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A comparative study between two ignition sources: electric igniter versus pyrotechnic igniter

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Abstract

The risk assessment of combustible explosive dust is based on the determination of the probability of dust dispersion, the identification of potential ignition sources and the evaluation of explosion severity. It is achieved in most of cases with the two main experimental normalized devices such as the Hartmann tube (spark ignition) and the 20L spherical bomb (with the 5 kJ pyrotechnic ignitors).

Ignition energy of the 5kJ ignitor is well calibrated and generates a reproducible ignition. But on the other hand this ignition is not punctual and the over pressure produced is nearly 2 bars. Moreover, the pyrotechnic igniter accelerates the combustion with multi ignition points in a large volume and that disturbs the kinetics. In this way, this ignition source does not allow to analyse the combustion products because the composition of the pyrotechnic igniter was found in the combustion products.

This article deals with the comparison of two ignition sources in the 20 L spherical bomb. A large panel of classical explosive dusts is studied with electrical and pyrotechnic ignitors, in order to evaluate the possibility to establish a correspondence between parameters obtained with these two ignition technics.

Severity parameters of Aluminium powder, titanium alloy and nicotinic acid CaRo 11 were measured by using the two types of ignition system in our 20 L spherical bomb equipped with the Kühner dihedral injector. The maximum explosion overpressure P_{max} and dust deflagration index K_{st} were measured in a large range of concentration allowing to propose correlations between electrical and pyrotechnic ignition for each parameter and each type of powder. The relevance of these correlations will be discussed.

Keywords: Dust explosions, Pyrotechnic ignitor, Electric spark ignitor, Aluminium, Titanium, Nicotinic acid.

1. Introduction

Safety features are essential for determining the risks of explosion when handling combustible dust and for designing safety measures. This dust safety-related properties are often inspected without considering the influence of the ignition source as mentioned by (Askar & Schröder, 2019).

The explosion characteristics severity maximum explosion pressure P_{max} and maximum rate of explosion pressure rise $(dp/dt)_{max}$ are determined in closed vessels such as the 20-L-sphere.

Tests are performed according to the international standards, for example the EN 14034 series (2004-2006).

For explosion tests on dusts, chemical igniters are primarily used (DIN EN 14034; ASTM1226). There are standardized chemical igniters with defined energies ranging from 1000J to 10000J. The igniters generate a large spherical flame with a volume over the 20 L bomb, as described by (Proust, et al., 2007), and the ignition is not punctual but multipoint. This last point contradicts one of the original objectives of the sphere which was to have a central point ignition. Moreover, the pyrotechnic igniter accelerates the combustion and disturbs the kinetics. In this way, this ignition source does not allow to analyze the combustion products because the composition of the pyrotechnic igniter was found in the combustion products.

The need for alternative ignition sources arises due to several drawbacks of pyrotechnic igniters, in addition to their high cost and high energy input compared to most ignition sources used in practice. This type of ignition source should be less expensive, generally available, and allow the operator to use it without a certificate of competency. Another ignition source that fulfils these requirements is the "spark ignition".

A previous paper from (Scheid, et al., 2013) reports the test results of a comparative study between two ignition sources: pyrotechnical igniter and exploding wire. P_{\max} and $(dp/dt)_{\max}$ values from 5 different dusts were determined with both ignition sources in the range of 100 J to 1 kJ. The P_{\max} values determined with exploding wire were less than 10% lower than values determined according to the test standard. The influence of the ignition energy of the igniter on the maximum explosion pressure seems to be almost negligible. In contrast to that $(dp/dt)_{\max}$ values determined according to the test standard led to 30% higher values.

(Spitzer, et al., 2021) present results of a comparative calorimetric and visual study between four different types of ignition sources (Exploding wire, Chemical igniter, Induction spark and Surface-gap spark). The influence of the electrode-orientation, distance as well as ignition energy on the reproducibility of the exploding wire igniter was tested.

For the study maximum explosion pressure and maximum explosion pressure rise values from CaRo11, aluminium and titanium dusts were determined with both ignition sources. Dust explosions are generally characterized by complex reaction mechanisms, which depend on the chemical composition of the dust, dust concentrations and flow conditions. (Van der Wel, 1993) distinguishes between different reactions mechanisms depending on whether the reaction takes place in the gas phase by evaporation or at solid surface in form of gaseous products or solid or liquid material.

