called steelmaking iron sinter was carried on a laboratory pan of an inner diameter of 100 mm and a layer height of 600 mm. The mix was composed mainly of a concentrate of a very small grain size of up to 0,05 mm, characterized by a very low silica (SiO_2) content. Table 1. show the basic chemical composition of sinter mix components and their maximal grain size. The addition of limestone and lime was varied in the range from 0,69 to 16 %, while the coke addition was 11,5 %, 16,8 % and 21 %, respectively. The mix of moisture content from 7 to 8 % was pelletized in a 1,0 m-diameter pelletizer for approx. 10 s. After pelletizing, the mix was tested for permeability, and then a sample was taken for the determination of chemical and grain composition. The average bulk density of the mix was 1,662 t/m^2. The average grain composition of the mix was as follows: above 10 mm – 3,21 %; 10 to 8 mm – 5,47 %; 8 to 5 mm – 14,84 %; 5 to 3 mm – 18,69 %; 3 to 2 mm – 26,95 %; 2 to 1 mm – 22,54 %; and below 1 mm – 8,30 %. Return sinter of a grain size from 5 to 5,0 mm was poured onto the grid up to a height of 20 mm and then a specially prepared mix was poured on the return sinter. Chemical composition of sinter mix components is given in Table 1. The percentage content of the fraction above 5 mm served as the sinter strength index. The analysis of off-gas was determined by taking the gas under the sinter plant's grid. The mix in the pan was ignited with a burner flame at a temperature of about 1180 °C. After completion of sintering, samples were taken from the sinter formed with the aim of determining chemical and mineralogical compositions. The obtained sinter was also tested for strength by dropping it onto a

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Table 1. **Chemical composition of sinter mix components**
Tablica 1. **Kemijski sastav komponenti mješavine sintera**

Material	Content / %								Grain size / mm
	Fe	Fe_2O_3	CaO	SiO_2	MgO	Al_2O_3	P_2O_5	S	
Concentrate	71,20	68,80	0,02	0,41	0,73	0,04	0,01	0,05	0 - 0,05
Limestone	0,31	0,32	5,41	1,42	1,56	0,56	0,01	0,03	0 - 3,0
Lime	0,26	0,36	93,00	0,61	0,96	0,24	0,01	0,02	0 - 0,5
Coke ash	16,42	25,01	4,30	45,6	1,53	21,32	0,54	0,01	Coke 0 - 3

steel plate from a height of 2 m. The determination of the physicochemical properties of the sinters was done on a thermogravimeter at a temperature of 600 °C, 800 °C and 1000 °C, respectively, in the atmosphere of air flowing at a rate of 2 l/min for 40 minutes. The degree of shrinkage was determined on a device, in which the sinter of a grain size of 5 - 10 mm was subjected to a piston pressure of 65 kPA in the atmosphere of hydrogen heated in a tube up to 1200 °C with a step of 10 °C. The porosity was determined by taking into consideration the real and the apparent densities. The difference of these quantities as related to the real density constituted the degree of porosity. The reducibility of the sinter was determined by passing hydrogen at a rate of 2 l/min for 60 minutes through the tube heated to 800 °C. The loss of oxygen in relation to the total amount of oxygen contained in iron oxides was taken as the index of reducibility.

DISCUSSION OF THE TESTS RESULTS

Tables 2., 3. and 4. show some of the more important tests results obtained. Chemical composition of sinters obtained in terms of their iron content varied in the range from 60,40 % to 71,31 %. The difference by almost 10 % resulted from the addition of CaO in the amount from 0,69 % to 16 % and coke breeze in the amount from 11,5 % to 21,0 % to the mix. These additives only slightly affected the contents of SiO_2, Al_2O_3, S and P_2O_5, while significantly influencing the contents of FeO and $Fe_{met.}$ The highest iron oxide content, 68,31 % FeO, was exhibited by the sinter with 0,54 % CaO, i.e. the sinter formed from the mixtures without the addition of lime or limestone. In this case, the coke breeze addition in the range from 11,5 % to 21 % increased the SiO_2 content from 0,63 % to 0,75 %.

Table 2. **Percentage composition of obtained sinters**
Tablica 2. **Postotni sastav dobivenih sintera**

CaO content in the mix / %	Coke content in the mix / %	Chemical composition of the sinter, %									
		Fe	FeO	CaO	SiO_2	MgO	Al_2O_3	C	S	P_2O_5	$Fe_{met.}$
0,69	11,5	71,31	68,31	0,54	0,63	0,10	2,15	3,14	0,052	0,003	11,62
0,69	16,0	71,60	53,95	0,59	0,69	0,10	0,16	3,19	0,053	0,005	23,49
0,69	21,0	71,96	51,60	0,63	0,75	0,12	0,23	3,44	0,061	0,006	28,69
8,5	11,5	66,10	47,10	7,62	0,58	0,11	1,11	3,24	0,054	0,009	21,31
8,5	16,0	66,11	39,21	7,84	0,54	0,12	1,23	3,41	0,056	0,013	29,42
8,5	21,0	65,91	31,33	8,21	0,61	0,12	1,41	3,62	0,061	0,018	36,48
16,0	11,5	63,20	36,71	15,32	0,72	0,12	1,10	3,30	0,063	0,020	20,41
16,0	16,0	62,81	28,32	16,03	0,68	0,12	1,20	3,51	0,066	0,022	28,32
16,0	21,0	60,40	20,43	16,41	0,70	0,13	1,30	3,68	0,070	0,022	34,42

