Environmental Durability and Stress Rupture of EBC/CMCs

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Abstract

This research focuses on the strength and creep performance of SiC fiber-reinforced SiC ceramic matrix composite (CMC) environmental barrier coating (EBC) systems under complex simulated engine environments. Tensile-strength and stress-rupture testing was conducted to illustrate the material properties under isothermal and thermal gradient conditions. To determine material durability, further testing was conducted under exposure to thermal cycling, thermal gradients and simulated combustion environments. Emphasis is placed on experimental techniques as well as implementation of non-destructive evaluation, including modal acoustic emission and electrical resistivity monitoring, to characterize strength degradation and damage mechanisms. Currently, little is known about the behavior of EBC-CMCs under these conditions; consequently, this work will prove invaluable in the development of structural components for use in high temperature applications.

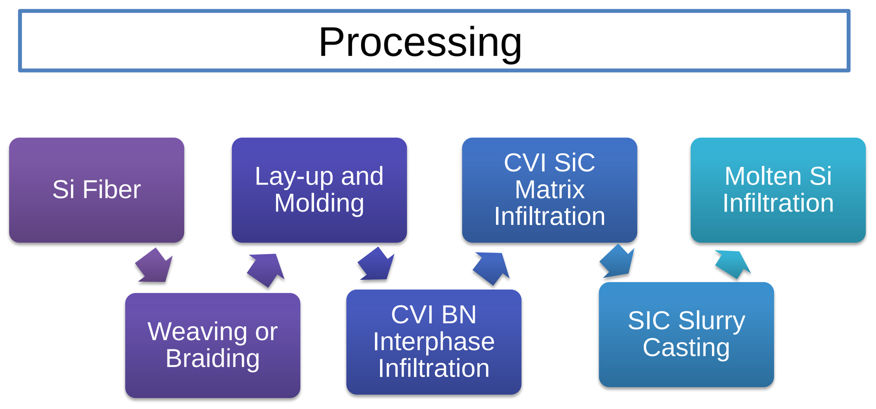
Research Objectives

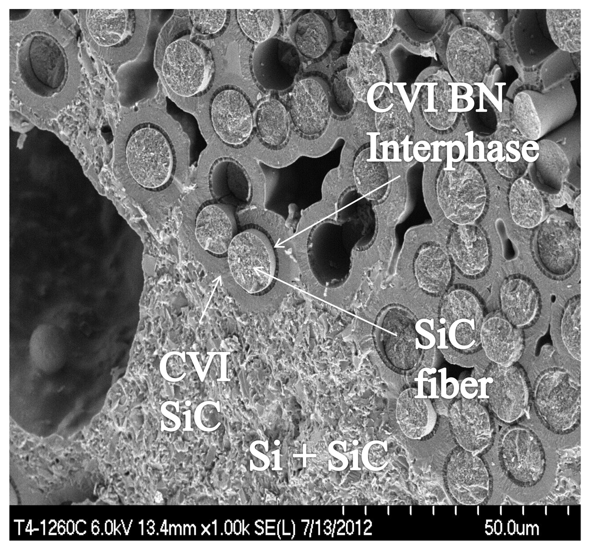
- Investigate strength and creep behavior of light-weight and high strength CMCs under simulated engine environments; including thermal and stress gradients, and environments.
- Incorporate the state-of –the-art of EBC compositions and processing.
- Develop Non-Destructive Evaluation (NDE) methodologies and physics-based CMC-EBC life prediction models.

Introduction

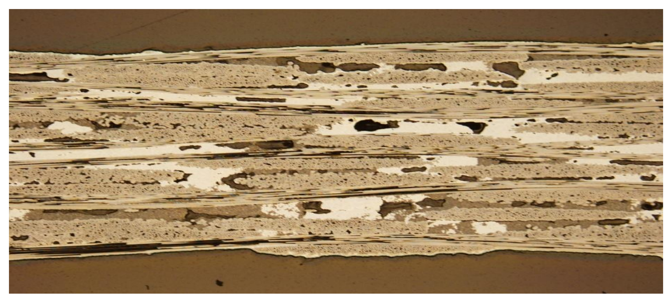
Melt Infiltrated (MI) SiC/SiC Ceramic Matrix Composites (CMCs)

➔ Being investigated for use as turbine hot-section structural components due to their superior material properties over traditional super alloys.



