Flowability Of Moist Coal Combution Fly Ash

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Abstract

In the combustion of coal the mineral contents remain as ash. The fine size fraction of the ash leaves the combustion zone with the off-gas from which it is separated as fly ash. Depending on the physical and chemical properties these fly ashes can be utilized. An essential parameter for the design and operation of transport equipment and storage facilities for fine grained materials is their flowability. The moisture content of the material has considerable influence on the flowability because of the increasing influence of the liquid bridges between the particles and the resulting capillary forces. In this study the influence of the moisture content on the flow characteristics of a coal combustion fly ash was investigated. The fly ash sample was collected from the dust discharge of the electrostatic precipitator of a power plant using Polish hard coal as fuel. The mass median diameter of the fly ash was approximately 20 μm. Microscopic images show that most of the particles are spheres. The flow properties of the fly ash were measured using a ring shear tester. The moisture content of the sample was adapted by addition of water. The dry fly ash was characterized by very good flow properties, the flowability ffc was in the category 'easy flowing'. Significant decrease in flowability was found at increased moisture contents. Additionally, the bulk density of the fly ash was influenced by the moisture content. Thus, the flow-relevant parameters which have to be considered in design of transport and storage facilities of fine granular material worsened with increasing moisture content.

Keywords: fly ash, coal combustion, moisture content, flowability

Introduction

When coal is combusted most of the mineral content of the coal remains in the form of ash. The coarse fraction of the ash is discharged at the furnace bottom, while the fine fly ash fraction has to be separated from the combustion off-gas. An annual production of coal combustion fly ash worldwide of 500 million tones is estimated (Ahmaruzzaman, 2010). From an environmental point of view this huge amount of fly ash should be utilized as much as possible because the disposal of such a large quantity of fly ash is a serious environmental problem. The utilization of fly ash varies widely from country to country. The world average utilization amounts to approximately 16% of the total fly ash (Ahmaruzzaman, 2010).

In utilization of coal combustion fly ash the composition of the fly ashes is crucial. Therefore, the composition of coal combustion fly ash has been studied widely (Asokan et al., 2005; Belviso et al., 2015; Fytianos et al., 1998; Shaheen et al., 2014). For the handling and storage of fly ash also mechanical parameters are important. For both the particle size and the particle size distribution of coal fly ash measured results are available in the literature. Mass median diameters between 6.8 and 98 μm were reported (Chindaprasirt et al., 2011; Kutchko et al., 2006), while the maximum particle size is approximately 150–250 μm.

An essential parameter for the design of transport equipment and storage facilities for fine grained materials is their flowability. It depends on various material properties, for example the grain size, the grain size distribution, and the grain shape (Lumay et al., 2012; Schulze, 2006). The 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 (Emery et al., 2009; Plinke et al, 1994; Schulze, 1991) Therefore, an increased moisture content leads to reduced flowability.

In this study the influence of the moisture content on the flowability of coal combustion fly ash was investigated. The flowability at increased water content is important because the dust is often wetted to avoid dust generation during handling and storage of the material.

Materials and methods

The investigated fly ash sample was collected from a power plant using Polish hard coal as fuel. The fly ash from this power plant is separated from the off-gas by a three-field electrostatic precipitator. It is utilized as a milling additive in the cement industry. A fly ash sample of approximately 5 dm³ was collected at the discharge system of the ESP of the off-gas de-dusting system. In the laboratory, the quantity of the collected fly ash sample was reduced to a volume suitable for the various laboratory tests using sample dividers which were applied repeatedly (Haver&Boecker HAVER RT, Quantachrome Micro Riffler).

In a first step the fly ash sample was dried in a compartment drier for twenty-four hours. For production of fly ash samples with different water content an Erweka AR 403/SW 1/S plough-share drum mixer was used where the dried fly ash was mixed with the appropriate amount of water. The

