EVALUATION OF REDUCIBILITY OF HIGH AND LOW BASIC SINTER IN ECONOMICAL POINT OF VIEW

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Abstract

The paper deals with a comparative analysis of reducibility of metallurgical sinter typical with high and low basicity. The samples were performed at 950°C of reduction test according to ISO 4695 which characterized their reducibility potential in CO atmosphere. Summing up the results, the differences in the testing of reduction processes were studied. The tests were accompanied with characterization of other properties such as density and apparent porosity to acquire comprehensive evaluation of the samples. All the data were used for interpretation and prediction of sample behavior in reduction processes in operation of the real blast furnace aggregate. Defining some processing parameters by mathematical model developed in Centre ENET, VSB - Technical University of Ostrava, financial costs for these samples processing were predicted on the basis of calculated coke reserve for the samples processing. Economical evaluation of processing of low and high basic sinter was carried out regarding the reduction gas consumption and costs estimation for metallurgical coke.

Keywords: Sinter, reduction, reducibility, coke reserve

1. INTRODUCTION

The kinetic studies of reduction processes in blast furnace [1]-[4] prove that these processes are determined by many factors such as reduction gas consumption, its temperature, size of feedstock reactive surface, diffusion and properties of used iron ore. This paper evaluates the basicity of two samples of metallurgical sinter. It compares their reducibility properties in relation with other physical properties such as porosity and density to present a comprehensive study for interpretation how the basicity of iron ore feedstock effect on economics of these materials processing in the shaft of blast furnace aggregate, production of pig iron and slag. [5] Purposely, there were used the samples of wide range of basicity - a sample with an extremely low and a sample with high one to present the proper effect of material properties neglecting other processing parameters on the costs for these materials processing.

The relations of the iron ore properties are widely studied. Relating to the basicity, the mineralogical structure, porosity, density and reducibility of sintered materials and its formation have been discussed in many research teams. Nishioka revealed that the pore sizes have a great influence on the effective thermal diffusivity as well as porosity. [6] McCann et al. discussed the specific heat capacity as well as chemical and structural changes of iron ores during its heating. [7] The attention was also paid to the statistical geometric characteristics of the pore structure. Aizawa et al. worked out a mathematical model to define effects of porosity, pore size, shape and their distribution.[8] Fröhlichova et al. analyzed the sinter structure in view of titanium addition to it. [9] Fu-You Tian et al. reported a characterization of sinter on its structural and thermophysical properties toward waste heat recovery applications. They used a fractal model to predict the effective thermal conductivity as a function of porosity. [10] Bölükbaşi et al. studied porosity and structure of metallurgical sinter in relation with its quality.

Also, the effect of iron ore properties on economics of its processing is discussed. Kardas et al. studied ironmaking process effectiveness by means of selected process parameters. [11] Konstanciak aimed at study of processing economic in the view of coke quality. [12] Bernasowski et al. developed for economic interpretation of ore processing a model in view of coke rate optimization. [13]

2. EXPERIMENTAL MATERIAL

For experimental procedure there were used two samples of metallurgical sinter from the operation of a metallurgical plant in the Czech Republic. The chemical composition of used samples is presented in **Table 1** together with their basicity and results of reducibility tests, apparent porosity and density testing. The sample basicity [B_2] was determined according to the ratio of basic oxides to acidic ones (1):

$$B_2[-] = \frac{CaO + MgO}{SiO_2 + Al_2O_3} \tag{1}$$

Tests of sinters reducibility dR/dt (%/min) were conducted according to ISO 4695:2007. The samples of size range 10.0 mm - 12.5 mm were oven-dried to constant mass at 105 °C ± 5 °C and before preparation of the test portions they were cooled to the room temperature. The test portion of 500 g was isothermally reduced at 950 °C in a fixed bed of reduction tube with a removable perforated plate inside to ensure a uniform gas flow using reducing gas consisting 40.0 % of CO and 60.0 % of N2.The portion was weighed at specified time intervals until its degree of reduction reached 65 %. The degree of reduction Rt [-], relative to the iron (III) state after t min is calculated, as follows (2) [14].

$$R_t = \left(\frac{0.111 w_1}{0.430 w_2} + \frac{m_1 - m_2}{m_0 \cdot 0.430 \cdot w_2}\right) \cdot 100 \tag{2}$$

where: m_0 is the start mass of the test portion before heating to reduction temperature 950 °C [g]
m_1 is the mass of the portion heated for 950°C and immediately before starting the reduction [g]
m_t is the mass of the test portion after reduction time t [g]
w_1 is the iron (II) oxide content [%]
w_2 is the total iron content [%]

The reducibility index dR/dt [-], expressed as the rate of reduction at the atomic ratio of O/Fe of 0.9 [%/min] is calculated from equation (3) and presented in **Table 1**.

$$\frac{dR}{dt}\left(\frac{O}{Fe} = 0.9\right) = \frac{33.6}{t_{60} - t_{30}} \tag{3}$$

where: t_{30} is the time to attain a degree of reduction of 30% [min]
t_{60} is the time to attain a degree of reduction of 60 % [min]

