

# STUDY ON DISINTEGRATION OF METALLURGICAL SINTER

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The paper deals with properties of metallurgical sinter which are significant in the view of ironmaking optimization. It aims at study of metallurgical sinter disintegration. It presents experimental procedure for disintegration testing. The paper presents results of tests carried out in gaseous environment containing 30 % of carbon oxide and 70 % of nitrogen at temperature of 550 °C. It discusses them in relation with other properties of metallurgical sinter such as basicity  $P_2$  and content of FeO. The article summarizes relevant studies and extends it with actual laboratory experiments.

## KEYWORDS

sinter, reducibility, disintegration, iron-making, optimization

## 1 INTRODUCTION

Typical phenomenon of reduction process in high-temperature area represents the fact that the reduction process takes place in a real aggregate according two different schemes – direct and non-direct reduction. Their differentiation is essential for the economic operation of aggregate. The task of non-direct area determination is actually a specification of temperature of direct reduction initiation dependent both on metallurgical properties of assessed ore and reactivity of performed reducing agent, mostly coke. As Konstanciak presented in the work for optimal blast furnace process are significant properties such as reducibility and disintegration of feedstock material - sinter, pellets or lump iron ore [Konstanciak 2012]. The reducibility refers to oxygen removal from iron oxides in gaseous atmosphere. The amount of removed oxygen is measured as mass loss of sample or through material balance of oxidation and reduction gas. The disintegration is characterized by rate of ore material destruction as a result of collision, abrasion, pressure and volume changes at high temperatures in the reduction atmosphere. The disintegration of iron ores mainly occurs during the reduction process from hematite to magnetite in the temperature zone of 400 °C – 700 °C, and many researchers indicate in their studies that the main reason for the disintegration is the stress concentration caused by the volume expansion of magnetite [Pimenta 2012]. The disintegration of ores basically depends on their reducibility. The relation between these two properties is studied in the atmosphere of hydrogen. Murakami et al. studied reduction and reducibility behavior under  $H_2$  in mixture with  $H_2O$ ,  $CO$ ,  $CO_2$  and  $N_2$  at 500 °C. Their research work referred that the reduction degree of the sinter reduced under  $CO-H_2$  gas increased with time [Murakami 2015]. Their other results of previous experiments showed a remarkable increase in the reduction degree ( $dR/dt$ ) and disintegration index (RDI) [Murakami 2012]. Also, Mu et al. described the effect of hydrogen addition on sinter disintegration. The increasing content of  $H_2$  with proportional decrease of  $CO$ ,  $CO_2$  and  $N_2$  resulted in higher disintegration index. [Mu 2012] Takeuchi et

al. confirmed these results. They studied sinter properties in relation to gas permeability of blast furnace. It was investigated with reduction degradation and under-load-reduction tests again in hydrogen atmosphere. The reduction degradation of sinter was deteriorated by increasing  $H_2$  concentration in the reduction gas under the condition of below 3.8 %  $H_2$ . However, over 3.8 %  $H_2$ , increase of  $H_2$  had no effect on the reduction degradation. On the other hand, the under-load-reduction test showed that the increase in  $H_2$  concentration of reduction gas and decrease in slag ratio in sinter are effective to improve gas permeability of lower part of blast furnace rather than reducibility of sinter [Takeuchi 2014]. The blast furnace burden quality has been studied by many teams. Chaigneau et al. studied the blast furnace burden quality through simulation of its reducibility, degradation including swelling, its shrinking and permeability. The simulation was set up by vertical probings in the blast furnace at different radial positions [Chaigneau 1997]. To the same topic devoted Jaffarullah et al. several years later in 2008. They studied reduction and degradation behaviour of sinter under simulated vertical probe trial condition and their results confirmed that for minimizing sinter degradation and improving reduction degree in the blast furnace, low temperature holding zone has to be avoided and high temperature holding zone has to be minimized [Jaffarullah 2008]. Shengli et al. studied its behavior in Corex aggregate. They focused on disintegration behavior under atmosphere with  $H_2$  in Corex shaft furnace in comparison with blast furnace aggregate. They evaluated the influence of temperature, reduction time and gas composition on the reduction disintegration index of lump ore samples. The results showed that the disintegration behavior of lump ores in COREX shaft furnace could be generally divided into three steps and the disintegration mainly occurred in the second step, which was in the temperature zone from 450° C to 650° C with low reduction degree [Shengli 2015]. This article deals with disintegration of metallurgical sinter in atmosphere of  $CO$ .  $CO$  gas as a reducing agent significant for the process of non-direct reduction of iron ores sinter in the blast furnace aggregate. It is important to understand its effect on the disintegration behavior because it significantly affects the gas permeability of the upper part of the blast furnace. Its knowledge contributes to the optimizing of pig iron production process. The fundamental understanding of reduction disintegration of metallurgical sinter is a basic tool for optimal sinter production to ensure the stable blast furnace operation [Kardas 2012]. The article is aimed at contemplation of effect of basicity and grade of oxygenation (FeO in sample) on the sinter reduction disintegration. The article studies the reduction disintegration of sinter typical for Czech metallurgical companies. While there are published effects of basicity and FeO on sinter reducibility, effect of these properties on sinter disintegration of operational sinter used in the Czech Republic has not been published yet.

