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Ignition characteristics of metal dusts generated during machining operations in the presence of calcium carbonate

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ABSTRACT

Metal dust explosions in machining industries have caused large losses in recent years. In order to evaluate and control the ignition likelihood of metal dusts generated during machining operations, it is necessary to determine the ignition characteristics such as minimum ignition energy (MIE) and minimum ignition temperature (MIT). The aim of this paper is to investigate the inerting effect of calcium carbonate ($CaCO_3$) on these ignition characteristics. Six kinds of typical metal dusts and two kinds of pure atomized metal powders were used to determine the MIE and MIT of dust cloud in the presence of $CaCO_3$. To provide a practical guidance for metal dust explosion prevention, the recommended percentage of $CaCO_3$ were discussed based on the inerting effect.

1. Introduction

Metal dusts can represent significant dust explosion hazards due to their high ignition sensitivity and explosion severity. In August 2, 2014, a catastrophic aluminum dust explosion accident occurred in a buffing workshop of Kunshan Zhongrong Metal Products Co., Ltd. in Jiangsu province of China, which caused 146 deaths and 114 serious injuries. The direct financial loss was 351 million CNY.

Previous studies have shown that the addition of an inert powder into a combustible dust and air mixture is a recognized method to reduce or eliminate the fire and explosion likelihoods (Dastidar et al., 1999; Amyotte, 2006; Amyotte et al., 2007; Eckhoff, 2003; NFPA 654, 2013). The inert powder can reduce the ignitability and explosibility of the mixture through the absorption of heat. And there have been many studies on the explosion characteristics of the pure metal dusts and the incendivity suppression effects by introduction an inert powder (Dastidar et al., 1999; Yuan et al., 2014a, 2014b; Vignes et al., 2012; Mittal, 2014; Kuai et al., 2011a, 2011b; NFPA 499, 2004; National Materials Advisory Board, 1980; Cashdollar, 2000).

Metal dusts give usually strong explosions with pressures more than 1 MPa, with possibility of deflagration to detonation transition (DDT). Introduction an inert powder usually need too much material to decrease the explosion severity to a safety level. However, metal dusts generated during machining operations are quite different from the pure metal powders due to the introduction of many non-metal materials and the fact that they are usually alloy dusts (Myers, 2008). It is expected that the ignition sensitivity and explosion severity of mechanical processing generated dusts are lower than pure metal powders, and their ignition sensitivity may be much easier to be suppressed by adding inert content. Therefore, it is necessary to investigate the ignition characteristics of these mechanical processing generated metal dusts and provide a practical guidance for ignition prevention.

The main ignition sources expected in mechanical processes are mechanical sparks, hot surfaces, non-explosion-proof electrical apparatus, electrostatic discharge and hot-work. Hot-work ignition sources such as welding and cutting, which have very strong ignition capability, can't be avoided during maintenance or repairing. In this case, ignition prevention has to be implemented by safety management, such as cleaning the dust and other combustible materials in the hot-work operation areas. Ignition sources from electrical apparatus can be avoided by using explosion proof electrical apparatus. Electrostatic spark discharge (ESD) ignition sources, can be avoided by proper bonding and grounding due to the

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electric conductibility of metal dusts.

The main objective of this paper is to investigate the possibility to prevent mechanical sparks and hot surfaces by adding inert dust. The mechanical sparks in mechanical processing industry are mainly generated from collision and friction of large particles and tools under normal operation conditions, such as grinding, polishing, sand blasting and shot blasting. These ignition sources are not as strong as that from welding or cutting. The hot surfaces are mainly the shells of the electrical apparatus.

In this paper, the ignition characteristics of six kinds of metal dusts and two kinds of pure atomized metal powders in the presence of calcium carbonate ($CaCO_3$) were determined. Considering that the minimum layer ignition temperature (LIT) of metal dust was usually very high, and the metal dust was seldom ignited as a layer, the minimum ignition energy (MIE) and the minimum auto ignition temperature (MAIT) of a dust cloud were used as the ignition characteristics.

2. Materials and apparatus

2.1. Materials

$CaCO_3$ was used as the inert powder added into the samples because of its attractive price. Eight kinds of metal dusts were chosen for the experiments. Samples 1–6 were metal dusts obtained from the sites of typical machining operations such as shot blasting, sand blasting and polishing. Samples 7 and 8 were pure aluminum and magnesium powders made by atomization method, which were used as reference samples. The sources of the eight samples are listed in Table 1.