This paper concerns the comparison of two ignition sources in the 20 L spherical: electric igniter versus pyrotechnic igniter. A large panel of classical explosive dusts is studied with these igniters, in order to evaluate the possibility to establish a correspondence between parameters obtained with these two ignition technics. The dusts were selected such that different combustion mechanisms were considered: Aluminium powder, titanium alloy and nicotinic acid CaRo 11.

2. Materials and Equipment

2.1 Materials

Aluminium powder used in the present work is a commercial micron sized aluminium powder (purity>99.7%) supplied by the company M&C “Métaux & Chimie” and referenced F3915. For titanium, Ti6Al4V powders were manufactured by TLS Technik spezialpulver. The size distribution of these powders was determined with a laser diffraction technique (Malvern). The result is presented in **Table 1**. This measure provides a statistical analysis via $D_v(10)$, $D_v(50)$ and $D_v(90)$.

Table 1: Particles size

	AlF3915	Ti6Al4V
D_{10} , μm	8	11.88
D_{50} , μm	35	26.42
D_{90} , μm	80	44.3

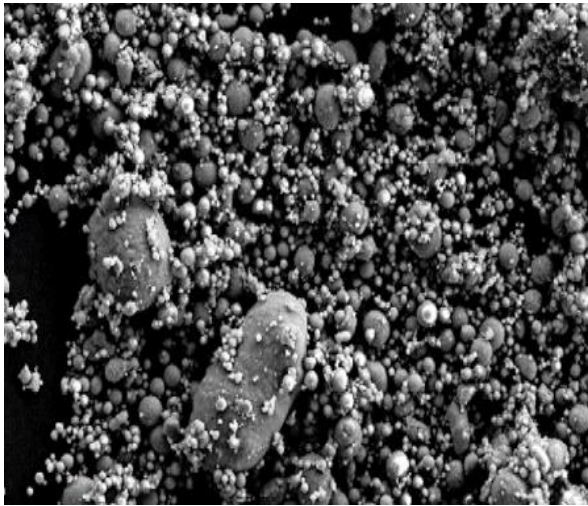


Fig. 1. SEM photograph of pure aluminium

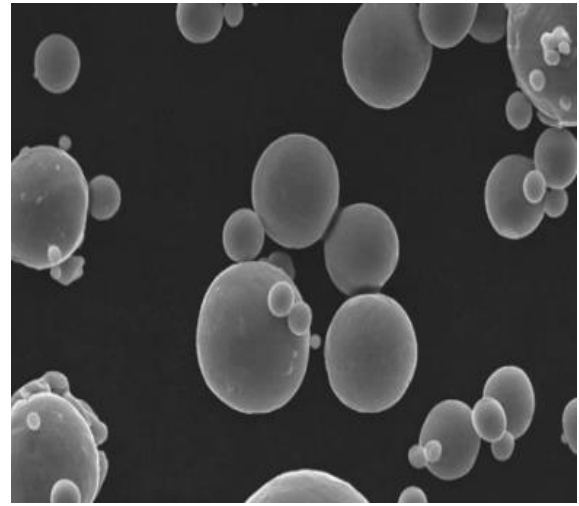


Fig. 2. SEM photograph of Ti6Al4V 26 μm

The SEM photography **Fig. 1** and **Fig. 2** showed that AlF3915 and Ti6Al4V particles are spherical. (Millogo, et al., 2018) and (Millogo, et al., 2020)

2.2 20L sphere

The explosions were carried out in a spherical 20 L explosion vessel designed at the PRISME Laboratory (**Fig. 3**) in accordance with the international standard EN 14034-3 (British Standards Institution, 2006) in order to characterize the ability of powders to explode. The parameters measured are the maximum explosion overpressure P_{max} and the maximum rate of pressure rise in the sphere, $(\frac{dP}{dt})_{max}$ over the explosive range for a given dust.

This experimental setup consists of a hollow sphere made of alloyed steel, a dust storage container connected with the chamber through a dust outlet electro valve (Kühner AG). The dust was injected at the bottom of the tank with the standard compliant dihedral injector. A rebound nozzle (Kühner AG) (**Fig. 4**) disperses the particles with the air in the chamber generating a turbulent flow in order to reach homogeneous dust dispersion. At the end of the injection period, the atmospheric pressure is reached. The explosion signal is measured by a

Kistler 701A sensor and the acquisition is performed by a Keysight digital oscilloscope and recorded on a computer.

