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

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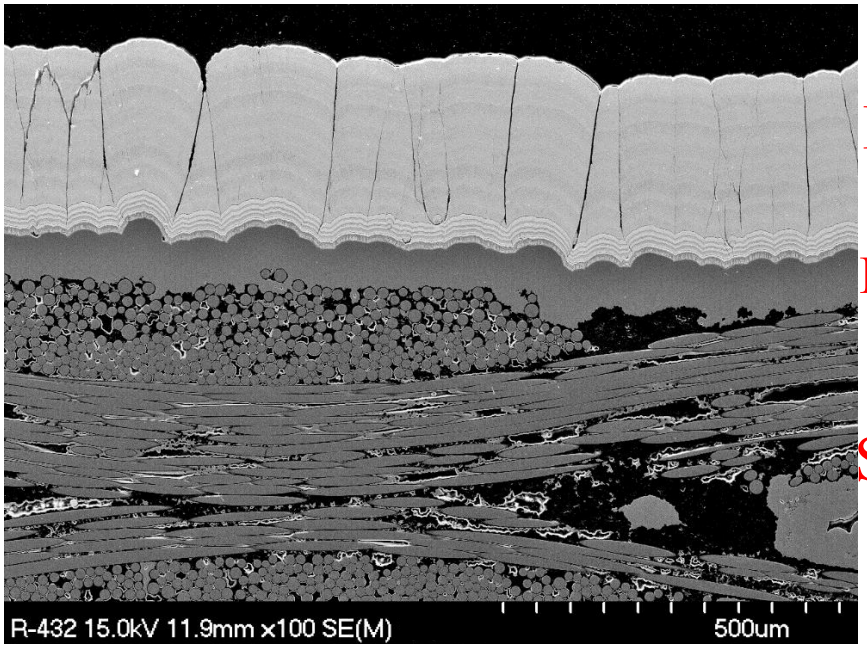
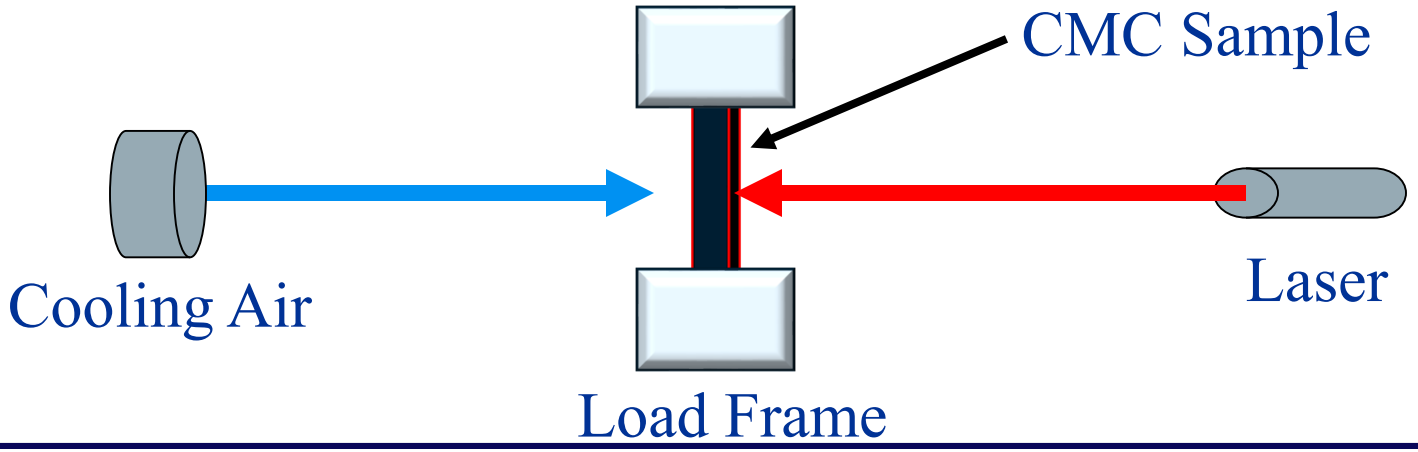
Material

- 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?

