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Study of the main metallurgical characteristics of iron ore raw materials (sinter and pellets)

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Abstract. The paper presents the results of studies of the chemical, phase composition and metallurgical characteristics of titanomagnetite sinter. The iron ore used in blast furnaces of JSC ‘EVRAZ NTMK’ is titanomagnetite sinter obtained from ores of the Gusevogorsky deposit. Samples of sinter with different basicities as well as with addition of binding polymers in the amount of 300 and 500 g per ton of sinter were investigated. The results of industrial tests of the production and blast furnace smelting of sinter with different basicities and additives of binding polymers are presented on the example of the operation of blast furnaces no. 5 and 6 of JSC ‘EVRAZ NTMK’. It was shown that an increase in the basicity of the sinter from 2.1 to 2.4 and the introduction of a polymer binder (in the amount of 500 g per ton of sinter) positively affect the complex of sinter metallurgical characteristics – durability after reduction, reducibility, softening and melting temperatures, and also decrease the coke rate in blast furnace smelting by 1.0–1.2%.

1. Introduction

The consumption of stocks of traditional magnetite raw materials forces us to reconsider our attitude to metal production methods and complex ore processing schemes, taking into account market demands and the use of regional resources. Ores with a low titanium content (Gusevogorsky deposit) are processed according to the metallurgical scheme, including the smelting of pig iron in blast furnaces of JSC ‘EVRAZ NTMK’.

The use of Ural titanomagnetites consists in the efficient provision of high-quality raw materials for blast furnace production of JSC ‘EVRAZ NTMK’. Raw materials processing technologies continue to develop continuously [1], therefore, those measures that are aimed at producing sinter with improved metallurgical characteristics are of particular interest [2–4].

2. Chemical and phase compositions of titanomagnetite sinter

Samples of titanomagnetite sinter with a basicity of 2.1 were selected for the study. The chemical composition of the studied samples of sinter is given in Table 1. The designation of the samples is as follows: 1 – sinter of current production (sinter machine no. 1); 2 – sinter (lower part of the pallet, sinter machine no. 1); 3 – sinter (middle part of the pallet, sinter machine no. 1); 4 – sinter (upper part of the pallet, sinter machine no. 1).

Figure 1 shows a typical diffraction pattern of samples of sinter. The main phase in sinter no. 1–4 is Fe_3O_4 (magnetite), Fe_2O_3 (hematite) is contained in a smaller amount, and Ca-containing silicate of a complex composition – $Ca_{2,3}Mg_{0,8}Al_{1,5}Fe_{8,3}Si_{1,1}O_{20}$ – is also well manifested (named SFCA in literature [5–7]). The sinter contains γ-Ca_2SiO_4 (dicalcium silicate). In samples of sinter with a basicity of 2.1, the increase in the unstabilized γ-Ca_2SiO_4 phase goes from the top of the layer to the bottom. Since the presence of this phase leads to disintegration of the initial sinter, a similar pattern is expected during further experiments on reduction and durability after reduction.

Table 1. The chemical composition of the samples of sinter.

Probe	Fe_{total} (%)	FeO (%)	Basicity
1	54.18	10.44	2.1
2	54.66	8.13	
3	54.97	8.80	
4	55.87	10.5	
5	54.20	8.95	2.4
6	54.31	8.30	
7	53.82	10.27	
8	53.08	8.38	
9	52.60	8.22	2.4
10	52.70	7.24	
11	53.00	8.42	
12	52.20	10.50	
13	52.60	12.50	
14	52.30	9.67	

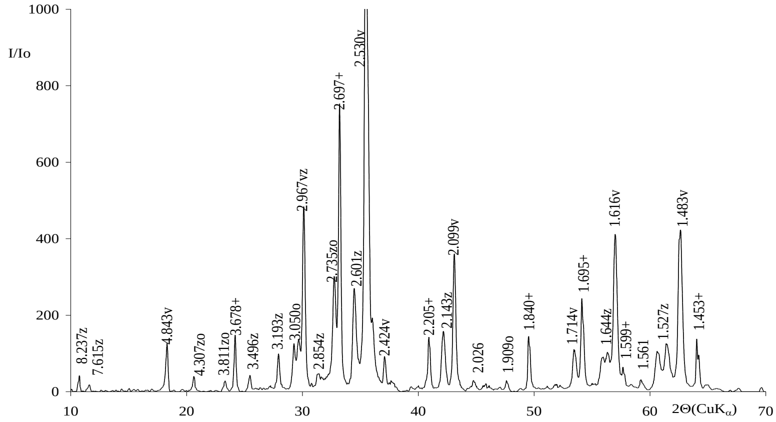


Figure 1. Diffractogramm of sinter of current production:
v – Fe_3O_4; + – Fe_2O_3;z – $Ca_{2,3}Mg_{0,8}Al_{1,5}Fe_{8,3}Si_{1,1}O_{20}$; o – γ-$Ca_2SiO_4$.

