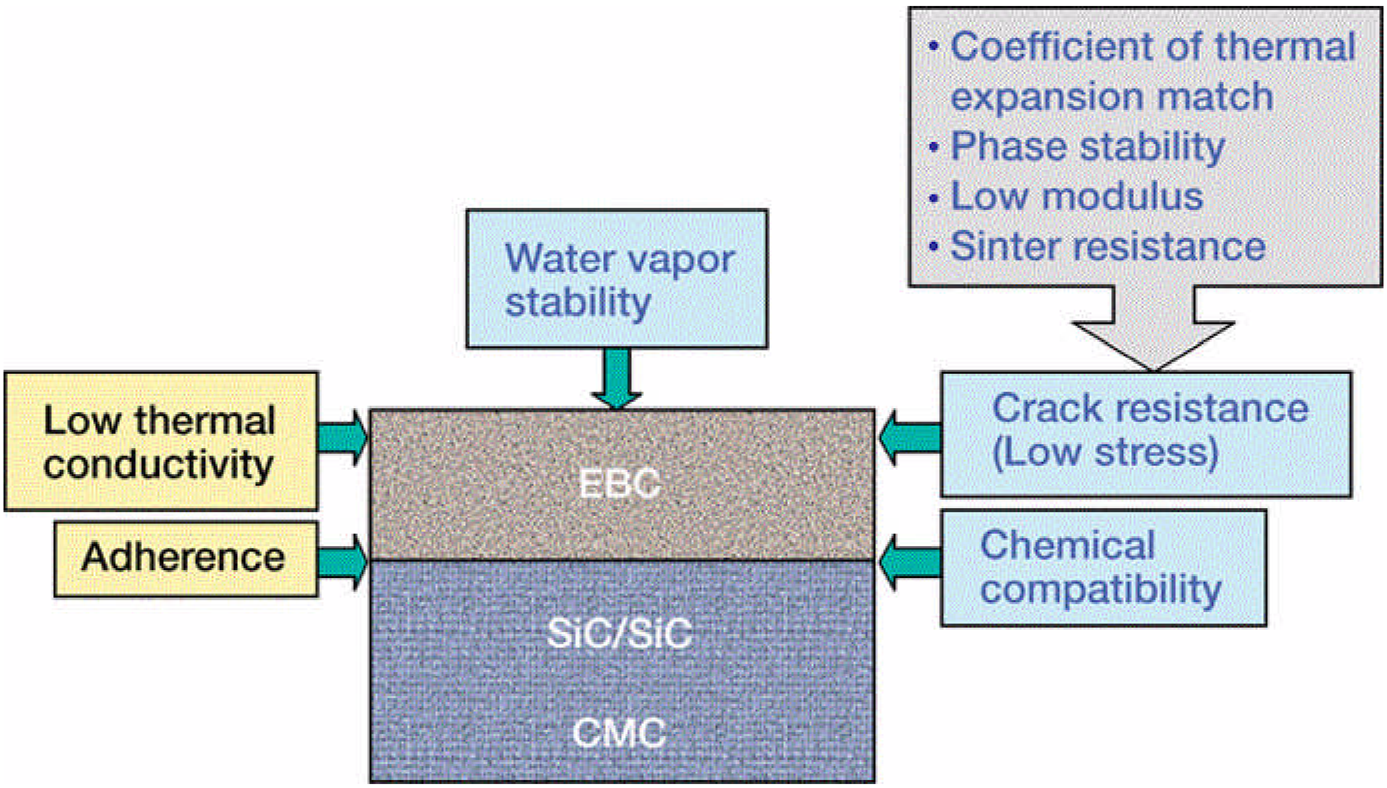
Advanced Environmental Barrier Coatings Developed for SiC/SiC Composite Vanes

Ceramic components exhibit superior high-temperature strength and durability over conventional component materials in use today, signifying the potential to revolutionize gas turbine engine component technology. Silicon-carbide fiber-reinforced silicon carbide ceramic matrix composites (SiC/SiC CMCs) are prime candidates for the ceramic hot-section components of next-generation gas turbine engines. A key barrier to the realization of SiC/SiC CMC hot-section components is the environmental degradation of SiC/SiC CMCs in combustion environments. This is in the form of surface recession due to the volatilization of silica scale by water vapor. An external environmental barrier coating (EBC) is a logical approach to achieve protection and long-term durability.



Key EBC requirements.

Long description. The diagram shows (1) EBC requirements for low thermal conductivity, water vapor stability, coefficient of thermal expansion match, phase stability, low modulus, sinter resistance, and crack resistance (low stress); (2) EBC interface with SiC/SiC requirements of adherence and chemical compatibility; (3) layer order: top-EBC, middle-SiC/SiC, bottom-CMC.

