TESTING ULTRA-HIGH-TEMPERATURE CERAMICS FOR THERMAL PROTECTION AND ROCKET APPLICATIONS

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The work is focused on experimental aerothermodynamic characterization of Ultra-High-Temperature Ceramic materials for aerospace applications. These materials are assuming an increasing importance in aerospace research because their high temperature resistance makes them interesting to develop components for extreme applications, such as thermal protection systems for hypersonic or atmospheric reusable re-entry vehicles, specific components for propulsion, combustion chambers, engines intakes or rocket nozzles. In order to test the materials behavior in extreme relevant environments, different facilities are available, including supersonic arc-jet wind tunnels and lab-scaled rocket motors.

Typical activities include the design of prototypes for the experimental campaigns, tests on material samples in both re-entry and combustion environments, numerical modelling and simulations of reacting flows around test articles.

To investigate the typical materials behavior in atmospheric re-entry conditions, relevant tests are carried out with arc-jet facilities, with a maximum flow total enthalpy higher than 20 MJ/kg, supersonic Mach number and temperatures up to 2000°C in a gas atmosphere with high concentration of atomic oxygen. The facility, fed by an electric arc-heater and working in a continuous fashion, is able to reproduce, for long exposition times, heat fluxes and dynamic pressures of interest to simulate hypersonic flight conditions, in order to test the ablation resistance of TPSs, as well as to investigate aero-thermochemical issues. Samples with different shapes have been investigated to simulate the conditions reached in the stagnation point of a re-entry vehicle, with flat or hemispherical specimens, or on leading edges. Typical sizes of the samples are in the order of 1 cm and the maximum heat flux is in the order of 10 MW/m². Larger facilities allow to test models of larger size. Particular attention has been focused on thermo-chemical surface instabilities of SiC-ZrB₂ ceramics in high enthalpy dissociated supersonic air flows resulting from the catalytic activity of a surface oxide scale. Pyrometry and thermography techniques allow to perform temperature and emissivity measurements on the samples. The microstructures of the UHTCs sample are analyzed thanks to a collaborative partnership with CNR-ISTEC Institute in Faenza (Italy); the most promising materials are characterized by layered multiphase configurations of oxide scales protecting the unoxidized core material.

The experimental activities are supported by numerical simulations, that become a viable and largely recommended tool not only to predict the thermo-chemical evolution of the gas but also to characterize the flow-field surrounding the proof article inside the (ground) testing chamber. In addition, because the flow conditions generated in the high-enthalpy plasma wind tunnel are very complex, the verification of the free-stream flow conditions must be a combined effort of experimental diagnostics and computational fluid dynamics (CFD) simulations.

Furthermore, the Aerospace Propulsion Laboratory allows, besides the characterization of hybrid rocket propellants, for which it is mainly conceived, also to investigate rocket components or subsystems manufactured in innovative materials, such as nozzles and nozzle inserts, in highly relevant operating conditions. Computational models for numerical simulations of the rocket internal ballistics and of the nozzle exhaust jet are developed to support the experimental activities.

This presentation will be an overview of the main research activities performed so far, as well as of the current programs, regarding the characterization of Ceramic Matrix Composites with an Ultra-High-Temperature Ceramic matrix (UHTCMC), in both propulsion and atmospheric re-entry environments, in the framework of the European Project C³HARME – Next Generation Ceramic Composites for Combustion Harsh Environment and Space.