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HYBRID ROCKETS WITH NOZZLES IN ULTRA-HIGH-TEMPERATURE CERAMIC COMPOSITES

Abstract

The inner surface of high performance rocket nozzles, where the propellant flow is accelerated to supersonic conditions, is typically subjected to very high shear stresses and heat fluxes and high pressure in a chemically aggressive environment. These severe conditions usually lead to removal of surface material due to heterogeneous reactions between oxidizing species in the hot gas and the solid wall. Thus, the requirement that dimensional stability of the nozzle throat should be maintained guaranteeing a stable engine operation makes the selection of rocket nozzle materials extremely hard. For instance, among the typical materials used, graphite performs well with the least oxidizing propellant but is generally eroded severely. In recent years, Ultra-High-Temperature Ceramic (UHTC) materials, including zirconium or hafnium diborides or carbides, are assuming an increasing importance because of their high melting points, temperature strength and oxidation resistance. Bulk UHTCs with addition of silicon based ceramics, in the form of particles, short fibers or whiskers have been developed with good oxidation and ablation resistance at ultra-high temperature. However, due to their low fracture toughness and poor thermal shock resistance, the reliability of these materials must be improved to develop larger components with enhanced mechanical properties. Composites with carbon fiber as reinforcement and UHTC or C/SiC–UHTC as matrix can be expected to perform good erosion resistance properties compared to C/C and C/SiC composites, as well as good thermal shock resistance and damage tolerance and then to be the potential candidates for use in propulsion applications. This so-called Ultra High Temperature Ceramic Matrix Composites (UHTCMC), are the subject of the Horizon 2020 European C^3HARME research project, focused on materials design and preparation, development of components from small to larger scale and testing in representative environments, including rocket nozzles.

In this work the experimental characterization of UHTCMCs for applications in hybrid rockets with HDPE and oxygen have been carried out with a novel, dedicated test set-up. UHTCMC samples exposed to the supersonic exhaust jet of a 200N-class hybrid rocket are characterized at temperatures higher than 2400 K. The most suitable materials compositions are selected to develop nozzle throat inserts and

complete nozzles. Then, the performances of the rocket with graphite and UHTCMC nozzles are compared and discussed.

The experimental activities are supported by proper numerical models able to accurately predict the complex flow field in the hybrid rocket combustion chamber, the thermo-fluid dynamic conditions on the material and the corresponding thermal behavior.