## 2 MATERIAL AND METHOD

Experimental testing was done on samples originated from real metallurgical industrial operation of a Czech metallurgical company. There were tested ten samples of sinter which was prepared as a component of blast furnace feedstock for pig iron production. Their properties (Tab. 1) were determined by RTG fluorescent spectrometry. For the planned tests of sinter there were specified total Fe important as input information for study of samples reducibility and their following disintegration. Beside it, FeO and basicity  $P_2$  defined (1) was determined.

$$P_2 = \frac{CaO + MgO}{SiO_2 + Al_2O_3} \quad (1)$$

The study of basicity  $P_2$  and FeO effects on sinter disintegration might be complicated as the properties of the samples are not extremely variable. On the other hand, the study of these

samples from current industrial operation contributes to results application in industrial practice.

sample	1	2	3	4	5	6	7	8	9	10
FeO [%]	9.05	9.48	11.70	10.30	11.90	9.9	7.9	8.6	8.1	9.1
Fe [%]	55.14	55.12	59.6	56.2	55.0	60.3	56.3	54.6	58.0	58.3
$P_2$ [-]	1.33	1.27	0.98	1.16	1.12	0.83	1.05	0.76	0.89	0.71

Table 1. Properties of tested samples

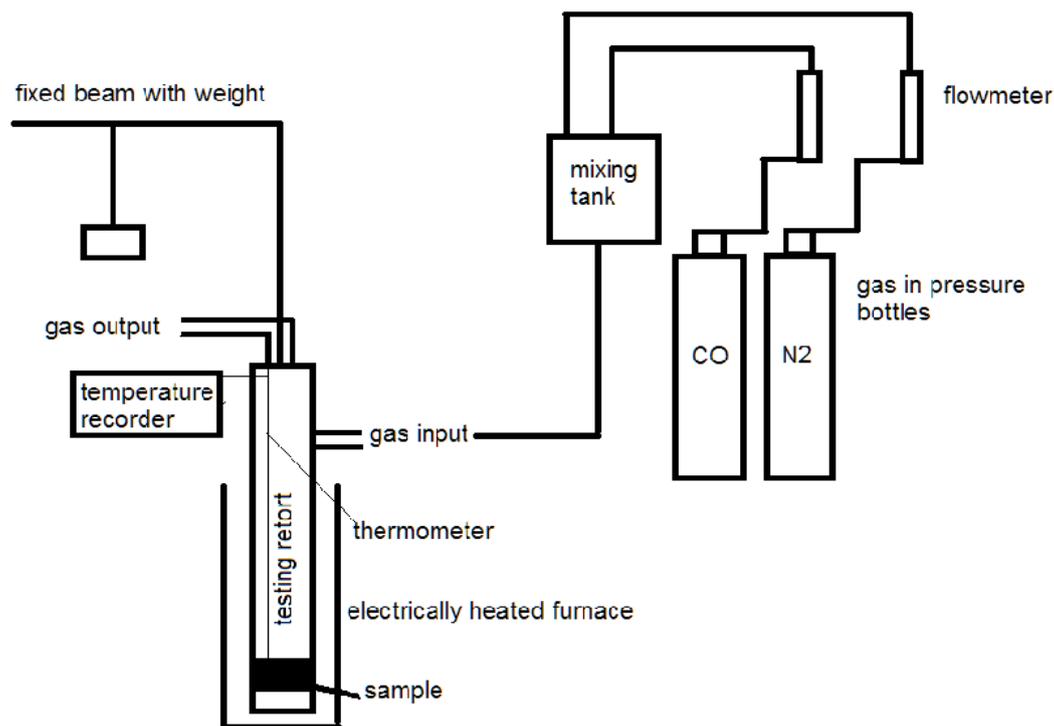


Figure 1. Schematic set up for low temperature reduction

The disintegration testing was based on simulation of conditions for sinter processing in blast furnace aggregate. There was simulated low temperature reduction and strain of material to which it was exposed in a shaft aggregate. The low temperature reduction was conducted in the set up schemed at Fig. 1 according to ISO 4696-2. The samples of size range 16-20 mm before preparation of the test portions were oven-dried to constant mass at 105 °C and then cooled to room temperature. Subsequently, they were processed according the procedure in Fig. 2.

The test portion of 500 g was isothermally for 30 minutes reduced at 550 °C, at temperature typical with the initiation of sinter disintegration in blast furnace shaft and indicated in the standard ISO 4696-2 for the disintegration testing. The sample was set in a fixed bed of testing reduction tube (Fig. 4) with a removable perforated plated inside to ensure uniform gas flow of reducing gas consisting 30.0 % of CO and 70.0 % of  $N_2$ . The test portion was tumbled for 30 minutes in a specific tumble drum for 900 revolutions and then sieved with a sieve having square openings of 2.8 mm. The mass retained on the sieve was determined and record as  $m_1$  for further calculation. Material lost during tumbling and sieving was considered to be part of -2.8 mm fraction. The reduction-disintegration index,  $RDI_{-2.8}$  [%] is calculated from ISO 4696-2 equation (2):

