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Short communication

Experimental study on ignitability of pure aluminum powders due to electrostatic discharges and Nitrogen's effect

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ABSTRACT

In order to prevent dust explosions due to electrostatic discharges (ESD), this paper reports the minimum ignition energy (MIE) of aluminum powders in the air and the effective nitrogen (N_2) concentration for the inert technique. The Hartman vertical-tube apparatus and five kinds of different sized pure aluminum powders (median particle size, *D*50; 8.53 μm–51.2 μm) were used in this study. The statistic minimum ignition energy (MIE_s) of the most sensitive aluminum powder used in this study was 5 mJ, which was affected by the powder particle size (*D*50; 8.53 μm). In the case of aluminum powder, the inerting effects of N_2 were quite different from the polymer powders. The MIE of aluminum powder barely changed until the N_2 concentration was 89% in comparison with that of the normal air. When the N_2 concentration was 90%, the MIE of aluminum powders suddenly exceeded 1000 mJ, which does not occur easily with ESD in the industrial process.

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1. Introduction

The electrostatic charges are generated in processes involving powders. This charging phenomenon may lead to electrostatic discharges (ESD). Dust explosions and fires occur continuously in industrial processes. Some of these are related to ESD as an ignition source. These accidents, especially metallic powder explosions, often lead to worker casualties, property damage, and significant fiduciary penalties for companies. However, fine aluminum powders of several tens μm have been commonly used in the industries in forms such as chemical and powder painting processes. Therefore, aluminum explosion hazards have increased. In order to prevent dust explosions caused by ESD, the minimum ignition energy (MIE) of powders must be considered. The MIE is a very important aspect of technical safety indices [BSI, 2002]. Many studies have been conducted on the MIE of polymer powders. Including our previous study, some research has been done on the MIE of aluminum powders [Choi et al., 2010; Bernard et al., 2012; Gascoin et al., 2009; Wu et al., 2010; Weir et al., 2013]. The present study focuses quantitatively on the MIE of several aluminum powders in normal air.

On the other hand, as a useful method for preventing dust explosions, industries often use nitrogen (N_2), an incombustible gas to dilute the oxygen (O_2) concentration in an explosive atmosphere. This paper clearly and specifically shows the relationship between the N_2 concentration and the MIE of aluminum powders. A primary objective of this paper is to communicate new, necessary information on ESD risk assessments that will be important to individuals working in the area of accident prevention and mitigation.

2. Experimental

2.1. MIE apparatus and method

The Hartman vertical-tube (1.2 L) apparatus (MIKE-3) is shown in Fig. 1(a) [BSI, 2002]. The main range of the dust concentrations for the MIE test with several aluminum was from 0.25 kg/m^3 to 1.5 kg/m^3. Because the aluminum powders stuck to the electrodes of ESD, stable ESD was not generated within a dust concentration of more than 2.0 kg/m^3. The energy of the ESD was varied by changing the capacitance of the capacitor and the applied voltage in the discharge circuit. The sample powder was placed at the bottom inside the explosion vessel to be tested. Then, the sample powder was dispersed by means of air stored in the reservoir (70 kPa),

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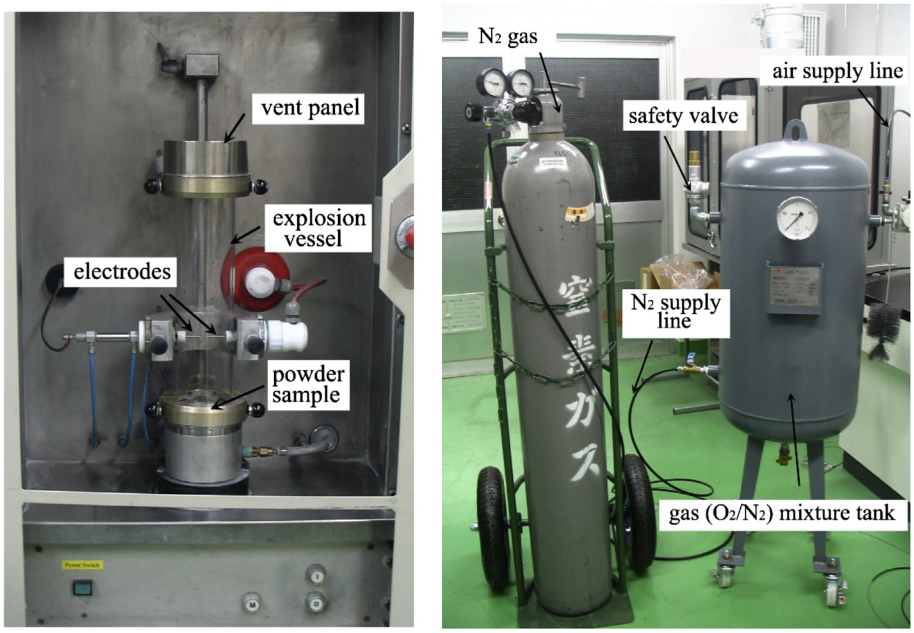

