M. FRÖHLICHOVÁ*, D. IVANIŠIN**, A. MAŠLEJOVÁ**, R. FINDORÁK*, J. LEGEMZA*

IRON-ORE SINTERING PROCESS OPTIMIZATION

OPTYMALIZACJA PROCESU AGLOMERACJI RUDY ŻELAZA

The work deals with examination of the influence of the ratio between iron ore concentrate and iron ore on quality of produced iron ore sinter. One of the possibilities to increase iron content in sinter is the modification of raw materials ratio, when iron ore materials are added into sintering mixture. If the ratio is in favor of iron ore sinter, iron content in resulting sintering mixture will be lower. If the ratio is in favor of iron ore concentrate and recycled materials, which is more fine-grained, a proportion of a fraction under 0.5 mm will increase, charge permeability property will be reduced, sintering band performance will decrease and an occurrence of solid particulate matter in product of sintering process will rise. The sintering mixture permeability can be optimized by increase of fuel content in charge or increase of sinter charge moisture. A change in ratio between concentrate and iron ore has been experimentally studied. An influence of sintering mixture grain size composition, a charge grains shape on quality and phase composition on quality of the produced iron sinter has been studied.

Keywords: iron ore, iron concentrate, sintering process, particulate matter, recycled materials

Publikacja dotyczy zagadnienia oceny wpływu proporcji między koncentratem rudy żelaza a rudą żelaza na jakość wyprodukowanego spieku. Jedną z możliwości zwiększenia zawartości żelaza w spieku jest zmiana proporcji materiałów surowcowych, które dodaje się do mieszanki spiekalniczej wraz z materiałami zawierającymi rudę żelaza. Jeśli proporcja ta jest korzystna dla spieku, to będzie to mieć wpływ na mniejszą zawartość rudy żelaza w końcowej mieszance aglomeratu. Jeśli proporcja ta jest korzystna dla drobnoziarnistego koncentratu rudy żelaza i materiałów wtórnych, to wtedy: udział frakcji poniżej 0,5 mm ulegnie zwiększeniu, przewiewność wsadu oraz wydajność taśmy spiekania ulegną zmniejszeniu, zaś zwiększy się liczba cząstek stałych (emisji) pochodzących z procesu spiekania. Przewiewność mieszanki spiekalniczej można optymalizować poprzez zwiększenie zawartości paliwa we wsadzie albo poprzez zwiększenie wilgotności. Przeprowadzono eksperymentalną kontrolę zmiany proporcji między koncentratem a rudą żelaza. Zbadano wpływ składu granulometrycznego mieszanki aglomeratu oraz kształtu ziaren wsadu na jakość i skład fazowy wyprodukowanego spieku.

1. Introduction

The sintering mixture, necessary for iron ore sinter production, is composed of various kinds of iron ores, fluxes, recycled raw materials and fuel. A new composition and new grain size of sintering mixture have been examined in a laboratory testing sintering pot [1], where the height of sintered layer corresponded to a height of sintered layer under operating conditions. A need for further reduction of released particulate matter arose due to more stricter environmental legislation. Emissions discharged have been reduced under 10 mg/Nm3 [2]. If a wide range of iron ore raw materials has been used, a more advantageous method of mixing the sintering mixture is to establish primary homogenized piles and/or secondary homogenized piles [3, 4]. From all characteristics of components of raw materials suitable for sinter production, grain size is one of more important aspects of material suitability [5,6]. The highest allowable grain size for sintering

process may not exceed 10 mm. The most convenient grain size for the raw materials processing by sintering is grain size under 5 or 3 mm [7]. The most frequently used additives for sinter production are limestone, dolomite and burnt lime and recycled materials. The grain size of additives has to meet a condition of 90% of grain size below 5 mm. However, there are also plants demanding 100% under 3 mm [8,9]. If additives are coarsely ground, an incomplete calcination can occur on sintering band, additives won't react completely with iron mixture components. Such non-reacted additives will be screened with hot sinter, which results in decreased sinter basicity as against expected basicity value, and also decreased sinter strength. The main fuel at sintering is coke breeze. The coke breeze is obtained from abrasion of coke during transport into skip bins at the blast furnace. The anthracite can also been used as a substitute for coke in ratios for 30 to 50%, which means substitution coefficient from 0.9 to 1.0. The fuel grain size is 85+5% under 3 mm. The ratios concentrate/sinter ore

