Detonability of Aluminium-Oxygen Suspensions

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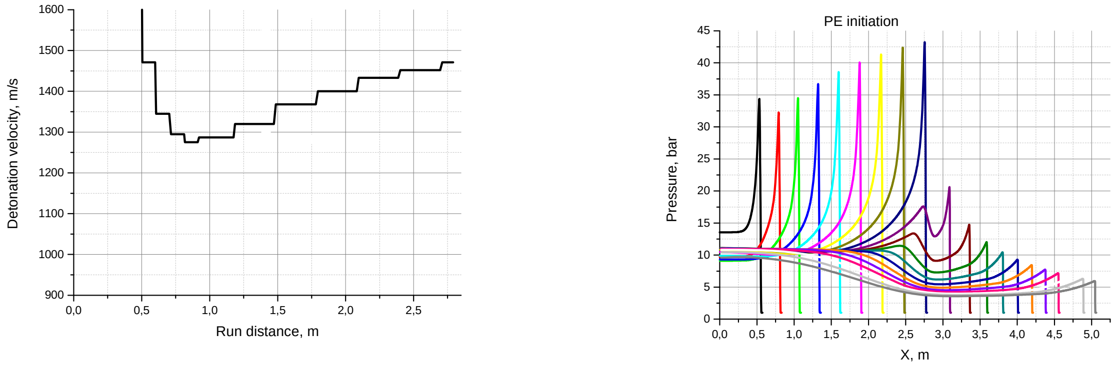
1 Introduction

In a previous work [1], we had predicted the critical conditions for direct initiation of unconfined detonations in aluminium-air and aluminium oxygen suspensions. For aluminium-air the critical initiation energy came out to be E_c = 11 kg of TNT and the critical detonation radius R_c = 8m. These predictions where confirmed by experiments of Zhang et al. [2] in an unconfined (3 m x 3 m cross section and 18 m long) cloud of flaked aluminium particles suspended in air, with a mass concentration of about 290 g/m^3. When they initiated the mixture with a charge of 8 kg of C4 (which is close to 11kg of TNT), they observed the onset of a detonation after 11 m of propagation. Beyond 15 m to the end of the cloud, a quasi-steady wave propagated with an average velocity of 1460 m/s, that is about 150 m/s smaller than the CJ velocity for the corresponding mixture. With the same model, we had predicted for a stoichiometric aluminium/oxygen suspension, a critical initiation energy for direct detonation initiation to be about E_c = 1 kg of TNT and a critical detonation radius about R_c = 1 m (note that this value corresponds to about 10^5 J, whereas the minimum detonation initiation energy for most of the hydrocarbon-oxygen mixtures is ranging between 10^{-3} J and 1 J) These last predictions were based on the cell size estimated at about 5-10 cm, according to the results of Ingignoli et al. [3]. However, due to the very reduced number of existing data on the detonation cell structure of aluminium-air and aluminium-oxygen suspensions, it comes out that it should be necessary to get a more definitive experimental evidence of these predictions. Hence, we have decided to conceive an experiment in order to investigate the detonability of aluminium-oxygen suspensions. Moreover, as the detonation initiation of an unconfined spherical charge is the more severe test for deciding of the detonability of a mixture, this is the configuration which we have chosen.

2 Estimation of test dimensions by numerical simulations

At a first stage, it is necessary to estimate what are the suitable dimensions of the experimental configuration to acquire relevant results. Therefore, we have performed numerical simulations of detonation initiation in an unconfined spherical aluminium particle-oxygen cloud with 2.8 m radius. Aluminium particles considered are flakes (equivalent in mass to 8.6μm particles, according to the results of Ingignoli et al. [3]) and their concentration in the cloud is 1.49 kg/m^3 (at 1 bar and 293 K initial conditions), that is stoichiometric composition (at r =1, D_{CJ} =1623 m/s and P_{CJ} =34 bar, while P_{ZND} =66 bar). The kinetic model is the same as that described in [4]. First simulations were made with the assumption of initiation by a central point explosion by a 1kg of C4 charge. The results of velocity and pressure evolution are presented in Fig 1-a and 1-b. One can observe that after the decaying of the incident strong shock, velocity and pressure begin to re-increase beyond about 1m of propagation, indicating that the detonation is being formed. When the leading front reaches the limit of the cloud, it is transmitted to the air outside and velocity and pressure progressively drop.



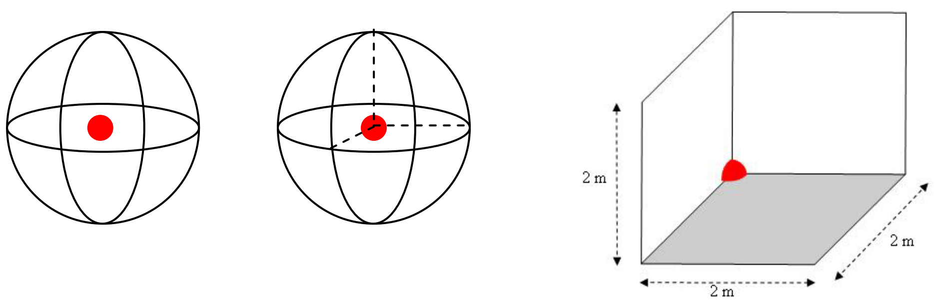
a – Velocity b - Radial pressure profiles

Figure 1. Evolution of the calculated shock velocity and radial pressure profiles with run distance in the case of initiation by point explosion (1 kg C4).

