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 (CaCO₃) 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 CaCO₃. To provide a practical guidance for metal dust explosion prevention, the recommended percentage of CaCO₃ were discussed based on the inerting effect.

Keywords – dust explosion, MIE, MIT, metal dust, inert, machining industry

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 [1-5]. 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 [1, 6-14].

Metal dusts give usually strong explosions with pressures more than 1MPa, 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 [15]. 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 electric conductivity 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.

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	

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 [16-19]. The test chamber was a 1.2L glass Hartman tube, and the spark generator was basically identical with the one described by Zhong et al[20]. The electric spark was triggered by the movement of an electrode and the inductance of the circuit was 1.47mH. 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 [21-23] 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.

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 Fig. 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.

Fig. 1 particle size distributions of the eight samples

5-Al alloy

6-Al-Mg alloy

7-Al

8-Mg

Fig. 2 SEM photographs of the eight samples

Fig.3 Particle size distribution of the inert powder (CaCO_3)

Fig.4 SEM photograph of the inert powder (CaCO_3)

Table 2 Details of the particle size distributions

Items	1-Al alloy	2-Fe alloy	3-Al alloy	4-Fe-Al alloy	5-Al alloy	6-Al-Mg alloy	7-Al	8-Mg	CaCO_3
d_{10} (μm)	6.7	3.7	13.1	5.1	13.6	5.8	3.3	5.4	18.8
d_{50} (μm)	16.3	16.9	46.3	19.2	43.2	20.2	6.0	12.3	37.7
d_{90} (μm)	45.6	49.0	128.7	54.9	138.6	50.2	10.5	30.4	72.9
Specific surface area (m^2/g)	0.50	0.75	0.25	0.55	0.21	0.56	1.11	0.73	0.20
surface area averaged diameter (μm)	12.0	8.1	24.3	10.9	28.6	10.7	5.4	8.2	30.7

Fig. 5 Compositions of samples 1~6

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 1000mJ, no further measurement was carried on because the ignition [likelihood](#) of the dust became very low.

Table 3 The MIE test results (mJ)

CaCO ₃ percentage	1-Al alloy	2-Fe alloy	3-Al alloy	4-Fe-Al alloy	5-Al alloy	6-Al-Mg alloy	7-Al	8-Mg
0%	90~100	180~200	250~300	140~160	300~350	45~50	16~18	10~12
25%	300~350	450~500	400~450	350~400	500~600	80~90	35~40	25~30
50%	600~700	>1000	700~800	800~900	800~900	160~180	90~100	35~40
75%	800~900		>1000	>1000	>1000	250~300	120~140	90~100

Fig. 6 The MIEs of the eight samples as functions of the CaCO_3 percentage.

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 250~300mJ and 300~350mJ respectively, but the MIE of sample 1 is much lower, which is 90~100mJ. 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.

Table 4 The MAIT test result ($^{\circ}\text{C}$)

CaCO_3 percentage	1-Al alloy	2-Fe alloy	3-Al alloy	4-Fe-Al alloy	5-Al alloy	6-Al-Mg alloy	7-Al	8-Mg
0%	450	470	570	410	590	470	350	350
25%	510	590	610	510	650	550	370	350
50%	650	770	790	670	810	730	410	370
75%	710	910	850	730	890	810	430	410

Fig. 7 The MAITs of the eight samples as a function of the CaCO₃ percentage.

Generally the MAIT test results are similar with the MIE. The samples also fall into 2 groups according to the inerting effect of CaCO₃. 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), because the inerting effect on it is also much better than that on the pure atomized metal powders (samples 7 and 8). Moreover, when the particle sizes are approximate, the MAITs of the Al-Mg alloy dust and the Al alloy dust are also very close rather than the MIEs.

Except the Al-Mg alloy dust, the inerting effect of CaCO₃ on the MAIT is very similar with that on the MIE. The inerting effect on the Fe alloy dust (sample 2) is still the best in the MAIT tests. Adding CaCO₃ into the pure atomized metal powders (sample 7 and 8) still has almost no obvious inerting effect even that the CaCO₃ content in the mixture reaches 75%. And the increasing regularity of the MAITs of the Al alloy dusts (samples 1, 3, and 5) along with the CaCO₃ percentage can reveal that for Al alloy dusts with similar composition, lower particle size yields lower MAIT, but the inerting effects of CaCO₃ on them are almost the same.

3.4 Recommendation of dust inerting for the mechanical processing dusts

It is a common sense that when MIE > 1000 mJ, the dust is very hard to be ignited by spark ignition sources. Therefore, MIE > 1000 mJ can be set as the energy criterion for inerting effect. To prevent ignition of combustible dusts, surface temperature of electrical apparatus is restricted to a series of temperature values ranged from 85°C to 450°C [12]. So MAIT > 450°C can be set as the temperature criterion for inerting effect.

As can be seen in the MIE test results, the Al-Mg alloy dust (sample 6) is hardly to be inerted by CaCO₃ like the pure metal powders (samples 7 and 8) because the MIE is still much lower than the criterion even that the CaCO₃ percentage is up to 75%. If 80% of the criterion is acceptable, the recommended mixing ratios of CaCO₃ for samples 1~5 are listed in Table 5.

Table 5 Recommended CaCO₃ percentage for samples 1~5

Sample	CaCO ₃ percentage (%)	MIE(mJ)	MAIT(°C)
1-Al alloy	75	800~900	710
2-Fe alloy	50	>1000	770
3-Al alloy	75	>1000	850
4-Fe-Al alloy	50	800~900	670
5-Al alloy	50	800~900	810

4. Conclusion

By determine the ignition characteristics of eight kinds of metal dusts, it can be concluded that (1) adding CaCO_3 into the pure atomized Al or Mg powder or Al-Mg alloy dust is far from enough for the ignition [likelihood](#) minimization, (2) and more Mg or Al content in the metal [dusts](#) generated during machining operations always led to higher incendivity. However, adding CaCO_3 may be still an effective method [for ignition prevention](#) in some cases. If $\text{MIE} > 1000\text{mJ}$ and $\text{MAIT} > 450^\circ\text{C}$ are set as the criterion for inerting effect, in order to ensure that the ignition characterizes are higher than or very close to (80%) the criterion, the recommended CaCO_3 percentages in the mixture are: 75% for the Al alloy dust, and 50% for the Fe alloy dust and Fe-Al alloy dust. In industry, for the metal dust explosion [hazard assessment](#) and control, CaCO_3 could be added into the dust collector before maintenance and repairing, or the duct between cyclone and bag filter during operation of dust collection.

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