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HIGH-SiO_2 IRON ORE SINTERING: CENTRAL & EASTERN EUROPE SCENARIO

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Sinter plants in the region of Central & Eastern Europe are typical for the processing of iron ores with high SiO_2 content, which leads to an unusual high silica ratio in the sinters compared to the rest of the world. This study describes the scenario in sinter plants in Central & Eastern Europe and analyzes some iron ores exploited in Russia and Ukraine using the XRF and light microscope analytical methods.

Key words: iron ores, sintering, chemical composition, microstructure, Europe / Central & Eastern

INTRODUCTION

For the traditional blast furnace ironmaking route, iron ore supply is a most important topic. Today, the largest world ore exporters are Australia and Brazil [1], which supply European ironworks as well. While in Western Europe almost only imported ore is blended, sinter plants located in Central & Eastern (C&E) Europe use European sources in high ratios.

PRESENT SITUATION

There are three large iron ore deposit localities in Europe: Kiruna (Sweden), Kursk magnetic anomaly (Russia) and the Ukrainian shield (Ukraine). In Kiruna, magnetite concentrates for pelletizing is almost solely produced, thus it will not be considered further in this study.

Kursk magnetic anomaly is a large banded iron formation (BIF) deposit, but only three mines are operating: Mikhailovsky GOK (mining-beneficiation plant), Lebedinsky GOK and Stoilensky GOK, all as open-pit. For sintering purposes, Mikhailovsky GOK produces concentrates and sintering ore, Lebedinsky GOK concentrate and Stoilensky GOK concentrate and sintering ore. The ore products from Stoilensky GOK are blended in Novolipetsk Steel as 90 % charge by sintering [2].

The Ukrainian shield is divided into three deposits [3]: Kremenchuk, the Krivoy Rog basin and Belozerka. Exploited ores from Kremenchuk are directly processed into Poltava pellets. The Krivoy Rog basin is the largest deposit with more open-pit and shaft mines producing sintering ore as well as concentrates. In Belozerka, sintering ore is produced by the Zaporozhskiy ZRK (iron ore combine). The geographic situation of the mentioned deposits and mines is shown in Figure 1, where the sintering plants C&E Europe are marked as well.

Besides the Ukrainian and Russian, a few mines operate in the region, however, only of local importance: siderite mine Erzberg in Austria, where the whole production is consumed by the voestalpine works [4] and the Prijedor limonite mine in Bosnia and Herzegovina owned by ArcelorMittal [5].

The peculiarity of sintering ores from C&E Europe is, that they are of a high silica nature on the level of 7 – 10 wt. % SiO_2 (Mikhailovsky up to 20 wt. % SiO_2); currently, higher grades with comparable quality of world ores are also available [6]. Using these ores rapidly increases the silica ratio in produced iron ore sinters.

Ore blending and chemical composition of sinters of selected (anonymous) sinter plants in C&E Europe are summarized in Table 1. Note that the data were not collected during the same period and the sinter parameters are always related to the actual blast furnace requirements, which can change. As seen, the ratio of ore materials from the Commonwealth of independent states (CIS) + Ukraine are in an absolute majority, mostly the whole blend.

The highest SiO_2 content was reached in sinters from plants A, F and G (all around 10 wt. %); however, the basicity is also an important factor – in plant C, the high CaO content pressed the silica ratio on 8,47 wt. %. The lowest SiO_2 content was in sinters from plants D and H thanks to mixing richer concentrates, in the case of H the whole mixture was only blended with concentrates. On the other hand, despite a higher amount of concentrates plants F and G produced high-SiO_2 sinters because of lower-grade concentrates.

The effort of keeping the quality of sinters in recent years led to changes by blending. To eliminate the ele-

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Table 1 **Blending and chemical characterization of iron ore sinters produced in C&E Europe / wt. %**

Sinter plant	A	B	C	D	E	F	G	H
Concentrate/ore ratio	40/60	45/54	55/45	60/40	65/35	70/30	75/24	100/0
CIS* materials ratio	80	100	100	80	100	100	100	100
Fe_{tot}	55-58,8	57-57,8	47,17	58,59	54,6	51,2-57,6	48,6-54,4	58,2
FeO	6,1-13,6	8,04-8,33	6,48	5,96	17,2	9,1-15,6	10,7-12,1	11,6
Fe_2O_3	N	72,4-73,2	60,25	77,15	58,95	N	N	70,32
CaO	7,3-10,2	7,09-8,07	18,08	7,95	12	N	12,6-19,5	8
SiO_2	7,9-10	7,46-7,57	8,47	5,57	7,4	9,2-10,4	7-9,1	4,9
Al_2O_3	0,9-1,18	0,79-0,89	0,99	0,83	1,5	N	N	1,1
MgO	1,5-2	1,49-1,61	3,22	1,58	1,9	N	1,74-2,8	2,7
CaO/SiO_2	0,8-1,2	0,95-1,07	2,13	1,43	1,62	1,2-1,8	1,58-2,38	1,63