The tests with the pyrotechnical igniters (5kJ) as an ignition source were performed using the standard control unit of the 20L sphere. For tests with electric spark, a spark generator device is made by the laboratory itself according to the standard requirements, was used. Its design was detailed in (Bernard, et al., 2010)

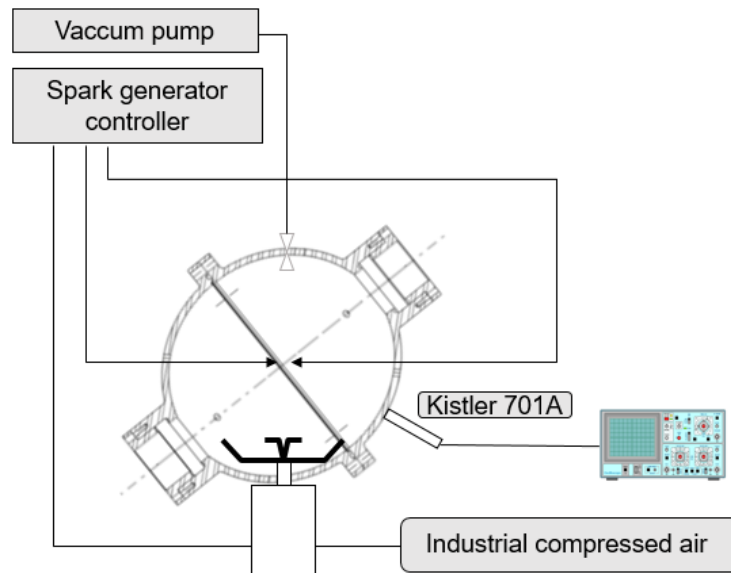


Fig. 3. Design of spherical chamber of 20 liters volume



Fig. 4. The rebound nozzle

2.3 Ignition source

2.3.1 Ignition processes

Ignition of combustible dust clouds occurs only in the presence of a flame source or a sufficient heat source. In general, ignition is triggered in a variety of ways from low-energy to high-energy ignition sources (Amyotte & Eckhoff, 2010). However, the ignition source differs in terms of power and energy. The ignition source can significantly influence the dynamics and course of the scattered dust explosion (Yuan, et al., 2015). In the industry, there can be several types of significant ignition sources that can cause dust to explode. These are typically a spark, a hot surface, overheating, direct fire, etc. These ignition sources are characterized by the

fundamental parameter of "ignition energy"(the energy of the ignition source that ignites a cloud of dust) and the dynamics of the ignition process (spark is punctual source, fire/combustion is a "slow" source, in terms of dust burning rate), (Amyotte, 2014, Eckhoff, 2002, Kuracina, et al., 2021).

One of the fundamental differences of these ignitors is the ignition mechanism. While for the ignition spark an electric arc is generated the pyrotechnical igniter emits flames and burning solids.

2.3.2 Electrical ignition system

The electric arc ignition system consists of a high voltage generator, whose discharge initiates an arc between the electrodes. A generator provides the ignition energy by capacitor discharge, and whose delivered voltage and current, as well as the arc holding time, are adjustable. The system produces spark at nearly constant power and controls the spark energy by controlling the duration of the spark. The spark current is adjustable between 2 and 8 A and was set to 4 A in this study. The arc voltage is 82.5 V. As the voltage and current intensity are constant, energy is inly proportional to the spark duration: $E = U_{arc} \cdot I_{arc} \times \tau_{arc}$, this time could be changed over the range of 1 μ s-100ms. The arc energy value achieved with such an arrangement is in the range from 10 mJ to 500 J, making possible to measure the ignition energy of the less ignitable dusts as detailed by (Bernard, et al., 2010).The energy deposited in the discharge reaches 66 J. In this paper we only recall the electric scheme (**Fig. 5**). The spark generator has, in addition, a "trigger" output (synchronized on the beginning of the cycle at cycle at time t_0) which allows to trigger an external device. Pointed electrodes made of tungsten were used with a 2.4 mm diameter. The electrodes' extremities are shaped at an angle of 40°. This configuration allows minimal erosion of the electrodes and provides a conical shape to generate the spark.

