Particuology 25 (2016) 68–71

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic

Short communication

Flowability of various dusts collected from secondary copper smelter off-gas

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ARTICLE INFO

Article history:
Received 11 September 2014
Received in revised form
11 December 2014
Accepted 22 May 2015
Available online 23 July 2015

Keywords:
Copper smelter
Dust
Flowability
Shear test

ABSTRACT

Stable flow of off-gas dust from dust collector hoppers and storage silos is important for smooth operation. Flow properties of the collected off-gas dust are critical to achieve suitable flow. Various dust samples collected from secondary copper smelter off-gases were studied. The median diameter of the fine-grained dusts varied from 0.8 to 1.4 μm and the flowability ranged from "cohesive" to "very cohesive". The flowability of shaft and anode furnace dust improved slightly with increasing consolidation stress and their wall friction angles decreased, which is a typical behavior. In contrast, the flowability of converter dust decreased with increasing consolidation stress and its wall friction angles increased. Pre-shear treatment of converter dust worsened its flowability, increased the wall friction angle, and improved the flowability with increasing consolidation stress. This is believed to occur because pre-shear treatment fragments small agglomerates in the dust that improve flowability. The presence of such agglomerates was confirmed by sieving tests. A diagrammatic representation of the flowability showing that the unconfined yield strength is dependent on consolidation stress can be improved by using logarithmically scaled axes.

Introduction

Large quantities of dust are separated from the off-gases of various industrial processes, for example, in secondary copper production, and information is required on their handling and processing characteristics. One of the major problems with dust separation is to obtain reliable and consistent flow out of the hoppers of dust collectors and storage silos. The material flow properties are critical to ensure smooth operation of these processes. Powder flowability depends on several material properties: grain size, grain size distribution, grain shape, and humidity (Lumay et al., 2012; Schulze, 2008). Jenike (1970) pioneered the application of shear cells to measure powder flow properties. In the last 20 years, ring shear testers have become increasingly popular because measurements with these instruments are more reproducible owing to an automated test procedure (Schulze, 2011).

Quantitative characterization of the flowability of a fine-grained solid is possible using the flow factor *ffc*, which is the ratio of consolidation stress σ_1 to unconfined yield strength σ_c (Schulze, 1996). The consolidation stress is equal to the major principal stress of the Mohr's stress circle that runs through the point of steady-state flow and is tangential to the yield locus. The unconfined yield strength results from the stress circle that runs through the origin and is tangential to the yield locus (Jenike, 1970). A larger *ffc* value indicates a better solid flow. The usual classification to define flow behavior is shown in Table 1.

Flowability of a fine-grained solid depends on the consolidation stress. A larger consolidation stress usually yields better flowability. Because of this dependence, it is not possible to describe the flowability of a bulk solid with only one numerical value. Good visualization of the flowability can be given in a diagram showing the unconfined yield strength that is dependent on the consolidation stress if the diagram also includes lines of constant flow factor (Schulze, 1996). The aim of this work was to investigate the flowability of various dusts collected from secondary copper production off-gases. Results measured for a dust show a decreasing flow factor with increasing consolidation stress and these are discussed in detail. The above-mentioned diagram is logarithmically scaled in order to better present the results.

Materials and methods

Dust samples (~2 dm^3) were collected from various process steps in an Austrian secondary copper smelter. Samples were taken

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http://dx.doi.org/10.1016/j.partic.2015.05.003
1674-2001/

Table 1
Flowability according to Schulze (1996).

Description of bulk solids flow	*ffc*
Not flowing	*ffc* < 1
Very cohesive	1 < *ffc* < 2
Cohesive	2 < *ffc* < 4
Easy-flowing	4 < *ffc* < 10
Free-flowing	10 < *ffc*

Table 2
Measured dust properties.

Dust sample	Moisture content (%)	Bulk density (kg/m^3)	Mass median diameter, d_{50} (μm)
Shaft furnace dust	0.3	610	0.99
Converter dust	0.7	900	0.81
Anode furnace dust	0.6	650	1.39

from the dust discharge systems of fabric filters installed for dedusting the off-gas from the melting furnace (shaft furnace) and the refining furnaces (converter and anode furnace).

The sample moisture content was determined gravimetrically. Samples were dried at 105 °C for 1 h. A Sympatec HELOS/RODOS laser diffraction instrument (Sympatec GmbH, Clausthal-Zellerfeld, Germany) with dry sample dispersion was used to measure the particle size distribution of the dust samples. The relative distribution span was calculated as the quotient of $(d_{90} - d_{10})$ and d_{50}. d_{90} is the particle size with 90% of the material mass consisting of particles smaller than this size and the remainder consisting of larger particles. d_{10} and d_{50} are defined in a similar way to d_{90} (Rumpf, 1990).

The bulk density was determined according to BS EN ISO 60 (1999) using an instrument with calibrated measuring cylinder (Landgraf Laborsysteme HLL GmbH, Langenhagen, Germany).