* DEPARTMENT OF FERROUS AND FOUNDRY METALLURGY, TECHNICAL UNIVERSITY OF KOŠICE, LETNÁ 9, 042 00 KOŠICE, SLOVAK REPUBLIC

** U. S. STEEL KOŠICE, S.R.O. VSTUPNÝ AREÁL U. S. STEEL, 044 54 KOŠICE, SLOVAK REPUBLIC

\# Corresponding author: Maria.Frohlichova@tuke.sk

are varying, in most cases they oscillate around 1.0. If this ratio is lower than one, the Fe content in charge will also decrease. On the other hand, in the case of a higher ratio of concentrate/ sinter ore, a larger amount of fine-grained concentrate is in the charge and herewith production of particulate matter is increased. An increase of concentrate share in the charge will result in increase of share of grains smaller than 0.5 mm, which results in decrease of charge permeability and decrease of sintering belt output [10,11]. Recycled materials contribute to the permeability deterioration due to a very fine grain size composition. If a fuel has a higher grain size, operating issues will come about, hot nests will be created and sinter strength will markedly decrease. If a fuel is overground and has a lower grain size than the optimal one, an effect of apparent lack of fuel will arise [12]. Too fine grains of fuel will quickly burn down and won't deliver heat to metallic charge, thus correct burning and heat transfer on sintering belt won´t come about. Higher fuel humidity has to be taken into consideration as well.

Grain size and morphology of individual materials is used to evaluate suitability of iron ores and additives for sintering process. The theoretical conditions for good pelletability and creation of micropellets at third mixing stage in addition to chemical, mineralogical composition of applied concentrates are also their grain size, shape and surface properties of material. Grain size and grain shape have a significant impact upon concentrate pelletability. The number of contact places increases with the decrease in particle size [13,14]. The concentrates contain the grains with a shape of polyhedrons, balls, plates or branched dendrites. From the viewpoint of the strength of micropellets a total surface of grain contact in a mixture to be pelletized is crucial. This surface is the largest, if the grains have a shape of polyhedrons, and it decreases with a change into plate, spherical or dendritic shape and the strength of micropellets decreases. The grains of coke have a shape of sharp angular lamels even needles and contribute to a poor pelletability of the sintering mixture [15].

The grain shape determines a behavior of material during micropelletizing process, as well as during drying and sintering. The grain shape factor determines a deviation of the circle periphery of projection plane of a grain from the circle. In case of a circle, the shape factor equals to 1.0. The shape factor for polyhedron is 0.91, for square is 0.79, for triangle is 0.6 and for rectangle 0.75 [16].

Some iron bearing materials were evaluated prior to laboratory experiments and the grain shape factor was determined. The material shown in Fig. 1 is composed of the grains with sharp edges of polyhedron shape with a size of several μm up to 30-40 μm. The shape factor has a value of 0.59; it tabularly represents a rectangle form with sides ratio 1:3.

The material shown in Fig. 2 is composed of the grains with very sharp edges of polyhedron shape with smooth surfaces with a size of several μm up to about 50 μm. The shape factor has a value of 0.94; it represents a polyhedron form. The material shown in Fig. 3 is composed of the grains with partially smooth edges of polyhedron shape with a size of several μm up to about 100 μm. The shape factor has a value of 0.78; it represents a square form.

The material shown in Fig. 4 is composed of the grains with mostly smooth edges of polyhedron shape and lamels with size of several μm up to 250 μm; it represents two-times

up to three-times larger grains in comparison with the other concentrates discussed herein. The shape factor has a value of 0.7; it represents a rectangle form with sides ratio of 1:2 [17].
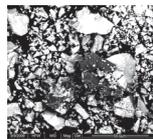
Fig.1. Shape factor 0.59
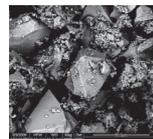
Fig.2. Shape factor 0.94
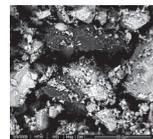
Fig.3. Shape factor 0.78
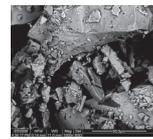
Fig.4. Shape factor 0.70

