Investigation on the Explosion-Driven Dispersion and Combustion of Aluminium Particles

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Shock wave dispersion and ignition of solid combustible particles is a fundamental problem of great importance for various applications. For example, metallized explosives are designed and produced to generate specific effects different from those obtained with homogeneous ones, such as delayed energy release; but their exact working mechanism remains roughly known. Previous studies at ISL [1], [2] were carried out on charges made of a mixture of liquid explosive saturated with aluminium particles, which were exploded in a semi-confined area. The goal was to investigate the global mechanisms involved during the explosion of thermobaric charges. The charges studied at that time where quite similar in formulation, shape and mass to those used in some military devices. Interesting results concerning that kind of heterogeneous explosives have been also reported by Frost et al. [3]. Zhang et al. [4] also conducted studies on particle dispersion by an explosive. They worked on packed beds of solid particles saturated with a liquid explosive. Neuwald et al. [5] have studied explosion driven dispersion of aluminium particles on a much smaller scale using a micro-calorimeter. Aluminium particles, on account of their particular physical and chemical properties are a privileged candidate for this domain of applications. Problem of detonation initiation in aluminium suspensions has been reviewed for example by Veyssière [6]. The purpose of the present work is to get a better understanding of the mechanisms of particle dispersion and ignition by an explosive.

1 Experimental study

The experimental configuration was chosen to facilitate acquisition of new information on explosion driven dispersion and ignition of particles rather than to reproduce realistic conditions. Therefore, explosion of unconfined spherical charges was studied in free field. They were made of a central sphere of high explosive surrounded by particles contained in a 92mm diameter spherical casing. The charge is mounted 1.50m above the ground to delay the perturbations coming from the ground reflected shock wave. The booster explosive is a 125g sphere of C-4. Experiments were conducted either with inert glass particles (15, 100 and 200µm) or with reactive aluminium particles (atomized with 5µm, 30µm, 100µm and 200µm mean diameter). Pressure evolution in the flowfield around the charge is recorded with PCB 137A gauges located at 0.6, 0.8, 1, 1.5 and 3m from the charge. The whole explosion process is followed with a high frame rate video camera (Photron, APX Fastcam).

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The observation field is a 4m long, 60cm high area along a horizontal axis intersecting the explosive charge. Most of registrations were performed at 40000f/s. Direct observation allows to follow the self emitted light, thus the propagation of burnt products zone. In addition, by coupling with a Background Oriented Schlieren (B.O.S) method [7], it is possible to analyze the propagation of shock waves and particle bundles. More details concerning the experimental setup, measurement devices and diagnostic techniques can be found in [8]. In addition, a sample dispersed particles was captured with the help of a 30cm diameter, 5cm thick transparent wax cylinder placed at 0.85m from the charge. After each test, the wax block was recovered and analyzed by different techniques.

2 Results

At first the blast effect of bare 125g C4 charges has been characterized. Arrival times of the leading shock wave as well as pressure levels at the front recorded by the pressure gauges reasonably agree with tables [9], and with numerical simulations by the EFAE computer model for multiphase reactive flows of the Laboratoire de Combustion et de Détonique (LCD) of Poitiers [10]. Confronting analysis of high frame rate images by a BOS technique with pressure measurements and numerical simulations allows building the complete x-t diagram of shock propagation even at places where pressure gauges are not disposed. More details can be found in [8].

Dispersion of solid particles by the same initiating charge results in different effects following the particles are inert or reactive. Glass particles notably delay the arrival time of the leading shock front registered by the pressure gauges. In the case of aluminium particles, the arrival time depends on the particle size. In the case of 100µm particles, the arrival time is comparable to that recorded for the 125g bare charge, slightly longer. On the opposite, for 5µm particles, the leading shock wave may arrive sooner. The influence of particles is more striking on pressure evolution registered by pressure gauges. Fig. 1 displays the pressure evolutions recorded at 1m, respectively in the case of the explosion of the C4 charge alone, with addition of 470g of 100µm glass particles and with addition of 370g of aluminium particles. Calculated profile in the case of the C4 charge alone is displayed in the same figure and fits very well the experimental one. The damping effect of glass particles is clearly observed at the shock front: the overpressure is decreased by about 50%. On the opposite, in the case of aluminium particles, the pressure amplitude at the front depends on particle size; here, in Fig. 1 (100µm particles), the front overpressure is about 30% lower than that for the bare C4 charge. For glass particles, during the pressure evolution behind the leading front, the amplitude remains always smaller than that due to the C4 charge alone, whereas for aluminium particles, it becomes larger beyond about 200µs.

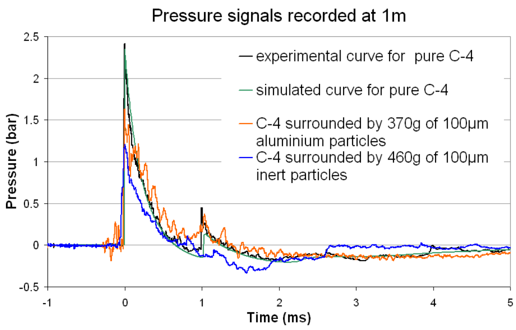

Figure 1. Comparison of pressure signals recorded by the pressure gauge located at 1m

Further information is given by the x-t diagrams shown in Fig. 2 (same conditions as in Fig. 1).

