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EXPERIMENTAL STUDY OF ABLATION CHARACTERISTICS OF HAFNIUM-BASED COMPOSITES IN THE HYBRID ROCKET NOZZLE

Abstract

In a rocket system, nozzle structures, especially throat, are exposed to an extremely high-temperature and tremendous heat flux of high-pressure compressible combustion gases. Ablative materials like graphite and pyrolytic composite were generally introduced to hybrid motors, where adopting a cooling system on the nozzle is an inherently challenging problem. However, the surface of ablative material is exposed to combustion gases and easily suffered from ablation under highly oxidizing environment. Severe ablation causes serious degradation of combustion performances such as a significant drop of chamber pressure and specific impulse. Thus, the application of advanced material which has enhanced refractoriness and superior oxidation resistance into the nozzle is necessary for guaranteeing stable combustion performance. Ultra-High Temperature Ceramics (UHTCs) are recently noticeable for stabilized mechanical and chemical properties at elevated temperature. Especially, mono-carbides or diborides of hafnium generate refractory oxide layer showing superior oxidation and ablation resistance when it oxidized. This self-generating oxide layer of UHTC protects base materials by hampering further oxygen diffusion and heat flux into interior structures. Selected materials of this study were high purity HfC-SiC and HfB_2-SiC composite presenting enhanced ablation and oxidation resistance. The ceramic composite without fiber reinforcement was regarded as susceptible for a thermal shock because of low fracture toughness and extreme temperature gradient on the nozzle surface in the early stage of combustion. The feasibility of adopting hafnium-based composites as the nozzle insert was evaluated through the combustion test.

In this work, 250 N scale hybrid thruster using high test peroxide and High-Density Poly-Ethylene (HDPE) was designed. The ablation characteristics of hafnium-based UHTC were tested under 25 sec of exposure with high chamber pressure over 30 bar to produce significant erosion. Surface erosion of graphite, which did not have any protection layer when it oxidized, was analyzed for comparing UHTC ablation mechanism since the existence of the refractory oxide layer was the key role of ablation resistance of UHTC. Visualization and quantitative measurement of ablation have been carried out with Laser 3D-scanning. The nozzle inserts of HfC-SiC and HfB_2-SiC composites showed near zero erosion meanwhile throat area of graphite increased over 85% compared to the initial throat area. In correlation with the enlarging throat results, the chamber pressures were intact for the test using UHTC whereas chamber pressure seriously decreased approximately 40% from the initial pressure for the graphite. Moreover, thermal behavior of the UHTC was profoundly analyzed.