* - incl. Ukraine, N – no data

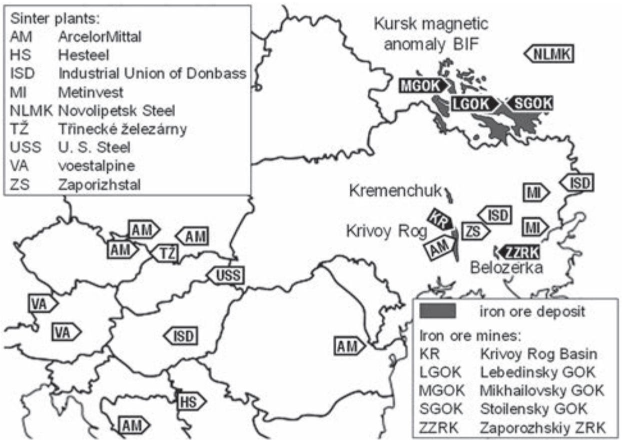

Figure 1 Situation of iron ore deposits and sinter plants in C&E Europe

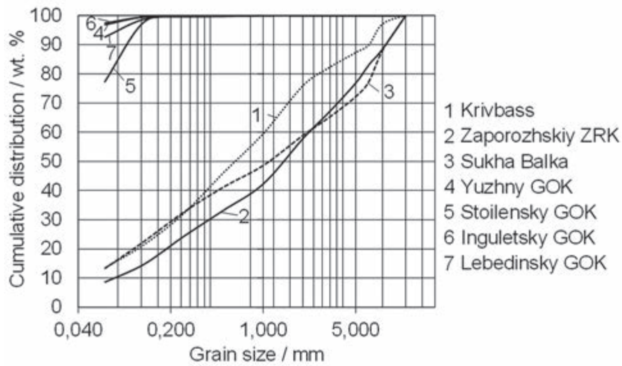

Figure 2 Sieve analysis of ores and concentrates

vated gangue content of hematite ores blended in Poland, the ratio of sintering ore to fine grained concentrates in the sintering mixture was gradually decreased from 1,3 to 0,5 during 2001-2010 [7].

In Hungary, the SiO_2 content in sinters reached 18 wt. % at the beginning of operation in 1958 and decreased gradually to a level of 6 wt. % in 2014. At the same time, the CaO content remained almost unchanged ~10 – 12 wt. %, so the basicity increased with the implementing of rich ores up to 3,5 [8].

Increased import of rich ores can improve sinter properties in the future, but the use of ores from C&E Europe will probably be further kept on high ratios because of lower prices, which are 1,5 – 2 times less compared to the prices of imported ores [3].

MATERIALS AND METHODS

For the characteristic of ore materials exploited in Eastern Europe, samples of 4 concentrates (Inguletsky and Yuzhny from Ukraine, Lebedinsky and Stoilensky from Russia) and 3 sintering ores (Krivbass, Zaporozhskiy and Sukha Balka, all Ukrainian) were chosen. To analyze the size distribution of the materials, sieve analysis on a vibrating screen with 11 sieve fractions was undertaken. For the chemical characterization, the XRF method with a Niton spectrometer was used. Ore mineralogy was examined with a Leica DM4500P optical light microscope.

RESULTS

The sieve analysis of ores and concentrates is plotted in the diagram in Figure 2. With the exception of Stoilensky with 20 wt. % of the 0,063-0,125 mm, all concentrates are from at least 92 wt. % finer than 0,063

Table 2 **Chemical composition of the granulometric fractions of concentrates / wt. %**