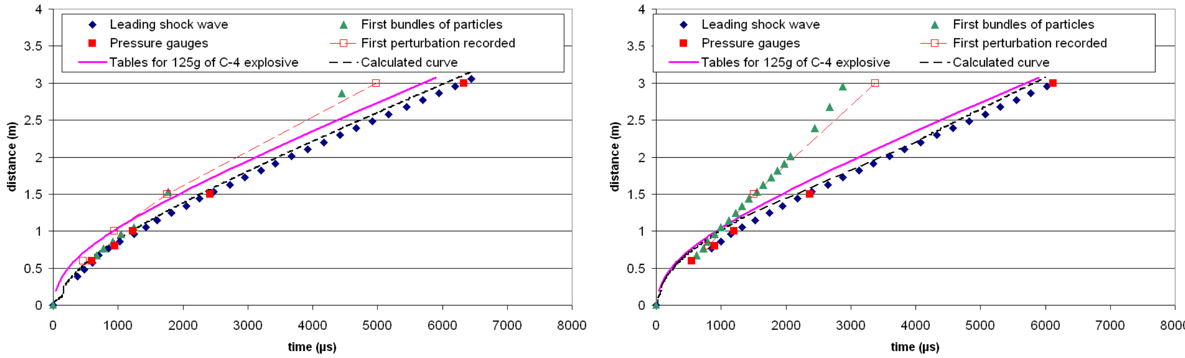

Figure 2. x-t diagrams obtained for a 125g of C-4 sphere surrounded by 460g of 100µm glass particles (left) and by 370g of 100 µm aluminium particles (right)

For both glass and aluminium particles, the calculated shock trajectories are in good agreement with experiments. Moreover, at about 1m from the initiating charge, glass particles are detected in front of the shock wave. These are supposed to be some particles bundles or agglomerates (represented by green triangles on Fig. 2-left). Other agglomerates are detected later during the propagation and clearly have a higher velocity than the leading shock front. The phenomenon is better seen in the case of aluminium particles (Fig. 2-right): the agglomerates seem more numerous and propagate much faster (~ 800 m/s) than the shock wave (~ 400 m/s at 3 m). In the present example with aluminium particles, when the front of particle bundles is detected at a distance of 3m, the leading shock wave is 1m behind (and reaches the same position with 3 ms lag).

3 Particle modifications due to interaction with the shock wave

Typical transparent wax blocks obtained after experiments are displayed in Fig. 3. Numerous craters due to particle impacts are detected. Statistic analysis indicates (see Fig. 4) that the number of particle impacts is about the same for glass and aluminium particles of close size (100µm). Two main types of craters have been identified: large craters (diameter approximately 5 mm) surrounded by small craters distributed on the particle trap surface. Whereas small crater depth did not exceed a few millimetres, large crater extended up to a few centimetres. Conversely, the depth of craters is very different following the particles are inert or reactive: it does not exceed 15 mm for glass particles, but almost reaches 35 mm for aluminium ones.

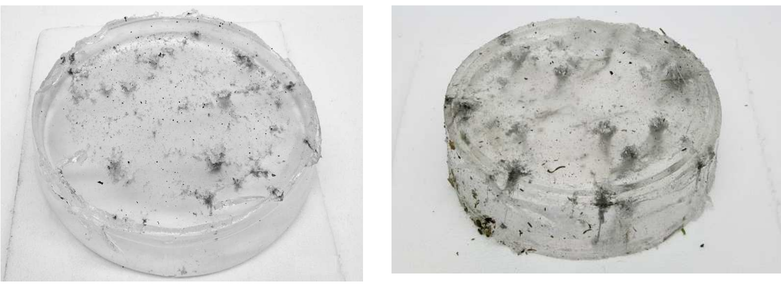

Figure 3. Block of wax photographed after the explosion of a 125g C-4 charge surrounded by 465g of 100µm glass particles (left) and by 360g of 100µm aluminium particles (right)

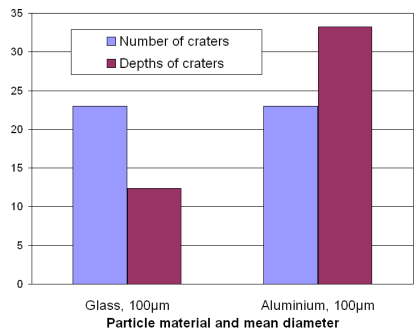

Figure 4. Number of main craters formed in the blocks of wax during the explosions and their mean depth (mm)

A few agglomerates of glass particles (average size around 1mm) were collected. They are fragile and can easily be crushed into powder. Examination of glass particles reveals that most of them were broken in fragments at least 5 times smaller than the original particles [8]. In the case of experiments with aluminium, very large particle agglomerates have been extracted from craters: some of them may have a diameter larger than 3mm. Rough examination of these large particles reveals that they contain an important quantity of metal. This indicates that an important amount of aluminium did not react and unburnt particles melted together to form larger agglomerates. This difference in the characteristics of particle agglomerates could also explain why much fewer glass agglomerates were found and the larger crater depth measured for the aluminium particles.

4 Conclusions

Comparison of pressure profiles generated by the dispersion of glass and aluminium particles by a spherical 125g charge of C4 indicates that 100 µm particles have a rather similar effect at the shock front, regardless they are inert or reactive: they slightly delay the arrival time and the amplitude of shock pressure. On the opposite, the subsequent evolution differs markedly: for glass particles, the pressure remains always smaller that for the case of a bare C4 charge, whereas for aluminium particles a pressure augmentation is observed about 200 µs behind the leading front, which is undoubtedly due to an additional energy release by aluminium combustion. Furthermore, in experiments with inert and reactive particles after about 1m propagation, some particle bundles or agglomerates clearly overtake the leading shock front. Samples of particles collected after the experiments suggest that the burning of aluminium particles is incomplete. Additional investigations on this problem should be done to precise the burnt fraction of particles after the explosion.

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