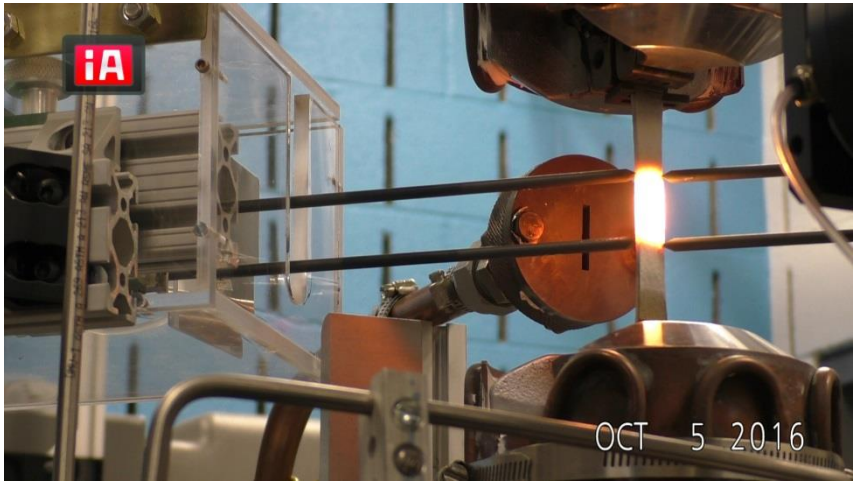


Fatigue Testing of CMCs under Thermal Gradient Conditions

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



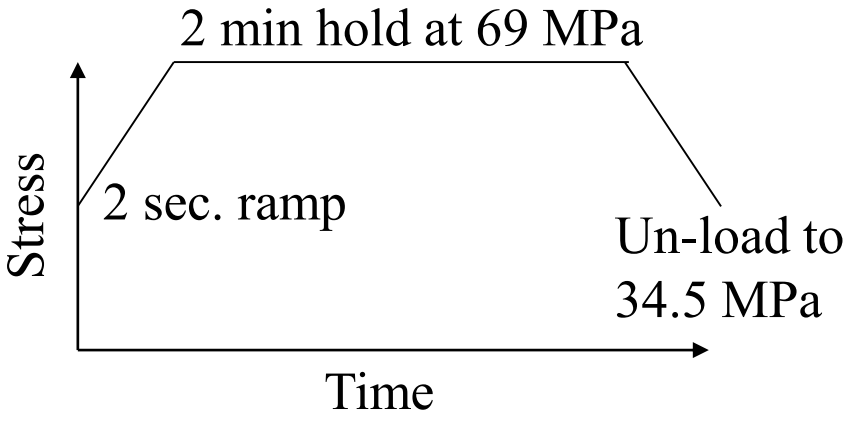
- Servohydraulic , 25 kN Load Cell
- Water-cooled Wedge Grips
- Two 1 in. Gage Length, Water-Cooled Extensometers; 6 in. Long Tensile Specimens
- Frequencies up to 30 Hz
- Load and Stroke Control

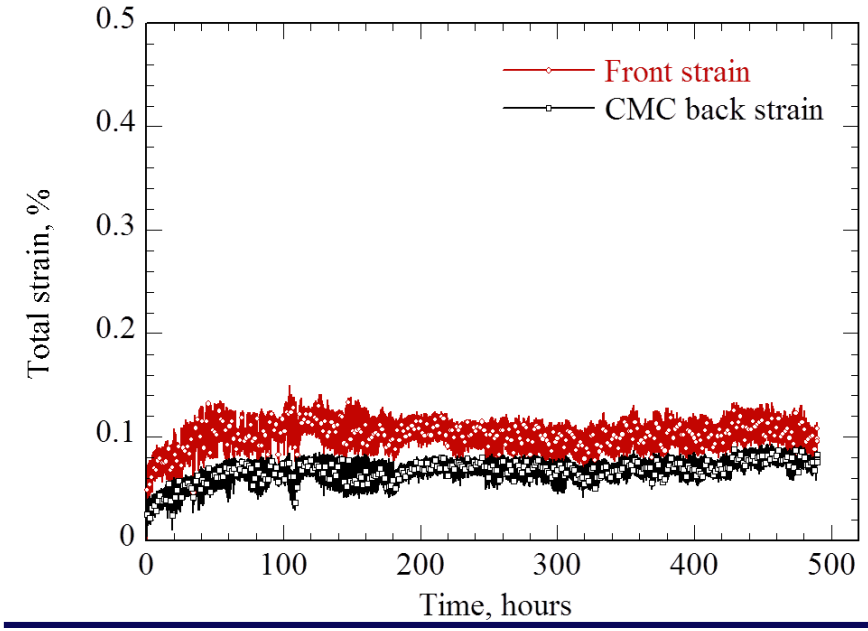
Test Issues

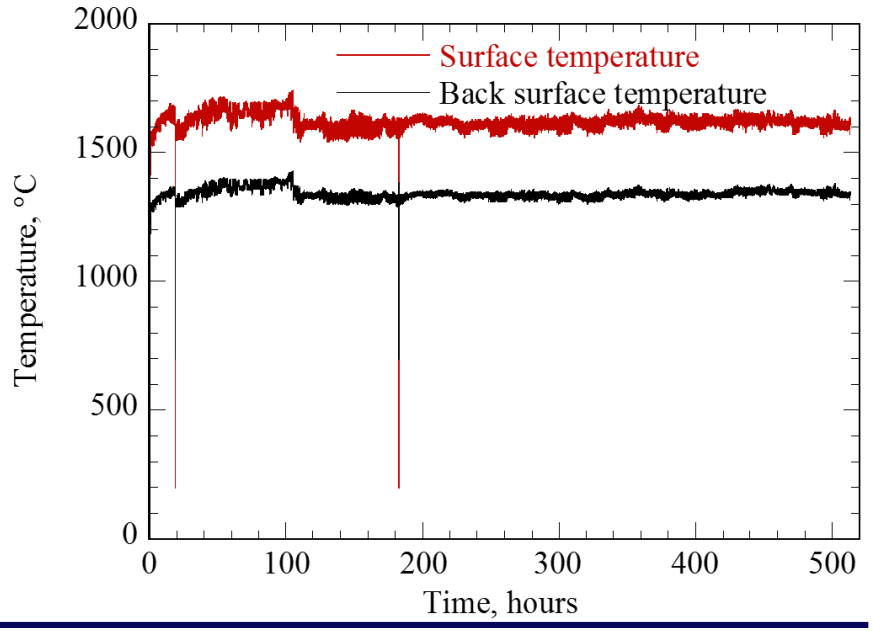
- Accurate measurement of through-thickness thermal gradient
  - Pyrometers were used to measure surface temperature
  - Emissivity of the EBC is required to measure temperature with the pyrometer
  - EBC emissivity will change over time
  - Isothermal furnace tests are being done to compare thermocouples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

