Research paper

Explosibility characteristics of magnesium dust and detection of igniting spark in shredding process

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Abstract

Influence of size and shape of magnesium dust, inert component in the dust (particle) and moving velocity of magnesium dust cloud on the magnesium dust explosion, and explosion index, both volume and surface resistivities for electrostatic safety, detection of igniting spark to prevent the explosion, etc. were studied. Larger dust required larger ignition energy and fibrous (flake) dust was hard to form explosive dust cloud. Inert components in material contributed to suppress explosive character basically but too much of the component (Ca) could not be blended because of casting characteristic, thus making inert component (Ca : about 1 wt%) ineffective to reduce the magnesium explosibility. The dust cloud was not ignited when the dust cloud moved fast (over about 4 ms^{-1}). The K_{st}value was 321 [$\times 10^2$ $kPa{\cdot}ms^{-1}$], showing extremely strong explosion severity. Monitoring a spark could be practical to assess the ignition risk of the dust cloud. The volume resistivity was 6.5×10^9 $\Omega{\cdot}m$ and surface resistivity was 8.3×10^{11} Ω, indicating slightly poor conductive characteristic.

Keywords : magnesium, explosion, spark, ignition

1. Introduction

Magnesium is receiving big concern for industrial application recently because of mechanical strength and weight. However, big attention has to be paid for fire and explosion in the applications. Many explosion accidents have been reported[1)−3)] related to magnesium handling.

Dust explosion is influenced by many factors, such as characteristics of powder (particle size, shape, etc.), dust cloud contact duration to an ignition source, amount of energy supplied to the dust cloud, etc. Many researches on ignition of dust explosion have been carried out[4)−9)] and the ignition characteristics are elucidated to some extents. However, it is still necessary to investigate actually the explosibility of a specific powder which we handle. This is particularly true when we pay practical attention to prevent the dust explosion of a specific process and dust.

Paying attention to those backgrounds, the authors investigated the influence of size and shape of magnesium dust, inert component in the dust (particle) and moving velocity of magnesium dust cloud on the magnesium dust explosion, and explosion index, etc. Also, it was studied how to detect igniting spark to prevent the explosion. Regarding electrostatic hazards during handling of magnesium dusts, both volume and surface resistivities were measured.

2. Experimental

Standardized Hartmann apparatus[10)] was used to investigate the dust explosibility. The minimum ignition energy was measured using a power supply which provided a single pulse with an adjustable charge voltage, electric current and discharging time.

The motion effect of dust cloud on the ignition energy was investigated using a vertical explosion tube (Fig. 1 : inner diameter 40 mm, 750 mm long) made of glass to form a dust cloud. Test powder was placed in a dust cup placed in the center of air passage and blown off by air. Air stream velocity was regulated by two air volume valves. The dust cloud was ignited at a pre−arranged time after the dust sample was blown off, using a relay timer which was adjustable with 0.001s interval.

To observe igniting spark, five types of sensors

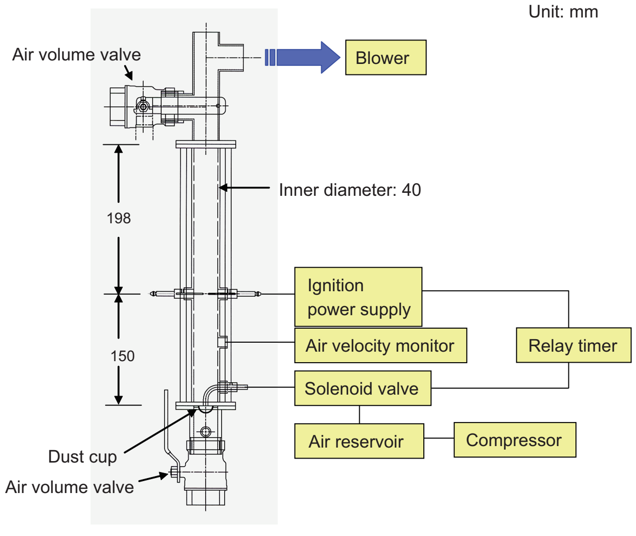


Fig. 1 Details of an explosion tube to investigate the influence of dust cloud velocity on Mg dust explosion.

Fig. 2 Sensors to observe igniting sparks.