2. Materials and methods

Six kinds of sintering mixtures were prepared for testing in a laboratory sintering pot (S-Ax, S-Bx, S-Cx, S-Dx, S-Ex, S-Fx). For needs of an experiment the amount of 500 kg was taken from each raw material that was homogenized, quartered and was subsequently used for a sintering mixture. The mass of one charge for sintering in laboratory pot consisted of required 250 kg of consistently homogenized sintering mixture. A grain size analysis was performed on the screens with mesh size: 8 mm; 5.6 mm; 4 mm; 2 mm; 1 mm; 500μm; 250μm; 125μm; 63μm according ISO 4701:2008 requirements. A mixture S-Fx didn't contain sinter ores AR-1 and AR-2. A concentrate portion of the mixture consisted of two raw materials KC1 and AR-5. The proportion of these two components was changed at each examined charging mixture. A proportion of an iron ore AR-5 gradually increased in the concentrate portion of the mixture, see Table 1. The first mixture S-Ax was used as a „base case", it contained sinter ores (AR-1, AR-2, AR-3 and AR-4), concentrate KC1, additive components (dolomite, limestone), the recycling materials (micropellets, slag) and a fuel (breeze coke). In this reference mixture a proportion of sinter ores and concentrate was determined as 1:1. This proportion had to be maintained during the whole experiment for a successful passage through all tests. The amount of recycling materials (micropellets and slag), the manganese ore and a fuel similarly remained unchanged within all tests. An amount of additives – dolomite and limestone was determined by calculation for particular charges.

In the second mixture S-Bx a concentrate portion was changed, 25% of concentrate KC1 was substituted by tested sinter ore AR-5. The total proportion of sinter ores and concentrates remained unchanged. In the first test stage a proportion of tested sinter ore AR-5 in concentrate part of the mixture was raised in each test by 25%. Thus the sinter ore proportion was raised in particular mixtures from 0% (S-Ax) to 25% (S-Bx), 50% (S-Cx), 75% (S-Dx) and/or 100% (S-Ex). In (S-Fx) 66% of concentrate were substituted by sinter ore AR-5 – from the perspective of verification of obtained results. The suction surface of a laboratory sinter pot constituted 0.25m². The height of charge layer was 400 mm. The negative pressure in individual tests of the total experiment was 7 kPa. The fan with a constant speed was used for suction. Each test was repeated twice, in order to exclude possible measuring error during sintering. If a large difference occurred among particular sintering processes, it would be necessary to perform another sintering test. When preparing mixtures, a determining factor was a permeability of mixtures. It was set up for the reference

TABLE 1

The composition of sintering mixtures used during the sinter pot tests

Sintering mixture	S-Ax	S-Bx	S-Cx	S-Fx	S-Dx	S-Ex
Concentrate substitute ratio by AR-5	0	25	50	66	75	100
	[%]					
Sinter ores:						
AR-1	5.88	5.84	5.80	0	5.76	5.73
AR-2	2.35	2.34	2.32	0	2.31	2.29
AR-3	16.06	15.96	15.86	21.31	15.75	15.65
AR-4	11.75	11.68	11.61	13.7	11.53	11.45
Sum	**36.04**	**35.82**	**35.59**	**35.01**	**35.35**	**35.12**
Concentrate:						
KC1	36.04	26.86	17.79	11.91	8.84	0
New sinter ore:						
AR-5	0	8.95	17.79	23.10	26.51	35.12
Sum	**36.04**	**35.81**	**35.58**	**35.01**	**35.35**	**35.12**
Ratio AR/KC	1.00	1.00	1.00	1.00	1.00	1.00
Recycled materials:						
Micropellets	0.78	0.78	0.77	0.76	0.77	0.76
Slags	1.57	1.56	1.55	1.52	1.54	1.53
Mn ore	1.18	1.17	1.16	1.43	1.17	1.16
Dolomite	8.35	8.23	8.01	7.86	7.97	7.85
Limestone	12.64	13.26	13.94	15.02	14.48	15.07
Coke	3.38	3.38	3.38	3.38	3.38	3.38