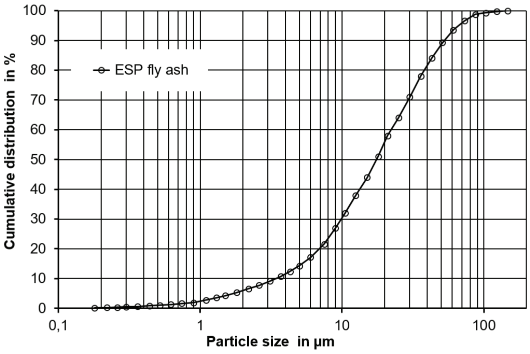

Fig. 1. Size distribution of the fly ash

Rys. 1. Rozkład wielkości uziarnienia popiołu lotnego

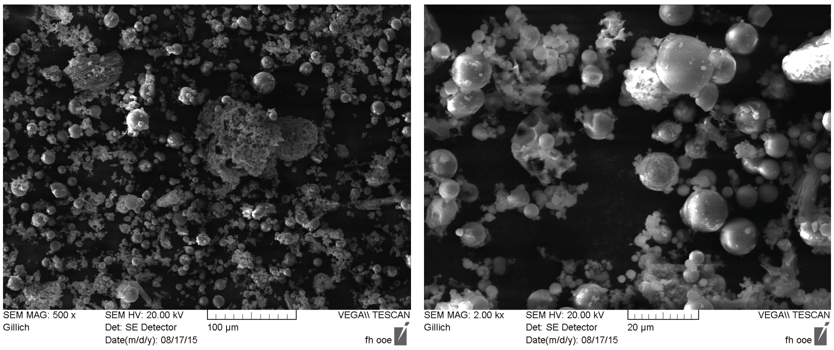

Fig. 2. Scanning electron microscope images of fly ash particles

Rys. 2. Obrazy ziaren popiołu lotnego ze skaningowego mikroskopu elektronowego

speed of the mixer was 300 rpm and the mixing time was 10 minutes. Afterwards, the moisture content of the samples was determined gravimetrically with a Sartorius infrared moisture analyser MA35M at 105°C.

The particle size distribution of the fly ash was measured using a laser diffraction instrument with dry sample dispersion from Sympatec, type HELOS/RODOS. The calibration of the instrument was checked with a Sympatec SiC-P600'06 standard.

Microscopic images of particles from the various size fractions were taken with a scanning electron microscope TESCAN, type VEGA LM.

The yield locus was determined using a Schulze RST-XS ring shear tester with a 30 cm³ shear cell. The bulk density of the material in dependence of the consolidation stress was also determined with the shear tester.

For a quantitative characterization of the flowability of a granular material the factor ff_c can be used, which is the ratio of the consolidation stress σ_1 to the unconfined yield strength σ_c (Schulze, 1996) The larger the value of ff_c, the better a granular material flows. The consolidation stress is equal to the major principal stress of the Mohr stress circle which is tangential to the yield locus and runs through the point of steady-state flow. The unconfined yield strength results from the stress circle which is tangential to the yield locus and runs through the origin (Jenike, 1964). The usual classification used to define flow behaviour consists of five categories: not flowing: $ff_c < 1$; very cohesive: $1 < ff_c < 2$; cohesive: $2 < ffc < 4$; easy-flowing: $4 < ff_c < 10$ and free-flowing: $10 < ff_c$ (Schulze, 1996). The flowability of a granular material often depends on the consolidation stress. For many powders better flowability will be achieved at a higher consolidation stress. This can be visualized best in a diagram showing the unconfined yield strength dependent upon the consolidation stress when the diagram also includes lines of constant ff_c ratio. Logarithmically scaled axes improve the representation of the results in the diagram (Lanzerstorfer, 2016).

Results and discussion

The particle size distributions of the fly ash is given in Figure 1. The mass median diameter was 18 µm. Thus, the size of the fly ash is within the reported size range.

Figure 2 shows scanning electron microscope (SEM) images of the fly ash. Most single particles have a rounded, nearly spherical shape. However, there are also some agglomerates and some particles with a different shape.

The unconfined yield strength dependent upon the consolidation stress is shown in Figure 3 for various values of the moisture content. Generally, the flowability decreases with increasing moisture content.

At a moisture content of 0.55% the fly ash was easy-flowing. Thereby, the flowability improved with increasing consolidation stress. At a moisture content of 0.95% the flowability was reduced (cohesive to easy-flowing) and at 2.25% the flowability was already very low (very cohesive to cohesive). At low values of the consolidation stress, a further increase in the moisture content had little influence on the flowability, while at higher values of the consolidation stress the flowability still decreased. Thereby, the effect of the improving flowability with increasing consolidation stress nearly diminished.