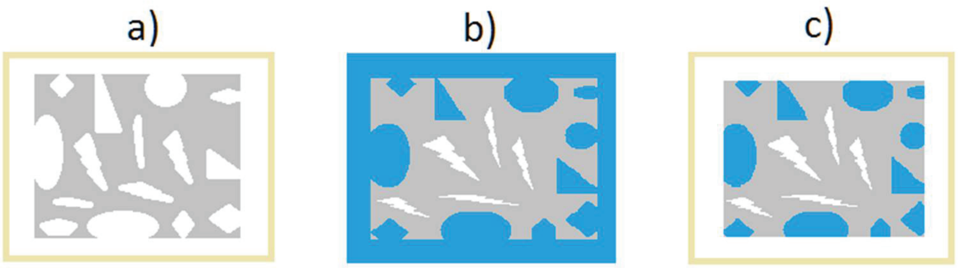

Figure 1 Definition of samples during porosity testing [14]

The porosity of the tested sinters ϕ [%] was evaluated by immersion method applying Archimedes principle as the buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object. The samples were under pressure saturated in the water. For the final porosity calculation (4) the differences of sample weight have to be recorded. There are used values of dry sample weight before saturation (a), its suspended weight meaning weight of sample submerged into the water (b) and then weight of soak sample saturated in the water with flooded open pores but whipped on the surface (c). The sample phases are presented in **Figure 1**.

$$\phi[\%] = \frac{G_3 - G_1}{G_3 - G_2} \cdot 100 \tag{4}$$

where: G_1 dry weight [g]
G_2 suspended weight [g]
G_3 soaked weight [g]

The apparent density ρ [g/cm^3] was calculated using data acquired during porosity measurements following Archimedes principles, as follows (5):

$$\rho_z[g \cdot cm^{-3}] = \rho_{(H_2O)} \frac{G_1}{G_3 - G_2} \tag{5}$$

where: ρ_{H_2O} density of water 998 kg·m^{-3}

2.1. Results and Discussion

Table 1 sums up the results of sample properties testing. The low basicity of acidic sample affects also its reducibility. The reducibility index of sample one is rather low and shows its demanding processing in the industrial order. Its porosity and density also reaches low values. High basicity of sample 2 affects positively its reducibility. It reached a high index of reducibility 1.31. Porosity and density of this sample correspond to the sample reducibility characteristics.

Table 1 Properties of samples and results of physical tests

sample	Fe [%]	FeO [%]	B_2 [-]	dR/dt [-]	Φ [%]	P_z [g·cm$^{-3]}$
1	56.10	13.7	0.7	0.65	6.46	3.76
2	55.98	8.27	2.33	1.31	9.82	4.21

Table 2 presents results of kinetic constants calculated by mathematical model developed at Centre ENET at void fraction 0.4. The kinetic constants describe speed of oxides reduction from hematite to magnetite to wüstite and finally to iron.

Table 2 Kinetic constants calculated for samples

sample	k_1	k_2	k_3
1	0.0045	0.00307	0.00029
2	0.0094	0.0045	0.00081

The sinter usage in production is further evaluated. The interpretation is focused on its effect on reduction gas consumption. **Figure 2** and **Figure 3** present the changes in oxidation grade of ore feedstock and in the gas. At the same time, it brings information about changes in concentration of oxides during the descent of the feedstock through the area of non-direct reduction in the blast furnace. The differences in changes in oxidation grade of tested samples are obvious. Changes of oxidation grade of basic sinter are quicker. The oxidation of gas during its processing presented by curve X descents quicker than for acidic sample 1. The changes in oxidation of basic sample start also earlier than in case of acidic sample 2. It proves better reducibility of basic sample 2 and its easily processing relating with lower consumption of reduction gas.