Shear tests were conducted according to ASTM D 6773 (2008) using an RST-XS Schulze ring shear tester (Dr.-Ing. Dietmar Schulze Schüttgutmesstechnik, Wolfenbüttel, Germany). Values for the vertical load during sample consolidation in the pre-shear step were 600, 2000, 6000, and 20,000 Pa. The wall friction angles were determined for structural steel S235JR (1.0038) as the wall material. Shear tests were performed in triplicate. Average values were used for the diagrams.

An ANALYSETTE 3 PRO laboratory sieve shaker (Fritsch GmbH, Idar-Oberstein, Germany) was used to sieve the dust.

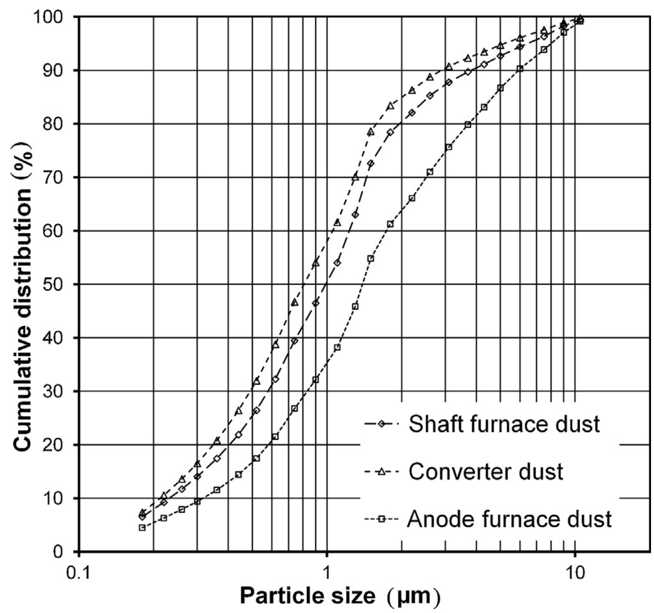

Fig. 1. Particle size distributions of the various dust samples.

Results and discussion

Humidity and bulk density results are summarized in Table 2. The dust sample particle size distributions are shown in Fig. 1. All three dusts are fine-grained. The mass median diameters, d_{50}, ranged from ~0.8 to 1.4 μm and the cumulative distribution curve shapes are very similar. Thus, values for the relative span are also quite close.

In general, the dust sample flowability was poor. Most samples were "very cohesive" and only one was categorized as "cohesive". These results are not surprising because of the small particle size. The flow factors of the dusts are summarized in Fig. 2. In the diagram with linear scaled axes, the results at low consolidation stress are close together. Therefore, the diagram is also shown with

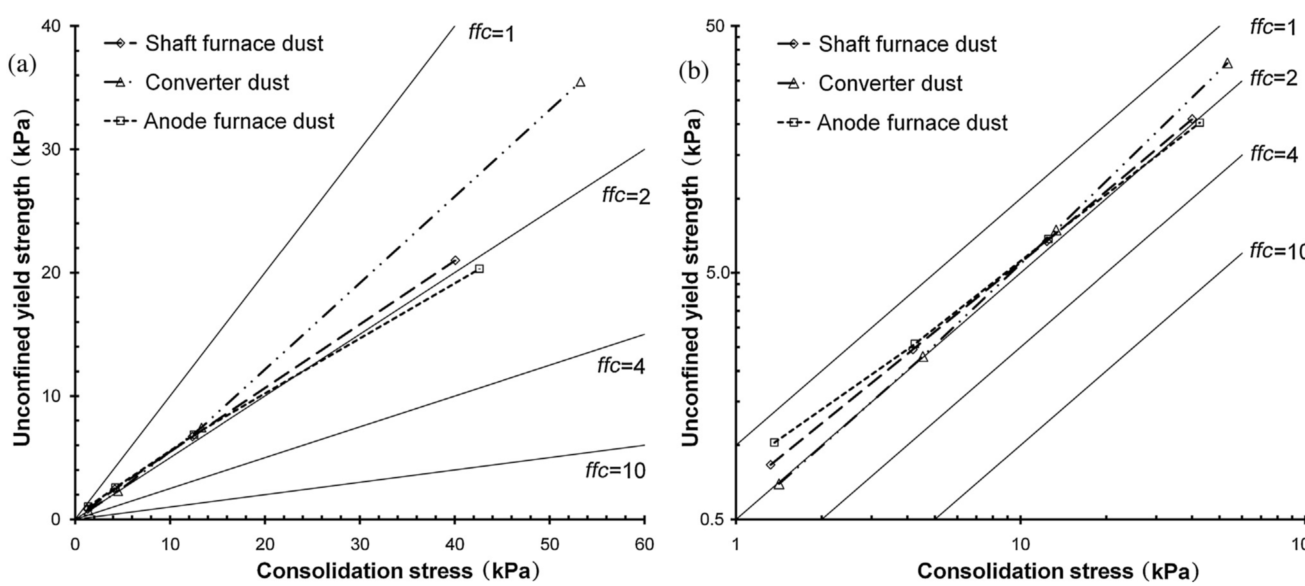

Fig. 2. Flowability of the various dusts: linear scale (a) and logarithmic scale (b).