The experimental ignition conditions for the electrical ignition system are summarized in **Table 2** (Bernard, et al., 2017)

Table 2 : Ignition condition in the 20 L spherical bomb

Parameter	Value
Spark current intensity,A	4
Spark power,W	330
Spark energy,J	66
Electrodes gap,mm	4
Electrode shape	Conical (40°)

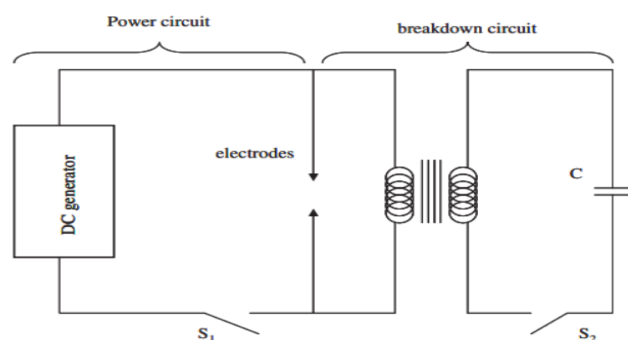


Fig. 5. Electric scheme of the spark generator (Bernard, et al., 2012)

2.3.3 Pyrotechnic Igniter

The ASTM E1226-12a standard specifies the exact composition and quantity of the mixture in a chemical igniter. The chemical igniters consist of small plastic or aluminium buckets filled with a firing charge of 40% zirconium, 30% barium nitrate and 30% barium peroxide. A sealing cap keeps the firing charge inside. An electrical fuse head is connected to two wires for a precise electrically controlled ignition from the outside of the apparatus (see DIN EN 14034). The ignition source was placed in the middle of the sphere and connected to the electrodes of the lid of the chamber, such as it is described in the test standards.

3. Results and discussion

3.1 Severity parameter results: K_{st} and P_{max}

3.1.1 CaRo11

The calibration of our 20 L sphere was performed by using Caro 11 powder and compared to “round robin results”. The K_{st} max value obtained with the pyrotechnical igniter is well in the range of results given by “round robin tests”. While for the electric spark igniter, the ratio between round robin measurements and our tests is 1.47 (Bernard, et al., 2017). For each experimental test, at least two runs were performed. **Fig. 6** present the evolution of the pressure and the k_{st} as a function of the dust concentration with both ignition sources. The highest value of P_{max} (6.64 bara) is obtained at a concentration of 500g/m^3 for the electric spark igniter and for the pyrotechnical igniter, the highest value of P_{max} (7.99 bara) is obtained at a concentration of 500g/m^3 . While the $K_{st_{max}}$ for the pyrotechnical igniter was 242bar.m/s at a concentration of 750g/m^3 , it was 134bar.m/s for the electric spark igniter at a concentration of 750g/m^3 .

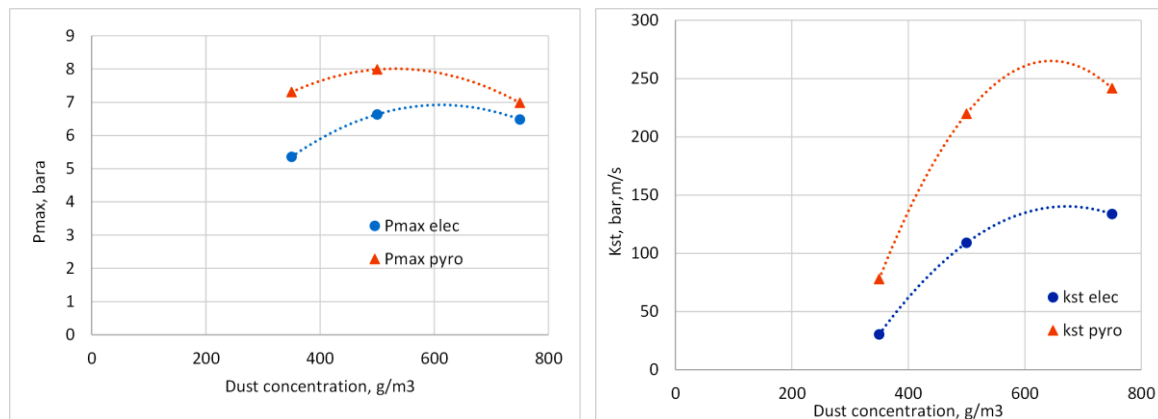


Fig. 6. Severity parameters of CaRo 11 as function of concentration determined with electric spark igniter and pyrotechnical igniter

The curves were fitted according to a polynomial of order 2 and the K_{st} is written as follows as a function of the concentration C : $K_{st} = a_0 + a_1 \cdot C + a_2 \cdot C^2$

Where the fitting coefficients for the electrical spark igniter are respectively $a_0 = -339.03$, $a_1 = 1.4275$, $a_2 = -1.063 \cdot 10^{-3}$ and for the pyrotechnical igniter are $a_0 = -628.62$, $a_1 = 2.76989$ and $a_2 = -2.144 \cdot 10^{-5}$.