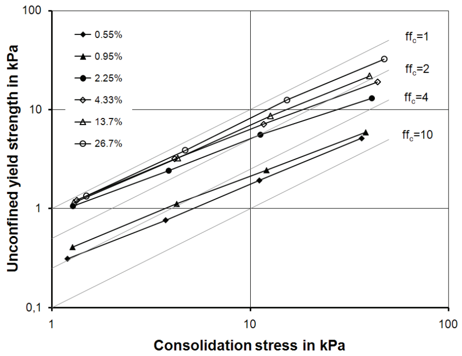

Fig. 3. Unconfined yield strength vs. Consolidation stress

Rys. 3. Nieskończona granica plastyczności w stosunku do naprężenia sumarycznego

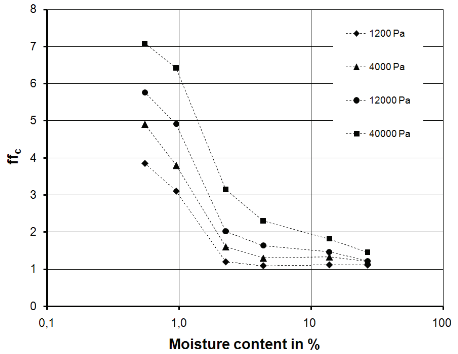

Fig. 4. Flowability as a function of the moisture content

Rys. 4. Sypkość jako funkcja wilgotności

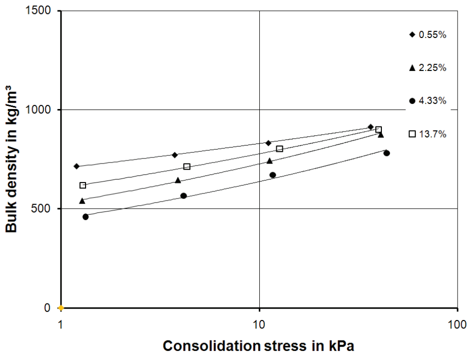

Fig. 5. Bulk density as a function of the consolidation stress for various values of the moisture content

Rys. 5. Gęstość nasypowa jako funkcja naprężenia dla różnych wartości wilgotności

Figure 4 shows the flowability as a function of the moisture content for various values of the consolidation stress. At low consolidation stress the flowability decreases rapidly with increasing moisture content. At the moisture content of 2.25% the minimum of ff_c was reached. A further increase of the moisture had little influence on the flowability. At the highest value of the consolidation stress the decrease in flowability was less steep. Thus, the minimum value of ff_c was reached at a higher value of the moisture content.

Generally, the bulk density of fine granular material increases with increasing consolidation stress (Lanzerstorfer, 2017). This was also observed for the investigated fly ash. At lower values of the moisture content the bulk density decreased with increasing moisture content. The minimum bulk density was measured at a moisture content of 4.33%. At the moisture content of 13.7% the bulk density was higher.

Conclusion

The measurements showed a significant influence of the moisture content on flow-relevant parameters of coal combustion fly ash. In the low moisture-content range of 0–3% the flowability decreased significantly with increasing moisture content, while at higher moisture content (>3%) the variation was rather small. The influence of the moisture content also strongly depends on the value of the consolidation stress.

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Płynność popiołu lotnego ze spalania mokrego węgla

Przy spalaniu węgla zawarte w nim minerały pozostają w postaci popiołu. Drobna frakcja popiołu opuszcza strefę spalania z gazem odlotowym, z którego jest oddzielana jako popiół lotny. W zależności od właściwości fizycznych i chemicznych można wykorzystać popioły lotne. Istotnym parametrem dla projektowania i eksploatacji urządzeń transportowych i magazynów materiałów drobnoziarnistych jest ich zdolność płynięcia. Zawartość wilgoci w materiale ma znaczący wpływ na zdolność płynięcia ze względu na rosnący wpływ mostków cieczowych między cząstkami i wynikającymi z nich siłami kapilarnymi. W pracy zbadano wpływ zawartości wilgoci na charakterystykę przepływu popiołu lotnego ze spalania węgla. Próbka popiołu lotnego została pobrana z odbiornika pyłu z elektrofiltra elektrowni z wykorzystaniem polskiego węgla kamiennego jako paliwa. Mediana średnicy ziarna popiołu lotnego wynosiła około 20 μm. Obrazy mikroskopowe pokazują, że większość cząstek to kule. Właściwości przepływu popiołu lotnego mierzono za pomocą testera ścinania pierścieniowego. Zawartość wilgoci w próbce zmieniano przez dodatek wody. Suchy popiół lotny charakteryzował się bardzo dobrymi właściwościami płynięcia, płynność ffc była w kategorii „łatwo płynący". Znaczny spadek płynności stwierdzono przy zwiększonej zawartości wilgoci. Dodatkowo zawartość wilgoci ma wpływ na gęstość nasypową popiołu lotnego. Zatem istotne dla przepływu parametry, które należy wziąć pod uwagę przy projektowaniu urządzeń do transportu i przechowywania drobnego materiału ziarnistego, pogarszają się wraz ze wzrostem zawartości wilgoci.

Słowa kluczowe: popiół lotny, spalanie węgla, wilgotność, sypkość