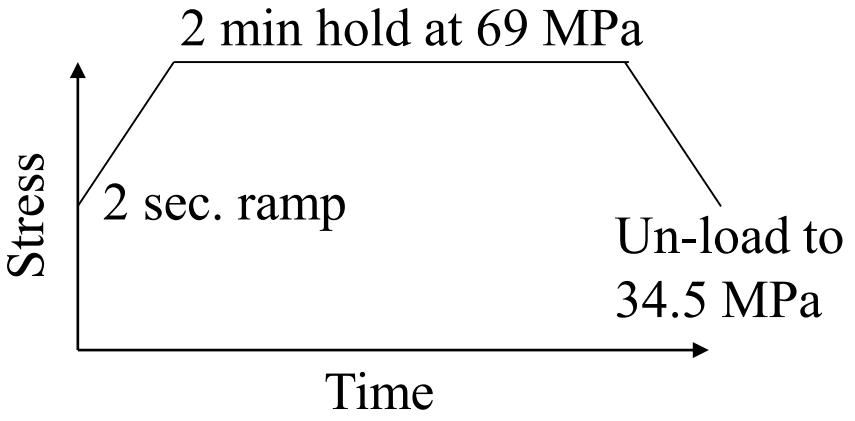


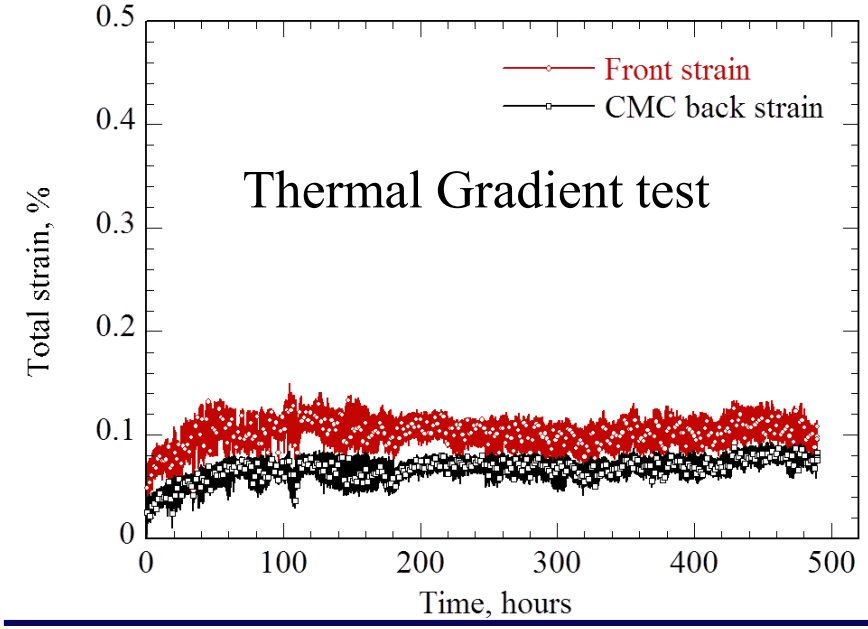


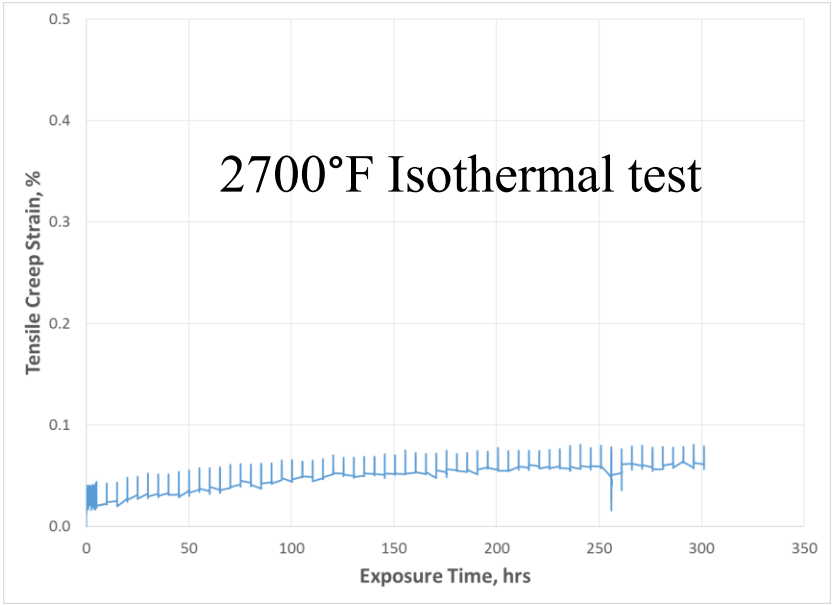


SPLCF Results
Thermal Gradient Compared to Isothermal Conditions

- 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

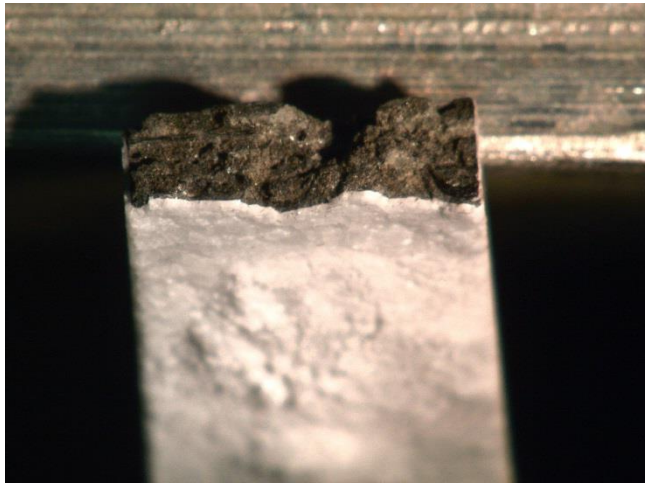






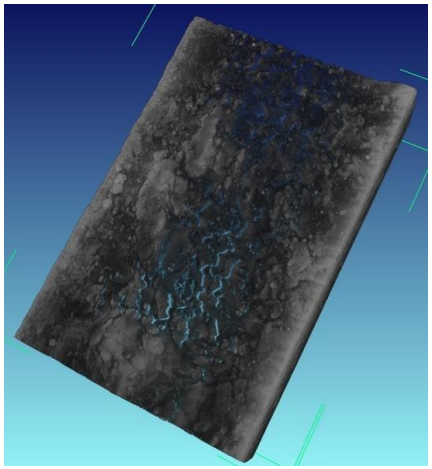
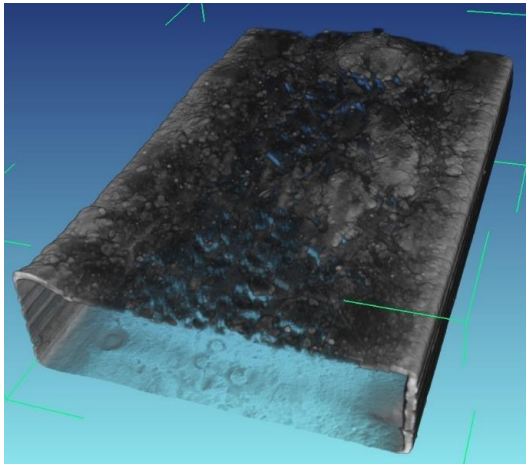
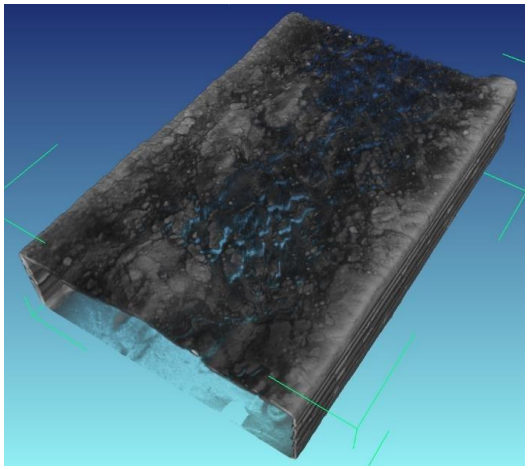
Examination of Sample that Broke During 487 Hour Thermal Gradient SPLCF

