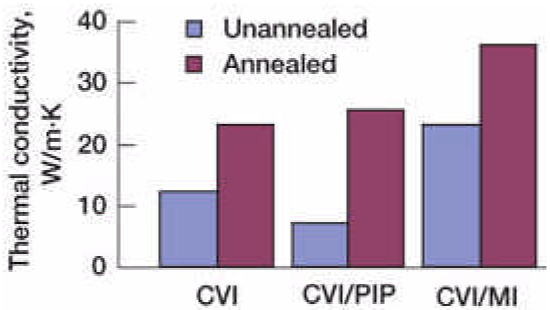
Method Developed for Improving the Thermomechanical Properties of Silicon Carbide Matrix Composites

Today, a major thrust for achieving engine components with improved thermal capability is the development of fiber-reinforced silicon-carbide (SiC) matrix composites. These materials are not only lighter and capable of higher use temperatures than state-of-the-art metallic alloys and oxide matrix composites (~1100 °C), but they can provide significantly better static and dynamic toughness than unreinforced silicon-based monolithic ceramics. However, 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 lifetime. Since the high-temperature structural life of ceramic materials is typically controlled by creep-induced flaw growth, a key composite property requirement is the ability to display high creep resistance under these conditions. Also, because of the possibility of severe thermal gradients in the components, the composites should provide maximum thermal conductivity to minimize the development of thermal stresses.

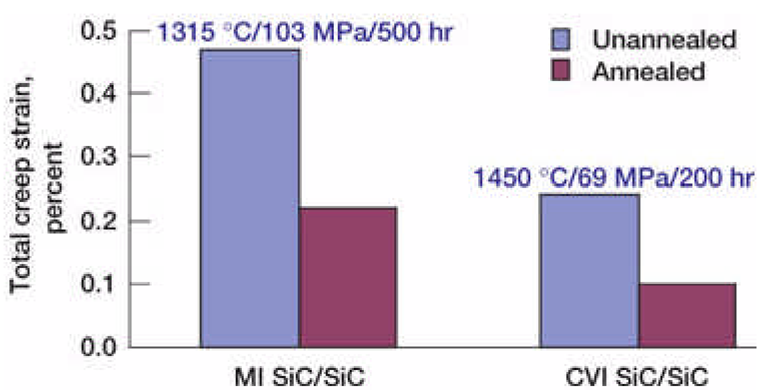
State-of-the-art SiC matrix composites are typically fabricated via a three-step process: (1) fabrication of a component-shaped architectural preform reinforced by high-performance fibers, (2) chemical vapor infiltration of a fiber coating material such as boron nitride (BN) into the preform, and (3) infiltration of a SiC matrix into the remaining porous areas in the preform. Generally, the highest performing composites have matrices fabricated by the CVI process, which produces a SiC matrix typically more thermally stable and denser than matrices formed by other approaches. As such, the CVI SiC matrix is able to provide better environmental protection to the coated fibers, plus provide the composite with better resistance to crack propagation. Also, the denser CVI SiC matrix should provide optimal creep resistance and thermal conductivity to the composite. However, for adequate preform infiltration, the CVI SiC matrix process typically has to be conducted at temperatures below 1100 °C, which results in a SiC matrix that is fairly dense, but contains metastable atomic defects and is nonstoichiometric because of a small amount of excess silicon. Because these defects typically exist at the matrix grain boundaries, they can scatter thermal phonons and degrade matrix creep resistance by enhancing grain-boundary sliding.

To eliminate these defects and improve the thermomechanical properties of ceramic composites with CVI SiC matrices, researchers at the NASA Glenn Research Center developed a high-temperature treatment process that can be used after the CVI SiC matrix is deposited into the fiber preform. Using Glenn-developed Sylramic-iBN SiC fibers (ref. 1) and BN-based fiber coatings (ref. 2), which are stable in their functions under the treatment conditions, Glenn researchers observed minimal strength loss for composite panels formed from two-dimensional architectural preforms. More importantly, significant improvements were observed in composite thermal conductivity and creep resistance, as indicated in the left and right bar charts, respectively. For these panels, total fiber and coating volume fractions were ~35 and 5 vol%, respectively, and the CVI SiC matrices were deposited at ~50 and ~35 vol%. Porous areas that remained open in the 35 vol% CVI SiC matrices were filled either by repeated polymer infiltration and pyrolysis of a SiC yielding polymer, or by the melt infiltration of silicon near 1400 °C. The left bar chart also shows the detrimental effect of trapped porosity in the full CVI SiC matrix and the beneficial effect of pore filling for the hybrid CVI plus MI SiC matrix. However, the full CVI SiC matrix is best in creep resistance and allows temperature capability beyond 1400 °C (see the right bar chart on the preceding page), which is near the upper use temperature for the CVI plus MI SiC matrix (ref. 3).

Improvements in thermal conductivity of SiC/SiC CMCs will reduce thermal stresses in gas turbine engine components, such as combustor liner and turbine blades. Improvements in creep resistance will increase the life of CMC components in gas turbine engines.



Effect of Glenn annealing treatment process on the room-temperature through-the-thickness thermal conductivity of Sylramic iBN SiC/BN/SiC composite panels containing full chemical vapor infiltration (CVI) (~50 vol%) SiC matrix, CVI (~35 vol%) plus polymer infiltration and pyrolysis (PIP) SiC matrix, and CVI (~35 vol%) plus melt infiltration (MI) SiC matrix.
Thermal conductivity of SiC/SiC ceramic composites is improved by thermal treatment (annealing) process developed at Glenn. The annealing studies were conducted on CMCs processed by three different methods: (1) CVI only, (2) combination of CVI and PIP, and (3) combination of CVI and MI. The thermal treatment increased thermal conductivity of CMCs processed by all three methods.



Effect of Glenn annealing treatment process on the tensile creep strain of Sylramic-iBN SiC/BN/SiC composite panels with a CVI (~35 vol%) plus MI SiC matrix and with a full CVI (~50 vol%) SiC matrix.
Creep resistance of SiC/SiC ceramic composites improved by thermal treatment (annealing) process developed at Glenn.

References

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