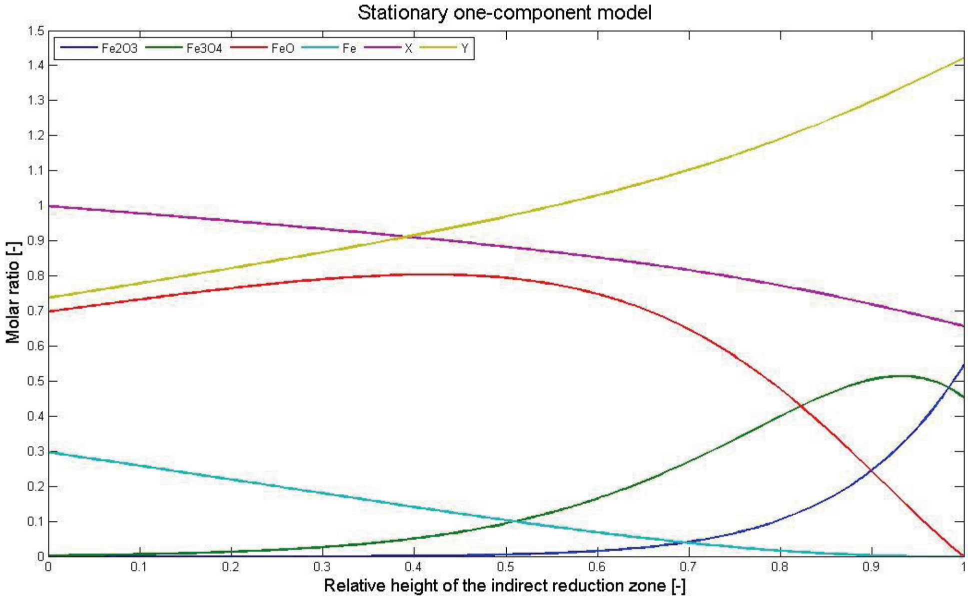

Figure 2 Changes in oxidation grade of sample 1

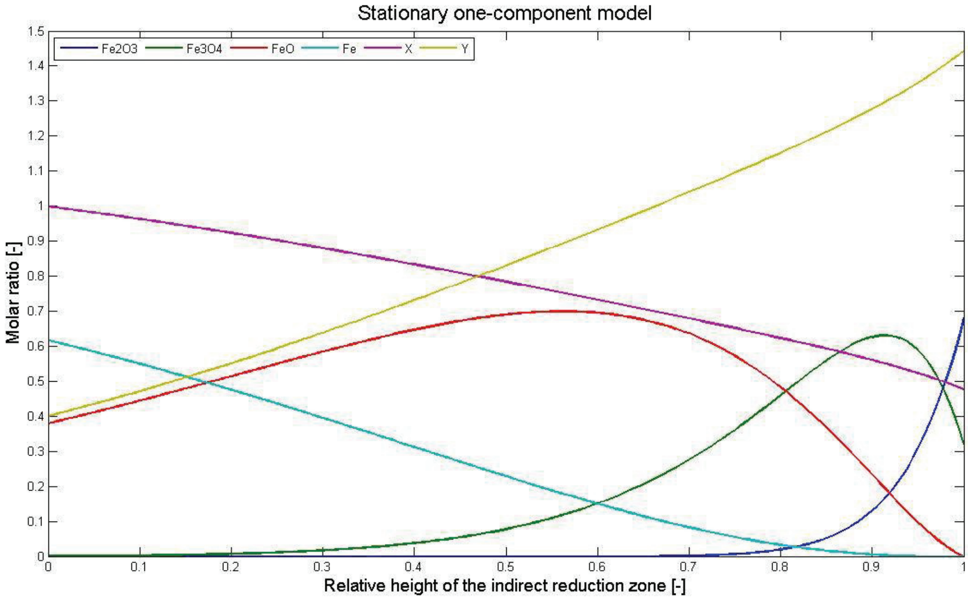

Figure 3 Changes in oxidation grade of sample 2

Carbon consumption differs at time of feedstock stay in the area of non-direct reduction. As the time is shorter, the limit kinetic curve of carbon consumption is of higher values. The productivity of blast furnace aggregate is affected by feedstock descent. The rate effects on the time of feedstock stay in the area of non-direct reduction. The shorter time results in the increase in ratio of direct reduction and the increase of heat demand relating to coke consumption. The mathematical model calculated a possible coke reserve ω [-] for sample 1 and sample 2 to interprete an effect of basicity of samples on metallurgical coke consumption in relation with reduction gas consumption. The parameter ω is defined by calculation based on Rist's diagram and describes possible savings in reduction gas consumption generated from carbon included in coke used in the technology. It is information about reserve of the process. **Table 3** sums up possibilities of parameter ω calculated at different level of reduction gas utilization in case of processing of acidic and basic sinter. It clearly presents how coke reserve expressed by parameter ω is affected by consumption of reduction gas. Generally, the higher value of parameter omega, the higher reserve in metallurgical coke consumption is estimated.

Table 3 Parameter ω at different reduction gas consumption

Sample 1		Sample 2	
Reduction gas consumption [mol]	ω [-]	Reduction gas consumption [mol]	ω [-]
2	0.1878	2	-0.2154
3	0.4723	3	0.045
3.5	0.621275	3.5	0.19

The carried out calculation proved lower reserve in carbon consumption in processing of basic sample 2. The recommended level of reduction gas consumption in this case is 3. For lower reduction gas consumption was not defined a reliable reserve. The processing of acidic sample 1 shows higher reserve in carbon consumption. This sample is hardly reducible and its processing in blast furnace aggregate presents higher costs for metallurgical coke. The total savings of metallurgical coke in optimal production process might present million values.

3. CONCLUSION

The study presented in the paper recommends production of metallurgical sinter of higher basicity and porosity. This sinter proved higher reducibility and it is estimated to be processed in the blast furnace with lower costs for metallurgical coke as a reducing agent and fuel of the blast furnace process. The mathematical model simulating the processing of studied types of sinters confirmed lower reserve in carbon consumption for processing of basic sinter.

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