- 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

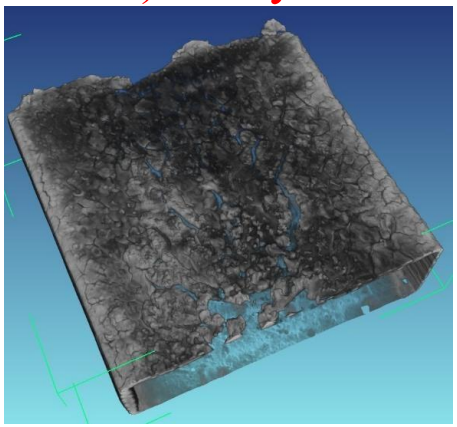


CT Images Before and After Thermal Gradient SPLCF

Before Testing- Only EBC Shown

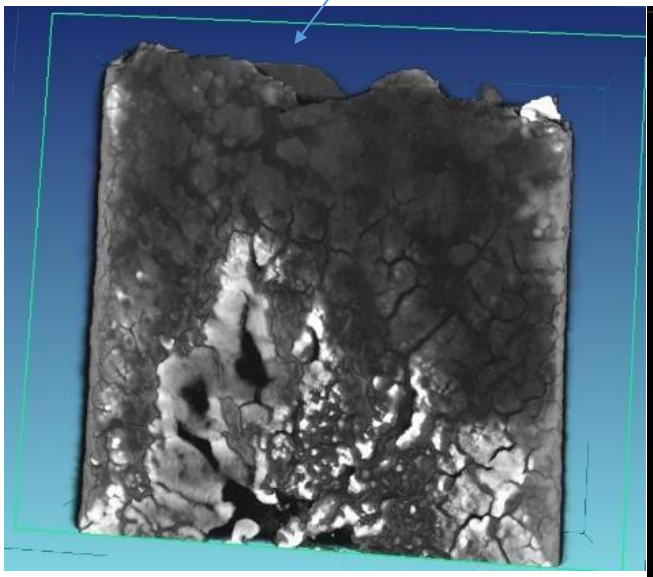
After Laser SPLCF (69 MPa, 487 hr)- Only EBC Shown

