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Influence of the Moisture Content on the Flowability of Fine-Grained Iron Ore Concentrate

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***Abstract*—**The iron content of the ore used is crucial for the productivity and coke consumption rate in blast furnace pig iron production. Therefore, most iron ore deposits are processed in beneficiation plants to increase the iron content and remove impurities. In several comminution stages, the particle size of the ore is reduced to ensure that the iron oxides are physically liberated from the gangue. Subsequently, physical separation processes are applied to concentrate the iron ore. The fine-grained ore concentrates produced need to be transported, stored, and processed. For smooth operation of these processes, the flow properties of the material are crucial. The flowability of powders depends on several properties of the material: grain size, grain size distribution, grain shape, and moisture content of the material. The flowability of powders can be measured using ring shear testers. In this study, the influence of the moisture content on the flowability for the Krivoy Rog magnetite iron ore concentrate was investigated. Dry iron ore concentrate was mixed with varying amounts of water to produce samples with a moisture content in the range of 0.2 to 12.2%. The flowability of the samples was investigated using a Schulze ring shear tester. At all measured values of the normal stress (1.0 kPa – 20 kPa), the flowability decreased significantly from dry ore to a moisture content of approximately 3-5%. At higher moisture contents, the flowability was nearly constant, while at the maximum moisture content the flowability improved for high values of the normal stress only. The results also showed an improving flowability with increasing consolidation stress for all moisture content levels investigated. The wall friction angle of the dust with carbon steel (S235JR), and an ultra-high molecule low-pressure polyethylene (Robalon) was also investigated. The wall friction angle increased significantly from dry ore to a moisture content of approximately 3%. For higher moisture content levels, the wall friction angles were nearly constant. Generally, the wall friction angle was approximately 4° lower at the higher wall normal stress.

***Keywords*—**Iron ore concentrate, flowability, moisture content, wall friction angle.

I. Introduction

THE iron content of the feed material is crucial for the productivity and coke consumption rate in blast furnace operation: the higher the iron concentration, the higher the productivity and the lower the coke consumption [1]. Therefore, to increase the iron content, iron ore is usually processed in beneficiation plants. In such plants, the particle size of the ore is reduced in several comminution stages. The iron oxides are thereby physically liberated from the other constituents of the ore. To obtain an iron ore concentrate, physical separation processes are subsequently applied [2]. The flowability of the concentrates produced is crucial for transport and storage of this fine-grained material.

The flowability of granular material depends on some material properties: the grain size, the grain size distribution, and the grain shape [3], [4]. Moisture content of the material also has considerable influence on the flowability. Because of the increasing influence of the liquid bridges between the particles and the resulting capillary forces [5]-[9], high moisture content leads to reduced flowability. However, when nearly all the pores between the particles are filled with water, the particles form a suspension in water, and the cohesive forces decrease for most materials [5], [7], [8], [10]-[12].

Jenike [13] pioneered the application of shear cells for measuring powder flow properties. In the last 20 years, ring shear testers have become increasingly popular since the measurements with this instrument are more reproducible due to an automated test procedure [14].

In this study, the flowability of the Krivoy Rog magnetite iron ore concentrate was investigated. Iron ores are usually stored on open stockpiles and exposed to the weather. Therefore, the moisture content of ore concentrate can vary within a broad range. The aim of this study was to investigate the influence of the varying moisture content on the flowability of the ore. Special focus was placed on the relation between the flowability and the saturation of the pores between the particles.

II. Materials and Methods

A. Iron Ore Concentrate

The moisture content of the magnetite concentrate from Krivoy Rog investigated was 7.3% (w/w). The ore concentrate was dried in a compartment drier for 24 hours. The moisture content of the iron ore samples was adjusted by mixing with tap water for 5 minutes in an Erweka AR 403/SW 1/S plough-share drum mixer. The speed of the mixer was 300 rpm. The moisture content of the samples produced was determined gravimetrically before and after the shear tests with a Sartorius infrared moisture analyser MA35M at 105 °C.

B. Characterization of the Material

The particle size distribution of the iron ore concentrate was measured with a laser diffraction instrument with dry sample dispersion by Sympatec, type HELOS/RODOS.