3.1.2 Aluminium tested dusts

For each experimental test, at least two runs were performed. The severity of the explosion was measured in terms of the maximum pressure reached, reflecting the overall energy release, and the deflagration index K_{st} , reflecting the rate of pressure rise and thus the reaction rate. The dust concentration is an important factor that affects the severity of the explosion. (Jing, et al., 2021) present the determined explosion pressure P_{max} and K_{st} evolution as a function of the dust concentration with both ignition sources. Both curves show a comparable course. The highest value of P_{max} (8.2 bara) is obtained at a concentration of 1000g/m^3 for the electric spark igniter while for the pyrotechnical igniter, the highest value of P_{max} (9.5 bara) is obtained at a concentration of 750g/m^3 . While K_{st} for the pyrotechnical igniter was 425 bar.m/s at a concentration of 750g/m^3 , it was 317 bar.m/s for the electric spark igniter at a concentration of 1250g/m^3 . (Millogo, et al., 2020) obtained around 7.7 bars for the overpressure and 317.58 bar.m/s for the k_{st} using the electric spark igniter. (Lomba, et al., 2015) also obtained around 8 bars for the overpressure.

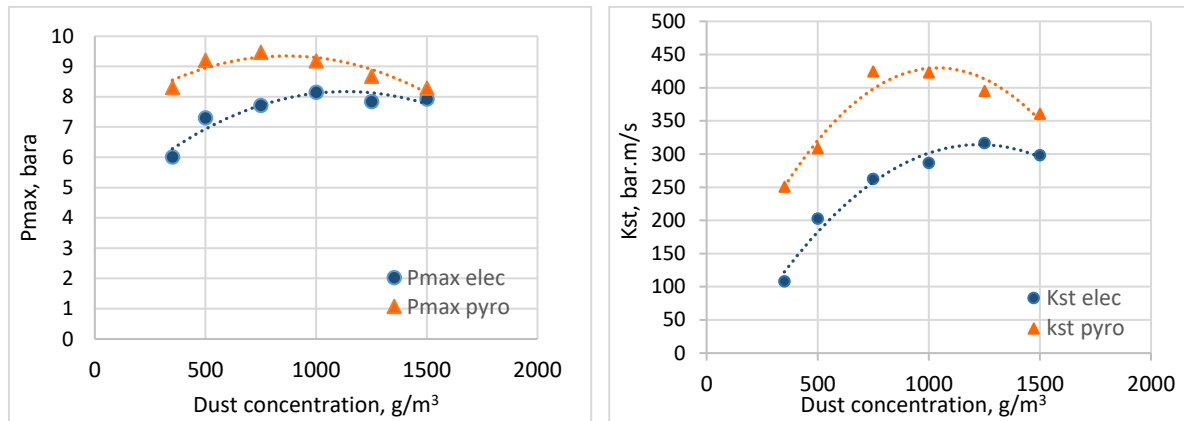


Fig. 7. Severity parameters of AlF3915 as function of concentration determined with electric spark igniter and pyrotechnical igniter

The curves were fitted according to a polynomial of order 2 and the K_{st} is written as follows as a function of the concentration C : $K_{st} = a_0 + a_1 \cdot C + a_2 \cdot C^2$

Where the fitting coefficients for the electrical spark igniter are respectively $a_0 = -61.6641$, $a_1 = 0.6129$, $a_2 = -2.4988 \cdot 10^{-4}$ with $R^2 = 0.9717$ and for the pyrotechnical igniter are $a_0 = -628.62$, $a_1 = 2.76989$ and $a_2 = -2.144 \cdot 10^{-5}$ with $R^2 = 0.9456$

As well the determined values for P_{max} as for $K_{st_{max}}$ were markedly higher for tests with the pyrotechnical igniter.

3.1.3 Ti6Al4V

The parameters of the explosive combustion of Ti6Al4V were studied according to the concentrations between 350 g/m^3 to 1500 g/m^3 . The highest value of P_{max} 7.1bara is obtained at a concentration of 1000g/m^3 for the electric spark igniter while for the pyrotechnical igniter, the highest value of P_{max} 6.7bara is obtained at a concentration of 1500g/m^3 . While K_{st} for the pyrotechnical igniter was 100.8 bar.m/s at a concentration of 1000g/m^3 , it was 89.7 bar.m/s for the electric spark igniter at a concentration of 1000g/m^3 . (Millogo, et al., 2018) notice for high concentration an electric ignition the presence of TiN particles in combustion products, it means that after consume all oxygen the combustion continue with the exothermic nitration reactions.