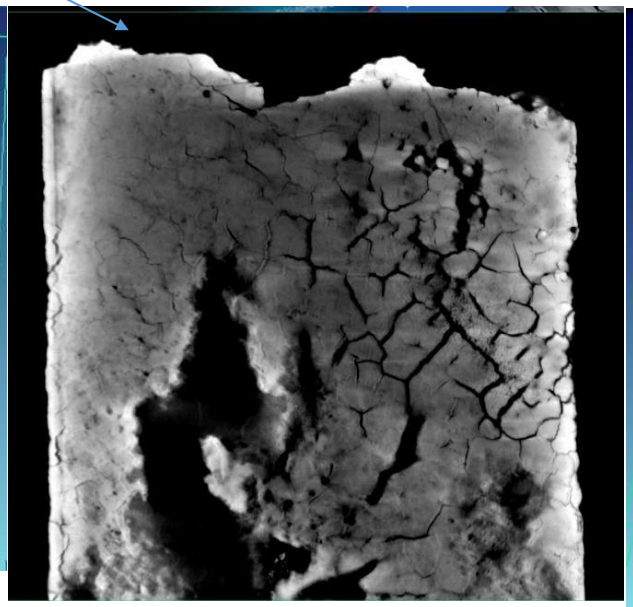



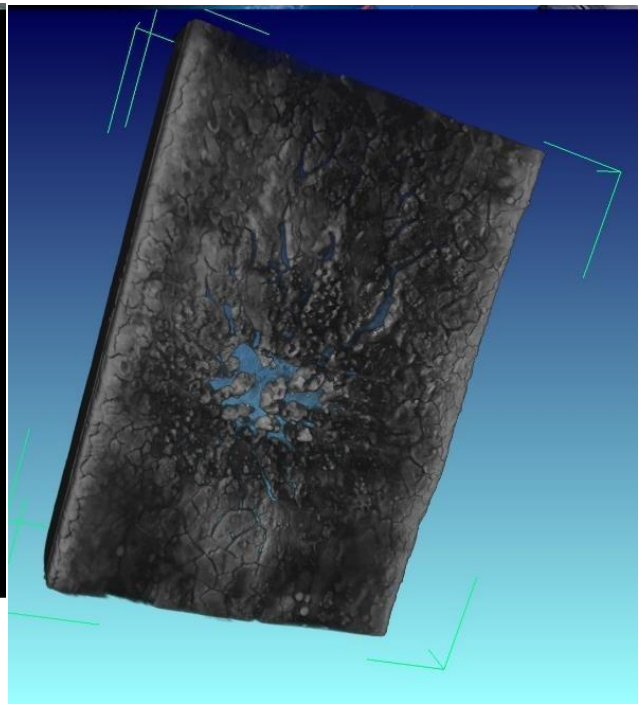
CT Images After Thermal Gradient SPLCF

Fractured End

Image of the EBC Only

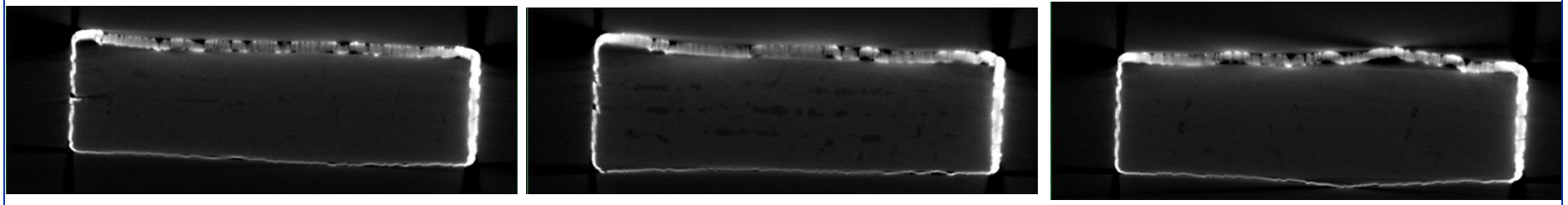