As a result of these simulations, it was decided to build an experimental plant allowing the propagation of the incident shock wave up to a radial distance of 2m from the initiation point.

3 Experimental setup

On the basis of the above simulations, the objective was to design and build an experimental setup allowing to initiate the detonation with a charge of at least 1kg of C4 placed at the centre of an aluminium particle-oxygen cloud having a 2m radius, as shown in Figure 2-a.



a – theoretical configuration with an initiation charge of 1kg

b – practical configuration with an initiation charge of 125g

Figure 2. Determination of the experimental configuration

According to the spherical symmetry of the problem, it is possible to reduce the configuration to a sector of 1/8th of the sphere bounded by solid walls (see Figure 2-b), thus allowing to initiate the cloud contained in the sector with a charge of 125g instead of 1kg. An experimental set-up based on this principle has been built on the test site of ISL. A scheme is shown in Figure 3.

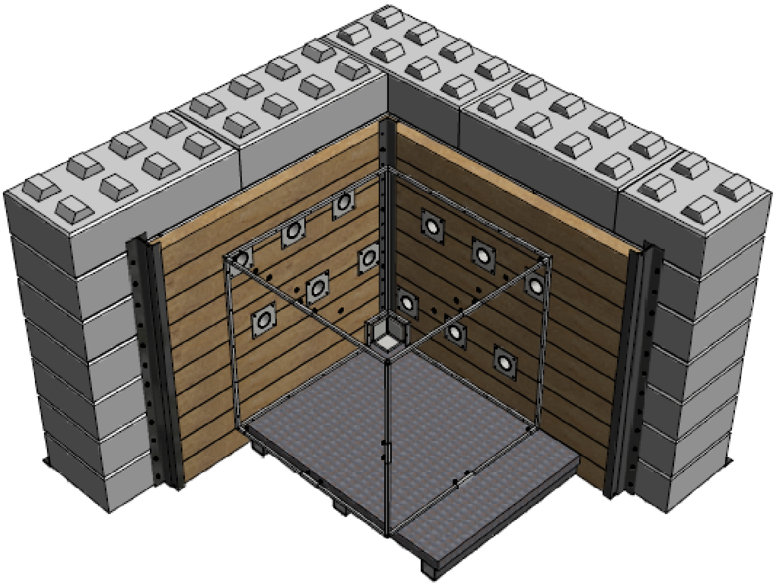


Figure 3. Scheme of the experimental set-up

Preparing a two-phase suspension of solid particles in controlled conditions and with a sufficiently uniform distribution over such a large volume is a very difficult task. The cloud is prepared in a polyethylene tent of 8 m^3. For achieving a stoichiometric mixture, it is necessary to disperse a minimum mass of about 13-16 kg of aluminium flakes. This mass is shared among the 12 individual containers displayed in Fig.3. The experiment is processed in the following way: the tent is, at first, filled with oxygen; then, the aluminium flakes are injected simultaneously from the containers in a very rapid sequence (a few hundred of milliseconds) and the C4 explosive charge is fired immediately at the end of this sequence, at from the corner of the sector. The evolution of the leading shock front velocity and pressure is recorded by means of four pressures gauges disposed along the solid wall, at distances 0.55, 1.24, 1.59 and 1.94 m from the initiating point.

3 Experimental results

Preliminary experiments were performed to characterize the evolution of the blast wave generated by a 125 g C4 charge in the surrounding atmosphere. Pressure measurements show that this evolution is in good agreement with the standard curve of TNT proposed by Kinney and Graham [5]. At the farthest pressure gauge (1.94 m from the initiation point), the shock velocity had decreased down to 600 m/s.
The first series of experiments performed in the conditions described above, with 125 or 150g of C4 to initiate the Al/O_2 mixture, have shown that after 1 m, the shock wave propagates with a velocity varying between 1300 and 1600 m/s and peak pressures in the range of 40-50 bars. Especially, in one experiment, the velocity 1628 m/s has been recorded at the farthest pressure gauge. These values are rather close to those of the ideal CJ detonation parameters for the stoichiometric mixture: D_{CJ} = 1623

m/s, P_{CJ} = 34 bar and P_{ZND} = 66 bar. Therefore, it is reasonable to conclude that in the present conditions, the detonation has been formed.

4 Concluding remarks

Work reported above has permitted to define the characteristics of an experimental configuration relevant to study the direct initiation of aluminium-oxygen suspensions, based on an estimation of the critical initiation energy of 1 kg TNT and the critical detonation radius of the order of magnitude of 1m. First experiments have displayed that a shock front velocity of about 1600 m/s could be reached at 1.94 m from the initiation point, which is very close to the theoretical CJ value of 1623 m/s and permit to validate our predictions on the detonability of aluminium-oxygen suspensions. Our previous estimation of the value of the detonation cell width as being of the order of 10 cm seems reasonably consistent with present results, but should be confirmed by further experiments.
Additional experimental results and comparison of experimental pressure profiles with numerical simulations will be presented at the colloquium.

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Acknowledgments

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