Detonation of Hydrogen-Based Gaseous Mixtures with Suspended Aluminium Particles

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Abstract

The cellular detonation structure has been recorded for hybrid hydrogen/air/aluminium and hydrogen/oxygen-argon/aluminium mixtures. Addition of aluminium particles to the gaseous mixture changes its detonation velocity. It appears that the correlation between the cell size and the detonation velocity of the hybrid mixture is similar to the correlation between the cell size and the rate of detonation overdrive displayed for homogeneous gaseous mixtures.

Introduction

Previous works on detonation of hybrid mixtures made of detonable gaseous mixtures with suspended reactive solid particles[1,2] have shown that several detonation regimes exist. The single-front detonation (SFD) corresponds to a detonation supported by both gaseous reactions and reactions between particles and gases in a unique reaction zone. On the opposite, when the particles react behind the CJ plane, the detonation is supported only by heat release from gaseous reactions: it is a pseudo-gas detonation (PGD). In certain cases, a two discontinuity front structure may exist; the first front is supported by gaseous reactions, the second one by reactions between particles and gases, which is the so-called double-front detonations (DFD). It was demonstrated that the propagation regime is controlled globally by the heat release rate from solid particles relative to that of gases, which depends on the size and mass concentration of particles[1,2].

But until now available data on the influence of suspended particles on the detonability of gaseous mixtures including detonation initiation are very limited. The detailed kinetics of reaction of particles with gases is not known and it is impossible to predict whether and how the addition of solid particles may influence the so-called cellular detonation structure, in the absence of experimental data on this subject. In the present work, we have studied the dependence of the propagation regime on the reactivity of particles and attempted to display their influence on the cellular structure for hydrogen-air mixtures or hydrogen-oxygen-argon mixtures with aluminium particles in suspension.

Experiments

Experiments have been performed in an experimental setup similar to that used previously by Veyssiere[3]. The 69-mm diameter circular cross section detonation tube is disposed vertically and has been lengthened so that the distance available for detonation propagation is now about 6m. Dispersion of particles in the gaseous mixture is achieved by elutriation of particles from a fluidized bed. The tube is filled by the flow of the different components from the bottom to the top of the tube. Quasi-direct initiation of the detonation is achieved by a blasting cap. Evolution of the characteristic parameters of the detonation wave during its propagation along the tube is recorded by ionization and light probes and piezo-electric pressure gauges. The characteristic cellular structure of the detonation regime is recorded on 1-m long metallic soot plates mounted at the walls in the terminal part of the tube.

Three kinds of aluminium particles have been used: 3.5µm (“A1”) and 13µm (“A2”) atomized particles, and flakes (“F”) with a characteristic thickness of 0.5-1µm and of variable length (up to 45µm). The latter were supposed to be more reactive than the atomized particles. Lean, near stoichiometric and rich hydrogen-air mixtures have been experimented. Fig. 1 displays the detonation velocity recorded for the lean (r=0.87) mixture. It can be seen that addition of 3.5µm particles A1 increases the detonation velocity while it is decreased by coarser particles A2. The sufficiently small diameter of particles A1 allows their rapid ignition and augmentation of the heat release in the reaction zone supporting the detonation. On the contrary, particles A2 ignite later and act as a heat sink in the reaction zone of the gaseous explosive, which results in a decrease of the detonation velocity. This behavior is confirmed by computational results obtained with the numerical model built previously by Khasainov and Veyssiere[1,2]. Particles F promote the same effect as particles A1, due to the greater specific surface of flakes, which confer to them a greater reactivity.

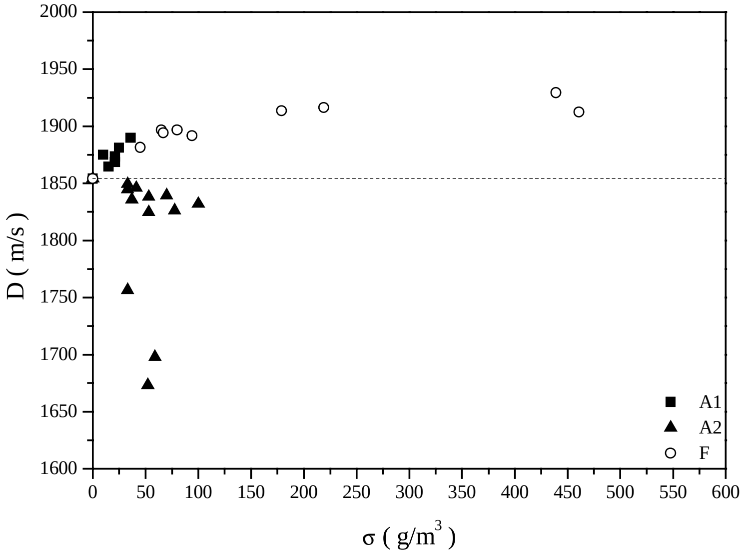

Fig.1 - Detonation velocity versus mass particle concentration for different aluminium particles

