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Explosibility of metallic waste dusts

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ABSTRACT

Among the industrial sectors that are affected by dust explosions, the metal working industry is one of the most frequently involved. Metal dusts are often the by-products of mechanical workings. Dust producing machines are widely distributed, small in size and are generally located in workplaces. Abatement plants are also often located in the working area. The companies that are involved in these explosions are often small, and thus often have limited resources. These factors generally lead to difficulties in managing the risk of explosions.

This paper has the aim of investigating the flammability of waste dust produced by metal workings, and to define the dust properties that are more likely to lead to an explosion. For this purpose, a simple and fast flammability test has been used as a cheap way of characterise the flammability of the samples. The test has been called the Speedy Esplosibility Test (SET), and it is similar to the procedure suggested in the new ISO/IEC standard (ISO/IEC 2016) that came into force recently. SET is composed of 4 different tests, derived from standard procedures, each of which represents a different ignition mechanism:

- High voltage continuous arc ignition and glowing wire ignition in a Hartman 1.2 l tube (based on UNI EN 13821:2004);
- Dust cloud ignition in a G-G furnace and dust layer ignition on a hot plate (based on UNI EN 50281:1999).

The SET results are compared with the standard flammability classification obtained according to ISO, 2016ISO/IEC 80079:2016, with the standard K_{St} measurement in the 20-L Siwek Sphere, and with tests in the 20-L sphere with 2×1 kJ igniters, respectively according to the UNI EN 14034: 2011 part 2 and part 3. Moreover, the morphology and chemical nature of the dusts have also been determined and their effects on dust explosibility are discussed.

1. Introduction

Metal working is one of the most widespread industrial sector in the world. Moreover, metal working technologies generally imply phases that produce dust, mainly as a by-product. Examples of these phases are mechanical cutting, laser cutting, brushing, polishing and sand-blasting.

Metal working has notoriously been affected by dust explosions over the years, and these explosions have ranged from episodes of huge magnitude to less severe but more frequent ones, as reported by Marmo et al. (2004, 2015), Cavallero et al. (2004), Lembo et al. (2001), Miao et al. (2016), and Keown (2016). Li G. et al. (2016) have recently described an episode that occurred in China, in which an aluminum dust explosion killed 146 people, injured 114 and provoked a direct financial loss of about 351 million CNY, thus demonstrating the high hazard potential of metallic dust. Matsuda and Yamaguma (2000) reported on the investigation of a Tantalum dust deflagration that occurred in 1997 in Japan, in which a bag filter device was involved, which resulted in one casualty and one serious injury. Many other episodes can be found in various review papers and books (Eckhoff, 2003; Abbasi and Abbasi, 2007; Marmo et al., 2015; Amyotte, 2013).

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Nomenclature

P_{ex}	maximum peak pressure obtained in the explosion test (bara)
K_{St}	dust deflagration index (bar * m/s)
$\Delta P_{ignitors}$	maximum rise in pressure caused by the ignitor (bara)
P_i	absolute pressure at the time of ignition (bara)
V	volume of the test vessel (m^3)
dP/dt	rate of the pressure rise (bar/s)
Pm	corrected maximum pressure peak obtained in the explosion test (bara)
Ei	igniter energy (J)
PR	pressure ratio, defined as OSHA (2008), (-)
K	normalized maximum rate of the pressure rise (bar × m/s)
MCWF	metal cation weight fraction (%)

According to CSB statistics (2010), the metal industry accounts for 20% of all the dust explosions that occurred in the US between 1980 and 2005 (281 major dust explosions), being the third cause after the wood (24%) and food (23%) industries. Another statistic, presented by Nifuku et al. (2000), regarding a period of about 50 years in Japan, refers to a total of 269 dust explosions. Metal dusts were responsible for 24% of these explosions, with 39% of deaths and 27% of injuries. Abbasi and Abbasi (2007) examined the evidence from the events that have taken place in the past and discussed the cause and dynamics of dust explosions. They cited a data set by Matsuda (1993), in which metal dust explosions accounted for 60 cases out of 248 (24.2%) explosions that occurred in Japan in the 1952–1990 period. Metal dust explosibility has recently been discussed in detail by Ibarreta and Myers (2016), who indicated the particular features of metal dust explosions as being:

- Adiabatic flame temperature in the order of 3000–4000 K (Al, Mg);
- Possibly very high K_{St}, up to the ST3 class (such as Aluminium and Magnesium metal powders);
- Many combustible metals are water-reactive;
- A number of combustible metal dusts are not compatible with traditional fire suppression agents, such as water or carbon dioxide;
- Fires involving large quantities of combustible metal dust are extremely difficult to extinguish;
- The design of explosion suppression and isolation systems is complicated because of the high combustion temperatures and K_{St} values of metal dusts;
- Some metal dusts can react exothermically with the oxides of other metals in a thermite reaction (where a quite powerful ignition source is needed);
- Combustible metal dusts are electrically-conductive, as the presence of small quantities of dust can cause shorts in the electrical equipment.

