POROSITY OF METALLURGICAL SINTER AS AN INDICATOR OF IRON ORE REDUCIBILITY

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Abstract

The paper deals with porosity of metallurgical sinter. It is aimed at the research on relation between porosity and reducibility of sinter. It evaluates the relation between these two properties in economical point of view of pig iron production. In the introduction, the paper sums up international experience with testing of materials porosity. It defines main qualitative properties of metallurgical sinter beside porosity such as its reducibility and disintegration in relation with porosity determination. In the main part, the paper presents results of porosity tests. It describes the experimental method used for it and conditions for it. There is compared porosity of samples with high and low reducibility. The effect of porosity on reducibility is studied. It is interpreted on the economics of production process. The effect of porosity sinter characterized with indicator of reducibility on gas consumption during pig iron production is presented.

Keywords: Porosity, reducibility, economics of pig iron production, non-direct reduction

1. INTRODUCTION

Pore size and pore size distribution are important material characteristics in many processing applications. Determination of these material properties are significant for high product quality, optimized rejection rates and balanced economics of production processes such as those for catalysts, sintered materials, pharmaceutical products, and chromatographic carriers. In the field of metallurgical sinter, porosity of sinter relates to its reducibility and disintegration properties. [1] The aim of the paper is a study of relation between porosity and material reducibility respecting process parameters such as gas consumption or coke reserve. By comparison of lowly and highly reducible materials, the paper is focused on the description of possible porosity effects resulting in production process of pig iron. The paper contributes to the field of porosity material optimizing to define optimal properties of blast furnace feedstock for most convenient production meaning its productivity and economics.

The best metallurgical properties are generally contemplated in sinter with pores less than 4 mm equally dispersed in the material. Sinter with unequally dispersed big pores is hardly reducible and little solid. The most solid is that one which has monolith stone structure, on the other hand its reducibility is very low and processing of this kind of sinter is typical of high fuel consumption. [2] The sinter porosity is decreased by increasing fuel consumption, decreasing ratio of reversible sinter and decreasing sinter basicity. [3] The sinter porosity evaluation is relevant primarily for sinter created from iron- bearing waste materials [4-6] or sinter with a biomass ratio [7]. These tests of reducibility are not easy to carry out because of reasons such as chemical composition, or sample weight. The study of general principles and relation between the porosity and the reducibility enables a prediction of reduction process in a production aggregate.

In comparison with other kinds of material, there are just several work interested in porosity of metallurgical sinter. Shatokha et al. were concerned about sinter porosity analysis by application of 3D tomography method. In the paper the innovative X-ray tomography method for investigation of iron ore sinter porosity and experimental data about effect of sinter basicity and concentrate ration in the charge mixture on the total porosity of sinter have been presented. The paper compared the reducibility for samples with pre-measured porosity. There was observed intensive reduction of sinter with basicity 0,8 which was explained by higher porosity of sinter sample. Positive effect of porosity on reducibility is proved by many authors. The porosity of metallurgical sinter in relation with sinter quality and its properties such as reducibility and strength is also studied by Bölükbaşi et al. The structure of sinter includes the presence of ferrites has beneficial properties for sinter strength and reducibility. The optimum structure, formed by a hematite nucleus surrounded by an acicular ferrite lattice, has been detected. [8, 9]

We can classify pores according to how accessible they are to an external fluid. In this context, one category (closed pores) consists of pores that are inaccessible to an external fluid and totally isolated from their neighbors. Closed pores influence macroscopic properties such as bulk density, elasticity, mechanical strength, and thermal conductivity, but they are inactive in processes such as fluid flow and adsorption of gases. On the other hand, pores that have a navigable channel of communication with the external surface of the body are described as open pores. [1] Metallurgical sinter is highly porous material. Its porosity is usually from 30 % to 40 %.According the previous research, there are 21.5 % of open pores and 14.9 % of closed pores. [3]

2. EXPERIMENTAL MATERIAL AND METHOD

Samples of sinter used in Czech metallurgical companies were used for the study of porosity. There were chosen samples with very low and very high reducibility characterized by dR/dt index experimentally found out in laboratory LVVVS of Centre Enet at VSB - Technical university of Ostrava. Despite of different reducibility of these mentioned samples, their porosity was similar something above 30 %.