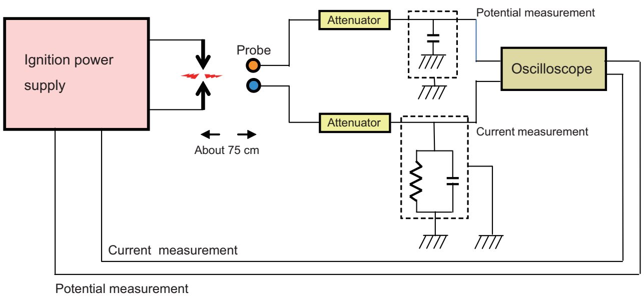


Fig. 3 Experimental system

(Tektronix 119−4146−00) were applied (Fig. 2) : No.1―Ball 3.5 cm, No.2―Stub 0.3 cm, No.3−Loop 6 cm, No.4―Loop 3 cm and No.5―Loop 1 cm. Each sensor was placed at the position of probe in Fig. 3.

Powders tested were standard Mg dust (size : under 45 μm, purity : 99.8 %, named as pure Mg dust), Mg dusts sampled in a laboratory and a factory (Ca free, named as AZ91 and contains Ca, named as AZX911), and pulverized Mg alloy (under 45 μm, contains Ca, named as AZX911 and standard sample). Ca was blended in Mg alloy to reduce the ignitability of Mg material. The shear dusts are usually long and flat like flakes and strings.

3. Results and discussions

3.1 Influence of size and shape of dust on Mg dust explosibility

Particle size has big influence on dust explosion as widely known and the authors have introduced that the effects were expressed by the following two equations[11]. The sample used was magnesium (Alfa Aesar : Mg purity 99.8%, under 45 μm, shape : irregular) and it was classified into approximately every 20 μm. The explosion test was carried out using Hartmann apparatus.

$$C_{MEC} = \alpha \cdot \exp(\beta \cdot d_{ps}) \quad \text{(eq.1)}$$

C_{MEC} = minimum explosive concentration 〔g・m^{-3}〕
d_{ps} = particle size (μm)
α = coefficient (approximately 63.02)
β = coefficient (approximately 0.015)

$$Eig = a \cdot d_{ps}^2 + b \cdot d_{ps} + c \quad \text{(eq.2)}$$

Eig = minimum ignition energy (mJ)
d_{ps} = particle size (μm)
a = coefficient (approximately 0.0089)
b = coefficient (approximately 0.0543)
c = coefficient (approximately −0.3482)

The minimum explosive concentration and the minimum ignition energy decreased with the decrease of particle size. In the case of actual shear dust, the homogeneous dust cloud was difficult to be produced because the sample was fibrous (flake). The minimum explosive concentration and the minimum ignition energy of the pure Mg dust over 74 μm were over 270 g/m^3 and over 80 mJ.

3.2 Effect of inert components in Mg alloy on dust explosion

The inert component has negative effect for combustion and will help reduce the risk of dust explosion. However, mechanical strength of Mg materials has to be maintained and there is a limit of the amount of inert components to blend in Mg alloy.

Figure 4 shows the explosibility of standard samples. The explosibilities (explosion probability and explosion development) were reduced slightly by blending 1% of Ca. In the case of shear dusts, the explosion probability slightly increased by blending of about 1% of Ca and the blending effect was not clear also.

3.3 Effect of flow velocity of Mg dust cloud on dust explosion

Figure 5 shows the influence of flow velocity of dust

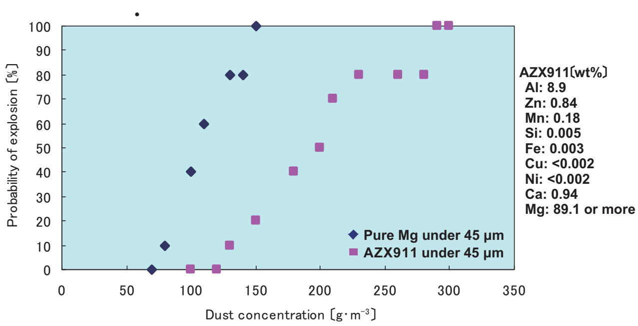


Fig. 4 Influence of Ca content on Mg dust explosion (standard sample, under 45 μm).

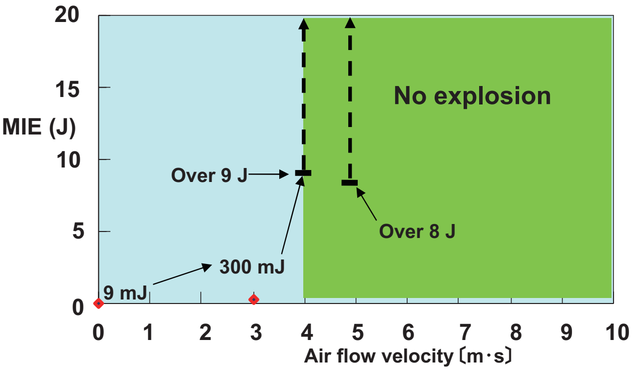


Fig. 5 Influence of flow velocity of dust cloud on the minimum ignition energy. (MIE : Minimum ignition energy [J])