2.1 Sinter with basicity 2.4

Samples of titanomagnetite sinter with increased basicity of 2.4 were selected for the study. The chemical composition of the sinter is shown in Table 1. The designation of the samples is as follows: 5 – sinter (sinter machine no. 2); 6 – sinter (lower part of the pallet); 7 – sinter (middle part of the pallet); 8 – sinter (upper part of the pallet).

Figure 2 shows the characteristic diffractogramm of samples of the sinter. The main phase in sinter no. 5–8 is Fe_3O_4, Fe_2O_3 is contained in a smaller amount, and Ca-containing silicate of a complex composition – $Ca_{2,3}Mg_{0,8}Al_{1,5}Fe_{8,3}Si_{1,1}O_{20}$– is also well manifested. There are small amounts contain γ-Ca_2SiO_4 (dicalcium silicate). In sinter samples with a basicity of 2.4, the increase in the unstabilized γ-Ca_2SiO_4 phase is opposite from the bottom of the layer to the top.

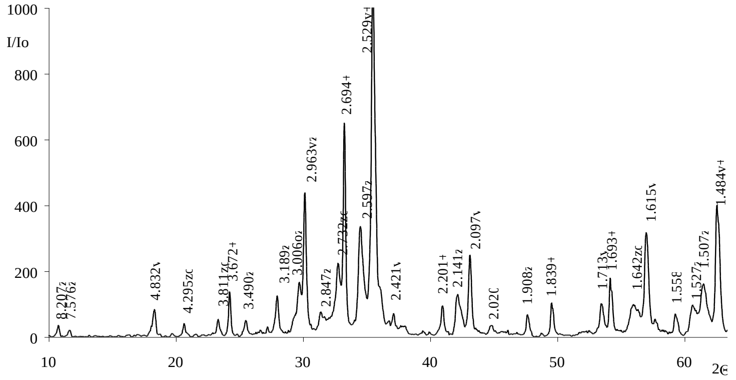


Figure 2. Diffractogramm of sinter with basicity 2.4:
v – Fe_3O_4; + – Fe_2O_3;z – $Ca_{2,3}Mg_{0,8}Al_{1,5}Fe_{8,3}Si_{1,1}O_{20}$; o – γ-$Ca_2SiO_4$.

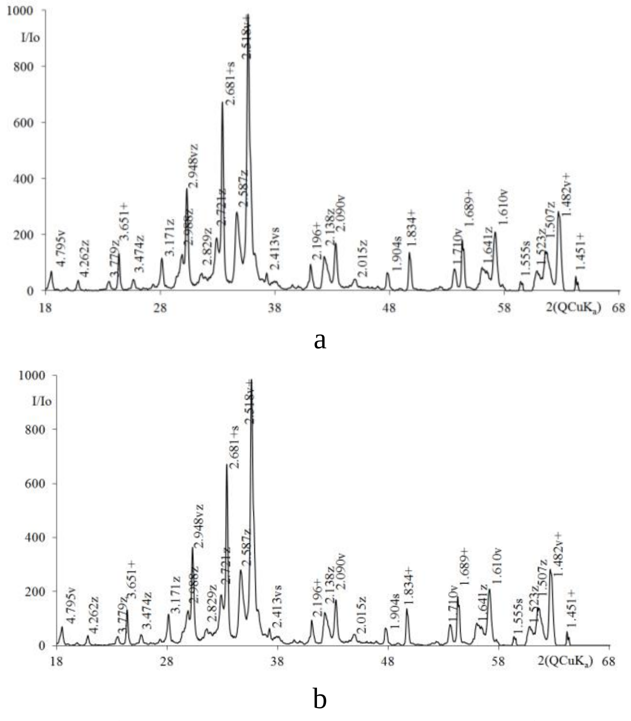
2.2 Sinter with additives of binding polymers 300 and 500 g/ton of sinter

Samples of titanomagnetite sinter with increased basicity of 2.4 and additives of binding polymers in the amount of 300 and 500 g per ton of sinter were selected for the study.

