Short Communication

Hydrophobized Limestone Powder as an Antiexplosive Agent

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Abstract

Coal dust explosions remain among the greatest hazards in coal mines. Unfortunately they still occur, often with a great number of victims and with huge environmental damage. The development of mechanization contributes to the increase of dust with a greater quantity of possible initials – only some of the factors influencing this problem.

Two methods of limestone dust hydrophobization as an antiexplosive agent are proposed: from stearic acid vapour and from silicone solution. A preliminary estimate of the properties of this waterproof dust was carried out according to the Polish Standard (PN-G-11020) and by using Powder Characteristic Tester methods. Moreover, adhesive force and shear test were measured. The laboratory-produced waterproof dust meets the Polish Standard requirements. Basic investigations of the physical and chemical properties of such dusts will give us some insight into the phenomena of hydrophobization of finely dispersed materials.

Keywords: coal dust explosions, limestone powder, hydrophobization

Introduction

The typical course of a coal mine explosion starts with the ignition of a flammable methane-air atmosphere that has been studied extensively at many experimental mines in many countries: for example at the Experimental Mine Barbara in Poland or the Bruceton Experimental Mine and the Lake Lynn Experimental Mine of the NIOSH Pittsburgh Research Laboratory in the USA. This typical scenario consists of impetuous winds from the primary methane explosion that disperses the coal dust. As a precaution against coal dust explosions, stone powder (usually limestone powder) is spread both within mine barriers and in different ways [1-4]. During an explosion the stone powder disperses, mixes with the coal dust and prevents flame propagation, acting as an inhibitor. Stone powder reduces the flame temperature to a point where devolatilization of the coal dust can no longer occur; starved of fuel, the explosion is inhibited. The amount of stone powder required to inert an explosion depends on particle size of the stone material, particle size, type of coal dust, and atmospheric composition (humidity, content of air, and methane) present in underground coal mines.

Two types of stone powder are produced (regular and waterproof) that are used for sprinkling and for constructing dust barriers. A regular limestone powder is most commonly used for these purposes. Its major defect is its tendency to lose volatility, because of agglomeration under humid conditions, often reaching 100% water saturation in mine atmospheres. Using the waterproof powder may eliminate this defect. Such a powder has been produced by coating regular powder with stearic acid during grinding in stone mills [5, 6]. In modernized quarries and plants, modern mills of a complex construction are employed, in which contamination by hydrophobizing agents is practically avoided. For this reason, new methods of modifying the character of limestone surfaces are sought.

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Experimental Procedures

Material and Manufacturing Methods

In this work lime dust from the Czatkowice Lime Quarry [7] was used as a raw material during research. Some of the basic properties of the material were analyzed. Fig. 1 presents the distribution of dust grain sizes marked with the use of an Analisette 22 C-Version laser analyzer produced by Fritch GmbH Laborgerätebau.

The chemical composition of lime dust was measured and the material contains: CaO=54, SiO_2+NR=1.5, MgO=1.5, Fe_2O_3=0.11, Al_2O_3=0.08, S^{-2}=0.03, SO_3=0.04, Na_2O=0.023, and K_2O=0.037 (% weight). Roasting losses (1000ºC/1h) amount to 43%. Water content is included in the roasting losses. The real density of the dust, marked with the method of helium picnometry with the use of the AccuPyc 1330 apparatus, amounts to 2.7642 g/cm^3.

Two methods of manufacturing hydrophobic material are proposed: hydrophobization from stearic acid vapour and from silicone solutions. The first one consists of stearic acid vapour and dust counter current flow [7] and it was carried out in an installation of our own design. The hydrophobisation apparatus scheme is shown in Fig. 2.

The second method consists of mixing raw dust with a silicone preparation with the marketing name SARSIL® H-15 produced by the Polish Silicones chemical plant in Nowa Sarzyna. The preparation volume that should be added to the dust in order to obtain optimal conditions for the contact of the preparation with a solid was determined in experiments.

Materials obtained in this way may be used as an anti-explosive agent in mining industry. These waterproof products protect human life so that its properties are important and should be well known.