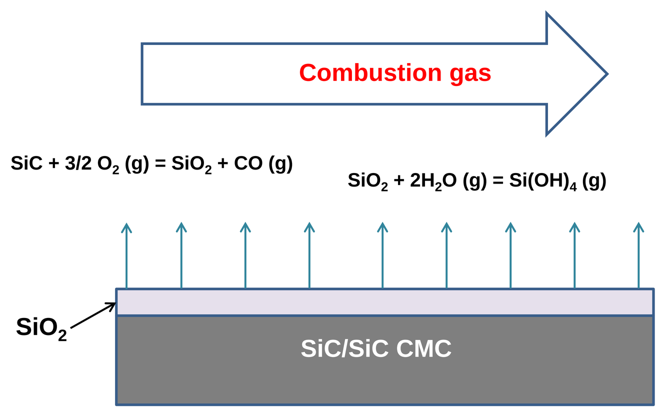


- **Matrix cracking and fiber-matrix debonding and sliding leads to increased toughness**
  - However matrix cracking allows to oxygen diffusion into the composite which can lead to strength degradation.
  - A BN layer is deposited to reduce fiber oxidation and provide a weak interphase to increase toughness.

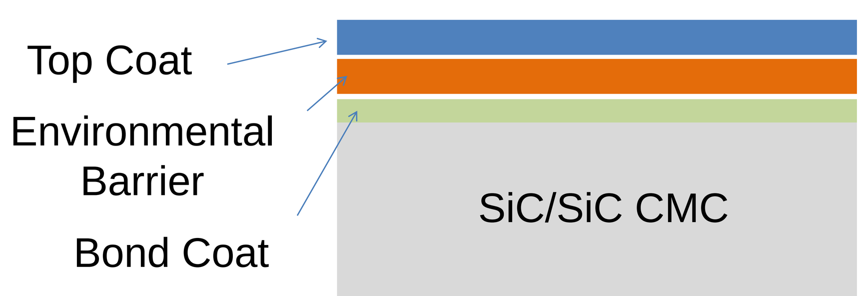


Need for Environmental Barrier Coatings (EBCs) for CMC Turbine Engine Components

- **Si-based ceramics react with high temperature water vapor in combustion environments causing recession**
  - Boundary layer gas transport
  - Degradation dependent upon temperature, system pressure, water vapor pressure, and gas velocity



➔ Therefore, without a protected surface, rapid recession of SiC in a combustion environment will occur…drastically limiting component life.



- **Multilayer coating** schemes optimized to meet environmental requirements

Acknowledgements

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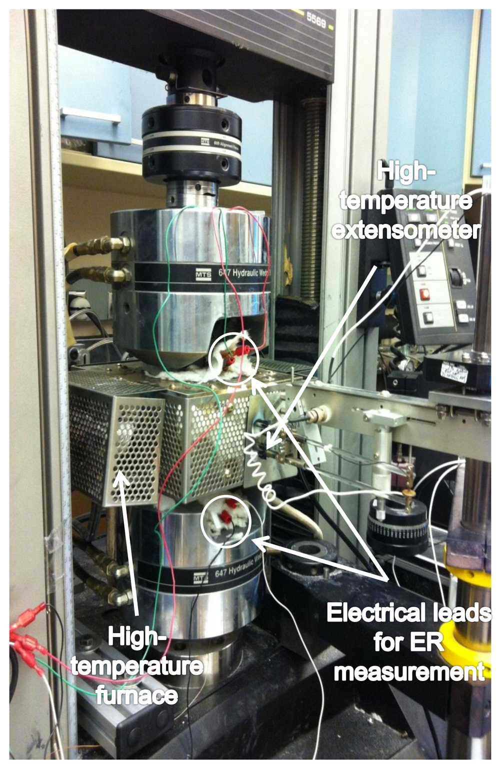
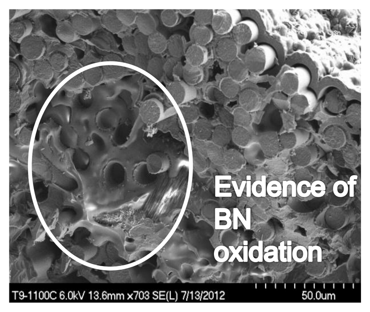
Experimental Methodologies

Isothermal Creep Characterization

- Isothermal Tensile Creep tests are widely used methods for characterizing life limiting viscoelastic behavior and investigating the relationship b/t creep strain and external variables.



