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Ignition and explosibility of aluminium alloys used in Additive Layer Manufacturing

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ABSTRACT

The ALM process (Additive Layer Manufacturing) uses metallic alloy powders with an average diameter in the range of 10–30 μm. This study concerns the characterization of an Al Si 10 Mg aluminium alloy spherical powder with a d_{50} of 17 μm and an oxide amount of 7–8 wt%. The MIE, P_{max} and K_{st} are respectively 11–14 mJ, 8.5 bara and 165 bar m/s. The particle temperature measurement shows two levels of temperature: 3050 K during the first steps of the combustion and the second of 2550 K which occurs a short time after the K_{st} time. Finally, ignition delays are almost constant on a large range of dust concentrations and are at the same level as hydrocarbons.

1. Introduction

The development of ALM processes (Additive Layer Manufacturing) in aeronautic industries increases the use of metallic powders for manufacturing high added value products. Some of the most used alloys are the Al-Si alloys. Industries are de facto confronted with the risk of dust explosion for sizes ranging from 10 to 30 μm. One recent paper, Li et al. (2016), reports a catastrophic accident due to the ignition of an Al-Si alloy dust cloud. The literature is very rich concerning aluminium dust explosions and gives a lot of data concerning MIE, P_{max} and K_{st} for various dust concentrations and various average diameters, c.f. Dufaud et al. (2010) or Baudry et al. (2007) and Bernard et al. (2012). These last two present results concerning the MIE and flame velocity of partially oxidized aluminium powder. Particle temperatures of aluminium powder were measured by Cashdollar and Zlochower (2007), Bernard and Gillard (2014) and Lomba et al. (2015). However, few studies concern aluminium alloys. Dreizin et al. (2002) studied an Al-Mg alloy and observed the combustion of powder in a micro gravity chamber with a d_{50} of between 7.9 and 9 μm and for an Mg content of 10, 20 and 30%. The author deduced the flame velocity at an equivalent ratio of 0.66.

A previous paper from Eckhoff et al. (1986) reports some values of MIE, P_{max} and dp/dt for various diameters of silicon powder, one of these batches with a mean diameter (d_{50}) of 13.8 μm gives a MIE of 50–70 mJ, P_{max} of 7.8 bar and $(dP/dt)_{Max}$ not over 170 bar s^{-1}. The values show that sensibility and explosibility of silicon dust are lower the for aluminium dust at the same particle diameter.

Shoshin et al. (2006) demonstrates that Al-Ti mechanical alloy powder ignition under thermal heating is due to the exothermic formation of a metastable LI_2 phase of Al_3Ti and shows that the ignition temperature can be predicted for these alloys for a wide range of experimental heating rates.

Zhang et al. (2012) studies Al-I alloys and shows that this alloy family is less reactive than the Al-Ti family.

The three reported studies show clearly that Al alloys ignite and burn in the air, but do not give data concerning the sensitivity and severity parameters measured.

This paper concerns the determination of the sensitivity and severity parameters of an Al-Si alloy powder used for ALM.

2. Experiments

The tested dust is AlSi10Mg aluminium alloy powder. The composition of this alloy is the following: 10 wt% of Si, Mg lower

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than 0.5 wt% and Alwt% the remainder. The parameters of this study are the dust concentration and the particle size and we have investigated their influence on the following measured recorded values: MIE, P_{max}, K_{st}, particle temperature and ignition delay.

The effect of ageing is investigated through two batches of the same alloy being studied. The first one was a 2 year old powder and the second was a fresh powder (just processed). Only a small quantity of sample was available and only the MIE was measured on this sample.

These two sets of powder were characterized by laser granulometry (particle size distribution), MEB coupled with EDS (morphology and composition). A TGA analysis completes the characterization of the sample for oxide amount estimation using the Baudry et al. (2007) method.

2.1. AlSi10Mg powder characterization

The tested powder came from the atomization of an AC - **43000**/43100/43200 - EN 1706 aluminium silicon alloy (corresponding to A13600 - ANSI A360.0 A03600 - ANSI 360.0 and ASTM B 85) and was used for the ALM process. Samples 1 and 2 were observed with SEM and it can be seen in Fig. 1 and Fig. 2 that spherical particles with the smaller size are agglomerated to the bigger one. The composition of each sample was measured and is reported in Table 1. The weight ratio of silicon is 2–3 wt% higher than in the composition given by standard EN 17061; this difference is probably due to the atomization process, which produces an evaporation of aluminium that is greater than silicon and magnesium.

Particle sizes were measured by spraytech laser granulometry provided by the Malvern Company. Sample 2 was divided into five samples by sieving in order to study the influence of particle size on ignition sensitivities and severity parameters. The results of these measurements are reported in Table 2.