(a) Ignition device part (b) gas mixture (O_2/N_2) supply part

Fig. 1. The MIE measurement apparatus used in this study.

which was suddenly released into the chamber using a solenoid control valve. For MIE measurements, the ESD was triggered under a discharge circuit consisting of the following: electrode spacing: 6 mm, electrode material and diameter: 2 mm of tungsten, inductance in the discharge circuit: 1 mH, the ignition delay time: 120 ms. Discharge conditions can affect the MIE of powders [Yamaguma et al., 2011]. The discharge conditions in this paper were the same as outlined in previous papers [Choi et al. 2005; Choi et al. 2006, K. Choi et al. 2015]. The energy value of the ESD was calculated from Eq. (1):

$$W = 0.5\, C \times V^2, \tag{1}$$

where W is the stored energy in joules (J), C is the total discharge capacitance in farads (F), and V is the voltage of the charged capacitor in volts (V).

In this paper, the value of W was measured using the MIKE-3 apparatus software and was checked in every ignition experiment by the spark monitoring system. The maximum energy of the ESD used in this study was 1000 mJ. Observations were made until the lowest possible energy at which the flame propagates through dust clouds was reached under constant testing conditions (10 times). In this experiment, ignition was considered to have occurred when the flame had propagated at least 10 cm away from the position where the electrostatic spark was first observed.

On the other hand, for test of the influence of N_2 concentration on the MIE of aluminum powder, the gas mixture (O_2/N_2) supply part was added the MIE apparatus (see Fig. 1(b)) and the standard process was changed. In the explosion vent panel mounted on the explosion vessel roof, there were two holes that were 4 mm in diameter. One of them was used to fill up the explosion vessel with the desired gas mixture (O_2/N_2). The other was used to measure the oxygen concentration in the explosion vessel using the oxygen analyzer. Thus, we know the N_2 concentration in the tested air.

The air venting system located above the MIE apparatus was turned off to stabilize the N_2 concentration in the explosion vessel during test. Half of the front glass was changed to metal mesh in order to release pressure due to dust explosions.

The procedure for a routine test at a certain dust concentration is as follows:

a) Set the desired concentration of O_2 in a gas mixture tank by adjusting the pressure gauges for both the normal air and the N_2 supply lines.
b) Place the sample powder at the bottom inside the explosion vessel to be tested.
c) Fix the air tube, which is connected to a gas-mixing tank 5 cm away from the bottom of the explosion vessel, and fix the other air tube, which is connected to an oxygen analyzer 5 cm away from the top of the explosion vessel.
d) Fill an explosion vessel with the desired gas mixture (O_2/N_2).
e) Disperse sample powder by means of the desired gas mixture stored in the reservoir.
f) Trigger the electrostatic spark for igniting the dust.
g) If ignition is obtained, the test is carried out again after lowering the energy level. If ignition is not obtained, the test is repeated 10 times under the same conditions.

All tests were carried out at room temperature, 23 ± 5 °C, and a relative humidity of 40 ± 5% RH.

2.2. Sample powders

The powders used in this experiment were five kinds of aluminum powders and are abbreviated in this paper as AL-1, AL-2, AL-3, AL-4, and AL-5. All of the kinds of aluminum were supplied from the same company (Yamaishi Metal Co., LTD). These samples were pure aluminum (Aluminum (Al) > 99.60%, Silicon (Si) < 0.18%, Iron (Fe) < 0.09%, Copper (Cu) < 0.03%), but had different sizes. Before any tests were carried out, the powder sample was dried up in a desiccator at 20 °C ± 5 °C for 24 h.

3. Results and discussion

Fig. 2 shows the ignition energy as a function of the dust

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