The chemical composition of the sinter is shown in Table 1. The designation of the samples is as follows: 9 – sinter with the addition of 300 g/ton of sinter (upper part of the pallet); 10 – sinter with the addition of 300 g/ton of sinter (middle part of the pallet); 11 – sinter with the addition of 300 g/ton of sinter (lower part of the pallet); 12 – sinter with the addition of 500 g/ton of sinter (upper part of the pallet); 13 – sinter with the addition of 500 g/ton of sinter (middle part of the pallet); 14 – sinter with the addition of 500 g/ton of sinter (lower part of the pallet).

As a polymer additive, a line of additives of the ‘Thermoplast SV’ series of the company ‘Polyplast – UralSib’ specialized for mining and processing plants was used [8].

Figure 3 shows the diffractogramms of the studied samples of the sinter.



a

b

Figure 3. Diffractogramms of sinter with an increased basicity of 2.4 and additives of binding polymers (a – no. 10, b – no. 13): v – Fe_3O_4; + – Fe_2O_3; z – Ca-Mg-Al-Fe-Si-O; s – CaO·TiO_2.

3. Metallurgical characteristics of sinter

The results of studies of Low Temperature Index ($LTD_{+6.3}$), also called Durability after reduction, in accordance with ISO 13930 [9], the temperature range of sinter samples in accordance with State Standard of Russian Federation no. 26517–85 [10], and sinter reducibility in accordance with State Standard of Russian Federation no. 17212–84 [11] are shown in Table 2.

On the whole, according to the samples taken from the middle and lower layers, the durability of the sinter (with a polymer additive content of 500 g per ton of sinter) significantly improved.

Table 2. Results of investigation of metallurgical characteristics of sinter probes.

Probe	$LTD_{+6.3}$ (%)	Reducibility (%)	Temperature of beginning of softening (°C)	Temperature of ending of softening (°C)	Temperature range (°C)
1	6.13	74.70	1180	1300	120
2	8.38	65.80	1200	1300	100
3	8.65	83.20	1220	1290	70
4	1.99	80.70	1240	1360	120
5	13.68	64.70	1140	1280	140
6	10.40	61.80	1200	1320	120
7	14.74	61.70	1260	1340	80
8	7.370	70.20	1210	1330	120
9	22.39	61.70	1200	1320	120
10	22.82	74.03	1160	1210	50
11	22.39	55.86	1120	1170	50
12	22.82	61.87	1260	1340	80
13	40.74	69.63	1170	1250	80
14	39.05	69.59	1130	1190	60

The reduction of the sinter with a polymer additive leads to the formation of metallic iron, wustite (FeO), partially magnetite (Fe_3O_4). Silicate phases are formed against the background of iron-forming phases: β-$2CaO \cdot SiO_2$ and $2CaO \cdot Al_2O_3 \cdot SiO_2$. Also, $3CaO \cdot Al_2O_3$ is weakly manifested in the samples.

4. Results of industrial tests of production and blast furnace smelting of sinter with different basicity and additives of binding polymers [12]

Tables 3–4 show some indicators of the quality of sinter and blast furnace (BF) smelting (BF no. 5, 6 of JSC ‘EVRAZ NTMK’) for the period April – October of 2015. This period can be conditionally divided into stages: April-May – stage 1 or basic (basicity of the sinter 2.1); June-July – stage 2 (basicity of the sinter 2.4); August-September – stage 3 (basicity of sinter 2.4 with a polymer additive); October – stage 4 (basicity of the sinter 2.4).

Coke rate at BF no. 5 (kg/t of pig iron) decreased 335.3 in April to 331.3, i.e. by 4.0 kg/t of pig iron (1.2 %), total fuel rate (kg/t of pig iron) decreased 483.2 in April to 478.5, i.e. 4.7 kg/t of pig iron (1.0 %). Coke rate at BF no. 6 decreased 390.5 in April to 386.7, i.e. 3.8 kg/t of pig iron (1.0 %), total fuel rate (kg/t of pig iron) fell 508.8 in April to 503.3, i.e. 5.5 kg/t of pig iron (1.1 %).