2.2. Apparatus and test procedures

The MIE of a dust-cloud is the minimum electrical energy discharged from a capacitor, which is just sufficient to effect ignition of the most easily ignitable concentration of a dust/air mixture at the atmospheric pressure and room temperature. The MIE is mainly used to assess the likelihood of an ignition by energy during dust processing and handling, such as the mechanical spark and electrostatic discharge. In the current research the MIE was tested by a standard apparatus referred to the relative standards (EN 13821, 2002; IEC 1241-2-2, 1993; ASTM E2019, 2003; GB/T 16428, 1996). The test chamber was a 1.2 L glass Hartman tube, and the spark generator was basically identical with the one described by Zhong et al. (Zhong et al., 2015). The electric spark was triggered by the movement of an electrode and the inductance of the circuit was 1.47 mH. The MIE lay between the highest energy at which ignition failed to occur in any dust concentration or ignition delay time within up to 10 tests, and the lowest energy at which ignition occurred at least once in any test conditions.

The MAIT is the minimum temperature at which a dust cloud will self-ignite under the specified conditions of test. The MAIT is mainly used to assess the likelihood of an ignition by hot surfaces, such as the hot surfaces of mechanical friction and heating. In this paper the MAIT was tested by a standard "Godbert-Greenwald" furnace referred to the relative standards (IEC 1241-2-1, 1994; ASTM E1491, 2006; GB/T 16429, 1996) and calculated as the average value of the highest temperature at which ignition failed to occur in any dust concentration or dispersion air pressure within up to 10 tests, and the lowest temperature at which ignition occurred at least once in any test conditions. The step range of the MAIT tests was 20 °C.

Table 1
Sources of the eight samples.

No.	Name	Source	Industry
1	Al alloy dust	Polishing station	Electronics parts
2	Fe alloy dust	Sand blasting dust collector	
3	Al alloy dust	Polishing station	Automobile wheels
4	Fe–Al alloy dust	Shot blasting station	
5	Al alloy dust	Polishing dust collector	Automobile parts
6	Al–Mg alloy dust	Polishing station	
7	Al powder	Atomized powder	Powder manufacturing
8	Mg powder	Atomized powder	

3. Results and discussion

3.1. Physical properties

These metal dusts usually have different microstructures and complex compositions. To obtain detailed information of the particle size of the eight samples and the inert powder, particle size distributions were measured by a laser particle size analyzer. The particle size distributions and the SEM photographs are shown in Figs. 1–4. The details of the particle size distributions are listed in Table 2.The compositions of samples 1–6 were determined by energy dispersive spectrometry (EDS) analysis, and the results are shown in Fig. 5.

3.2. Minimum ignition energy (MIE)

The MIE test results of the eight samples mixed with 0%, 25%, 50% and 75% $CaCO_3$ by mass are presented in Table 3. The MIEs as a function of the $CaCO_3$ percentage are shown in Fig. 6. When the MIE was greater than 1000 mJ, no further measurement was carried on because the ignition likelihood of the dust became very low.

Generally the samples fall into 2 groups according to the slopes of the curves in Fig. 6. The MIEs of samples 1–5 increase with $CaCO_3$ percentage much more obviously than that of samples 6–8, which means the inerting effects of $CaCO_3$ on them are much better. And among the samples 1–5, the inerting effects on the Fe alloy dust (sample 2) and the Fe–Al alloy dust (sample 4) are the best. The MIEs of them are both lower than that of the Al alloy dusts (samples 3 and 5) at first, but increase sharply with increasing $CaCO_3$ percentage and finally achieve the surpassing at the 50%. The compositions of samples 1, 3 and 5 are similar, while the particle size of sample 1 is much smaller. As a result, the MIEs of samples 3 and 5 are very close, which are 250–300 mJ and 300–350 mJ respectively, but the MIE of sample 1 is much lower, which is 90–100 mJ. It can be inferred that the particle size of Al alloy dust has a great impact on the MIE. However, the curves of samples 1, 3 and 5 in Fig. 6 are almost parallel, which means that the inerting effects are almost the same. So the particle size of Al alloy dust has a less impact on the inerting effect than that on the MIE. The particle size distribution of sample 6 is almost same as that of sample 1, but the inerting effect is much worse. The reason may be that the magnesium content can make it more active. So adding $CaCO_3$ into the Al–Mg alloy dust may be not a good method because of the bad inerting effect on the MIE.

3.3. Minimum ignition temperature of dust cloud (MAIT)

The MAIT test results of the eight samples mixed with 0%, 25%, 50% and 75% $CaCO_3$ by mass are presented in Table 4. The MAITs as a function of the $CaCO_3$ percentage are shown in Fig. 7.

Generally the MAIT test results are similar with the MIE. The samples also fall into 2 groups according to the inerting effect of $CaCO_3$. The only difference is that the Al–Mg alloy dust (sample 6) is in the same group with the other metal dusts (samples 1–5),