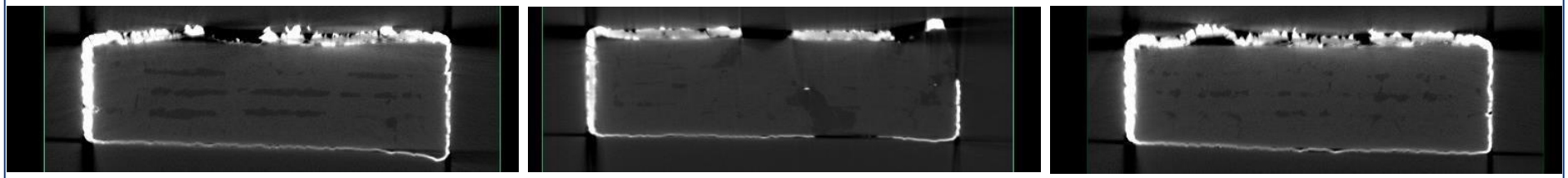


CT Cross-Section Images Before and After Thermal Gradient SPLCF

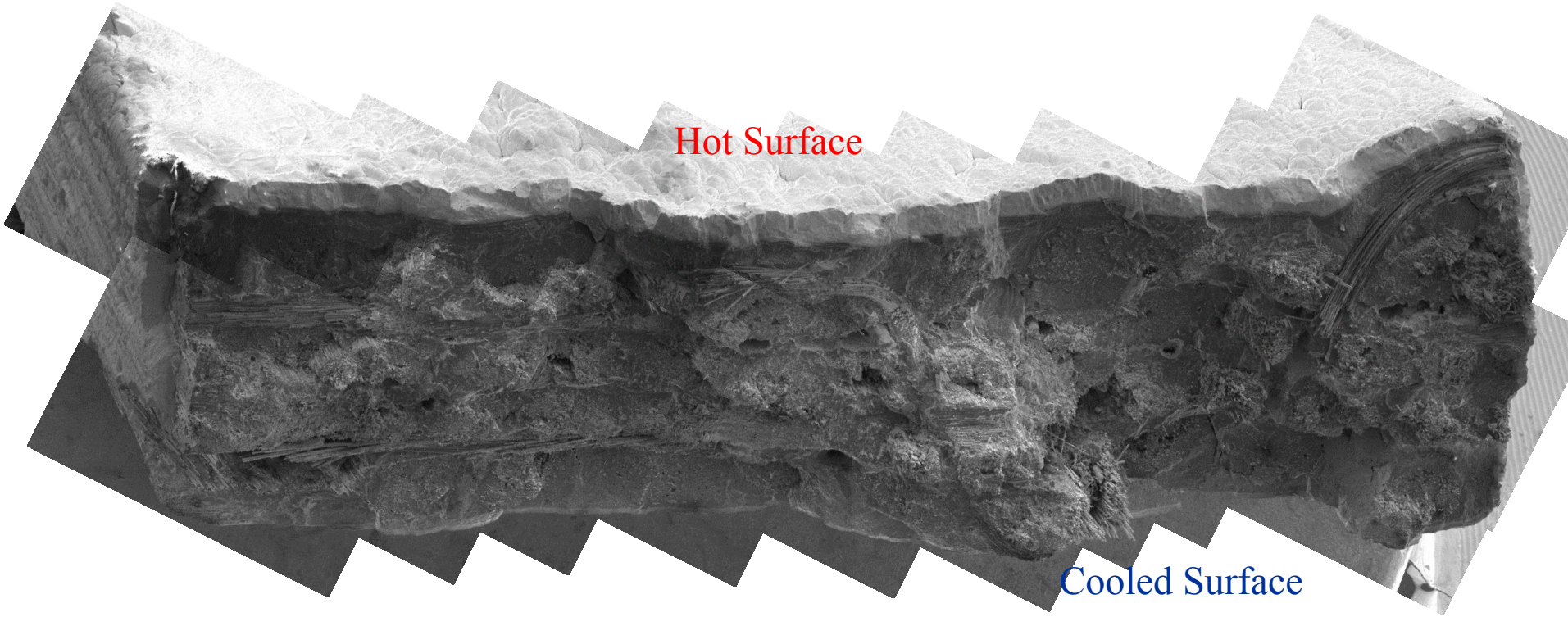
Before Testing



After Laser SPLCF (69 MPa, 487 hr)