The density of the iron ore concentrate ρ_S was determined according to ÖNORM EN ISO 8130-3 [15] using a 100 cm³ liquid displacement pycnometer where n-heptane with a density of 0.681 g/cm³ was used for the displacement of the

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air.

C. Shear Tests

The yield locus and the wall yield locus were determined using a RST-XS Schulze ring shear tester. For the yield locus measurement, a 30 cm³ shear cell was used. For the wall yield locus measurements, the wall friction shear cell was used, where the bottom ring of this cell is formed by a sample of ultra-high molecule low-pressure polyethylene (Robalon) or by structural steel S235JR (1.0038). The bulk density of the material as a function of the consolidation stress was also determined. Details of the shear tester measurements can be found elsewhere [16].

D. Calculations

The yield locus is defined by (1)

$$\tau = (\tan\Phi)\cdot\sigma + c \tag{1}$$

where σ is the normal stress, τ is the shear stress, Φ is the angle of internal friction and c is the cohesion, which is the intercept of the yield locus with the shear stress axis [17].

The saturation S of a packed bed of particles containing some liquid is defined by (2)

$$S = \frac{V_L}{V_P} \tag{2}$$

where V_L is the volume of the liquid water in the pores between the solid particles and V_P is the volume of the pores [18]. The voidage or porosity ε is defined by (3)

$$\varepsilon = \frac{V_P}{V_S + V_P} \tag{3}$$

where V_S is the volume of the solid particles [17]. With the density of the solid ρ_S, the density of the liquid ρ_L and X_{mL}, the ratio of the mass of the liquid to the mass of the solid, (2) and (3) can be combined to:

$$S = X_{mL}\cdot\frac{\rho_S\cdot(1-\varepsilon)}{\rho_L\cdot\varepsilon} \tag{4}$$

The bulk density ρ_B in the shear cell depends on the porosity of the material:

$$\rho_B = \rho_S\cdot(1-\varepsilon) + \rho_L\cdot\varepsilon\cdot S \tag{5}$$

With increasing normal stress the material is compacted, thus reducing the porosity and increasing the saturation. After elimination of the porosity by combination of (4) and (5), the equation for the saturation of the material in the shear cell becomes:

$$S = \frac{\rho_B\cdot X_{mL}}{\rho_L\cdot(1 + X_{mL} - \rho_B/\rho_S)} \tag{6}$$

III. Results

A. Characterization of the Iron Ore Concentrate

The particle size distributions of the iron ore concentrate measured are given in Fig. 1. The mass median diameter d_{50} of the material is 20.1 µm. The measured particle density of the iron ore concentrate was 4,790 kg/m³.

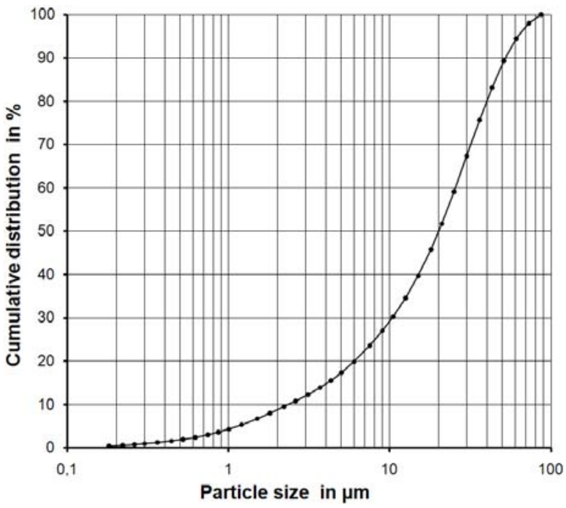

Fig. 1 Particle size distribution of the iron ore concentrate

B. Shear Test Results

The flowability ff_c as a function of the moisture content and the saturation is shown in Fig. 2. Generally, the flowability is better at the higher value of the normal stress. The flowability of the dry iron ore concentrate is good but decreases with increasing moisture content. At a normal stress of 20 kPa, constant value for the ff_c is reached at moisture content of approximately 5%, while at a normal stress of 1.0 kPa, ff_c is constant above approximately 3%. At the higher normal stress, the flowability improves significantly for moisture content above 9%. In contrast, this improvement was not observed at the lower normal stress.