Results

Fig. 2 shows typical soot plate record of the cellular detonation structure of a H_2/air mixture with aluminium particles. The structure presents a rather irregular shape and a significant dispersion of the cell dimensions, similar to that recorded in pure H_2/air mixtures. When adding particles A1 and F, the cell width becomes smaller than for the pure gaseous mixture. On the opposite, with particles A2, the cell size becomes larger. If the cell size normalized by the cell size of the pure gas (λ/λ_0) is plotted versus the detonation velocity normalized by the detonation velocity of the pure gas (D_p/D_0), the dimensionless value of the cell size decreases monotonously with augmentation of detonation velocity, similarly to what has been observed in gaseous mixtures for the dependence of the cell size on the rate of detonation overdrive[4]. In Fig. 3, our experimental results for the lean mixture (r=0.87) are compared with the correlation curve for the pure gaseous mixture. Though this curve was derived for the domain $D_p/D_0>1$, it has been extended here to $D_p/D_0<1$. It appears that for $D_p/D_0 > 1$, there is a good agreement between our experiments and the correlation derived for gases. For $0.98<D_p/D_0<1$, the experimental values fit quite well with the correlation curve, but for smaller values of D_p/D_0 deviate significantly.

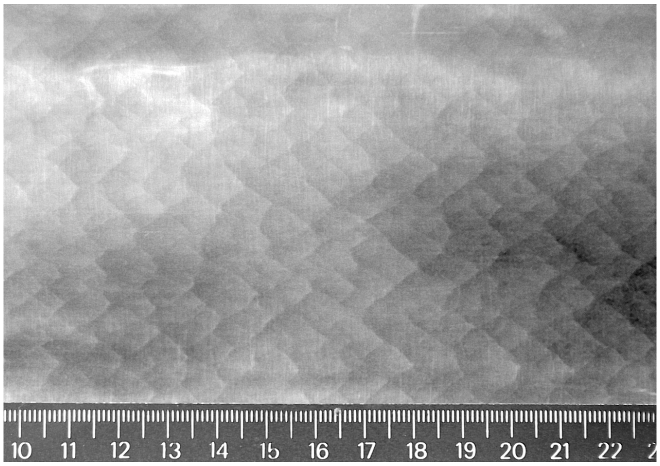

Fig.2 - Soot-plate record of the detonation in hydrogen-air mixture (r=0.87)
with aluminium particles F (flakes, σ=220g/m^3)

Additional experiments were performed in hydrogen-oxygen mixtures diluted by argon (r≈0.9; $Ar/O_2 \approx 11$). As expected, the cellular structure is more regular, but the cell dimension is smaller than in mixtures with nitrogen. The effect of particle addition is qualitatively the same as in hydrogen-air mixtures. We have particularly examined whether the secondary reactions of aluminium particles could give birth or not to a specific cellular structure. In the present state of our investigations and with the resolution of our registrations, it was not possible to provide evidence of the existence of such a structure.

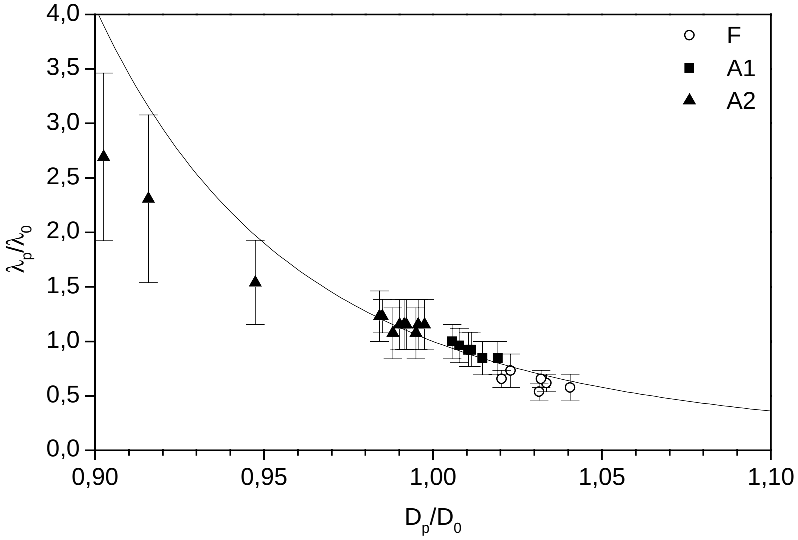

Fig.3 - Dependence of the detonation cell width on the ratio between the detonation velocity of the mixture with aluminium particles D_p and the pure gaseous mixture D_0.

Discussion

Further interpretation of results of Fig.3 may be done by taking account of the existence of several possible detonation propagation regimes for hybrid mixtures. Indeed, the case $D_p/D_0>1$ corresponds to the SFD regime, where the combustion of gases and particles occurs in a unique reaction zone behind the leading front: thus, burning of particles increases the velocity of the detonation front and has the same effect on the detonation cell size as a supported overdriven detonation in the pure gaseous mixture. On the opposite, at $D_p/D_0<1$, the effect of aluminium particles on the cell size is more complicated to interpret, as combustion of particles occurs downstream in a reaction zone separated from the gaseous one, with possibility of existence of the DFD propagation regime. This is the reason why the detonation velocity tends to decrease when particles are added, and could explain why the variation of the cell size does not follow the correlation with the detonation front velocity derived for gas mixtures. Further investigations are needed to get better understanding of the influence of particles on the cellular structure in this latter case.

References

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Acknowledgements

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