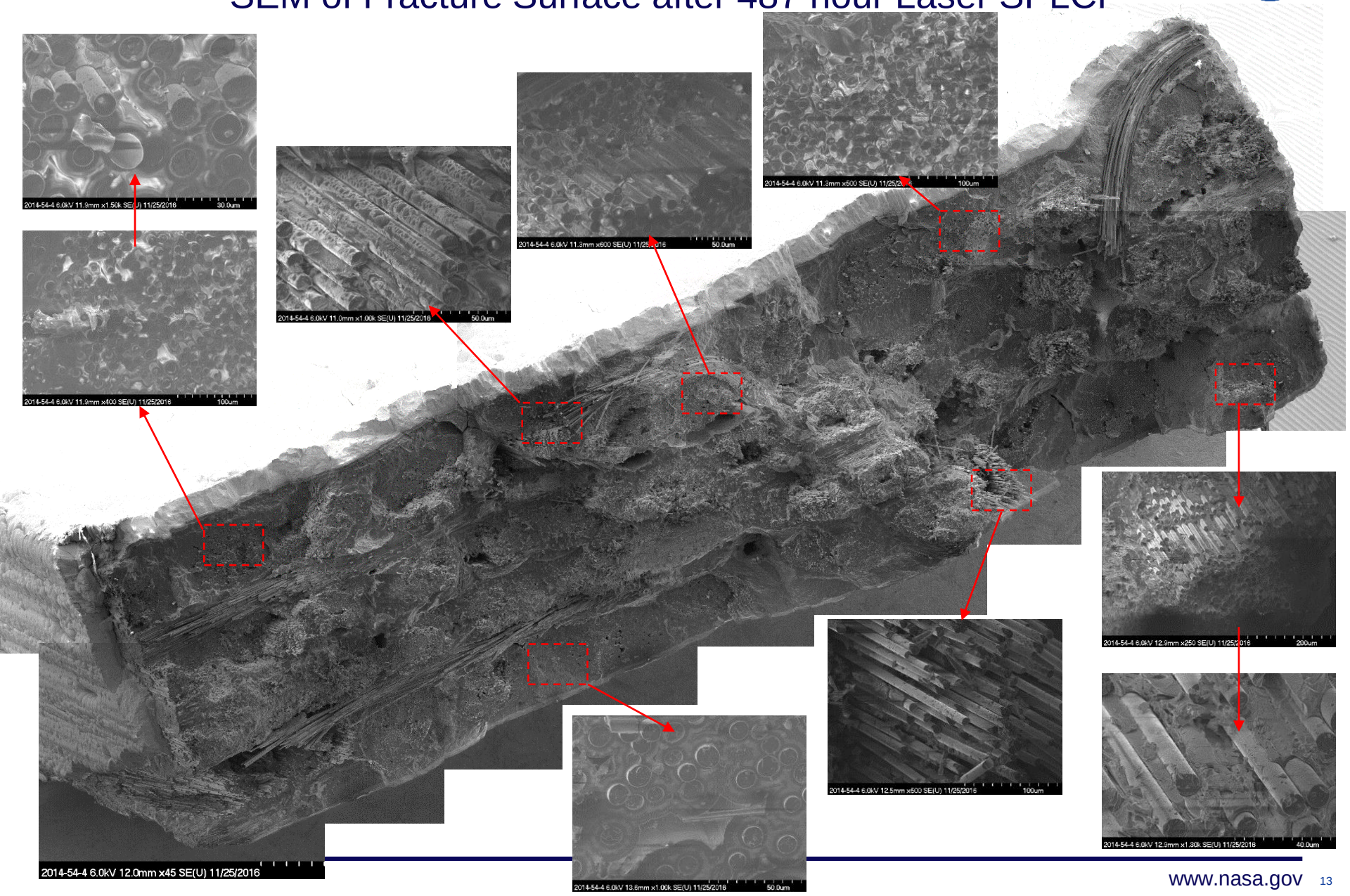


SEM of Fracture Surface after 487 hour Laser SPLCF

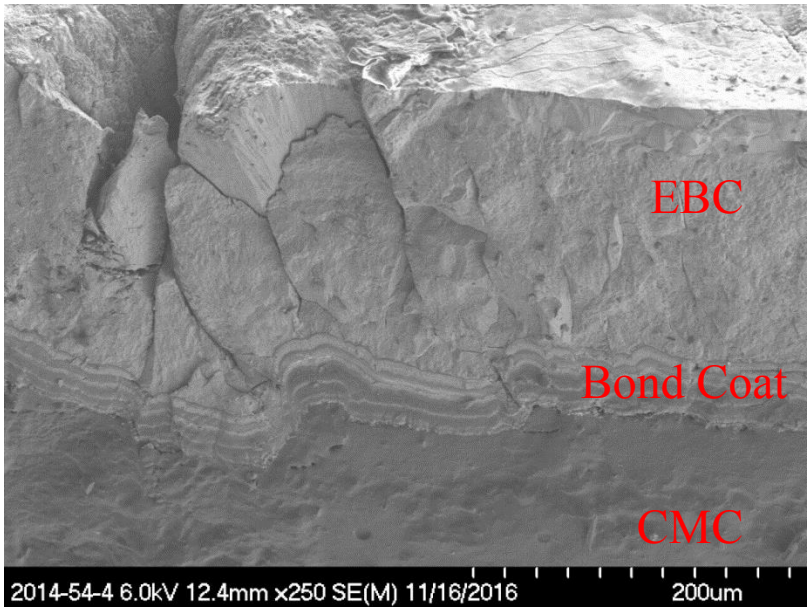


- Very flat fracture surface, little fiber pull-out

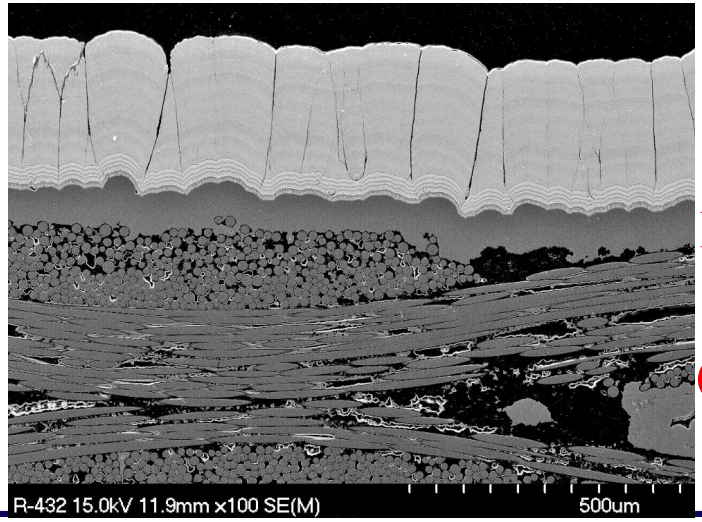
SEM of Fracture Surface after 487 hour Laser SPLCF



SEM of Fracture Surface after 487 hour Laser SPLCF