$$RDI_{-2.8} = 100 - \frac{m_1}{m_0} \cdot 100 \quad (2)$$

$m_0$  is the mass of test portion after reduction [g]

$m_1$  is the mass of the fraction retained on the sieve [g]

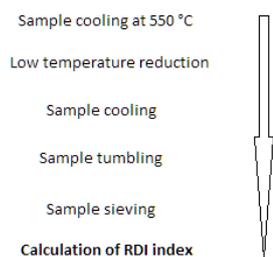


Figure 2. Procedure of RDI test



Figure 3. Detail of fixed bed of reduction tube

### 3 RESULTS AND DISCUSSION

RDI of tested sinter was lower than 20 %. The exception was sample 1 with highest basicity in the batch which reached RDI index = 24.1 %. On the contrary, the lowest disintegration had sample 10 RDI = 14.2 % with lowest basicity. The values of RDI in comparison with samples tested in international laboratories reached lower values. The recommendable disintegration presented in literature sources is for sinter of basicity = 1 and content FeO around 9 % recommended to be 20 – 24 % [Jasenska 1996].

sample	RDI -2 [%]
1	24.1
2	19.1
3	15.1
4	17.2
5	16.1
6	14.8
7	15.1
8	14.6
9	15.1
10	14.2

Table 2. Results of disintegration testing

In Fig. 4 – 6 graphical interpretation of studied effect on the disintegration is presented. There are many literature sources confirming the experience with basicity effect on reducibility and disintegration. Many researchers presented a positive effect of basicity on reducibility [Maeda et al. 1984], [Amadavi 2014], [Mousa 2014]. Zhang et al. studied effect of CaCl on sinter disintegration. Their research results showed as the concentration of chlorides was 2%, the disintegration of sinter was significantly reduced and RI was not be affected [Zhang

2010]. Research of Liu et al. explained as the basicity reaches 1.95-2.15, the burden structures with single sinter would achieve good softening-melting performance, and the maximum pressure maintained at a low level [Liu 2014]. However, experience of Yu et al. indicated a significant decrease of disintegration with increasing basicity varying from 1.0 – 2.0 [Yu 2015]. The results of disintegration testing of industrial sinter confirmed this experience. The sample with lowest basicity showed the lowest disintegration in the batch. Fig. 4 describes the linear correlation between basicity and disintegration presented by significant value of  $R^2=0.7107$ . There was also discussed the effect of FeO in the samples (Fig. 5). There was not indicated a correlation between these properties. The grade of oxidation did not confirm an effect on the material disintegration. The correlation between FeO and RDI is positively affected by the basicity (Fig. 6).