Table 1 Properties of experimental material

Sample	*dR/dt*	*Porosity* [%]	K_1 [-]	K_2 [-]	K_3 [-]
1	0.53	32.77	0.01221	0.00369	0.00089
2	1.31	34.28	0.00445	0.00307	0.00029

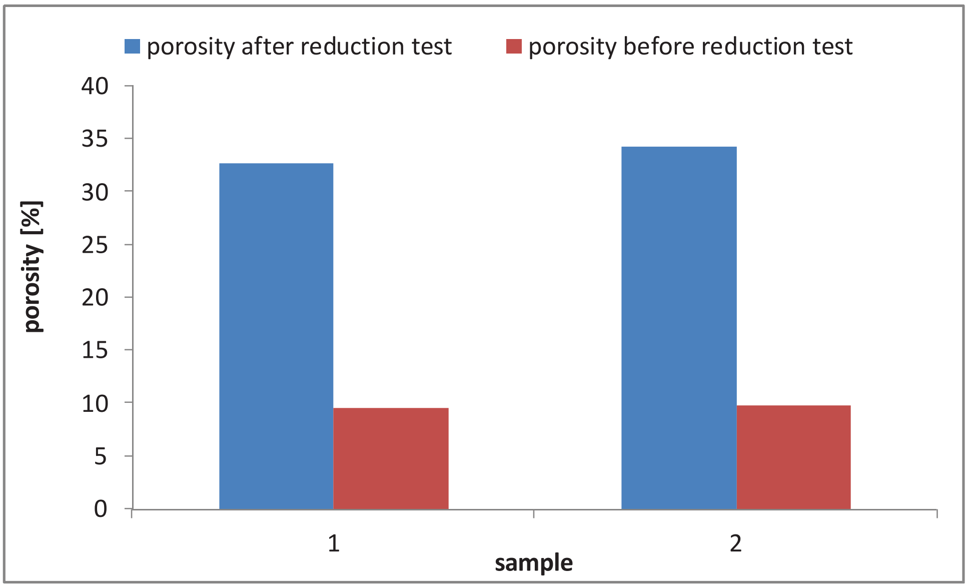

Fig. 1 Porosity of samples before and after reduction test

Table 1 summarizes the properties of the samples including the calculated kinetic constants characterizing their reduction from magnetite to hematite and iron oxide. The constants describe the reduction process of material and are important for further modelling of reduction process. **Fig. 1** presents the porosity of samples effected by test of reducibility according to ISO 4695. It is evident that reduction proces results in higher porosity of material. The porosity was tested by Archimedes immersion technique determing open pores of material. The porosity of samples was measured using Archimedes principle that the buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object. For the final porosity calculation (1) dry weights, soaked weights and immersed weights in water were used.

$$\text{porosity } [\%] = \frac{G_3 - G_1}{G_3 - G_2} \cdot 100 \tag{1}$$

G_1 *sample weight before immersion into water [g]*

G_2 *weight of immersed sample in water [g]*

G_3 *weight of soaked sample* [g]

3. RESULTS AND DISCUSSION

Fig. 2 and **Fig. 3** graphically present changes in concentration profiles of samples during reduction process. The output data calculated by mathematical model of reduction kinetics describe changes in concentration of iron oxides and in oxidation grade of blast furnace feedstock and blast furnace gas at the time of blast furnace feedstock descent in non-direct reduction zone in blast furnace aggregate. There is an obvious different in concentration changes between lowly and highly reducible samples.

