IAF SPACE PROPULSION SYMPOSIUM (C4)
Propulsion Technology (2) (5)

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ULTRA-HIGH-TEMPERATURE CERAMIC MATRIX COMPOSITES FOR HYBRID ROCKET NOZZLES

Abstract

Erosion resistance of rocket nozzles, whose inner surface is subjected to high shear stresses, pressure and heat fluxes in a chemically aggressive environment, is a research topic of major interest, since nozzle material ablation and subsequent throat section enlargement dramatically affect the engine performance. Ultra-High-Temperature Ceramic (UHTC) materials are considered promising candidates for such application, in light of their melting temperatures that exceed 3250 K, and good strength and oxidation resistance over 2250 K. On the other hand, the employment of monolithic materials is limited by their low fracture toughness, low thermal shock resistance and lack of damage tolerance. In this framework, University of Naples "Federico II" (UNINA) is involved in the Horizon 2020 European research project, C^3HARME, led by the Institute of Science and Technology for Ceramics of the National Research Council of Italy (ISTEC-CNR), which is focused on a new class of Ultra-High-Temperature Ceramic Matrix Composites (UHTCMC) for near zero-erosion rocket nozzles. An extensive experimental characterization campaign is ongoing, based on an incremental approach, envisaging tests on prototypes of increasing complexity and dimensions.

Material screening activities, carried out by exposure of sintered small UHTCMC specimens to the supersonic exhaust jet of a 200N-class hybrid rocket nozzle, identified ZrB_2-based ceramics with carbon fibers as promising candidates to develop rocket components with excellent erosion resistance. Larger and more complex samples are currently under investigation in the UNINA hybrid rocket laboratory, where a representative operating environment is reproduced, with temperatures over 3000 K, chamber pressure on the order of 10 bar and a considerably oxidizing environment. Flat disks to be placed inside the hybrid rocket combustion chamber were manufactured and tested to assess the capability of large components to withstand the considerable thermo-mechanical stresses expected inside the rocket without significant

erosion. Then, nozzle-throat inserts and complete UHTCMC nozzles were tested to validate the sintering technologies on samples having a shape and dimension close to the final application. Experimental measurements and micro-structural post-test analyses are presented and discussed to investigate the effect of several factors (such as carbon fibers architecture or porosity level) on material performance, in terms of structural toughness and erosion resistance, in order to optimize the manufacturing process.

In order to support the experimental activities, one-dimensional models based on chemical equilibrium and computational-fluid-dynamic models are defined and employed to provide additional information on the material samples operating conditions and correlating the effect of nozzle erosion on engine performance.