Some differences in mean diameter can be noted between the two powders and are due to irregularities in atomization process Sieving provides fives batches (Table 2) were mean diameter Dv50 are between 11 and 28 μm which is not exactly the expected Dv50 due to the sieve choice.

TGA analysis allows us to measure the oxide contained in the powder. This measurement is achieved by oxidizing the powder under air atmosphere at a constant temperature of 1600 °C for 4 h. The TGA measures the mass increase due to the oxide formation. After 4 h the oxidation is totally completed and it is then possible to calculate the initial mass of alloy in the sample and finally the oxide amount initially present in the alloy. For that calculation, we consider, in a first approximation, that Al produces Al_2O_3, silicon gives SiO_2 and the magnesium contribution, such as the other impurities, do not contribute to the oxide formation (due to their low concentration compared to Si and Al). The following equation is used:

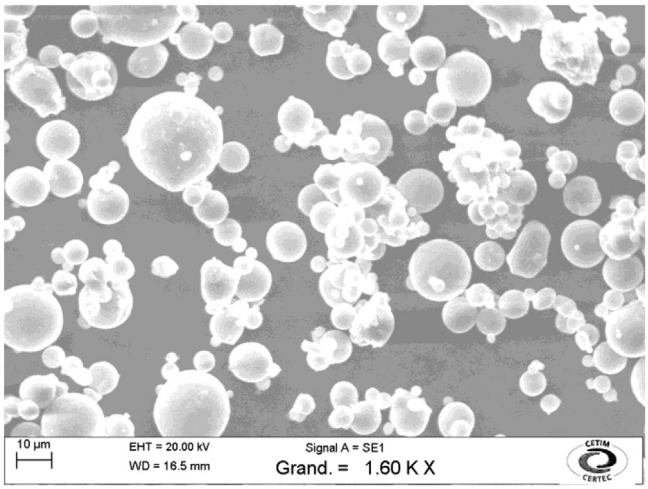

Fig. 1. Sample 1 SEM photography.

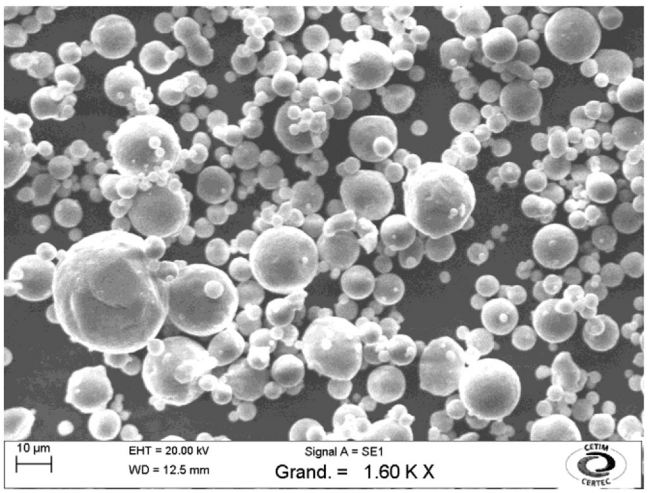

Fig. 2. Sample 2 SEM photography.

Table 1
AlSi10Mg powder composition.

elements	Sample 1	Sample 2	EN 43000 composition
Al	86.67 wt%	84.74 wt%	86.48 wt%
Si	12.69 wt%	14.81 wt%	11.00 wt%
Mg	0.72 wt%	0.45 wt%	0.45 wt%
others	Not measured	Not measured	2.07 wt%

Table 2
AlSi10Mg powder particle size.

Sample or sieved range	d_{50}, μm	d_{10}, μm	d_{90}, μm
Sample 1	19.7	7.5	26.9
Sample 2	16.9	7.0	25.5
<15 μm	11.3	7.2	18.5
15 μm-25 μm	12.7	7.4	20.9
25 μm −30 μm	15.2	7.6	26.6
30 μm −50 μm	28.1	7.8	40.9
>50 μm	19.5	7.4	59.0

$$2(1-y)Al + 2ySi + \frac{3-y}{2}O_2 \rightarrow (1-y)Al_2O_3 + 2ySiO_2$$

Where y is the molar fraction of Si in the alloy.

The composition of the alloy is given in weight ratio, in the following way: $y = \frac{\frac{w}{M_{Si}}}{\frac{w}{M_{Si}} + \frac{1-w}{M_{Al}}}$, where w is the weight ratio of silicon. Finally the weight ratio of oxide is given by:

$$X_{oxide} = 1 - \frac{2(1-y)}{(3+y)(1-w_{Si})}\frac{M_{Al}}{M_{O_2}}\frac{\Delta m}{m_0}, \text{where :}$$

M_{Al}, M_{Si} and M_{O2} are the atomic weight of Aluminium, silicon and oxygen, Δm the mass increase due to oxidation and m_0 the initial mass of the sample in the TGA crucible. The results of the TG analysis are given in Table 3:

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