- Stress rupture without the influence of stress/temperature gradients, and harsh environmental exposures

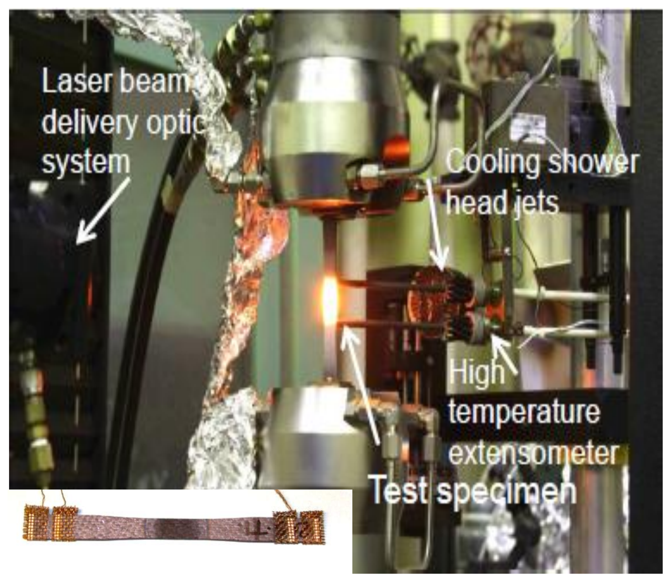


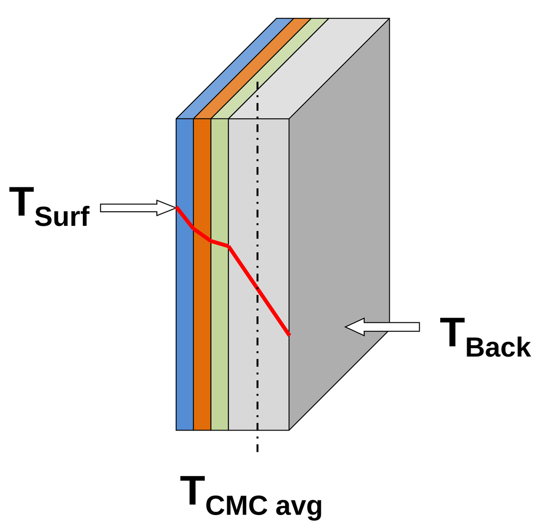
T = 1100°C
σ =103 MPa
t = 480 hr

Tensile specimen with attached ER electrodes

Laser Based High Heat Flux Tensile Testing

- Laser induced Thermal Gradient Tensile tests combine high heat flux with thermo-mechanical loading conditions.

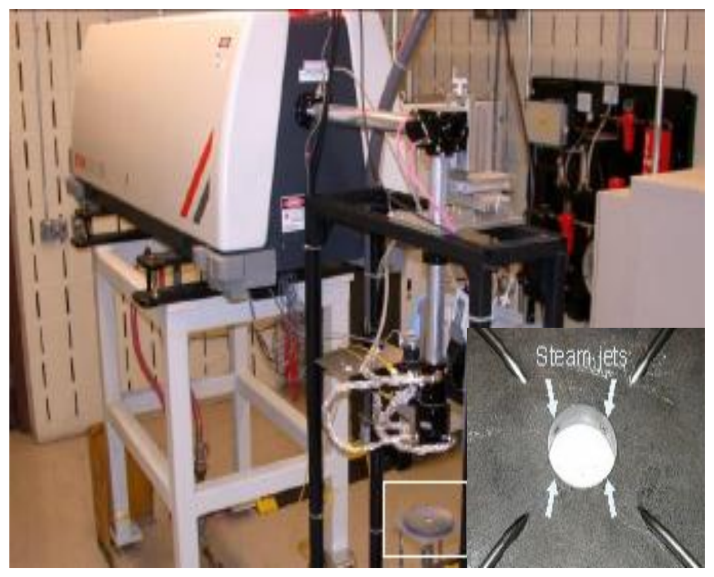




- In-situ **Electrical Resistivity (ER)** monitoring incorporated to assess material damage state
- Transverse matrix crack development and fibers strains/breaks limit the flow of current; increasing the overall resistance.