Sample	Fraction / mm	Fe_{tot}	SiO_2	CaO	Al_2O_3	MgO
Inguletsky	total	67,72	4,13	0,31	0,20	1,20
	+0,5	31,30	45,88	2,01	0,16	0,94
	0,25-0,5	28,26	50,59	3,43	0,17	1,21
	0,125-0,25	39,10	39,08	1,19	0,16	0,90
	0,063-0,125	39,80	39,81	1,34	0,14	1,01
	-0,063	68,52	3,54	0,27	0,20	0,55
Juzhny	total	67,91	5,74	0,27	0,10	0,00
	+0,5	27,00	14,87	23,78	0,49	1,93
	0,25-0,5	42,85	26,37	9,35	0,29	0,77
	0,125-0,25	35,17	37,52	14,42	0,67	1,05
	0,063-0,125	56,05	13,70	0,43	0,20	0,83
	-0,063	68,70	4,23	0,20	0,18	0,51
Lebedinsky	total	68,24	4,91	0,25	0,16	0,83
	+0,5	45,01	12,66	12,08	0,21	1,70
	0,25-0,5	46,94	20,15	5,19	0,26	2,12
	0,063-0,25	52,20	25,28	0,98	0,22	0,41
	-0,063	70,34	3,85	0,24	0,15	0,21
Stoilensky	total	65,12	6,43	0,30	0,16	0,53
	+0,25	42,05	23,05	1,75	0,22	1,02
	0,125-0,25	46,07	21,65	1,04	0,13	0,75
	0,063-0,125	62,70	9,02	0,43	0,10	0,61
	-0,063	68,02	5,33	0,20	0,14	0,54

Table 3 **Chemical composition of the granulometric fractions of sintering ores / wt. %**

Sample	Fraction / mm	Fe_{tot}	SiO_2	CaO	Al_2O_3	MgO
Zaporozhskiy	total	60,60	8,71	0,88	1,60	0,83
	+8	59,42	8,80	0,15	0,99	0,71
	6,3-8	58,34	9,10	0,28	0,82	0,68
	5-6,3	58,81	9,17	0,24	0,83	0,60
	3,15-5	60,88	9,51	0,30	1,04	0,80
	2-3,15	59,14	8,35	0,24	0,84	0,63
	1-2	60,19	8,20	0,40	1,03	0,90
	0,5-1	61,48	7,56	0,41	1,38	0,51
	0,25-0,5	60,86	7,00	0,75	1,55	0,51
	0,125-0,25	62,63	5,45	0,73	1,51	0,48
	0,063-0,125	63,66	5,45	0,89	1,40	0,35
	-0,063	63,36	5,78	0,91	1,46	0,42
Sukha Balka	total	61,74	9,61	0,11	0,98	0,86
	+8	48,41	17,40	0,07	0,75	0,73
	6,3-8	54,69	15,50	0,08	0,87	0,67
	5-6,3	59,13	14,10	0,08	0,75	0,49
	3,15-5	60,46	11,04	0,10	0,78	0,52
	2-3,15	59,52	12,52	0,09	0,69	0,61
	1-2	62,84	8,60	0,08	0,79	0,50
	0,5-1	63,05	7,87	0,11	0,98	0,41
	0,25-0,5	64,58	6,49	0,11	1,72	0,36
	0,125-0,25	64,29	6,85	0,12	1,61	0,31
	0,063-0,125	64,19	6,94	0,15	1,11	0,27
	-0,063	65,31	4,78	0,13	0,91	0,44
Krivbass	total	62,25	7,80	0,28	1,33	0,60
	+8	48,45	15,64	0,18	0,88	0,86
	6,3-8	56,86	11,28	0,17	1,21	0,89
	5-6,3	59,32	9,86	0,15	1,13	0,81
	3,15-5	58,64	10,14	0,13	1,17	0,84
	2-3,15	63,12	7,26	0,19	1,27	0,63
	1-2	64,51	5,89	0,19	1,19	0,71
	0,5-1	65,16	5,32	0,20	1,03	0,59
	0,25-0,5	64,12	4,86	0,23	1,79	0,67
	0,125-0,25	66,94	4,66	0,28	1,66	0,51
	0,063-0,125	66,23	4,07	0,22	1,52	0,41
	-0,063	65,96	4,38	0,26	1,60	0,42

mm. From the evaluated sintering ores, Krivbass has the finest granulometry, the most homogenous is the Sukha Balka ore.