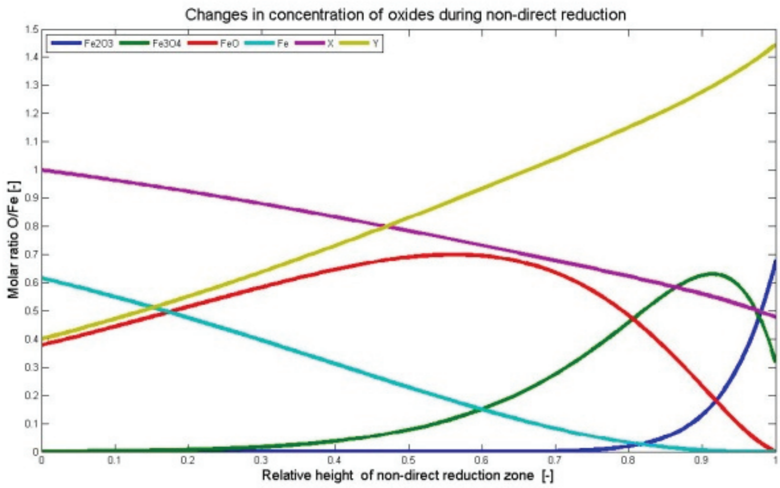

Fig. 2 Reduction process of sample 1

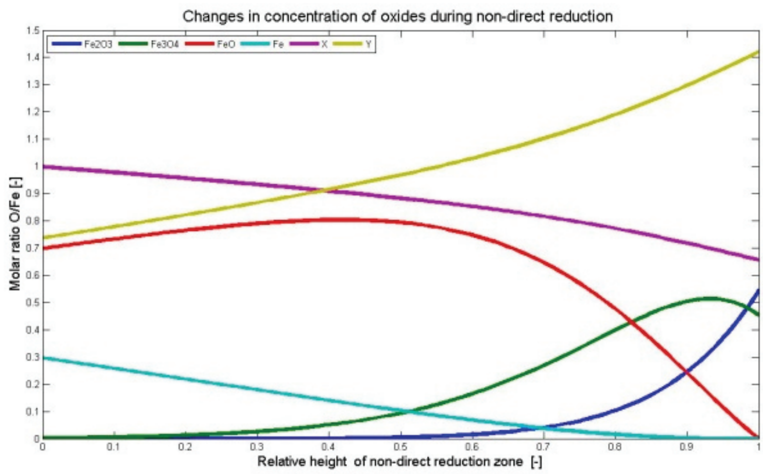

Fig. 3 Reduction process of sample 2

The effect of blast furnace reduction time in non-direct reduction zone is interpreted in **Fig. 3** and **Fig. 5**. There are simulated changes in kinetics trends limits of carbon consumption as process time gets shorter.

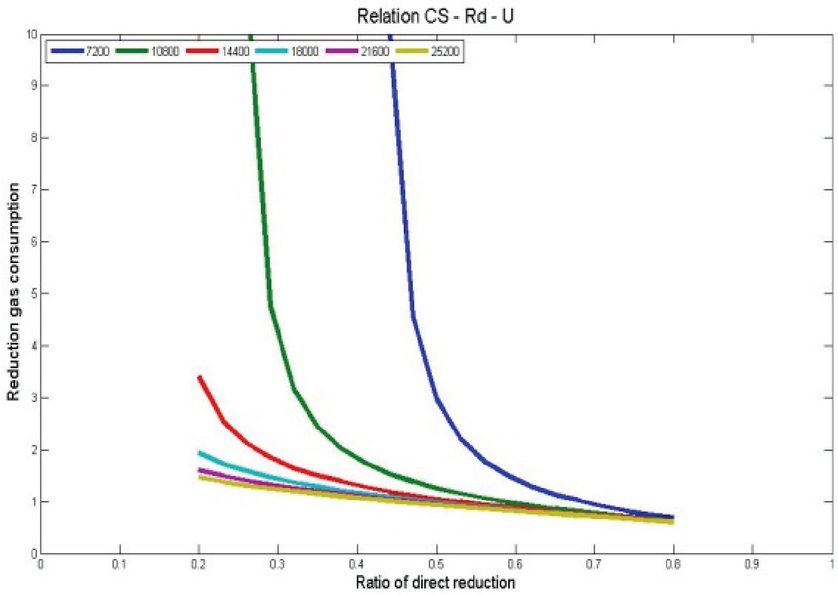

Fig. 4 Gas consumption of sample 1 reduction

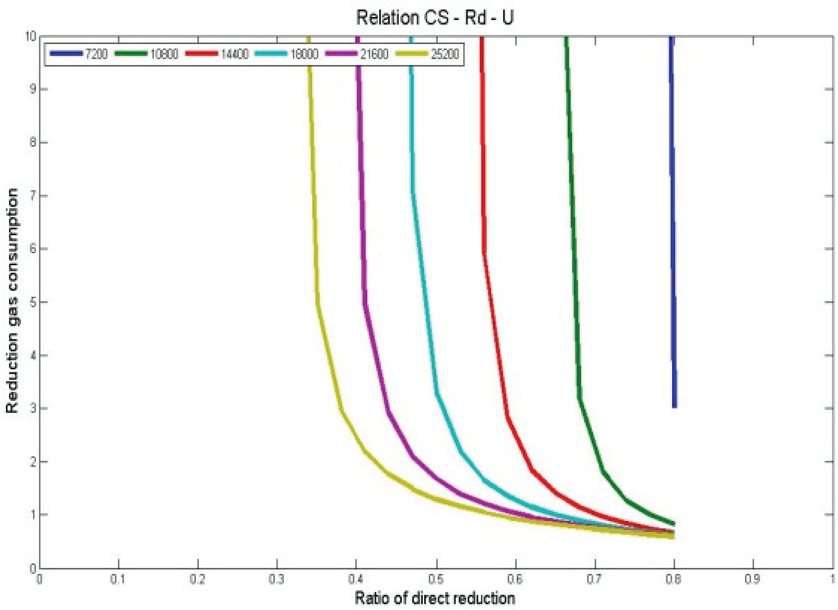

Fig. 5 Gas consumption of sample 2 reduction

As the process time gets shorter, kinetics trends limits of carbon consumption moves to higher values. Despite of high porosity, the lowly reducible sample 2 affects on reducing gas consumption significantly. There is not observed a movement in the kinetic trends limits relating to the shorter time.