Future Work

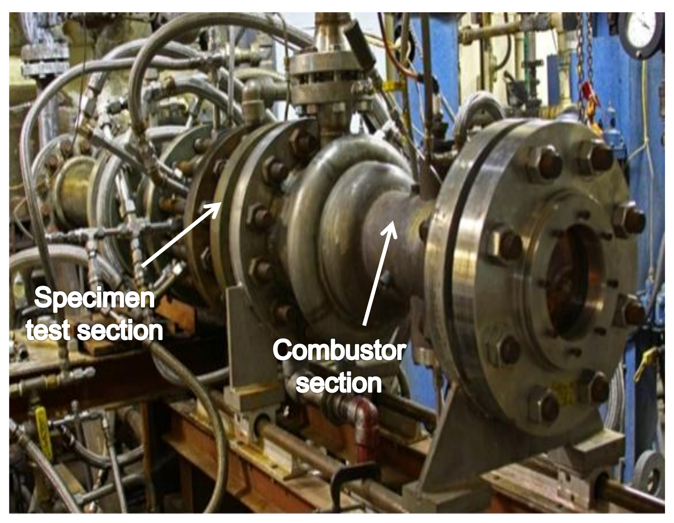
Laser Based High Heat Flux Testing with Water Vapor



- High heat flux steam rig can be used to test specimens under thermal gradients and water vapor exposure.

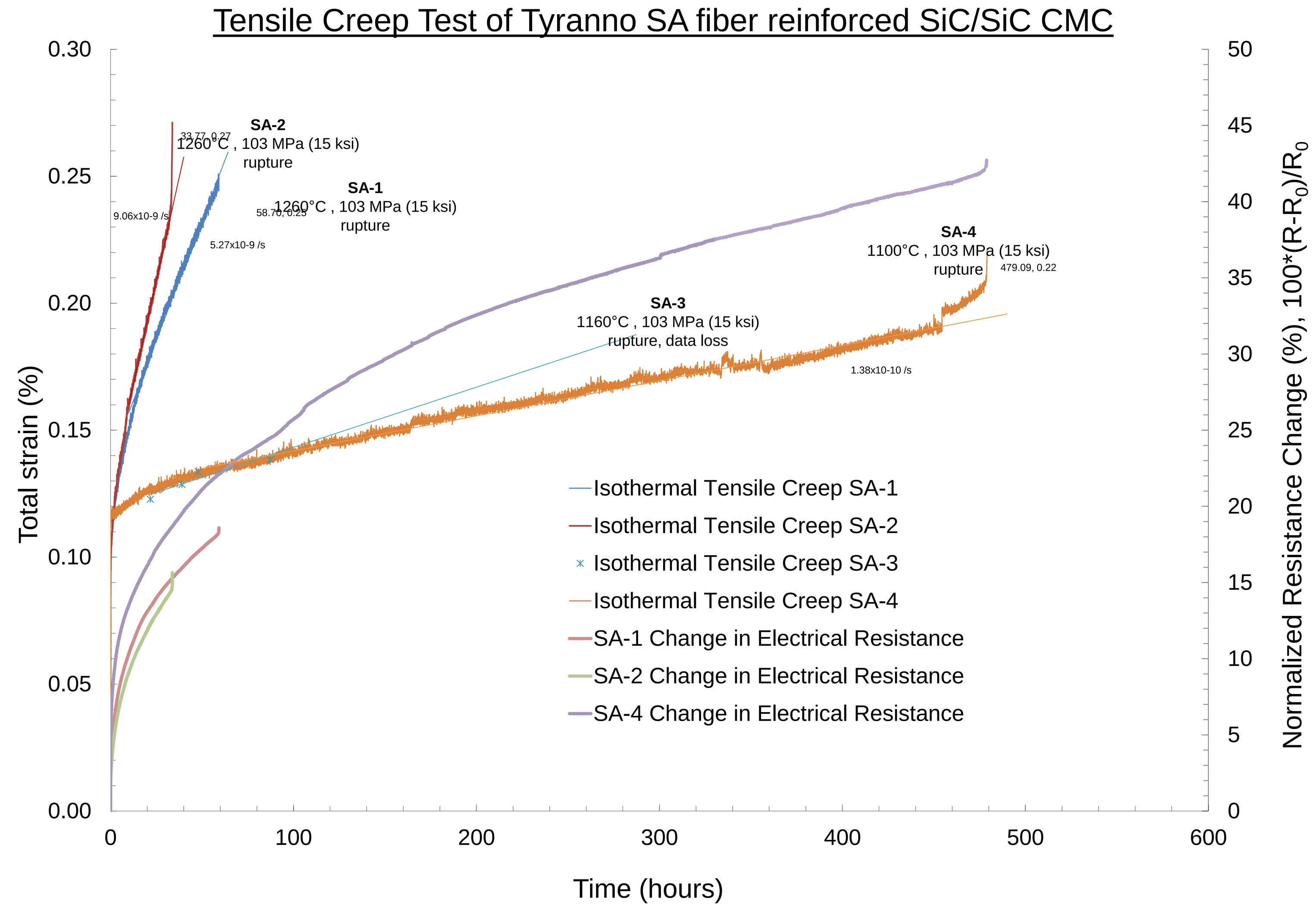
High Pressure Burner Rig Exposure

- High Velocity and High Pressure Burner Rig simulates temperatures, pressures, and gas velocities seen in combustion environments

