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Author: Mr. Stefano Mungiguerra
Università degli Studi di Napoli “Federico II”, Italy, stefano.mungiguerra@unina.it

Mr. Giuseppe Di Martino
University of Naples ”Federico II”, Italy, giuseppedaniele.dimartino@unina.it
Dr. Anselmo Cecere
Università degli Studi di Napoli “Federico II”, Italy, anselmocecere@hotmail.com
Prof. Raffaele Savino
University of Naples ”Federico II”, Italy, raffaele.savino@unina.it
Dr. Luca Zoli
CNR-ISTEC, Italy, luca.zoli@istec.cnr.it
Dr. Laura Silvestroni
CNR-ISTEC, Italy, laura.silvestroni@istec.cnr.it
Dr. Diletta Sciti
CNR-ISTEC, Italy, diletta.sciti@istec.cnr.it

CHARACTERIZATION OF CARBON-FIBER REINFORCED ULTRA-HIGH-TEMPERATURE CERAMIC MATRIX COMPOSITES IN ARC-JET ENVIRONMENT

Abstract

Thermal Protection Systems (TPS) in hypersonic vehicles call for a unique combination of properties, required to withstand the challenges of extremely demanding aero-thermo-dynamic conditions in harsh environments, including hypersonic Mach numbers, temperatures above 2000°C, the activation of gas dissociation/recombination reactions at extremely low oxygen partial pressures, which can substantially enhance the heat flux on the exposed surface of the spacecraft.

Research efforts identified Ultra-High-Temperature Ceramics (UHTC) composites, based on transition metals carbides and diborides and silicon carbides as potentially viable candidate systems for these applications, especially in light of their high melting temperatures, strength and oxidation resistance at temperatures over 2000°C. The dispersion of SiC or other Silicon based ceramics, in the form of particles, short fibers or whiskers, in the main refractory phase is frequently used to improve damage tolerance and oxidation resistance thanks to the formation of an oxide protective scale. Due to the poor fracture toughness and thermal shock resistance of monolithic UHTC materials, research is currently oriented towards Carbon Fiber reinforced Ultra-High-Temperature Ceramic Matrix Composites (UHTCMC), consisting of carbon fibers embedded in a UHTC-matrix, with the aim of developing large ultra-refractory components with enhanced mechanical properties and reliability for aerospace applications.

In this framework, University of Naples “Federico II” (UNINA) and the Institute of Science and Technology for Ceramics (ISTEC) are involved in the Horizon 2020 European C^3HARME research project, focused on a new class of UHTCMCs for near zero-ablation thermal protection systems. An extensive experimental characterization campaign is foreseen in the UNINA arc-jet wind tunnel, where atmospheric re-entry conditions are reproduced at maximum flow total enthalpies higher than 20 MJ/kg, supersonic Mach number, in a gas atmosphere with high concentration of atomic oxygen. Non-intrusive diagnostic equipment, including a two-color pyrometer and an infrared thermocamera, is employed to monitor the surface temperature of the samples, which generally exceeds 2000°C. Post-test inspections are carried out

to analyze the microstructures of the samples after the exposition to the aero-thermo-chemically aggressive flow.

The experimental activities are supported by Computational Fluid Dynamics simulations. Proper numerical models are defined, validated and employed to allow accurate prediction not only of the thermo-fluid-dynamic flow field around the test articles, but also of the thermal behavior of the materials samples, including an investigation of the effect of material surface properties, such as emissivity and catalycity.