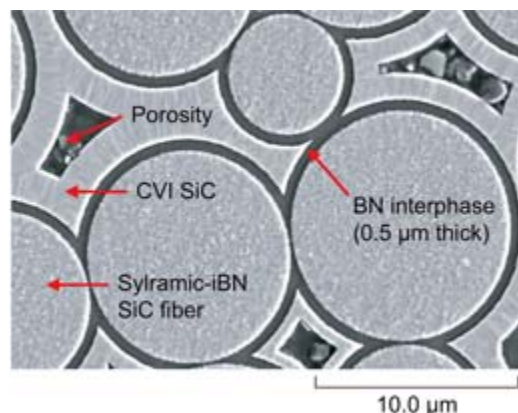


SiC/SiC Ceramic Matrix Composites Developed for High-Temperature Space Transportation Applications

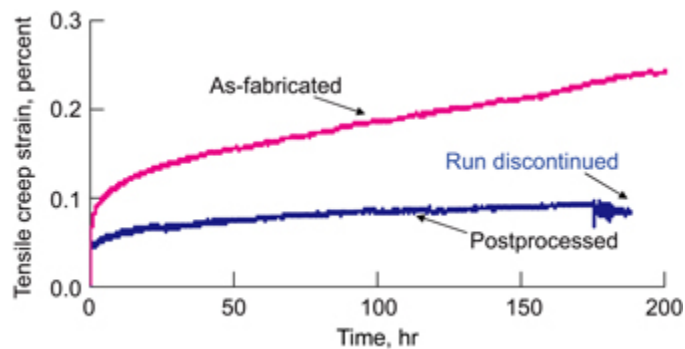
Researchers at the NASA Glenn Research Center have been developing durable, high-temperature ceramic matrix composites (CMCs) with silicon carbide (SiC) matrices and SiC or carbon fibers for use in advanced reusable launch vehicle propulsion and airframe applications in the Next Generation Launch Technology (NGLT) Program (ref. 1). These CMCs weigh less and are more durable than competing metallic alloys, and they are tougher than silicon-based monolithic ceramics (refs. 1 to 3). Because of their high specific strength and durability at high temperatures, CMCs such as C/SiC (carbon-fiber-reinforced silicon carbide) and SiC/SiC (silicon-carbide-fiber-reinforced silicon carbide) may increase vehicle performance and safety significantly and reduce the cost of transporting payloads to orbit.

The composite components of primary interest in the NGLT Propulsion Research and Technology Project were cooled CMC heat exchanger panels (ref. 4) and inserted uncooled CMC turbine blades. Our materials development task initially focused on C/SiC, which has typically been the primary CMC system of interest for reusable launch vehicle airframe and propulsion component applications. However, these components were expected to perform for at least 100 hot hours of operation at peak temperatures in the range of 1427 to 1650 °C (2600 to 3000 °F) in air or combustion gases under mechanical and thermal stresses. Because required material properties and characteristics included low permeability, oxidation and creep resistance, and the ability to withstand extreme thermal transients, we initiated the development of a high-temperature SiC/SiC CMC to take advantage of (1) the uncracked matrix of SiC/SiC (as-processed C/SiC has cracks in the matrix and fiber tows), (2) the superior oxidation resistance of SiC fibers, and (3) the use of a boron nitride (BN) interphase, which is more oxidatively stable than the C interphase used in C/SiC.



Microstructure of a Sylramic-iBN SiC fiber-reinforced CVI SiC CMC, showing the center of a fiber tow in the center of the specimen.

SiC/SiC composites developed in the past for aeronautics applications were clearly unsuitable for long-term application at 1450 °C because SiC fibers with inadequate creep resistance were used and/or melt-infiltrated (MI) SiC matrices (ref. 5) were used that had significant amounts of free silicon, which limits the maximum use temperature. In this study, full chemical vapor infiltrated (CVI) SiC/SiC CMCs containing state-of-the-art SiC fibers (Sylramic-iBN) and interphases (silicon-doped BN) were developed (see the preceding photomicrograph). These CVI SiC/SiC CMCs have survived over 500 hr of creep-rupture testing at 1450 °C in air under an applied stress of 69 MPa (ref. 1). In comparison, MI SiC/SiC developed in the NASA Ultra-Efficient Engine Technology Project (“1/01 Material”) experienced excessive specimen deformation and failed after approximately 50 hr under the same conditions. The improved durability of the CVI SiC/SiC is attributed to its more refractory matrix (unlike in MI SiC/SiC CMCs, the matrix does not incorporate free silicon, which becomes molten at temperatures >1410 °C). A postprocessing heat treatment (ref. 3) of the CVI SiC/SiC further improved the creep resistance and thermal conductivity of the material (see the graph). Eliminating the porosity that is inherent in CMCs densified via CVI through additional processing to densify the matrix could improve durability, and alternate processing routes are currently being evaluated at Glenn through Independent Research & Development funding.



Creep-rupture of as-fabricated (creep rate, $1.7 \times 10^{-9} \text{ sec}^{-1}$) and postprocessed (creep rate, $2.5 \times 10^{-10} \text{ sec}^{-1}$) CVI SiC/SiC CMCs in air at 1450 °C (2642 °F), under 69-MPa (10-ksi) loading.

NGLT SiC/SiC development ended in September 2004 because the program was cancelled. However, this material development effort indicated that CVI SiC/SiC is a viable candidate for high-temperature applications, including inserted CMC turbine blades, cooled CMC panels, and reusable space vehicle airframe applications. Recently initiated development at Glenn of MI and CVI SiC/SiC CMCs with higher proportional limits (through Independent Research & Development funding) is further improving material durability and providing materials that can be used in the new space exploration initiatives.

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Glenn contact: J. Douglas Kiser, 216-433-3247, James.D.Kiser@nasa.gov

U.S. Army Research Laboratory contact: Dr. Ramakrishna T. Bhatt, 216-433-5513; Ramakrishna.T.Bhatt@grc.nasa.gov

Authors: J. Douglas Kiser, Dr. Ramakrishna T. Bhatt, Dr. Gregory N. Morscher, Dr. Hee Mann Yun, Dr. James A. DiCarlo, and Jeanne F. Petko

Headquarters program office: NGLT

Programs/Projects: NGLT, Propulsion Research and Technology, Glenn IR&D (emphasis on improving resistance to matrix cracking), Exploration Systems (vehicle airframe or propulsion applications)