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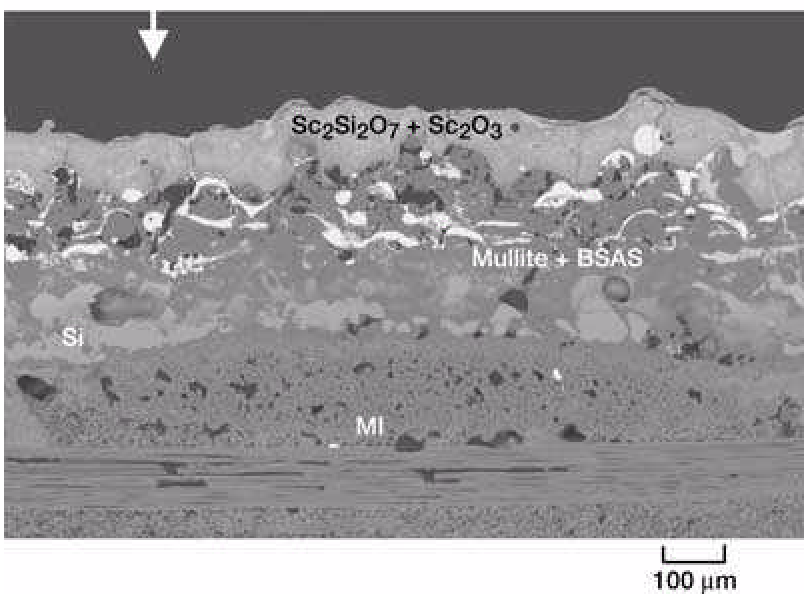
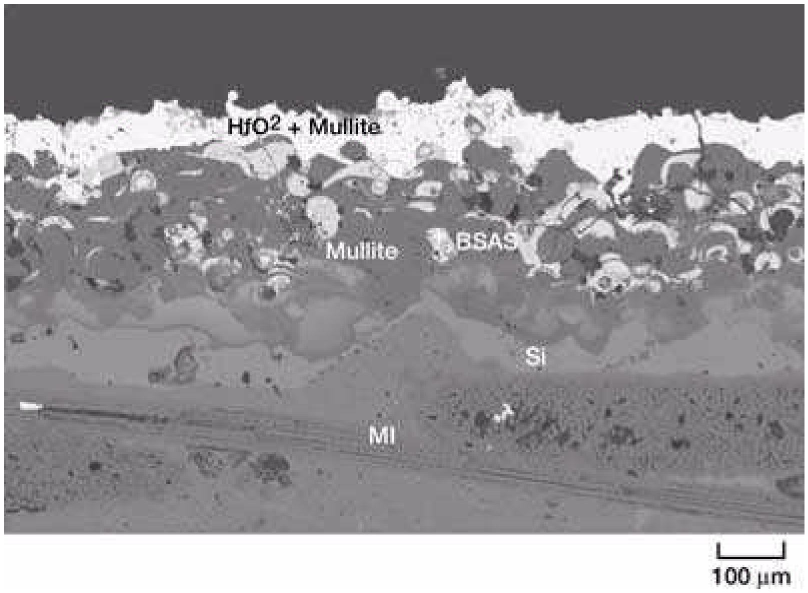
At the NASA Glenn Research Center, research was undertaken in the Ultra-Efficient Engine Technology (UEET) Program to develop advanced, multilayer environmental barrier coatings (EBCs), having a temperature capability of 2700 °F (1482 °C) at the EBC surface and 2400 °F (1316 °C) at the EBC/CMC interface. The preceding figure indicates the key requirements for a successful EBC. These include water vapor stability, chemical stability between the multiple layers of the EBC and at the EBC/CMC interface, low thermal expansion and phase stability for minimizing the stresses, and environmental durability in combustion environments. It is also desirable for an EBC to have a low thermal conductivity to maximize its thermal insulation potential.

Two very promising EBC systems have evolved from this work: silicon/mullite+BSAS/rare earth silicates and silicon/mullite+BSAS/hafnia-based oxides (U.S. patent pending). Mullite is an alumina-silica system, of the form $3Al_2O_3$-$2SiO_2$, and BSAS is a barium-strontium-alumina-silicate system, of the form BaO-SrO-Al_2O_3-$2SiO_2$. The photomicrographs show cross sections of melt infiltrated (MI) SiC/SiC CMCs coated with silicon/mullite+BSAS/scandium silicate+scandia EBC and silicon/mullite+BSAS/hafnia+mullite EBC, respectively, after 300 hr at 1400 °C with 1-hr cycles in a simulated combustion environment (90 vol% H_2O-balance O_2). Both coating systems show excellent performance with minimal oxidation, cracking, and chemical reactions.



Cross section of Si/mullite+BSAS/$Sc_2Si_2O_7$+Sc_2O_3 EBC-coated SiC/SiC CMC after 300 hr at 1400 °C with 1-hr cycles in a simulated combustion environment (90 vol% H_2O-balance O_2) .



Cross section of Si/mullite+BSAS/HfO_2+mullite EBC-coated SiC/SiC CMC after 300 hr at 1400 °C with 1-hr cycles in a simulated combustion environment (90 vol% H_2O-balance O_2).

The new EBCs meet or exceed the UEET Program goal. The coatings are stable in water vapor (no material recession) at 1500 °C, are chemically stable (no detrimental interfacial chemical reactions) at temperatures up to 1400 °C, and have demonstrated environmental durability in a simulated combustion environment at temperatures from 1316 to 1400 °C. The new EBC top layers possess thermal conductivity as much as a factor of 2 lower than that of zirconia-8 wt% yttria-the current state-of-the-art thermal barrier coating-making them excellent thermal barrier coatings as well. The new EBCs will be optimized, scaled-up, and applied on SiC/SiC vanes. The performance of the coated CMC components will be evaluated in Glenn's high-pressure, high-velocity combustion burner rig during the upcoming year.

Find out more about the research of Glenn's Environmental Durability Branch http://www.grc.nasa.gov/WWW/EDB/.

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