anelastic (recoverable) and viscoelastic (nonrecoverable) creep strain components; (2) below the matrix cracking stress, both creep strain components vary linearly with stress (tension and compression); (3) temperature effects (activation energies) on the creep strain components are the same as those measured for SiC fibers; and (4) composite creep strain with a primary and secondary stage (see the graph on the preceding page) can be analytically fit to a four-parameter mechanical analog model (ref. 3).

Although little, if any, composite creep data exist for stresses off the primary fiber direction, one can make initial assumptions for the directional behavior using composite and monolithic SiC creep theories. Then for finite element analyses, directional four-parameter models can be developed to generate stress-relaxation Prony series for input into commercial design codes such as ANSYS. This, in turn, should allow prediction of creep effects in SiC/SiC components that will be subjected to stress and temperature gradients. Glenn is currently working to develop these capabilities by generating the missing creep data and by doing preliminary finite element analyses to evaluate the degree of residual stress development in highly stressed sections of potential SiC/SiC components, such as within the leading edge of an internally cooled SiC/SiC turbine airfoil.

References

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An advanced multicomponent hafnia (HfO₂) and rare-earth-doped mullite/silicate thermal- and environmental-barrier coating (T/EBC) system was developed for high-temperature silicon nitride (Si₃N₄) turbine vane applications (refs. 1 to 3). The coating systems, along with a 2600 °F (1427 °C)-capable ceramic bond coat, showed improved water-vapor resistance and high-temperature dynamic rupture strength for AS800 and SN282 Si₃N₄ substrates (refs. 2 and 3). The current research effort at the NASA Glenn Research Center was focused on testing and demonstrating the T/EBC-coated Si₃N₄ vane durability, improving the robustness of the coating processing of complex-shaped components, and providing vital design data for coating technology development.

The coating systems for the component demonstration consisted of a low-expansion HfO₂ top coat, a rare-earth-doped mullite and/or ytterbium silicate (Yb₂SiO₃) environmental barrier coating system, and a multicomponent HfO₂-based bondcoat. Two types of coated nozzle vanes (Honeywell Engines of Phoenix, Arizona) were used for the High Pressure Burner Rig demonstrations at temperatures up to 2700 °F (1482 °C). The coating systems were deposited onto AS 800 Si₃N₄ nozzle vanes using room-temperature plasma spray. The total T/EBC thickness was about 127 to 180 μm (0.005 to 0.007 in.).

The top photograph on the next page shows the High Pressure Burner Rig and the AS800 Si₃N₄ vane testing
configurations. Single- and triple-vane test fixtures were designed and fabricated for the larger-sized and miniature-sized vanes for the burner rig tests, respectively, as shown in center and bottom photographs. The burner rig temperature conditions were characterized for the vane test fixture configurations. The following graph illustrates the flame gas temperatures as a function of fuel/air ratio and the location for the triple-vane test configuration. All vane tests were conducted under 6-atm pressure and 30-m/sec combustion gas velocity for up to 50 hot hours at the maximum gas temperature of 1632 °C (2970 °F). The vane temperature was monitored using a pyrometer and then fully modeled for the temperature distributions using finite element analysis (FEA) methods.

The three-dimensional plot on the next page shows the FEA-modeled temperature distribution for a vane test at the gas temperature of 1632 °C (2970 °F). It can be seen that the nozzle vane leading-edge temperature reached approximately 2700 °F (1482 °C). The vane leading-edge, which experienced the highest temperature and gas velocity (and thus also the highest stresses), generally showed more coating recession and damage accumulations. A tested vane is shown in the photograph on the next page. Durability of the coated-ceramic vane has been demonstrated for 50 hr at temperatures up to 2700 °F (1482 °C), providing essential coating design experience for silicon-based ceramic component systems. The advanced T/EBCs show great promise toward achieving the component performance goals for future advanced turbine engines.

Flame gas temperature distributions. T, temperature.
References

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FEM temperature distribution of the Si$_3$N$_4$ vane. This figure is shown in color in the online version of this article (http://www.grc.nasa.gov/WWW/RT/2006/RX/RX08D-zhu.html).