Decreasing values of ff_c were also reported for blast furnace dusts [19]. However, constant values for ff_c were found for moisture content higher than 8%. This difference might be explained by the difference in particle size. The mass median diameter of the investigated blast furnace dusts was five to ten times larger compared to the iron ore concentrate.

The dependence of the effective angle of internal friction on the moisture content is shown in Fig. 3. The effective angle of internal friction increases for both values of the normal stress with the moisture content up to approximately 5%, while from approximately 5% to 10% moisture content the effective angle of internal friction is more or less constant. At the maximum moisture content investigated (12.2%), the value of the effective angle of internal friction is nearly the same as for the dry iron ore concentrate.

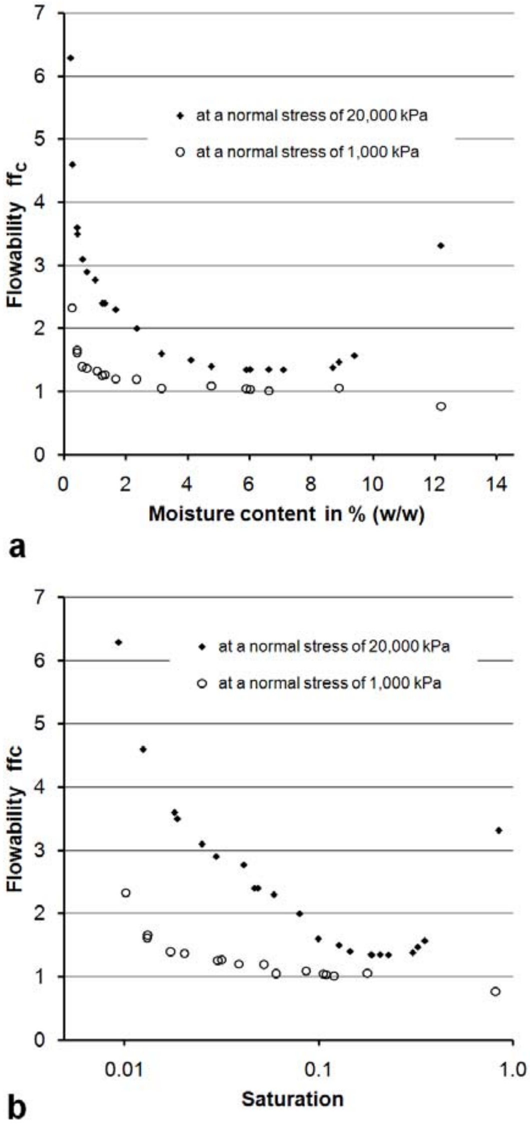

Fig. 2 Flowability ff_c as a function of the moisture content (a) and the saturation (b)

The dependence of the bulk density on the moisture content of the iron ore concentrate is shown in Fig. 4. For both values of the normal stress, the bulk density decreases with increasing moisture content. For moisture content between approximately 3% and 8%, the bulk density is broadly constant. At higher values of the moisture content, the bulk density increases again and reaches the maximum value at the maximum moisture content investigated.

In Fig. 5, the cohesion is shown in dependence of the saturation. A considerable difference was found between the results of the two measurements at different values of the normal stress. At low normal stress, there was only a slight increase in the cohesion with increasing saturation. As saturation approached the value 1.0, the cohesion increased significantly. At the higher normal stress, the cohesion increased steadily with saturation until a value of the saturation of approximately 0.2 was reached. Above this value, the cohesion decreased slightly and at saturation close to 1.0 the value of the cohesion fell to approximately half the maximum value.

