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) 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, the room temperature Vickers-indentation-fracture-toughness testing and high-temperature reaction studies with Calcium Magnesium Alumino-Silicate (CMAS or “sand”) are being conducted using advanced testing techniques such as high pressure burner rig tests as well as high heat flux laser tests.

Introduction

Advanced SiC/SiC ceramic matrix composites (CMCs) developed for gas turbine engine hot section component applications are susceptible to environmental attack from high-temperature combustion and high-temperature service. 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 environments, and are designed to integrate well with the CMC to ensure excellent thermal cyclic durability. Advanced multicomponent oxide and silicate composites are being developed to improve the coating mechanical integrity and environmental stability for CMAs.

CMCs gas turbine components generally require a layered environmental barrier coating system for improved performance, stability, and durability. EBCs are developed to improve the coating mechanical integrity and environmental stability for CMAs. These materials have to withstand the extremely high temperature and corrosive environments, and are designed to integrate well with the CMC to ensure excellent thermal cyclic durability.

Experimental Procedure

EBC Materials Tested

- Vickers Indentation Fracture Toughness
- Oxides
  - Silicate: Er₂SiO₅
  - Silicate: Barium Strontium Alumino-Silicate (BSAS)
  - Er₂SiO₅ + BSAS
- CMA Reaction
- Oxides
  - SiO₂ + 5wt%Y₂O₃
  - HfO₂ + 50wt% (HfO₂ + 20wt%Y₂O₃)
- SiC/SiC CMC Substrate

Sample Configurations

- 1in diameter x 1/8in thick disc specimens
- High pressure burner rig
- Laser high heat flux testing

Results

Fracture Toughness

Hardness Vickers

Laser Heat Flux Testing

High Pressure Burner Rig Test – Tyrannoxx SA and Er₂SiO₅

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 initial high porosity is present. Silicates reacted strongly with the CMAs generally decreasing the melting temperature 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/Plasma spray oxide-silicate 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-reacted Er₂SiO₅ seemed to be damaged (dilamination and disintegration) and had higher recession rates compared to the non-reacted Er₂SiO₅.

While these studies are not complete, the current results easily showed that CMAS can cause serious damage to the coating or coating materials. Coating that have improved resistance to CMAS may be desired and tested for advanced EBC systems.