HIGH TEMPERATURE INTERACTIONS BETWEEN ENVIRONMENTAL BARRIER COATING (EBC) CERAMICS AND CALCIA-MAGNESIA-ALUMINA-SILICATE (CMAS) GLASS

Laura R. Turcer, Brown University
laura_turcer@brown.edu
Amanda R. Krause, Brown University
Hector Garces, Brown University
Lin Zhang, Brown University
Nitin P. Padture, Brown University

Key Words: environmental barrier coating; CMAS glass; yttrium disilicate; yttrium disilicate; ytterbium disilicate; scandium disilicate

Ceramic-matrix-composites (CMCs) are being researched to replace current metallic hot-section components, which would allow for higher operating temperatures. Due to the oxidation of CMCs (usually SiC-based) in the presence of water vapor, dense environmental barrier coatings (EBCs) are needed. At temperatures above 1200 °C, silicate particles (sand, volcanic ash, fly ash, etc.) enter the engine, melt on the hot surfaces and form calcia-magnesia-alumina-silicate (CMAS) glass deposits. The molten CMAS glass can penetrate grain boundaries and cause dissolution, which leads to premature failure. New coatings are needed to protect CMCs from CMAS attack.

A new model, based on optical basicities, has been used to predict the reactivity between CMAS and potential EBC ceramics. Based on this analysis, several potential EBC ceramics have been identified: yttrium aluminate ($YAlO_3$), yttrium disilicate (γ-$Y_2Si_2O_7$), ytterbium disilicate (β-$Yb_2Si_2O_7$), and scandium disilicate (β-$Sc_2Si_2O_7$).

High-temperature (1500 °C) interactions of these four promising dense, polycrystalline EBC ceramics with a CMAS glass have been studied systematically. Although the optical basicities of all the EBC ceramics and the CMAS are similar, Y-bearing EBC ceramics react more with the CMAS. In Si-free $YAlO_3$, the reaction zone is small and it contains three regions of reaction-crystallization products: (i) needle-like Y-Ca-Si apatite(*ss*) grains, (ii) blocky grains of YAG(*ss*) or $Y_3Al_5O_{12}$(*ss*), and (iii) a mixture of Y-Ca-Si apatite(*ss*) and YAG(*ss*) blocky grains. In contrast, only Y-Ca-Si apatite(*ss*) forms in the case of Si-containing γ-$Y_2Si_2O_7$, and the reaction zone is an order-of-magnitude thicker. These CMAS interactions are analyzed in detail, and are found to be strikingly different than those observed in Y-free EBC ceramics (β-$Yb_2Si_2O_7$ and β-$Sc_2Si_2O_7$). This is attributed to the presence of the Y in the $YAlO_3$ and γ-$Y_2Si_2O_7$ EBC ceramics. There is little or no reaction found between the Y-free EBC ceramics and the CMAS. In the case of β-$Yb_2Si_2O_7$, a small amount of reaction-crystallization product Yb-Ca-Si apatite(*ss*) forms, whereas none is detected in the case of β-$Sc_2Si_2O_7$. Instead, the CMAS glass penetrates the grain boundaries and triple junctions of both Y-free EBC ceramics, and they suffer from a new type of 'blistering' damage comprising of large and wide cracks (Figure 1, C and D). This is attributed to the through-thickness dilatation-gradient caused by the slow grain boundary penetration of the CMAS glass. Based on this understanding, a 'blistering' damage-mitigation approach is devised and successfully demonstrated, where 1 vol% CMAS glass is mixed into the β-$Yb_2Si_2O_7$ powder prior to sintering. The resulting EBC ceramic does not show the 'blistering' damage, as the presence of the CMAS-glassy phase at the grain boundaries promotes rapid CMAS-glass penetration, thereby eliminating the dilatation-gradient.

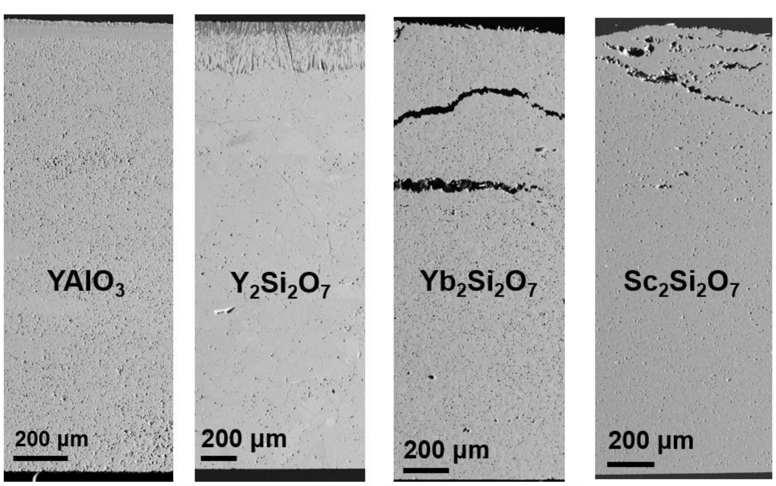

Figure 1 – Cross-sectional SEM images of CMAS-interacted (A)$YAlO_3$, (B) $Y_2Si_2O_7$, (C) $Yb_2Si_2O_7$ and (D) $Sc_2Si_2O_7$ after 24 hours at 1500 °C. Y-bearing EBC ceramics (A,B) show a reaction zone on the surface of the pellet (top), whereas Y-free EBC ceramics show 'buckling' cracks and a very limited or no reaction zone.