Dynamics of Non-Spherical Compound Metal Particle in Non-Uniform Flow Field

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Aluminized composite propellants used in solid rocket motors (SRM) contain a lot of metal (usually aluminium) particles because high combustion energy is generated and propulsion efficiency increases by burning metal particles [1]. To accurately design and predict the performance of SRMs with an aluminized propellant, the combustion behaviour of the aluminium particles and their dynamics in the non-uniform internal flow field is required. While many studies have centred on measuring and modelling burn rate characteristics of propellants, less effort has been focused on aerodynamics, heat transfer and combustion characteristics of agglomerates consisting of metal and its oxide and moving in non-uniform flow occurring in SRMs.

The major product of aluminium combustion is liquid aluminium oxide, which is formed from the condensation of aluminium sub-oxides. A fraction of the oxide diffuses back and deposits on the particle surface and is termed as the oxide cap (lobe). The oxide cap tends to accumulate on the lower end of the particle. The accumulation of the oxide on the particle surface and the porosity of the oxide cap result in a final oxide cap size of the order of the initial particle size. The other fraction of the oxide is transported outwards and is termed as the oxide smoke. The oxide cap results in fragmentation and jetting. The oxide cap effect on the burning time depends on the initial size of the particle [2].

The oxide cap acts as a dead weight which reduces the vaporization surface, leading to non-symmetrical combustion and a possible droplet spin. The oxide lobe affects the vaporization process. The outward flow decreases and becomes non-uniform. Concurrently, the inward diffusive flow from the vapour-phase flame zone increases at the surface region overlapped with oxide. This coupling of the diffusion rate with the outward flow leads to a possible growing of the oxide cap.

The particles are not stationary during combustion, and typically decelerate during combustion. The effect of forced convection on the burning rate and ignition delay is unknown, but remains of significant concern. Several questions remain about unsteady processes, such as spinning and fragmentation of particles. One important phenomenon is the formation of an aluminium oxide cap moving on the particle surface during combustion and movement of particle. It causes particle asymmetry and obstructs part of the aluminium surface, leading to spinning.

The development of robust models of aluminium particle dynamics and morphology is essential in the development of advanced propulsion systems. The study focuses on the numerical analysis of non-uniform flow field around moving aluminium particle with oxide cap inside combustion chamber of SRM. The mathematical model of two-phase flow around a single aluminium droplet with oxide cap has been developed and validated against experimental data. The model solves the continuity, momentum, energy and species continuity equations simultaneously to obtain the species and temperature profiles and the burn time. These equations allow calculating forces and angular moment acting on the particle. Geometry of the aluminium droplet and its oxide cap changes as mass is removed from the aluminium particle and oxide cap mass increases during aluminium combustion. It has been assumed that the oxide deposits uniformly on the particle surface and migrates to the downstream side to coalesce into an oxide cap.

References

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