Pure metal dusts usually result in powerful explosions, with peak pressures above 1 MPa in confined conditions. Metal dusts are among those that can result in deflagration to detonation transition, as discussed by Miao et al. (2016), who studied the ignition properties of 8 alloy dusts from machining operation sites (shot blasting, sand blasting and polishing), together with 2 pure atomized metal powders (Al and Mg). Moussa (Moussa et al. (2015)) discussed how thermal radiation could be a key enhancement factor of the flame speed in metal dust explosions, which can lead to very powerful deflagrations. Kuai et al. (2011) reported data on the explosion severity of Magnesium dust mixed with calcium carbonate as an inert material.

Li Q. et al. have recently (Li Q. et al., 2016) investigated micro-size Al dust in a 20 L sphere, and concluded that the optimum explosion concentrations for all of the selected aluminium dusts are almost equal to 500 g/m^3. The dust explosion severity $(dP/dt)_{max}$ increases exponentially as the particle size decreases. Moreover, they found an exponential increase in the flame propagation speed for finer dusts (surface mean diameter < than 10 μm) as the dust concentration increased.

Vignes et al. (2012) had gone further with the explosibility investigation of nanopowders of Aluminium and they found relevant decrease of dust MIE (below 1 mJ) and a Minimum Explosive Concentration of 30 g/m^3.

As far as explosion protection is concerned, among other studies, the one by Taveau et al. (2015) describes efforts that can be made to mitigate violent metal dust explosions, such as those involving aluminium dust. The authors underlined the efficacy of the suppression systems they tested to mitigate aluminium explosions when the nominal cloud concentrations were up to 500 g/m^3 and the K_{St} value was below 200 bar m/s. Again, the 500 g/m^3 concentration value was identified as the limit concentration in operational conditions for most industrial dust collector systems.

Metal dust is often encountered in the manufacturing industry. Most metal working activities produce very limited amounts of dust, due to the small size of many companies. Dust is often produced at many different working points, and it has characteristics that are difficult to predict, which depend on the source material (which is generally an alloy, thus increasing the problem), the performed operation, and the working parameters. Therefore, the resulting dust is often a mixture of various materials, some of which could be non-flammable. For example, a dust obtained from brushing can contain a certain amount of the used abrasive, and its particle size distribution will probably depend on the age of the brushing tool, and on the pressure and speed adopted to polish the piece. Laser cutting can produce partially oxidated dust, depending on the atmosphere in which the cutting phase is carried out.

Predicting the behaviour of such samples is a hard task, as it could have nothing to do with the pure metal or alloy of which the piece is composed (Myers, 2008; Marmo et al., 2011). Moreover, assessing whether the dust is flammable or not is in general challenging.

The aim of this paper is to use the Speedy explosibility test (Danzi et al., 2016) to provide a quick and cheap method that could be used to determine whether a metal sample is flammable. The test is composed of four different sub-tests: two tests in a modified Hartmann tube, a test in a Goodbert – Greenwald furnace and a test on a hot plate. All these tests were conducted at conditions that would maximize the ignition probability: a continuous arc and a glowing wire were used in the Hartmann tube, while temperatures as high as 800 °C and 400 °C were used in the GG furnace and in the hot plate test, respectively.

Various dusts from different piece finishing processes were submitted to SET, as well as to traditional tests in the 20-L sphere, to compare the results. In the latter case, the K_{St} indexes of the violence of explosion were measured according to UNI EN 14034-2 (2011a,2011b) using two 5 kJ igniters (Simex). Furthermore, all the dust samples were also tested using two 1 kJ igniters (Simex manufacturer) to compare the SET results with those obtained from standard methods (UNI EN 14034-3, 2011), and to check for explosion overdriving.

The chemical composition of the samples was determined by means of both Field Emission Scanning Electron Microscope plus Energy Dispersive X-Ray Spectrometer (FE-SEM + EDS) and Inductively Coupled Plasma Mass spectrometry (ICP).

2. Experiments

Fourteen metal alloy dust samples, collected from different process industries, were used in this study. Both SET and 20-L sphere tests were conducted. The morphology of the dust was determined using FE-SEM (ZEISS Supra 40 Field Emission Scanning Electron Microscopy). The chemical composition was determined both by means of EDS Oxford EDS microanalysis (Liquid-N_2 cooled Si(Li) detector) and traditional chemical methods. The latter method consisted in achieving the complete dissolution of the sample by attacking it with an acid solution, and then conducting ICP separation and recognition