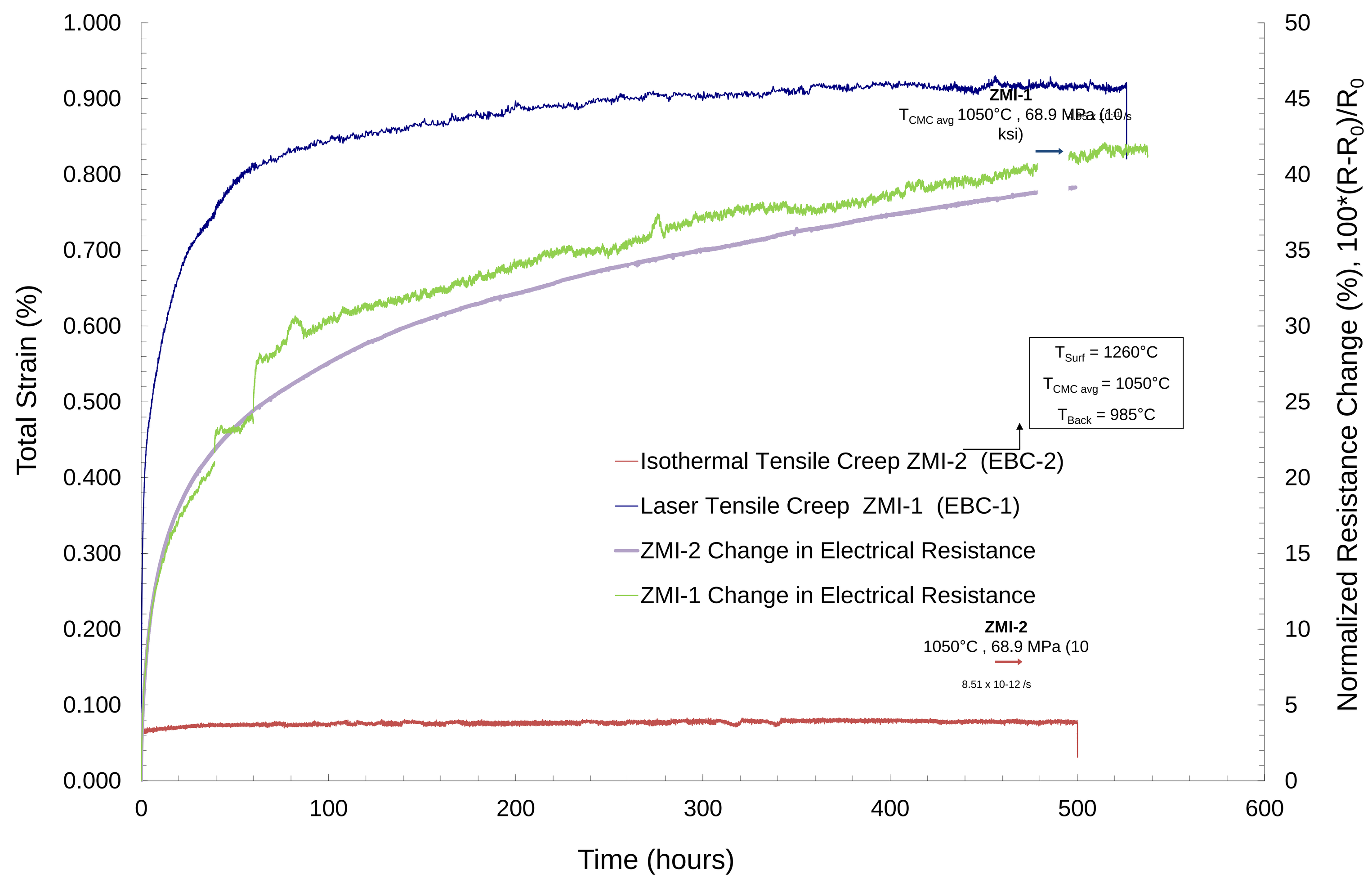


Results

Tensile Creep Test of Tyranno SA fiber reinforced SiC/SiC CMC

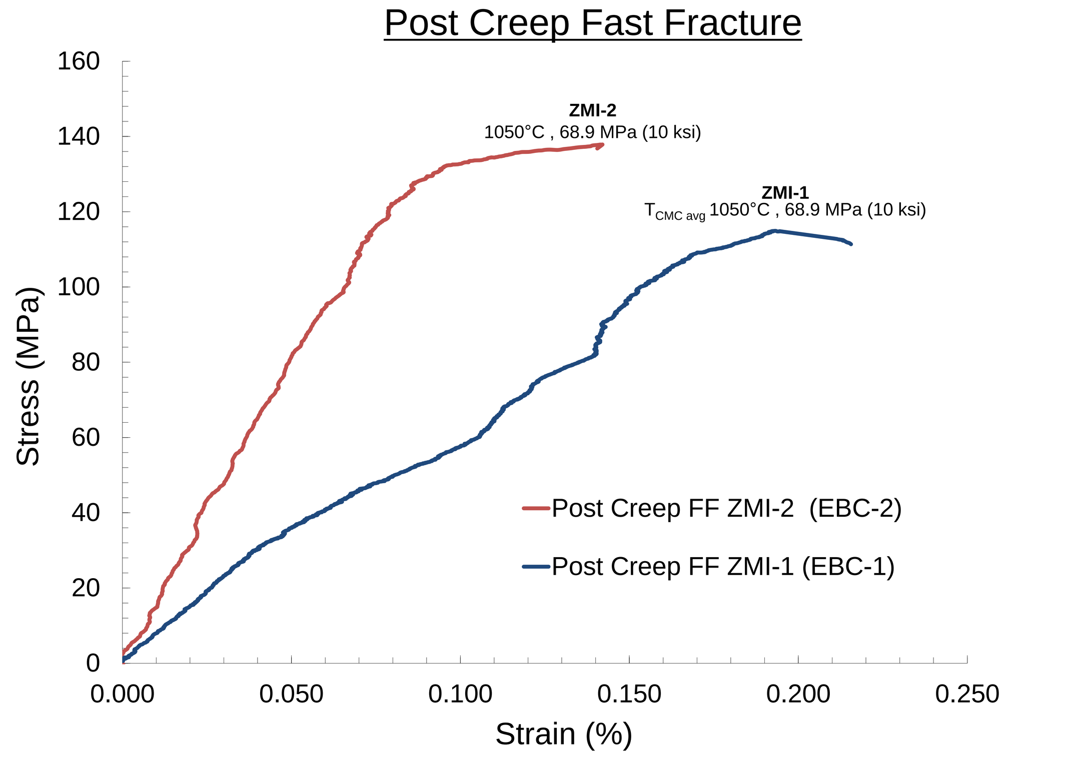


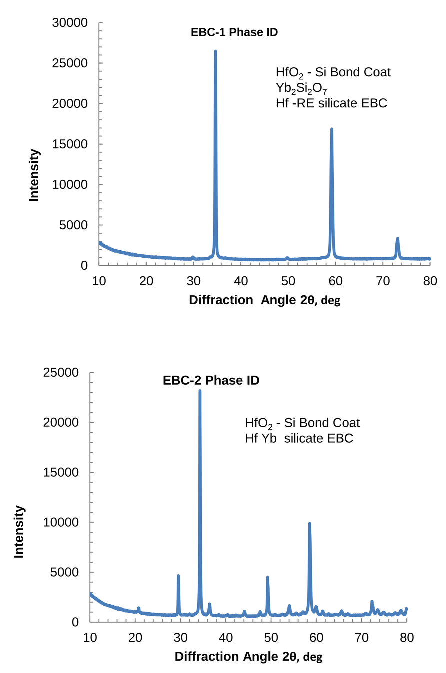
Tensile Creep Test of Tyranno ZMI fiber reinforced SiC/SiC CMC



Specimen	Test Conditions	$E_{@1050°C}$ Initial, GPa	$E_{@1050°}$C Post 500hr Creep, GPa	σ_{UTS}, MPa	Failure Strain, %
ZMI-1	Thermal Gradient	30.3	76.6	114.9	0.2156
ZMI-2	Isothermal	153.2	173.6	137.8	0.1414

Post Creep Fast Fracture





Conclusions

- Thermal gradients, common in many high temperature structural applications, appear to reduce material stiffness and creep resistance.
- This could be caused by a shifting of the neutral axis caused by stress relaxation in the hot side of the specimen.
- ER monitoring shows a change with time, we need to see how effective it is at correlating with damage mechanisms. Modeling of the mechanics behind this phenomenon are ongoing.