Mechanical Properties and Durability of Advanced Environmental Barrier Coatings in Calcium-Magnesium-Alumino-Silicate Environments

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Abstract

Environmental barrier coatings are being developed and tested for use with SiC/SiC ceramic matrix composite (CMC) gas turbine engine components. Several oxide and silicate based compositions are being studied for use as top-coat and intermediate layers in a three or more layer environmental barrier coating system. Specifically, advanced multi-component oxide and silicate composites are being developed to improve the coating mechanical integrity and environmental stability for CMCs.

Introduction

Advanced SiC/SiC ceramic matrix composites (CMCs) developed for gas turbine engine hot section component applications are susceptible to environmental attack from harsh combustion and general operation. This is why it is necessary to apply layers of environmental barrier coatings (EBCs) to protect SiC/SiC CMCs. EBC materials have to withstand the extremely high temperature and corrosive environment, and integrate well with the CMCs to ensure excellent thermal cyclic durability. Advanced multi-component oxide and silicate composites are being developed to improve the coating mechanical integrity and environmental stability for CMCs.

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EBC Materials Tested

- Sample configurations
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  - Sample preparation
  - High pressure burner rig
  - CMAS Reaction and Behavior
  - With Coatings
  - EBC Materials Tested
  - Vickers indentation toughness
  - Laser heat flux testing
  - SEM EDS
  - CMAS reaction
  - Barium Strontium Alumino-Silicate (BSAS)
  - ZrO2 + 4.5wt%Yb2O3 + 4wt%Gd2O3 + 3.5wt%Y2O3 (ZrO 311)
  - ZrO2 + 3.0wt%Y2O3 + 3.2wt%Gd2O3 + 3.7wt%Yb2O3 (ZrO 312)
  - HfO2 + 50wt% (HfO2+5wt%Y2O3)
  - Yb2SiO5
  - SiC/SiC CMC substrate

Experimental Procedure

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Results

- Fracture toughness
- Hardness Vickers
- Laser heat flux testing
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Concluding Remarks

Initial fracture toughness testing using the Vickers indentation approach has shown that the ZrO2 and HfO2 coating materials are the most fracture resistant. Further testing is being considered to determine the strength and fracture toughness of materials reacted with CMAS.

Seven mechanisms of CMAS interactions with the coating materials have been identified. While the oxides were more stable than the silicates, they were still affected by penetration and void generation from CMAS especially when high initial pressure is present. Silicates reacted strongly with the CMCs generally decreasing the melting point and causing the coating to change phases as evidenced from X-ray diffraction such as in Y2SiO5 case. Some coating materials experienced combinations of all of the effects. The laser-high heat flux tests showed the damage and potentially reduced temperature capability caused by the CMAS on a multilayer hybrid EB-PVD Plasmalloy oxidesilicate EBC. This can be fatal to the coating structure as the operating temperature approaches the melting point of these materials after reacting with CMAS. The HPPR tests showed that the CMAS reacts with Er2Si2O7 to cause damage and potentially reduced temperature capability caused by the CMAS on a multilayer hybrid EB-PVD Plasmalloy oxidesilicate EBC. This can be fatal to the coating structure as the operating temperature approaches the melting point of these materials after reacting with CMAS. The HPPR tests showed that the CMAS reacts with Er2Si2O7 to cause damage and potentially reduced temperature capability caused by the CMAS on a multilayer hybrid EB-PVD Plasmalloy oxidesilicate EBC. This can be fatal to the coating structure as the operating temperature approaches the melting point of these materials after reacting with CMAS. The HPPR tests showed that the CMAS reacts with Er2Si2O7 to cause damage and potentially reduced temperature capability caused by the CMAS on a multilayer hybrid EB-PVD Plasmalloy oxidesilicate EBC. This can be fatal to the coating structure as the operating temperature approaches the melting point of these materials after reacting with CMAS.

Figure 2: The initial vickers indentation results of non-CMAS-reacted coatings. (a) the mean value of each sample Kc was measured from the crack lengths. ZrO 311 was the toughest material. (b) the samples Hv as measured using the length of the diagonals. Hardness data was easily taken from the fracture toughness tests so (b) shows the hardest material as the Hf2O2 + 5wt%Y2O3.

Figure 4: (above) Laser-high-heat flux tests were conducted on three structurally identical samples. With surface concentration increasing from left to right it is evident that the CMAS is causing damage and melting of the coatings. (Left) the increase in conductivity is due to the continued sintering from the high temperatures.

Figure 6: (right) Shows the increasing thickness of various layers of mullite. Each layer represents a different effect CMAS had. Time in hours is on the x axis. Depth is on the y axis.

Figure 7: (left) SEM backscatter electron image of three images stitched together. Yb2SiO5 exposed to CMAS twice for a total of 100 hrs. This image illustrates the combined effects of penetration, void generation, reaction/chemical change, and melting.

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