Cyclic Fatigue Durability of uncoated and EBC coated 3D SiC/SiC Composites under thermal gradient conditions at 2700F in air

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Material

- **SiC/SiC CMC**
  - 3D angle interlock woven Sylramic-iBN fibers
  - Hybrid CVI/PIP Matrix
- **Silicon-Hafnia bond coat**
- **Rare Earth Silicate EBC deposited by Electron Beam Physical Vapor Deposition (EBPVD)**
Objective

• Explore the durability of CMC/EBC system in air
  – Future tests will be done in steam
• Isothermal and through-thickness thermal gradient tests were conducted
  – Thermal gradients are representative of the conditions within a cooled CMC component
  – Isothermal tests provide uniform baseline properties
• What we want to determine
  – What is the failure mechanism?
  – Will the EBC protect from oxygen diffusion?
Fatigue Testing of CMCs under Thermal Gradient Conditions

Laser Test Rig

- Laser Heating (4000 W) on Front (0.8 inch spot size)
- Backside Air Cooling
- Surface Temperature Measured with Pyrometers and/or IR Camera
- Surface Temperatures up to 3000 °F (Material Dependent)
- Thermal Fatigue and Combined Thermal Gradient and Axial Fatigue

- Uncoated SiC/SiC Composites
- EBC Coated SiC/SiC Composites

- Servohydraulic, 25 kN Load Cell
- Water-cooled Wedge Grips
- Two 1 in. Gage Length, Water-Cooled Extensometers; 6 in. Long Tensile Specimens
- Frequencies up to 30 Hz
- Load and Stroke Control
Test Issues

• Accurate measurement of through-thickness thermal gradient
  – Pyrometers were used to measure surface temperature
  – Emissivity of the EBC is required to measure temperature with the pyrometer
  – EBC emissivity will change over time
  – Isothermal furnace tests are being done to compare thermocouples and optical pyrometers

• CMC or bond coat temperatures must be estimated from heat transfer
  – The goal was to run isothermal and thermal gradient tests at the same CMC temperature
  – Only the EBC temperature could be monitored during the test
  – The laser power was held approximately constant to maintain constant surface temperature
  – Changes in EBC thermal conductivity over time will affect the CMC temperatures
SPLCF Results under Through-Thickness Thermal Gradient

- EBPVD Coated sample
- Average EBC surface temperature: 2950°F
- Average EBC/CMC interface temperature: 2742°F
- CMC back surface temperature: 2442°F
- Maximum EBC surface temperature: >3000°F

2 min hold at 69 MPa
2 sec. ramp
Un-load to 34.5 MPa

Time
Stress

Graph 1: Front strain vs. time, CMC back strain vs. time
Graph 2: Surface temperature vs. time, Back surface temperature vs. time
SPLCF Results
Thermal Gradient Compared to Isothermal Conditions

- Both CMC samples were the same system (architecture, matrix, bond coat, EBPVD EBC)
- Both loaded with the same stress profile
- 2700°F isothermal temp is similar to the CMC/EBC interface temp (2742°F) for laser test
- Strain of the isothermal sample is expected to be similar to the front strain of the laser sample

2 min hold at 69 MPa
2 sec. ramp
Un-load to 34.5 MPa
Examination of Sample that Broke During 487 Hour Thermal Gradient SPLCF

- The sample broke outside the hottest region
- The fracture surface was close to the edge of the hot zone (~2200°F)
- The EBC showed pitting/ cracking in the hot zone, below the fracture surface
CT Images Before and After Thermal Gradient SPLCF

Before Testing - Only EBC Shown

After Laser SPLCF (69 MPa, 487 hr) - Only EBC Shown
CT Images After Thermal Gradient SPLCF

Fractured End

Image of the EBC Only
CT Cross-Section Images Before and After Thermal Gradient SPLCF

Before Testing

After Laser SPLCF (69 MPa, 487 hr)
SEM of Fracture Surface after 487 hour Laser SPLCF

- Very flat fracture surface, little fiber pull-out
SEM of Fracture Surface after 487 hour Laser SPLCF
SEM of Fracture Surface after 487 hour Laser SPLCF

Polished section of the as-produced system for comparison
Most of the fiber tows exhibited brittle failure

Oxygen mapping of the cross-section was planned, but not yet completed
  - We want to know if the bond coat is oxidizing in air, before moving on to steam
  - Regardless, the sample lasted 487 hours
Conclusions

- Thermal gradient tests are relevant for cooled CMCs
- Interpretation of the data is complicated
- CT images of as-produced sample showed regions of thin coatings
- After the 487 hour SPLCF, some areas of the coating were missing
- The sample may have been overheated beyond 3000F (EBC temperature)
- This sample lasted 487 hours under thermal gradient SPLCF
- More tests are underway to evaluate the material
  - Steam exposure, more thermal gradient tests