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ScienceDirect
Journal of Loss Prevention in the Process Industries 20 (2007) 330–336
Journal of Loss Prevention in the process industries
www.elsevier.com/locate/jlp

Influence of the oxide content on the ignition energies of aluminium powders

G. Baudry, S. Bernard, P. Gillard*

LEES, Université d'Orléans, 63, avenue de Lattre de Tassigny, 18020 Bourges Cedex, France

Received 28 November 2006; received in revised form 17 April 2007; accepted 26 April 2007

Abstract

Some results of determination of ignition energies for an aluminium powder with various oxide contents are presented. Common use of processes like high-speed cutting produce explosive dust clouds, so that we focused this study on hazard of metallic powders. An industrial aluminium powder has been used for this work. An original process, based on the principle of electrochemical anodisation, has been developed to increase, under control, the oxide coating of particles.

The sensitivity study to spark ignition was performed in an Hartmann explosion tube of 1.3L. The Langlie test method was applied to evaluate the energies leading to a probability of ignition of 50% (E_{50}) of the selected samples. The results confirm that the ignition energies increase with the oxide content of the powder.

Keywords: Dust explosions; Aluminium powder; Oxide layer; Ignition energy

1. Introduction

Dust explosion hazard is a very important subject for safety management. Whereas this risk is well known in agronomic industries, this problem concerns a lot of fields like pharmaceutical and metal workings for example. It appears that the concerned industries are more or less aware of the risks involved and have difficulties in applying instructions of new regulations like European ATEX directives.

Because of their high energetic properties, metal dust explosions are often very damaging. Statistics presented by Nifuku, Matsuda, and Enomoto (2000) for a period of about 50 years in Japan register 269 dust explosions. Metal dusts concern 24% of them, 39% of deaths and 27% of injuries. It is difficult to find exact statistics on this subject but figures tend to show that the number of accidents decreases for organic powders whereas those of accidents involving metal powders increases. We are interested in this study with the case of aluminium dust explosions. The evolution of the industrial processes leads to the production of very small particles in metal workings (because of the use of high-speed cutting tools for example). The case of a company is described by Marmo, Cavallero, and Debernardi (2004). In this example, the annual production of aluminium dust is estimated to be about 20 t with a particle size from about 1 to 100 μm. Slight additions of abrasive substances and/or lubricants are present and the oxide content of the particles might achieve high values as the pieces are heated locally.

The presence of an oxide coating on aluminium particles will modify the sensitivity of the dust cloud. A lot of studies performed on the combustion of a single aluminium particle show that the ignition occurs after the crack of the oxide layer due to internal thermo-mechanical stresses (Rosenband, 2004). An extended reference list is given by Sarou-Kanian (2003). Therefore, we could expect an increase of the ignition energies of an aluminium powder with the oxide content. In this study, the evolution of the ignition energy thresholds of a commercial aluminium powder with the oxide content is presented.

*Corresponding author. Tel.: +33 2 48 23 84 72; fax: +33 2 48 23 84 71.
E-mail address: Philippe.Gillard@bourges.univ-orleans.fr (P. Gillard).

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doi:10.1016/j.jlp.2007.04.025

2. Materials and physicochemical characterisation

2.1. Raw material and oxidation process

The raw material used in the present work is a commercial micron sized aluminium powder (purity > 99.7%) supplied by the company "Métaux & Chimie" and referenced F3915. The size distribution of this powder was determined with a laser diffraction technique (Spraytec, Malvern), the result is presented in Fig. 1(a). This measure provides a statistical analysis via Dv (10), Dv (50) and Dv (90) values (with Dv (xx), the particle size below which xx% in volume of the particles has a smaller size).

The values of Dv (xx) reported in Fig. 1(a) are estimated with the laser system. It seems that these parameters are slightly over-estimated. This problem is inherent to the method of laser diffraction as the main hypothesis in this measure is that particles are assumed to be spherical but in the case of F3915, they are slightly elongated (as can be seen on the SEM picture in Fig. 1(b)).