cloud on the minimum ignition energy. When the dust cloud is moving, the surface temperature of particle will be reduced and heat transfer from ignition source to particle will be impeded. The same will be mentioned to the combustion transfer from particle to particle. The minimum ignition energy of pure Mg dust cloud increased with increase of dust cloud velocity (air velocity). The minimum ignition energy was 9 mJ at the air velocity 0 m/s and increased to 300 mJ at the air velocity 3 m · s^{-1}. At the velocity of 4 m · s^{-1}, the dust cloud was not ignited with the amount of energy (9J) that the ignition power supply could supply. This is positive information to prevent the dust explosion.

3.4 Explosion severity of Mg dust cloud

It is important to reduce the damage due to dust explosion in actual operation and the explosion severities of pure Mg dust are as follows.

Maximum explosion pressure : 10.3 [$\times 10^2$ kPa, Gauge]

Maximum rate of pressure rise $(dP/dt)_{max}$: 1,033 [$\times 10^2$ kPa·s^{-1}]

Explosion index (K_{st}) : 321 [$\times 10^2$ kPa ·ms^{-1}]

Explosion class : St3

As it is shown here, the magnesium dust has extremely strong explosion severity in spite of its somewhat larger minimum explosive concentration (about 90 g · m^{-3}).

3.5 Detection of igniting sparks

For recycling of used or waste materials, various types operations such as shredding, transporting and others are proceeded. These operations are possible to lead to form ignition source by collision, impact, electrostatic discharges, etc. The authors tried to evaluate the igniting source by observing a spark using the five sensors mentioned earlier. An example of the observed waveforms is shown in Fig. 6. The original waveform indicates both potential and electric current waveforms of a spark which is regarded as an ignition source. Observed waveform indicates the waveforms on sensors for potential and current.

Clear pulse discharge was generated in an original spark and the observed waveforms are corresponding nicely to the original waveforms (both potential and current waveforms) in all the observed waveforms. Among the observed waveforms, waveforms by the Loop

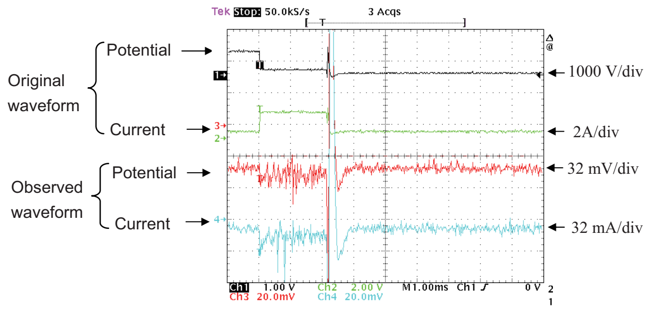


Fig. 6 Observed waveform by the Loop 1cm sensor (No.5).

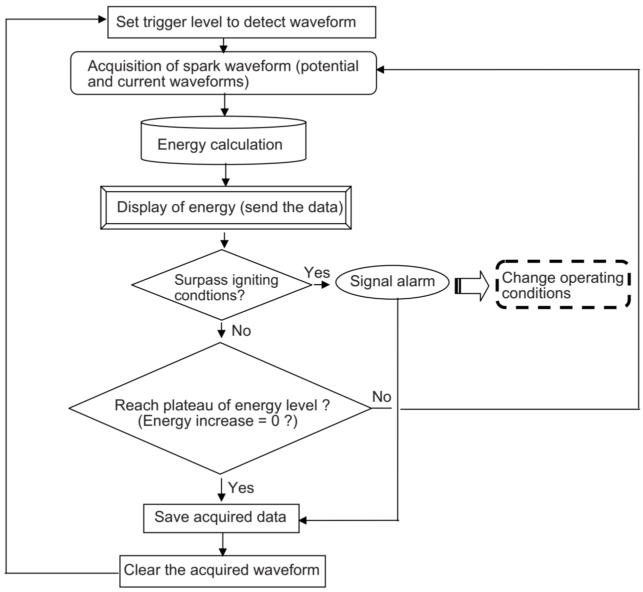


Fig. 7 Concept of detection and warning system for igniting sparks.