Fig. 6 and **Fig. 7** presents and optimizing area among reduction gas consumption, process time in non-direct reduction zone for well reducible sample number 1 and lowly reducible sample number 2.

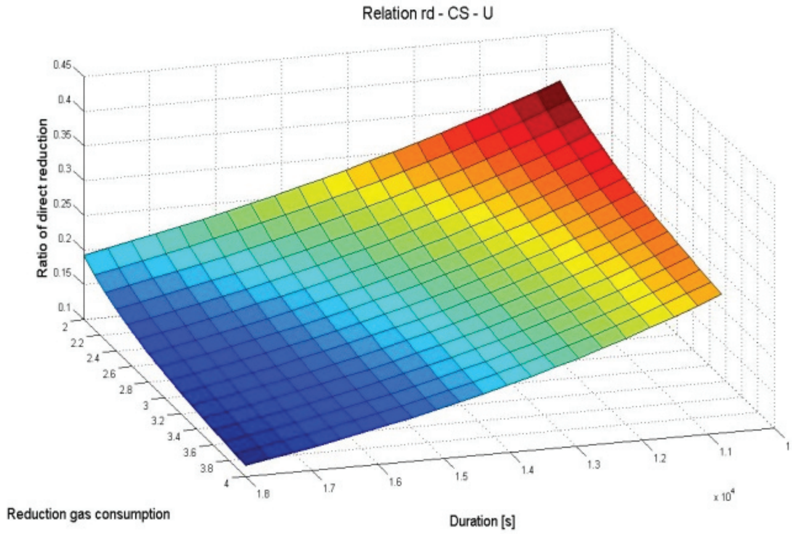

Fig. 6 Optimizing area of sample 1

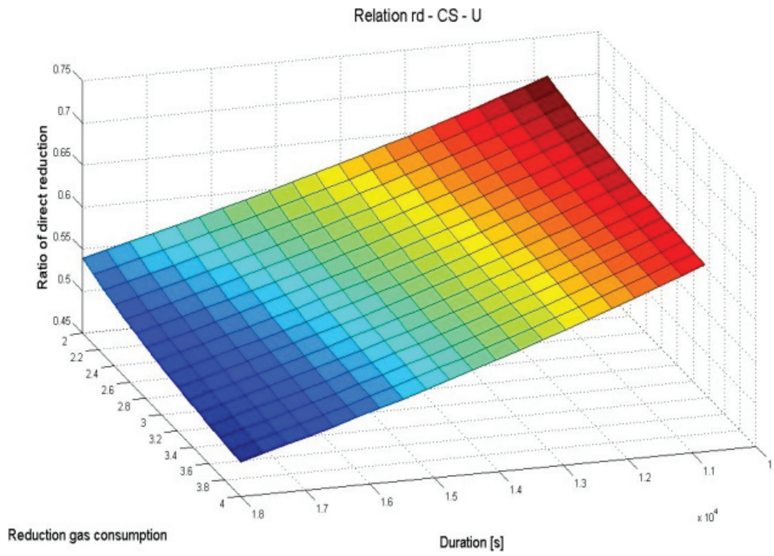

Fig. 7 Optimizing area of sample 2

3.1. Economical evaluation of samples

The reduction of sample 1 and sample 2 is studied in the economical point of view of carbon consumption. The indicator ω as *coke reserve* was by model expressed for sample 1 as (2) and for sample 2 as (3) where *CS* is *reduction gas consumption.*

$$\omega = -0.4348 + 0.1764\mathrm{CS} + 0.0168\mathrm{CS}^2 \quad (2)$$

$$\omega = -0.2366 + 0.2689\mathrm{CS} + 0.0056\mathrm{CS}^2 \quad (3)$$

The calculated *coke reserve ω* might be used as a recommendation for optimalization of blast furnace production to change wind humidity, amount of oxygen or to affect on iron ore feedstock reducibility, coke reactivity. It is a deviation determined from reducibility tests presenting a real coke reserve of used iron ores such as pellets or sinter. In economical point of view, fully exploitation of technological reducibility utilization of iron ore together with right orders management might present savings about 1.6 mil. CZK per year.[10, 11]

4. CONCLUSION

The study mentioned in the paper presented the relation between the porosity and reducibility of metallurgical sample. The relation of these two properties was interpreted in process parameters such as iron oxides reduction in blast furnace aggregate or reduction gas consumption. For the interpretation a model of reduction process kinetics developed at Centre ENET, VSB - Technical University was used. The presented calculation and graphical evaluation confirmed that relation between reducibility and porosity is limited. Higher porosity does not significantly optimize the reduction process of really lowly reducible sinter. Sample 2 presented in the paper with similar porosity to well reducible sample 1 did not prove a positive effect of porosity on its reducibility.

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