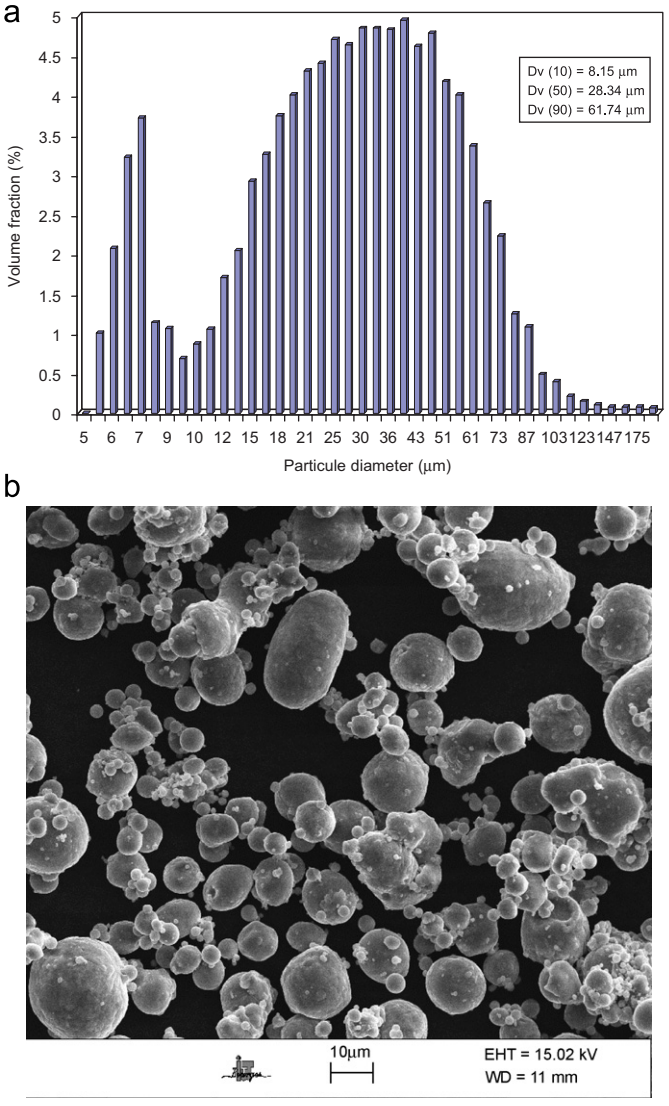

Fig. 1. (a) F3915 particles diameter distribution determined with a laser diffraction technique. (b) SEM picture of the F3915 powder.

In order to make the natural aluminium oxide layer thicker, the classical anodisation principle was used. The powder was placed in a tool specially designed to have a large area exposed to the ionic current. A DC is passed through a sulphuric acid solution with the tool serving as the anode. The voltage was set to 10 V and a variation of the process duration enables controlling the oxide content in powders.

2.2. Physicochemical characterisation

2.2.1. Thermogravimetry analysis

A SETARAM SETSYS 16/18 TG was used to determine the oxide content of the tested powders. The samples were heated under air atmosphere from 22 to 1590 °C and then held isothermally for 3 h (until no mass gain is observed). The mass gain observed in Fig. 2 is due to the oxidation of Al:

$$4Al(s) + 3O_2(g) = 2Al_2O_3(s). \quad (1)$$

The expected mass gain for reaction (1) is 89%. The effective mass gain leads to the evaluation of the aluminium part in the sample and the remaining part is alumina.

The loss in mass between 0 and 400 °C corresponds to residual water in the sample. Eq. (2) leads to the evaluation of the oxide content in the sample (m_0 corresponds to the initial mass of the sample minus the moisture content).

$$Al_2O_3(wt\%) = \left(1 - \frac{dm}{0.89 \times m_0}\right) \times 100. \quad (2)$$

2.2.2. SEM/EDS

Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) (LEO, model 1455 VP) were used for the observation of powders and for an

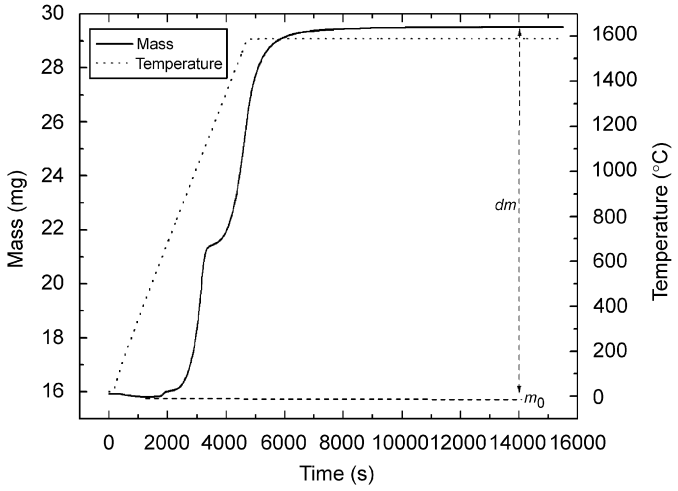

Fig. 2. Mass gain of an aluminium sample evaluate with TG analysis.