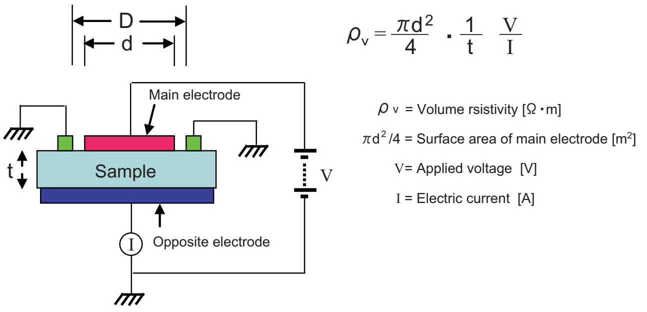
6cm sensor show better reproduction of the original sparks (Fig. 6).

Once the possible igniting source is observed, it is necessary to evaluate whether the source will lead to the ignition of dust cloud or not. The minimum ignition energy of a sample dust can be one of criteria to this evaluation. A concept for this observing the igniting spark and warning system is shown in Fig. 7. The fundamental idea is ; to acquire waveform from the original spark, to calculate the electrical energy, to evaluate if the energy surpasses igniting conditions or not, to signal alarm, to change the operating conditions of magnesium materials and to repeat this process.

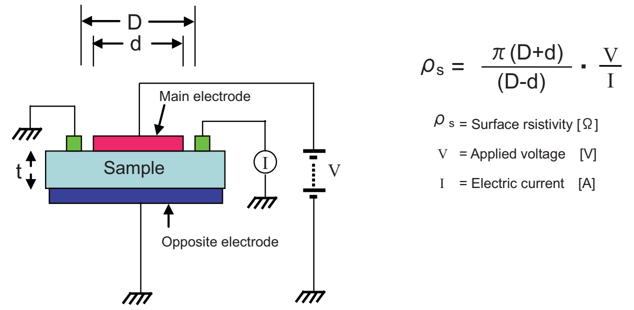
3.6 Apparent resistivities of Mg powder

In handling of materials, static electricity is often generated in any processes and this static electricity can lead to ignite dust cloud. Both the apparent volume resistivity (ρ_v) and surface resistivity (ρ_s) of pure magnesium powder were measured to evaluate the potentiality of static electrification (Fig. 8).

The result of Mg powder (under 45μm, purity 99.8 %) at 23.4°C, 42% R.H. was : $\rho_v = 6.5 \times 10^9$ [$\Omega \cdot$m] and $\rho_s = 8.3 \times 10^{11}$[$\Omega$]. Both the apparent volume and surface resistivities were mediocre side, indicating slightly poor conductivity. The measured data indicate that the surface of magnesium powder was already oxidized and that the



(a) Volume resistivity measurement



(b) Surface resistivity measurement

Fig. 8 Measurement of apparent resistivity

data do not show the resistivity of pure magnesium itself, because the resistivities are high as a magnesium metal. However, it is a good idea to discharge static electricity by grounding the operating system, thus reducing the risk of electrostatic ignition.

4. Conclusions

(1)It was shown that larger magnesium dust was difficult to lead to dust explosion. The actual shear dust was fibrous (flake), and the fibrous dust was hard to form explosive dust cloud.

(2)Inert component (Ca : about 1wt%) was ineffective to reduce the magnesium explosibility.

(3)The magnesium dust cloud was not ignited when the dust cloud moved fast (over about $4 ms^{-1}$).

(4)The K_{st} value of pure magnesium powder was 321 [$\times 10^2$ kPa·ms^{-1}]and the explosion class is St 3. The magnesium dust has extremely strong explosion severity.

(5)Monitoring both the current and voltage waveforms during sparking indicated to be practical to evaluate the ignition risk of the dust cloud.

(6)The apparent volume resistivity of pure magnesium powder was 6.5×10^9 Ω·m and the apparent surface resistivity was 8.3×10^{11} Ω, indicating slightly poor conductivity.

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マグネシウム粉じんの爆発性および破砕工程における着火性スパークの検知に関する研究

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マグネシウム材料の利用に伴うマグネシウム粉じん爆発災害の防止に関し，マグネシウム粉じんの粒度と形状，含有不燃物質（Ca），および粉じん雲の流動速度が爆発に及ぼす影響，爆発指数を調べ，静電気災害の見地から体積固有抵抗と表面固有抵抗，着火源となりうる火花の検知等を検討した。これらの実験結果より，粒度の増大に伴い，着火エネルギーが大きくなること，繊維状の粉じんは爆発性粉じん雲の形成が困難であること，不燃物質（Ca）の含有率１％では爆発抑制が困難であること，粉じん雲の流動速度が約４ ms^{-1}程度以上では着火しないこと，爆発指数は321［$\times10^2$kPa·ms^{-1}］でマグネシウム粉じんは激しい爆発性を有すること，体積固有抵抗は$6.5\times10^9\Omega\cdot m$，表面固有抵抗は$8.3\times10^{11}\Omega$で，導電性はやや弱いことなどが明らかになった。

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