mixture to $0.92+0.01$ m.s^{-1}. Regarding all other tests, we attempted to obtain the same permeability. The permeability property was measured by measuring pipe, it was an appliance consisting of a cylindrical vessel with a diameter of 150 mm and a height 300 mm, which was closed at the bottom by a grating. The vessel was filled to the brim with the tested mixture. The filled vessel was placed on a grate and closed with a conical cover furnished with a sealing, connected to a suction hose in appliance. A suction hose in a device was equipped with a flow-meter. An evaluation of permeability was performed on a basis of a difference of values shown by the flow-meter before and after a start of air suction. The suction lasted for 2 minutes. After addition of an amount of water calculated, a control sample was taken from the mixture to be pelletized. The permeability was determined at this sample. In case of a larger difference of permeability of the mixture than 0.05 m.s^{-1}, the moisture of the mixture was modified. The moisture of sintering mixture was 8%. A duration of sintering was measured from the start of heating of a charge by a fire in particular tests up to beginning of fall of temperatures measured under the sinter pot grate. Subsequently, after the maximum temperature was attained, the sintering process was finished.

3. Results and discussion

The twelve tests, the six pairing tests were performed in total. A duration of sintering process ranged from 32 minutes in tests with 100% substitute of sinter ore AR-5 to, at the most

62 minutes in tests with 0% substitute of sinter ore AR-5.

A typical appearance of AR-5 material grains is polyhedron shape with very sharp edges and smooth surfaces with size of several μm up to about 150 μm. The shape factor has a value of 0.86; it represents a polyhedron form. This material was typical its inhomogeneity. The measurement was performed by an image analyzer. It can be concluded that not only the chemical composition, the grain shape were effective for obtaining very good results with this type of iron bearing material.

With increasing share of concentrate in a tested sinter ore AR-5 a representation of granulometrically lower classes decreased, which is a logical consequence of adding larger amount of sinter ore in particular charges. After cooling down the sintering cake (for about 2 hours) it was dumped, and the sinter was then weighed. The stabilization was performed by a fall of sinter from the height of 4.5 m on a steel plate. This has to simulate the sinter crushing, as well as transportation hereof in the blast furnace bins. After sinter stabilization by a shatter test the sinter cake was divided into two fractions by screening. A fraction above 5 mm constituted a mass of a finished sinter. A fraction under 5 mm represented a return sinter. A proportion of return sinter and mass yield of a sinter produced were calculated. At 25% substitution of concentrate by sinter ore AR-5 a reduction of an undersized sinter by 2.35% and a decrease of sintering time, by nearly 10% occurred. This trend continued also at 50% substitution of concentrate by sinter ore AR-5. In case of such substitute a time of sintering dropped nearly by 30% and a proportion of the return sinter

dropped by 4.6% as compared with reference sample. At 66% substitution of concentrate by a sinter ore AR-5 an increase of volume of return sinter was found, thus the quality of sintering process declined. The sintering time slightly increased. At 100% substitution a continuing trend of increase in return sinter volume was confirmed. With such substitution a sintering time reached the minimum level. The process productivity increased up to a substitution ratio of 75%. At 100% substitution there was the best result of productivity. The highest FeO content was attained in a reference charge and in a charge with substitution of concentrate by sinter ore AR-5 at 66% level. An extremely low FeO content was obtained in the case of a test with 50% substitution. One of the most important parameters of the experiment from the quality point of view was an evaluation of the strength of sinter tested charges. The strength was evaluated by a drum abrasion test (ISO 3271:2007) TI (+6.3 mm) as Strength Index and AI (-0.5 mm) as Abrasion Index. From the TI strength point of view the best was a charge with 50% substitution of concentrate by sinter ore AR-5. An improvement by 6.8% was obtained, as compared with the reference charge. It is obvious from the grain size analysis of produced sinters that with the increasing substitution of a concentrate by sinter ore a grain size above 35.5 mm markedly decreased. A moderate increase was also observed at grain sizes above 10 mm, 16 mm and 25 mm. This implies that with an increasing substitution of concentrate by tested sinter ore the balancing of sinter grain size took place. The sinter richness gradually decreased, which is a logical consequence of gradual reduction of the proportion of concentrate in the charge. Addition of recycling materials was simulated in all tests, namely through delivery of micropellets and a slag into charges. A benefit of the substitution of concentrates by tested sinter ore became evident with a sulfur content, where almost in all tests. The increase in phosphorus content was registered only in the tests S-Cx and S-Ex, at 50% and 100 % substitution of concentrate by sinter ore AR-5. The zinc content remained unchanged during the whole experiment. An unchanged content of alkali was registered. This is a proof, that recycling materials are responsible for introduction of alkali into sintering process. The carbon content was low and this is a proof of almost complete fuel combustion.