Table 3. **Degree of metallization for different contents of coke and limestone and lime**
Tablica 3. **Udio metalizacije za različite udjele koksa i vapnenca i vapna**

CaO content in the sinter. Lime addition / %	Coke content in the sinter / %	Degree of metallization / %	CaO content in the sinter. Addition of limestone / %	Degree of metallization / %
0,69	1,5	16,29	0,69	16,29
0,69	16,0	32,28	0,69	32,28
0,69	21,0	39,86	0,69	39,86
8,5	11,5	32,23	8,5	18,97
8,5	16,0	44,50	8,5	32,43
8,5	21,0	55,34	8.5	40,27
16,0	11,5	32,29	16,0	19,43
16,0	16,0	45,08	16,0	33,41
16,0	21,0	56,98	16,0	41,43

Increasing CaO addition from 8,5 % to 16 % at a coke breeze content of 11,5 % and 21 % results in a decrease in FeO, respectively, from 47,10 % to 36,71 % and from 31,33 % to 20,43 %. The data indicate that during sintering of ore mixes reduction processes prevail over oxidation processes. The FeO content of sinter decreases according to the following relationship:

$$FeO = -1{,}93CaO - 1{,}70C_K + 85{,}58;$$
$$R = 0{,}984,$$

where C_K is carbon in coke mass in %.

It follows from the above relationship that each percent of increment in CaO and C_K results in a decrease in 3,63 FeO percentage of sinter. Decreasing FeO content of sinter as a result of the addition of CaO and coke C results in the proportional increase in the content of metallic iron. It is characteristic that $Fe_{met.}$ increases with the addition of CaO only up to 8,5 %, while with further increase in CaO up to 16 % at a coke breeze content of 11,5 % and 21 %, respectively, the $Fe_{met.}$ increase is stopped. The values of the obtained $Fe_{met.}$ are reflected in the index of metallization degree, which is given in Table 3. It can be seen from this table that the obtained degree of metallization varies from 16,29 % at the CaO content of 0,69 % and coke content of 11,5 % to 56,98 % at the CaO content of 16 % and coke content of 21 % in the mix.

Table 4. **Output of the sintering machine in t/m^2h**
Tablica 4. **Izlaz stroja za sinteriranje u t/m^2h**

CaO content in the sinter / %	Coke content in the mix / %	Lime / limestone content ratio / (%/ %)	Output /($t/m^2 \cdot h$)
0,69	11,5	0,0 / 0,0	0,93
0,69	16,0	0,0 / 0,0	0,76
0,69	21,0	0,0 / 0,0	0,62
0,69	11,5	0,0 / 0,0	0,92
0,69	16,0	0,0 / 0,0	0,76
0,69	21,0	0,0 / 0,0	0,63
8,5	11,5	0 / 100	1,00
8,5	16,0	0/100	0,85
8,5	21,0	0/100	0,65
8,5	11,5	100 / 0	1,12
8,5	16,0	100 / 0	1,00
8,5	21,0	100 / 0	0,78
16,0	11,5	0 / 100	1,08
16,0	16,0	0 / 100	0,98
16,0	21,0	0 / 100	0,72
16,0	11,5	100 / 0	1,37
16,0	16,0	100 / 0	1,28
16,0	21,0	100 / 0	1,08

The addition of CaO in the form of limestone to the mix decreases the amount of $Fe_{met.}$ in the sinter, whereby decreasing the degree of metallization, on average, from approx. 10 % up to as much as 15 %. This is caused by the fact that a considerable amount of heat from burned coke breeze is taken for the decomposition of the limestone, where the main component is $CaCO_3$. Table 4. shows that the output is influenced both by the addition of CaO in the form of lime and limestone and by the addition of coke breeze. The lowest output of 0,62 $t/m^2 \cdot h$ was obtained with no addition of lime and limestone. The highest output of 1,44 $t/m^2 \cdot h$ was obtained with the addition of 16 % of CaO in the form of powdered lime and 11,5 % of coke breeze to the mix. Increasing quick coke amount to 21 % resulted in a reduction of output down to 1,08 $t/m^2 \cdot h$.

This is understandable, because increasing the amount of quick coke in the mix will always result in a decrease of the vertical sintering rate, thus a smaller iron sinter will be obtained in a time unit. It should be emphasized that the obtained sinters with CaO contents from approx. 7 % to 16 % and SiO_2 from 0,6 % to 0,7 % can be used mainly to the steelmaking process and cannot be used for the blast-furnace process. The obtained sinters were subjected to the test of dropping from a height of 2 m. All obtained sinters were characterized by normal strength ranging from 64 to 69 % and only slightly deviated from the strength of sinters used for the production of pig irons.

CONCLUSIONS

1. There is a possibility of producing sinter of high CaO contents of up to approx. 16 % and small SiO_2 contents of approx. 0,7 %.
2. The addition of CaO in the form of powdered lime in the amount of 8,5 % and 16 % in relation to the addition of CaO in the form of limestone increases the index of metallization degree by 12 % to 15 %, on average.
3. The coke breeze addition in the mix from 11,5 % to 21 % with CaO in the mix being increased from 0,69 % to 16,0 % results in a decrease in FeO from 68,31 % to 20,43 % with $Fe_{met.}$ increasing from 11,62 % to 34,42 %.
4. The highest output of the sintering machine amounting to 1,37 t/m^2 x h was achieved with a CaO content of 16 % (with the lime being in the form of powder) and a coke breeze content of 11,5 % in the mix.
5. Sinters with high CaO contents and small SiO_2 contents, from the technology point of view, can be used for the steelmaking process.

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