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Detailed Analysis of a Quench Bomb for the Study of Aluminum Agglomeration in Solid Propellants

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Agglomeration of aluminum in solid propellants generally leads to the formation of large agglomerates that are known to be detrimental to the steady operation of solid rocket motors (nozzle erosion, two-phase loss, incomplete combustion,...). More recently, large burning agglomerates have been suspected to alter the unsteady operation as well by triggering thermoacoustic instabilities[1]. The physics of aluminum agglomeration is intricate which currently limits the development of reliable models. Therefore, the study of aluminum agglomeration essentially rests on experiments. A widely-used, simple and cheap set-up is the so-called quench bomb. A small sample of propellant burns in a closed bomb and particles are quenched and collected, generally in a liquid.

This work intends to study in detail the operation of the quench bomb used in SAFRAN-Herakles as depicted in Fig. 1. The drum, in which the sample is held, is partially filled with a quenching liquid (ethanol) and spins in order to centrifugate the liquid on its lateral walls. The set-up is pressurized with ambient temperature nitrogen. All the forthcoming analysis is performed on the same AP/Al/HTPB propellant (18 %w/w aluminum) and at 5 MPa.

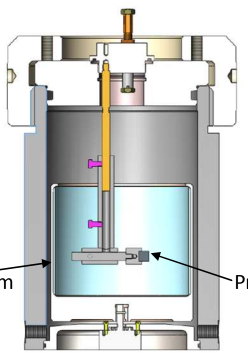

Fig. 1: Sketch of the quench bomb

For a typical test, the analysis of the collected particles shows a surprising result: in spite of a significant quenching distance (40 mm), a large quantity of unburnt aluminum is measured, about 20 %. The effect of quenching distance or sample orientation is investigated and essentially gives similar results, i.e large agglomerates with unburnt aluminum. With the help of numerical simulations, it is found that the high rotation rate of the drum induces a marked recirculation: burning aluminum particles are thus swept by a rapid flow of cold nitrogen that eventually stops the combustion. This suggests that particles are indeed quenched at a very early stage of combustion. This is proved by performing additional experiments in a modified quench bomb set-up wherein the propellant sample burns directly in the quenching liquid. This occurs to yield again similar results in terms of particle size or aluminum content, which shows that in both cases the combustion is stopped at its very beginning. This premature nitrogen quenching seems to be hitherto unreported.

A detailed analysis of collected particles is conducted: in particular, particles are sieved (see Fig. 2) and unburnt aluminum content is measured for each sieving class. A result is that the limit size between aluminum agglomerates and alumina residues seems to stand by 20 µm. Particles are also qualitatively studied by electronic

[1]Gallier and Godfroy, *J. Prop. Power*, 25(2), 2009

microscopy, including their interior. To this end, they were embedded in an epoxy resin and microcut using an ion polisher. As already noticed in literature, it occurs that most particles are hollow.

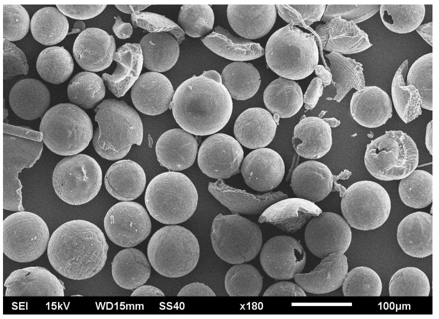

Fig. 2: SEM picture of aluminum agglomerates (sieving class : 60-100 µm)

Scarce studies actually investigate the alumina (aluminum oxide) residue of combustion - which is the ultimate stage of aluminum agglomerate combustion - since they are generally much more complicated to collect. In our quench bomb for instance, it has been seen that this is not possible due to an unwanted nitrogen quenching. To this end, we investigate the use of oxidizing pressurants, notably CO_2 and air. This time, it is found that the combustion is now allowed to proceed until completion. This was checked by measuring no or very little unburnt aluminum. The size of the obtained residues are about 10-20 µm, depending on the pressurant, which means that the nature of the oxidizer plays a marked role. This size is obtained both by laser granulometry and image analysis. The diameter ratio between final oxide residue and aluminum agglomerate for this propellant is about 0.2, which is smaller than reported in the literature for this class of propellants.

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