The typical produced sinter micro-structure, Fig. 5, showed very good sinter quality and a successful usage of a coarse AR-5 iron material in the sinter mixture. The microstructure is created from different parts of a porous type of pieces. The structure of standard sinters, especially when containing high flux additions and many different materials and recycled materials is very complex. Sinter in Figure 6 was very compact, composed of four main phases: iron oxides (from 40 to 70vol%), ferrites (from 20 to 50vol%), most of which are complex silico-ferrite of calcium and aluminum (SFCA), glasses (up to 10vol%) and dicalcium silicate (up to 10vol%), [18,19].
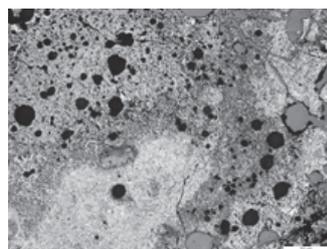
Fig. 5. Typical produced sinter structure
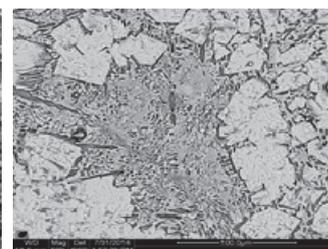
Fig.6. Compacted matrix structure of sinter

It may be unequivocally observed that a concentrate substitution in amount of 50% by tested sinter ore AR-5 (attempt S-Cx) proves the best results from the point of view of sinter strength and achieves a maximum firmness just with this particular substitution, see Table 2. This trend has a decreasing character after exceeding 50% substitution of concentrate by sinter ore. A difference between the best charge and the worst charge was 5.95%. The trend is obvious for an abrasive resistance as well as for the strength, where minimum was achieved in the test with a concentrate substitution by sinter ore AR-5 at the level of 50%.

It is applicable for all tests that during an experiment a very low FeO content was achieved which is typical for sintering with sinter basicity above 2.2. A probable reason was the lower fuel content during all tests of the whole experiment. Thus occurred also the decreased CO_2 emissions.

It is obvious that through suitable modification of the charge, it is theoretically possible to save from 8 to 4% of the costs for raw materials required for sinter production.

TABLE 2

The results of produced sinters quality in laboratory sinter pot device from tested sinter mixtures

Sample	Sinter weight	Productivity	Return sinter weight	Return sinter share	Yield	Sinter strength	Sinter abrasion	FeO content in sinter
	[kg]	[t/m²/day]	[kg]	[%]	[%]	[%]	[%]	[%]
S-Ax	148.90	13.83	61.90	29.50	70.50	61.10	10.80	4.85
S-Bx	146.10	16.19	62.40	30.20	69.80	61.80	10.60	4.46
S-Cx	147.70	19.34	54.90	27.30	72.70	66.20	6.80	2.95
S-Fx	144.30	22.47	55.80	28.70	71.30	66.60	8.50	4.86
S-Dx	139.80	19.17	63.00	31.40	68.60	64.60	9.00	3.74
S-Ex	125.20	23.26	62.20	34.00	66.00	60.40	7.90	4.17

4. Conclusions

The substitution of iron concentrate by a new type of iron ore raw material (AR-5) is efficient up to 50% from the technological point of view of sinter production, as well as from the point of view of improved quality of produced sinter and a positive particulate matter impact. From the business point of view it is possible through such charge modification to reduce the costs of used raw materials at least by 4% as compared with the reference charge.

Acknowledgements

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