The metallurgical characteristics of the sinter changed in stages as follows (Table 5). Attention should be paid to the uneven distribution of the quality indicator along the height of the layer; the sinter from the upper layer has the least value. An increase in the basicity of the sinter also led to an increase in ‘hot’ durability, which is confirmed by published data. In particular, in paper [13–15], an increase in the hot durability of the sinter is explained by an increase in the amount of the SFCA phase with an increase in basicity.

The results show a decrease in the position of the cohesion zone down in height and a narrowing of the temperature range, which should generally have a positive effect on the operation of the blast furnace.

Table 3. Indicators of BF no. 5 and quality of sinter in 2015.

	April	May	June	July	August	September	October
Coke rate (kg/ton of pig iron)	335.3	335.7	331.3	332.9	343.8	331.3	345.7
Natural gas rate (m^3/ton of pig iron)	106.0	105.8	104.0	104.5	107.2	104.9	114.6
Pulverized coal fuel rate (kg/ton of pig iron)	73.6	69.4	77.8	78.9	68.4	76.5	56.5
Total fuel rate (kg/ton of pig iron)	483.2	479.2	480.5	483.6	486.0	478.5	482.9
Degree of CO (%)	51.8	51.4	51.9	51	50.3	50.3	50.2
Burden rate (%): sinter	38.5	38.7	35.6	39.7	39.4	38.3	39.4
pellets	53.4	51.2	51.4	52.6	54.1	54.7	55.8
iron flux	8.1	10.0	12.9	7.7	6.5	7.1	4.8
Sifting (%)	16.2	16.3	15.4	15.6	12.8	13.4	13.9
Durability +5 mm (%)	74.6	73.8	74.3	74.9	75.8	75.9	76.0

Table 4. Indicators of BF no. 6.

	April	May	June	July	August	September	October
Coke rate (kg/ton of pig iron)	390.5	384.9	376.3	387.7	383.5	386.7	406.3
Natural gas rate (m^3/ton of pig iron)	118.4	113.4	102.4	110.4	107.2	118.5	119.5
Pulverized coal fuel rate (kg/ton of pig iron)	29.3	30.3	53.3	38.2	40.4	28.2	6.6
Total fuel rate (kg/ton of pig iron)	508.8	500.3	503.6	507.8	502.5	503.3	505.4
Degree of CO (%)	50.1	51.1	50.0	50.7	50.6	50.8	50.8
Burden composition (%): sinter	38.1	38.6	37.5	38.8	38.1	38.1	40.7
pellets	52.1	50.7	52.5	51.7	52.3	51.5	53.9
iron flux	9.9	10.6	10.1	9.5	9.6	10.3	5.4

Table 5. Metallurgical characteristics of the sinter by stages
(averaged values according to the measurement results).

	Stage 1	Stage 2	Stage 3	Stage 4
LTD+6.3 (%)	11.01	13.68	12.57	39.9
Reducibility (%)	74.75	64.74	64.90	69.61
Temperature of beginning of softening (°C)	1060	1140	1140	1150
Temperature of ending of softening (°C)	1200	1280	1190	1220
Temperature range (°C)	140	140	50	70

Conclusion

It was found that the reducibility of the sinter with a basicity of 2.4 compared to 2.1 is 10 % lower, which does not contradict the LTD data: the lower the reducibility, the higher the hot durability. According to LTD, sinter with a basicity of 2.4 shows higher values in all three quality indicators: +6.3, –3.15, –0.5. The temperature of the beginning and ending of softening of the sinter with a basicity of 2.4 compared with 2.1 increased by 80 °C. The softening interval has not changed.

The addition of a polymer binder in the amount of 500 g/ton to the sinter burden has a more significant effect on the quality of the sinter than the addition of 300 g/ton. The durability of the sinter during reduction significantly improved in all three indicators. So, $LTD_{+6.3}$ amounted to 39.9 % against 11.01 % in the base period. Attention should be paid to the uneven distribution of quality indicators along the height of the layer; the sinter from the upper layer has the least value. The reducibility of the sinter with the addition of a polymer binder in an amount of 300 g/ton, and especially in an amount of 500 g/ton, increased to 64.9–69.61 %. This indicator is close to recommended for the blast furnace process. The results of determining the softening and melting temperatures for sinter with polymer additives show a decrease in the cohesion zone down in height and a narrowing of the temperature range, which will generally have a positive effect on the operation of the blast furnace.

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