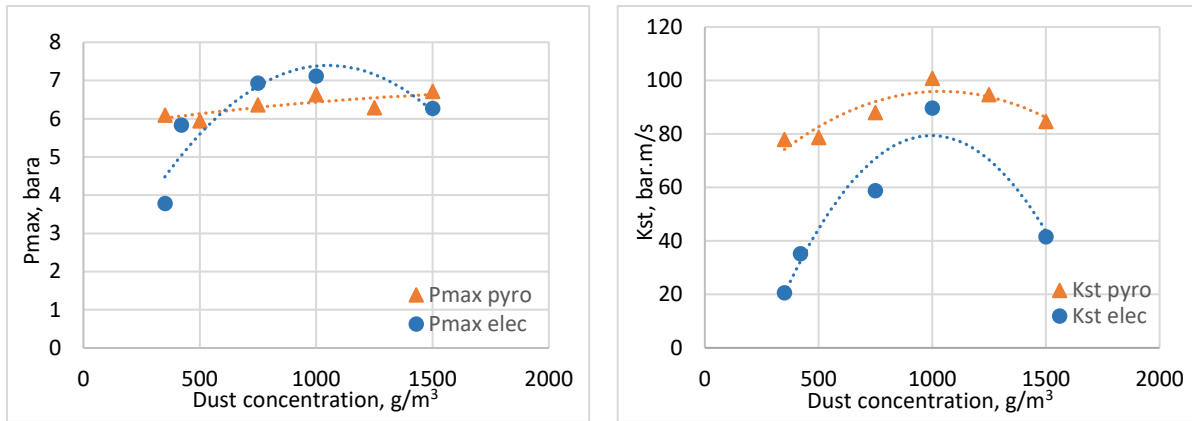


Fig. 8. Severity parameters of Ti6Al4V as function of concentration determined with electric spark igniter and pyrotechnical igniter

An attempt to fit curves by the same polynomial of order 2 as a function of the concentration C has been made: $K_{st} = a_0 + a_1 \cdot C + a_2 \cdot C^2$

The fitting coefficients obtained for the electrical spark igniter are respectively $a_0 = -61.3128$, $a_1 = 0.2823$, $a_2 = -1.4167 \cdot 10^{-4}$ with $R^2 = 0.9067$ and for the pyrotechnical igniter are $a_0 = 46.6133$, $a_1 = 0.09486$ and $a_2 = -4.5648 \cdot 10^{-5}$ with $R^2 = 0.8178$.

The P_{max} is higher with the electric igniter than the pyrotechnical igniter. The cause for this may be, that the TiN particles were not presented in the combustion product with chemical igniters compared to electrical igniters. Probably the combustion stop just after consume all the oxygen, this causes a decrease in pressure therefore the P_{max} is smaller for the pyrotechnical igniter, and the combustion kinetic seems to be affected by the chemical ignitor combustion.

Establishing a correspondence between severity parameters obtained for the same dust with two different ignition modes seems possible. Nevertheless, these 3 dusts with different behaviors show the difficulty of finding a relationship unifying all the data.

In fact, the combustion of aluminum powder only consumes oxygen from the air and does not produce gas in the combustion products, CaRo powder, like other organic powders although they consume when burning the oxygen also produces gases as combustion products and this contributes to the modification of the dp/dt . This increase is greater than the pressure gap introduced by the ignition system, as it is the case with chemical igniters.

Titanium powders, although not producing gas in the combustion products, seem to have their combustion kinetics affected by the combustion of chemical igniters, whereas this is not the case with electric ignition.

Probably, to establish this correspondence more precisely, it will be necessary to consider at least the three scenarios illustrated by this article.

4. Conclusions

In this work, the severity parameters of CaRo11, aluminium powder AlF3915 and titanium alloy Ti6Al4V were determined using both pyrotechnic and electric igniters and a correspondence is now possible between these two ignition sources over a wide concentration

range. The results show that these severity parameters are higher using the pyrotechnic igniter compared to the electric igniter. The P_{\max} values determined with electric igniter were less than 10% lower than values determined with pyrotechnic igniter. This can be explained by the use of a low ignition energy (electric spark of about 66 J) compared to the pyrotechnic igniter (5kJ). These results are not surprising since the pyrotechnic igniter accelerates the combustion with multi ignition points in a large volume and thus the Kst. It is partially due to the overpressure provided by the igniter just before the explosion really begins.

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