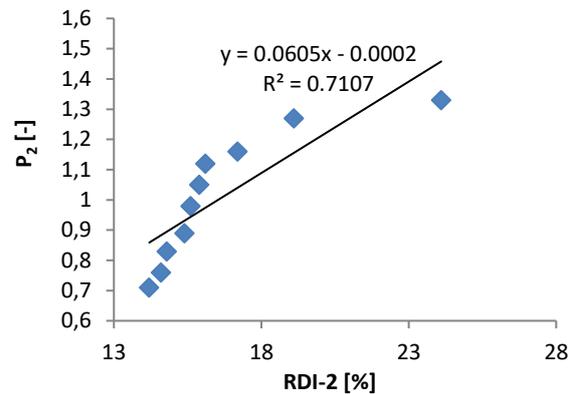


Figure 4. Relation basicity  $P_2$  and RDI-2

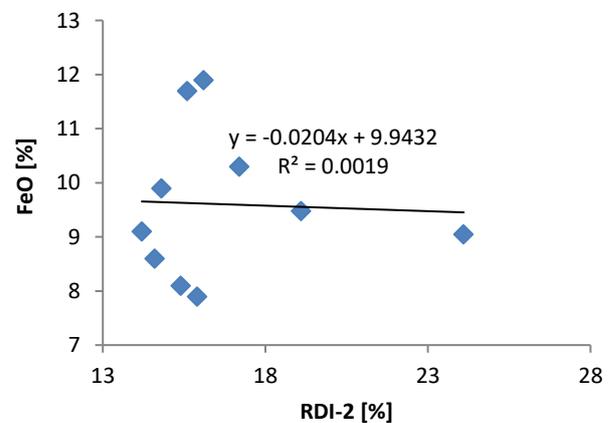


Figure 5. Relation FeO and RDI-2

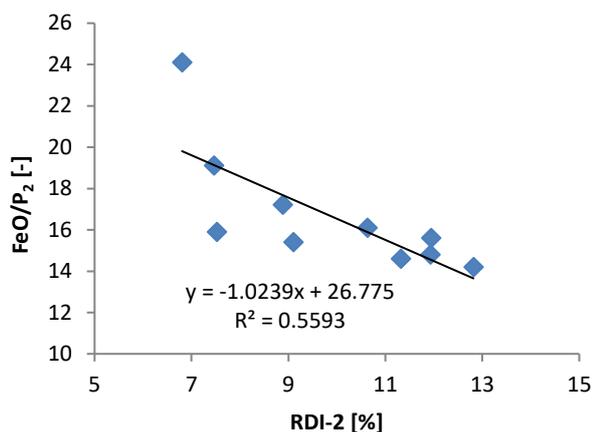


Figure 6. Relation FeO/P<sub>2</sub> and RDI -2

#### 4 CONCLUSIONS

There were carried out reduction disintegration tests (RDI) of ten samples of metallurgical sinter used in Czech metallurgical companies of grain 15 – 20 mm, basicity varying 0.71-1.33, FeO 7.9 %-11.9 %. in atmosphere of 30 % CO to extend relevant studies with knowledge of effect of basicity and FeO on disintegration of operational industrial sinter. The results were summed up:

- The samples reached RDI index in range between 14.2 – 24.1 %. The lowest disintegration (RDI=14.2) was reached by the sample of lowest basicity (P<sub>2</sub> = 0.71), the highest disintegration (RDI=24.1) by sample with basicity (P<sub>2</sub> = 1.33).
- The testing of ten samples confirmed effect of basicity on disintegration. There was indicated a linear correlation between these properties. The increasing basicity resulted in the increase on sinter disintegration.
- In batch of ten tested samples there was not confirmed effect of FeO on samples disintegration. There was found no significant correlation.

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