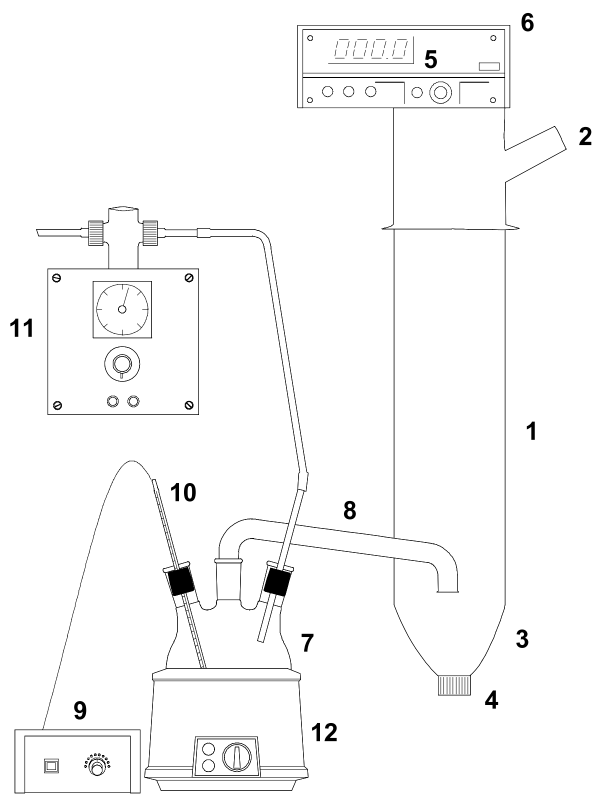

Fig. 2. The hydrophobization apparatus scheme: 1 – hydrophobization column, 2, 3 – hoppers, 4 – lock of hopper, 5 – control panel, 6 – feeder, 7 – boiler, 8 – ting-up pipe, 9 – thermoregulator, 10 – thermocouple, 11 – compressor, 12 – heater.

Methods Measurement of Powder Properties

One of the most important issues is the determination of the index of hydrophobization of samples. It is easy to determine when stearic acid is used as a modifier, because there is a standard that defines this measurement. The manufactured sample (S_18) contains 0.18% stearic acid, an acceptable level according to the Polish Standard [5].

In the case of the second method of powder hydrophobization, the author had to work out the method for determining hydrophobization C coefficient. It turned out that conducting research with the limestone dust helped to search for the method of examining the hydrophobization degree. This fact makes it possible to compare the hydrophobic properties of powders modified in the work with the properties of industrial anti-explosive dust (PH) available on the market. The film flotation method [8, 9] was used for this purpose when the commercial material was used as a comparative sample. The C coefficient defined to what extent the hydrophobic properties of the obtained S_SH15 sample are different from the hydrophobic properties of the commercial sample on contact with a suitable (10, 20, and 60% (w/w)) methanol solution. This was calculated from equation 1. The average value of the C=84% coefficient shows that the S_SH15 sample obtained sufficient hydrophobic properties.

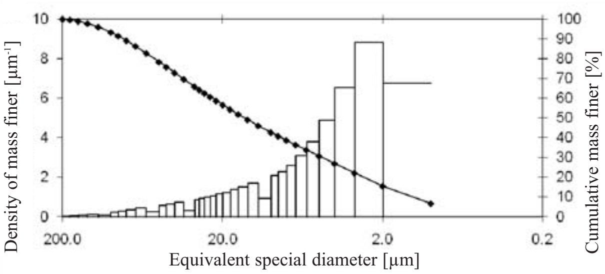

Fig. 1. Curve of grain distribution for raw dust.

$$C\,[\%] = \frac{f_{pi} \cdot 100}{f_p} \tag{1}$$

...where: f_{pi} and f_p are mass percentage of S_SH15 sample and PH sample floating on a selected methanol solution surface.

Obtained samples were also analyzed using the research methods originally applied in the powder technique due to the powder state of the material. Moreover, adhesive force and shear test were measured.

Table 1. Characteristics of raw and hydrophobized lime dusts.

Characteristics	Raw	S_18	S_SH15
Bulk density [kg/m^3]	724	798	790
Packed bulk density [kg/m^3]	1,475	1,377	1,414
Compressibility [%]	50	42	44
Repose angle [deg]	52	47	37
Fall angle [deg]	35	33	34
Difference angle [deg]	17	14	3
Dispersibility [%]	20	41	16
Carr's ratio [%]	50	42	44
Hausner's ratio	2.0	1.7	1.8

Results

Powder Characteristics Tester – Type PT-E, Ser. No. 90133

Carr [10, 11] has tried to evaluate powder's flow properties in a numerical manner using the combination of various physical characteristics listed in Table 1. The tables for the conversion of the measured figures into a common index were published [12].