The overall chemical composition of studied concentrates does not show the extraordinary high gangue contents (Table 2). In all samples, SiO_2 is the main gangue component, while other components do not exceed 1 wt. % (the only exception is the MgO content by Inguletsky – 1,2 wt. %). The fraction -0,063 mm is the richest in iron in all cases, with coarsening the particles the iron content rapidly decreases and the content of admixtures increase. The most evident is the concentration of SiO_2: by Inguletsky it reaches more than 50 wt. % within the fraction 0,25-0,5 mm. In other samples the increase of SiO_2 is milder. Interesting are the contents of CaO in the Yuzhny fractions higher than 0,125 mm; the coarse particles bigger than 0,5 mm mainly consist of CaO (almost 24 wt. %) followed by silica (almost 15 wt. %), while the iron content is only 27 wt. %. The Al_2O_3 content is low in all concentrates within all grain sizes, the MgO exceeds 2 wt. % only by Lebedinsky fraction 0,25-0,5 mm. Despite the drastic changes in the grain size, the overall composition of the concentrates is only slightly affected because of the very high ratio of the finest fraction.

The compositional trend by concentrates is also similar to sintering ores (Table 3): while fine fractions have properties of high-grade ores (~5 wt. % silica), coarsening of the particles gradually brings an increase in gangue content. Remarkable are the concentrations by Sukha Balka and Krivbass, where the particles +8 mm contain more than 15 wt. % of SiO_2.

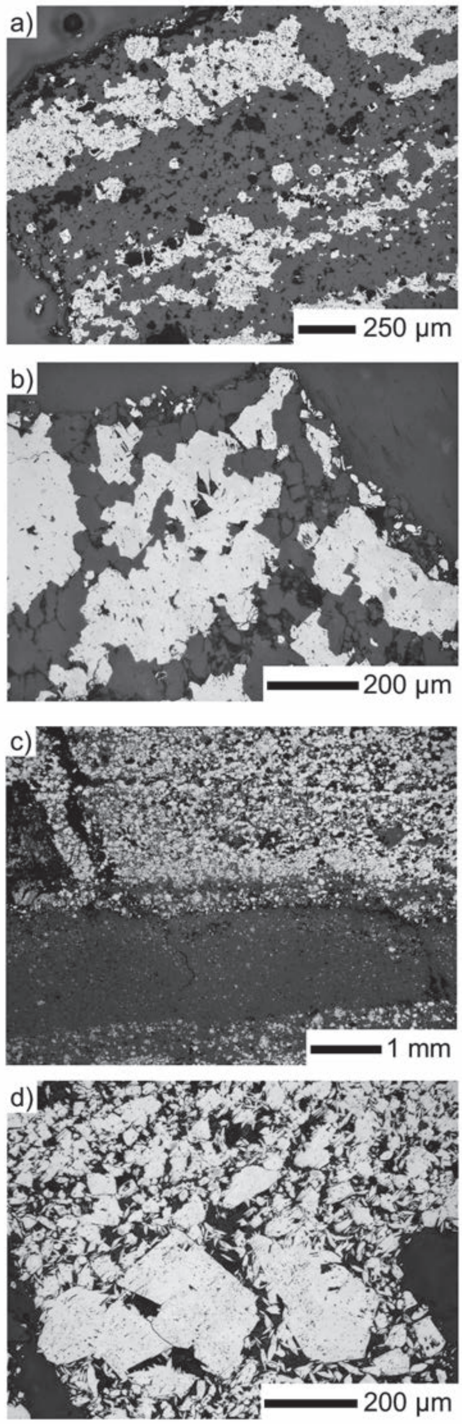

Figure 3 Light micrographs of ore microstructure: a) and b) Sukha Balka, c) and d) Zaporozhskiy

The microstructure of ores is a typical BIF structure with changing quartz and hematite layers. As shown in Figure 3 a) and b), the Sukha Balka ore consists of massive quartz bands (dark grey) and martite grains (white) with traces of relict magnetite. Mainly in the quartz parts, pores are easily observable. Also, for the Zaporozhskiy ore a banded structure is typical (Figure 3 c). The overall phase composition of Zaporozhskiy ore is similar to Sukha Balka, but, additionally, beside martite grains a higher ratio of specularite crystals (white elongated) are present (Figure 3 d).

CONCLUSIONS

The situation of sinter plants located in Central & Eastern Europe, where a high proportion of iron ores with high SiO_2 content are blended to produce sinter, were described. Selected iron ores and concentrates exploited in Ukraine and Russia were analyzed. Studied ore materials are heterogenic in the chemical composition of grain fractions: while fine material is iron rich, with coarsening of the particles the gangue content increases. The microstructure of ores consists of massive quartz and hematite bands, mostly in the form of martite and specularite with little relict magnetite.

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Note: The responsible for English language is Edward Peter Norris, Košice, Slovakia.