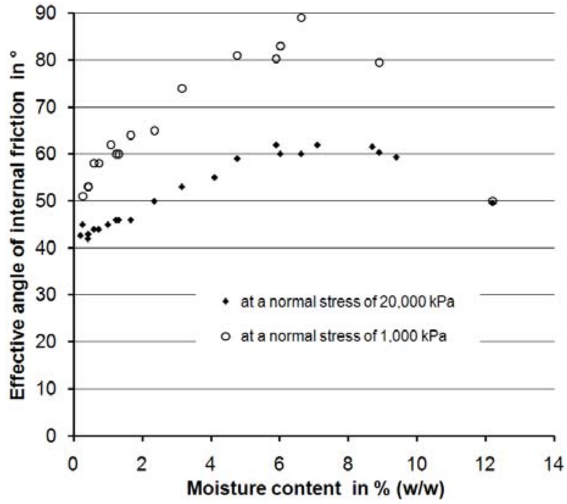

Fig. 3 Effective angle of internal friction as a function of the moisture content

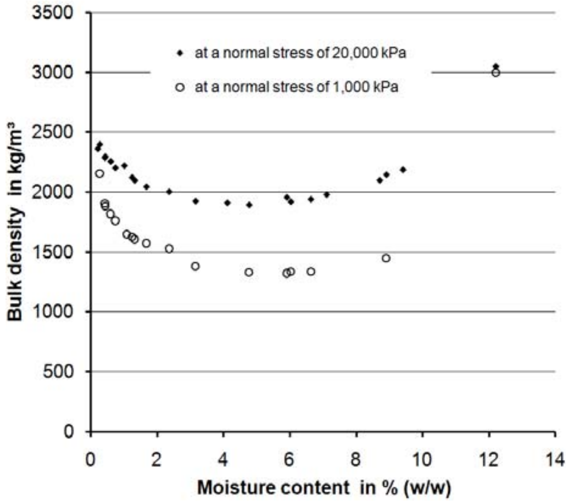

Fig. 4 Bulk density as a function of the moisture content

The values of the wall friction angles increase with the moisture content up to approximately 2%. At higher moisture content, the values are slightly scattered but do not show a certain trend. Generally, the values of the wall friction angle are somewhat lower for higher values of the wall normal stress. No general difference was found between the different wall materials at high wall normal stress and limited moisture content. However, at low values of the wall normal stress and at high moisture content, the wall friction angles with Robalon were typically 2-3° larger.

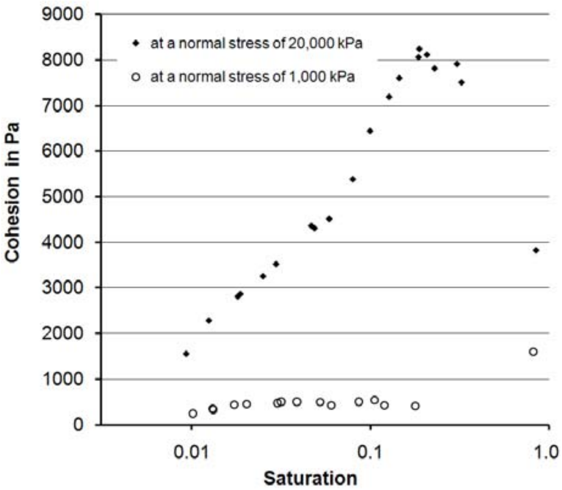

Fig. 5 Cohesion as a function of the saturation

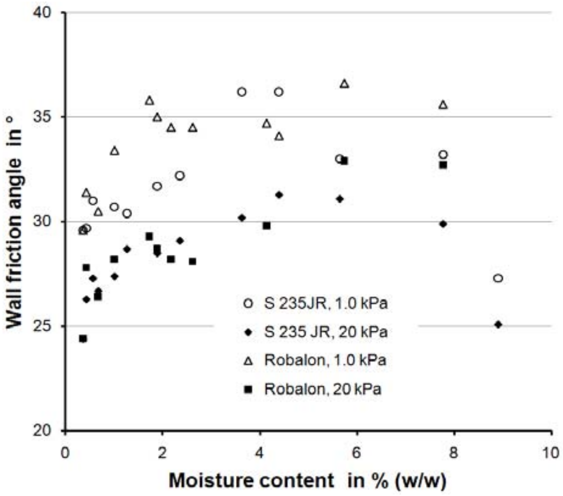

Fig. 6 Wall friction angle as a function of the moisture content

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