Improving Thermomechanical Properties of SiC/SiC Composites

A heat treatment increases thermal conductivity and increases creep resistance.

John H. Glenn Research Center, Cleveland, Ohio

Today, a major thrust toward improving the thermomechanical properties of engine components lies in the development of fiber-reinforced silicon carbide matrix composite materials, including SiC-fiber/SiC-matrix composites. These materials are lighter in weight and capable of withstanding higher temperatures, relative to state-of-the-art metallic alloys and oxide-matrix composites for which maximum use temperatures are in the vicinity of 1,100 °C. In addition, the toughness or damage tolerance of the SiC-matrix composites is significantly greater than that of unreinforced silicon-based monolithic ceramics.

For successful application in advanced engine systems, the SiC-matrix composites should be able to withstand component service stresses and temperatures for the desired component lifetimes. Inasmuch as the high-temperature structural lives of ceramic materials are typically limited by creep-induced growth of flaws, a key property required of such composite materials is high resistance to creep under conditions of use. Also, the thermal conductivity of the materials should be as high as possible so as to minimize component thermal gradients and thermal stresses.

A state-of-the-art SiC-matrix composite is typically fabricated in a three-step process: (1) fabrication of a component-shaped architectural preform reinforced by thermally stable high-performance fibers, (2) chemical-vapor infiltration (CVI) of a fiber-coating material such as boron nitride (BN) into the preform, and (3) infiltration of an SiC-based matrix into the remaining porosity in the preform. Generally, the matrices of the highest-performing composites are fabricated by initial use of a CVI SiC matrix component that is typically more thermally stable and denser than matrix components formed by processes other than CVI. As such, the initial SiC matrix component made by CVI provides better environmental protection to the coated fibers embedded within it. Also, the denser CVI SiC imparts to the composite better resistance to propagation of cracks, enhanced thermal conductivity, and higher creep resistance.

For adequate deposition of CVI SiC matrix material into a preform, it is typically necessary to perform the infiltration at a temperature below 1,100 °C. The use of an infiltration temperature in this range typically results in the formation of an SiC matrix that is fairly dense, but contains metastable atomic defects and is non-stoichiometric in that it contains a small excess of silicon. These defects typically exist at the matrix grain boundaries, where they can act as scatterers for thermal phonons and degrade matrix creep resistance by enhancing grain-boundary sliding.

In order to make it possible to eliminate these defects and improve the thermomechanical properties of ceramic composites that contain SiC matrices, researchers at Glenn Research Center (GRC) have developed a high-temperature heat or annealing treatment that can be performed after deposition of a...
Aerogel/Particle Composites for Thermoelectric Devices
Shrinkage is reduced through addition of titania powder.

NASA’s Jet Propulsion Laboratory, Pasadena, California

Optimizing solution chemistry and the addition of titania and fumed silica powder reduces shrinkage. These materials would serve to increase thermal efficiency by providing thermal insulation to suppress lateral heat leaks. They would also serve to prolong operational lifetime by suppressing sublimation of certain constituents of thermoelectric materials (e.g., sublimation of Sb from CoSb$_3$) at typical high operating temperatures. [The use of pure silica aerogels as cast-in-place thermal-insulation and sublimation-suppression materials was described in “Aerogels for Thermal Insulation of Thermoelectric Devices” (NPO-40630), NASA Tech Briefs, Vol. 30, No. 7 (July 2006), page 50.]

A silica aerogel is synthesized in a sol-gel process that includes preparation of a silica sol, gelation of the sol, and drying of the gel in a solvent at a supercritical temperature and pressure. The utility of pure silica aerogel is diminished by a tendency to shrink (and, therefore, also to crack) during the gelation and supercritical-drying stages. Moreover, to increase suppression of sublimation, it is advantageous to make an aerogel having greater density, but shrinkage and cracking tend to increase with density.

A composite material of the type under investigation consists mostly of titania oxide powder particles and a small addition of fumed silica powder, which are mixed into the sol along with other ingredients prior to the gelation stage of processing. The silica aerogel and fumed silica act as a binder, gluing the titania particles together. It is believed