Thermal Conductivity and Water Vapor Stability of Ceramic Coating Materials

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HfO$_2$-Y$_2$O$_3$ and La$_2$Zr$_2$O$_7$ are candidate thermal/environmental barrier coating materials for gas turbine ceramic matrix composite (CMC) combustor liner applications because of their relatively low thermal conductivity and high temperature capability. In this paper, thermal conductivity and high temperature phase stability of plasma-sprayed coatings and/or hot-pressed HfO$_2$-5mol%Y$_2$O$_3$, HfO$_2$-15mol%Y$_2$O$_3$ and La$_2$Zr$_2$O$_7$ were evaluated at temperatures up to 1700°C using a steady-state laser heat-flux technique. Sintering behavior of the plasma-sprayed coatings was determined by monitoring the thermal conductivity increases during a 20-hour test period at various temperatures. Durability and failure mechanisms of the HfO$_2$-Y$_2$O$_3$ and La$_2$Zr$_2$O$_7$ coatings on mullite/SiC Hexoloy or CMC substrates were investigated at 1650°C under thermal gradient cyclic conditions. Coating design and testing issues for the 1650°C thermal/environmental barrier coating applications will also be discussed.
Thermal Conductivity and Water Vapor Stability of HfO₂-Based Ceramic Coating Materials

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Abstract

HfO$_2$-based oxides are important thermal/environmental barrier coating materials for 3000°F ceramic matrix composite (CMC) applications. In this paper, thermal conductivity and high temperature stability of hot-pressed HfO$_2$-based disk specimens and plasma-sprayed coatings were evaluated at temperatures up to 1700°C using a steady-state laser heat-flux technique. Sintering behavior of the plasma-sprayed coatings was determined by monitoring the thermal conductivity changes under steady-state heat flux testing. Durability and failure mechanisms of the HfO$_2$-Y$_2$O$_3$ coatings on mullite/SiC hexoloy or CMC substrates were investigated at 1650°C under thermal gradient cyclic conditions.
Thermal and Environmental Barrier Coatings (T/EBCs) are Critical to Future Advanced Gas Turbine Engine Systems

- Advanced T/EBCs can increase engine temperatures, reduce cooling, lower emission, and improve engine efficiency and reliability

- Low thermal conductivity and long-term high temperature stability are important issues for developing advanced coating systems

(a) without T/EBC  
(b) with a T/EBC system  
(c) with an advanced T/EBC
Temperature Reductions by Ceramic Coatings will Increase for Future Advanced Low Emission and High Performance Engine Applications

— Advances in coatings technology will increase blade, vane and combustor temperature capability, help to achieve engine emission, efficiency and performance goals
Objectives

— Thermal conductivity and sintering behavior of HfO₂-Y₂O₃ based coating materials as compared to other baseline materials
  Hot-pressed specimens and plasma-sprayed coatings

— Water vapor stability of HfO₂-Y₂O₃ oxides at temperatures up to 1650°C (3000°F)

— The cyclic durability of HfO₂-Y₂O₃ coating systems at 1650°C (3000°F)
Experimental

— The coating systems include:
  • HfO₂-Y₂O₃ with 5, 10, 15, 20, or 25 mol% Yttria
  • advanced multi-component HfO₂ also investigated

— Test specimens were either hot-pressed disks (25.4 mm diameter, 3-4 mm thick), or plasma-sprayed coatings, coated on mullite/Si/SiC hexoloy or MI SiC/SiC ceramic matrix composite

— Water vapor determined by TGA and laser steam chamber

— Thermal conductivity and cyclic durability determined by a laser heat-flux technique for the coating systems on SiC hexoloy and CMCs
Laser High-Heat-Flux Approach for Advanced Thermal/Environmental Barrier Coatings Development

3.0 kW CO₂ High Power Laser

reflectometer
camera
laser beam/integrating lens
300 RPM
specimen
thermocouple
pyrometer
aluminum laser aperture plate
air gap
platinum flat coils
ceramic coating
bond coat
miniature thermocouple
TBC coated back aluminum plate edge
aluminum back plate
Ni base superalloy or ceramic substrate

7.9 μm pyrometer for \( T_{\text{ceramic-surface}} \)

\( q_{\text{delivered}} \)

\( q_{\text{radiant}} \)

\( q_{\text{thru}} \)

Optional miniature thermocouple for additional heat flux calibration

Two-color and 7.9 μm pyrometers for \( T_{\text{substrate-back}} \)
Thermal Conductivity Measurements of Hot-Pressed HfO$_2$-Y$_2$O$_3$ Coatings

Temperature dependence can be determined using the laser heat-flux test approach.
Thermal Conductivity of Hot-Pressed HfO$_2$-Y$_2$O$_3$ Coatings

- Thermal conductivity decreases with increasing yttria dopant concentration
- Porosity in the hot-pressed specimens can affect the conductivity measurements
Thermal Conductivity and Sintering Behavior of Plasma-Sprayed HfO$_2$-Y$_2$O$_3$ Coatings Compared with other Coating Materials

HfO$_2$ coatings showed low thermal conductivity and excellent high temperature stability.
Advanced Coatings Development
Sintering and Cyclic Response of Advanced HfO₂ Coating Systems on SiC Substrate Tested at 3000°F
— Initial 20 hr sintering testing and then thermal cyclic testing at 3000°F
— The advanced HfO₂ coating system showed excellent performance
Low Yttria-Hafnia Baseline Showed Severe Cracking and Spalling after Testing at 3000°F

— Sintering, high temperature phase stability along with the CTE mismatch stress are the major causes for the low yttria dopant HfO₂ coating’s failure
Water Vapor Stability of Advanced HfO₂ coatings

Advanced HfO₂ coatings showed excellent water vapor stability at high temperature.
Concluding Remarks

- Thermal gradient sintering and cyclic durability test approach is demonstrated for advanced 3000F (1650°C) T/EBC coatings development

- Phase stability, and sintering and thermal stress resistance are crucial for coating 3000°F durability

- HfO$_2$-Y$_2$O$_3$ are promising coating materials due to low thermal conductivity, good sintering resistance, and excellent water vapor stability
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