Polished section of the as-produced system for comparison



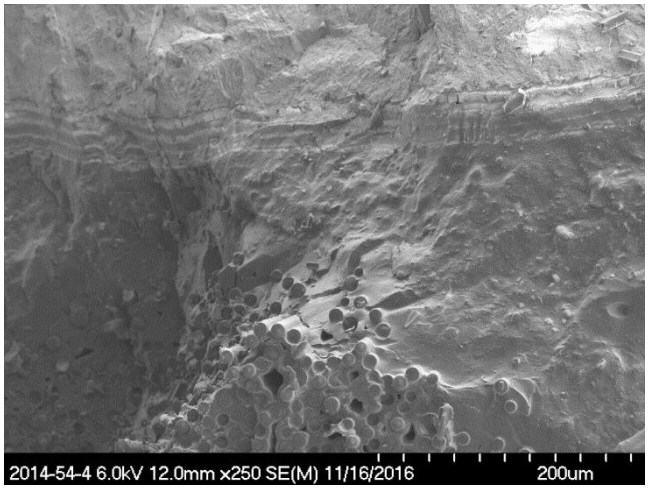
EBC

HfO_2-Si Bond Coat

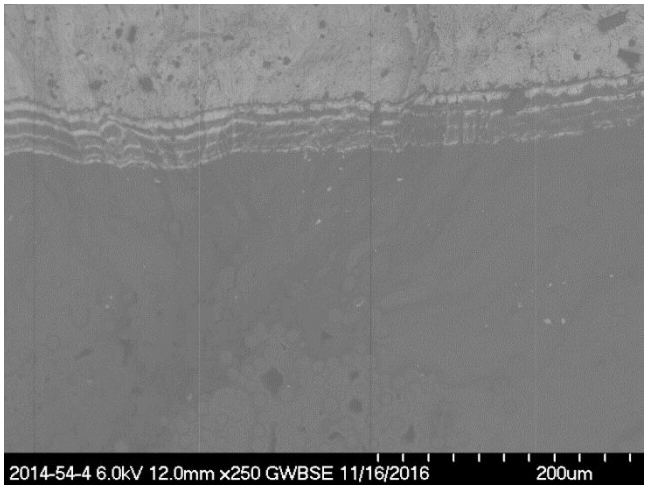
CMC

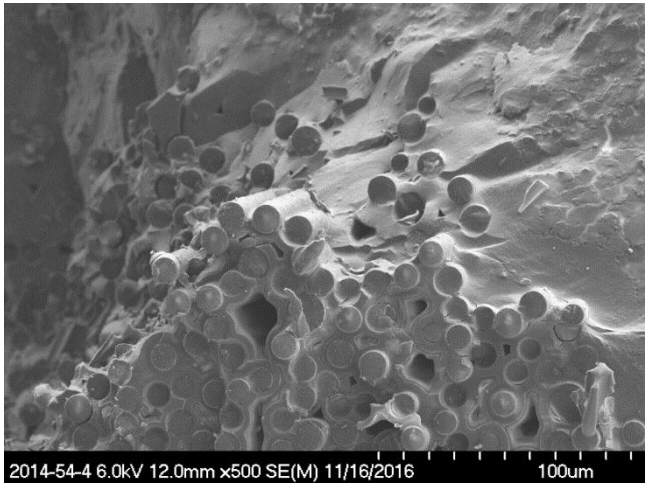
SEM of Fracture Surface after 487 hour Laser SPLCF

SEM



Backscatter





- 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