The compressibility value for the raw sample equals 50% and it is decreased slightly for the modified samples, but both the raw lime dust and the modified powders will settle in elbows, and the outlet will clog [10]. The fall angle of all dusts is much bigger than 10 degrees, so all the investigated samples have fairly high degrees of floodability [10]. The values of the difference angles for both raw and hydrophobized dust are low, as in the case of cohesive materials. A great difference between the dispersibility values was found only in the case of raw and the S_18 samples. So the measurement of this one cannot be used for evaluating the degree of hydrophobization. The dispersibility for all samples is less than 50% – substandard for easy flowing powders. Hausner's ratios [11] are bigger than 1.4, i.e. the three samples are characterized by all properties of cohesive powders. Carr's ratios obtained during research are much bigger than 30 and confirm the low flow rate of powder. Only compressibility could be used as a criterion for evaluating the degree of hydrophobization of modified dusts.

Shear Test

Data from shear tests is mainly an important basis for the design of reliable bulk solid handling equipment [13, 14]. The technique for measuring is described in many papers [15-19]. In this work shear tests were performed to determine the effect of hydrophobization on the powder's behaviour characteristics. We used the shear tester, which was made according to Jenike's method [15] and the European Standard [20]. The data obtained from shear experiments were the basis for determining yield loci for the tested materials (Fig. 3). The test was performed with the use of only one value of normal load during the pre-shear because the determination of the flowability of the limestone powder was not the aim of this research. Neither flow function nor flow index was calculated.

Some flow parameters graphically presented in Fig. 3 (cohesion, kinetic angle of internal friction) are comparable for all tested materials (modified and raw material).

In spite of the use of different modifiers and methods of hydrophobization, the changes of rheological properties of investigated materials was not sufficiently large to obtain the possibility of unequivocal interpretation. However, data from shear tests shows that the effect of surface modification on powder flowability measured with the Jenike shear cell method is observed in obtained results. It seems that carrying out the shear test at different powder humidity should broaden the interpretation of obtained results.

Measurement of Adhesive Force

The adhesion of particles to a surface is important in everyday life and in many industries [21]. The measurement of this property may be useful for characterizing solids from different points of view. In this work this one will be used for evaluating the degree of hydrophobization of modified dusts. There are known various techniques suitable for adhesive force measure [21, 22]. But it should be remembered that the examination of properties of fine-dispersional materials are not as simple as analyzing the same properties for solids with large surfaces [23].

The adhesive force in this work was measured with a technique described by Harnby et al. [24] for the coarser limestone particle fraction (0.385-0.400 μm) modified in the same way as the fine ones. The array of particles placed on a tacky surface was contacted with the metallic flat surface.

The obtained results for modified material were neglected. For raw material the adhesive force appeared at humidity of about 60%, then grew to a value of 0.008 N at 95% humidity. It is rather a small force but measurements show that the modified material lost its adhesive properties.

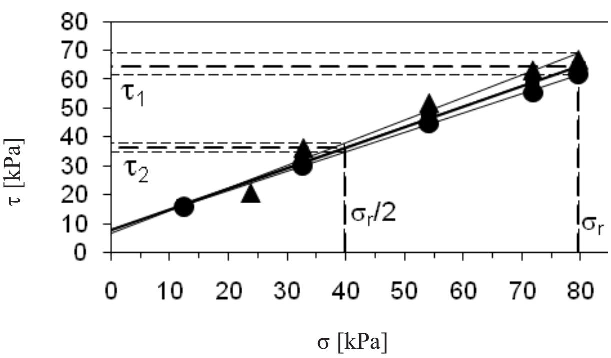

Fig. 3. Relations of shear stress-normal stress of tested materials (■ – raw, ● – S_18, ▲ – S_SH15).

I took this measurement only on contact with metallic flat surfaces. It would be better to conduct the same survey with the use of lime plate; these investigations are planned and then the sample method will be tested as well.

Conclusions

Both the S_18 sample and the S_SH15 sample acquired hydrophobic characteristics. Therefore, I can state that both proposed methods of hydrophobized lime dust manufacturing are useful.

It was interesting how the modification process influenced the change of typical lime dust properties. The obtained results enable us to make a characterization of lime dusts not only as a water-resistant material but also from the cohesion point of view.

Only two of the used research methods are useful in calculating the criterion for evaluating the degree of hydrophobization of modified dusts, i.e. the film flotation method and Powder Characteristics Tester.

On the basis of the result obtained during the shear test, it is noticeable that the method of modification is reflected in it. The adhesive force measurements show that the modified material lost its adhesive properties. The parameters obtained with the use of the Powder Characteristics Tester enable us to estimate the flow properties of dusts.

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