CMC Research at NASA Glenn in 2017: Recent Progress and Plans

Joseph E. Grady
Ceramic & Polymer Composites Branch
joseph.e.grady@nasa.gov

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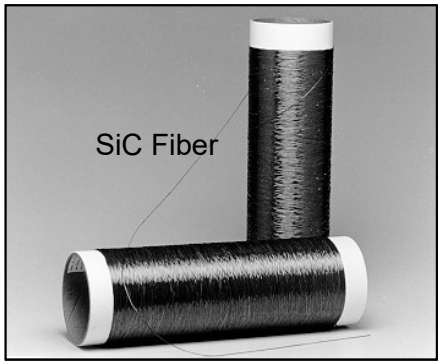
CMC Research at NASA Glenn

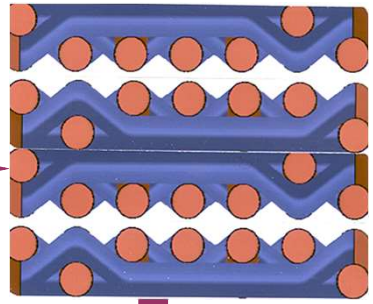
- Material Development & Characterization
- CMC / EBC Durability Modeling & Validation
- Advanced Manufacturing Technologies

CMC Development and Characterization

Hybrid Process for Dense SiC / SiC Composites



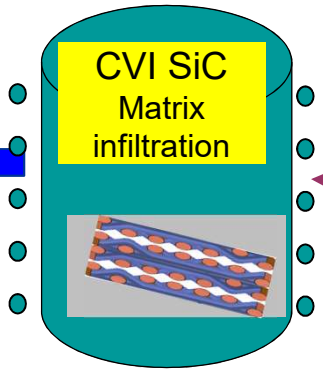
0/90 Fabric
Weaving



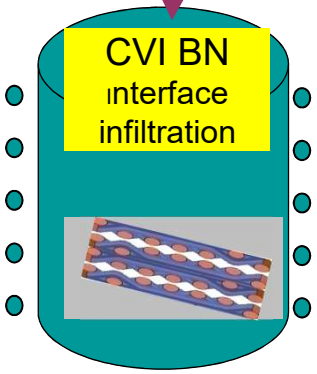
Pre-form by
Fabric Lay-up +
Fabric i-BN
Treatment

CVI BN

Tooling



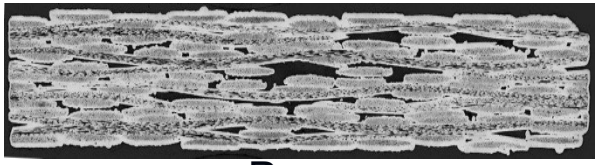
Reactor



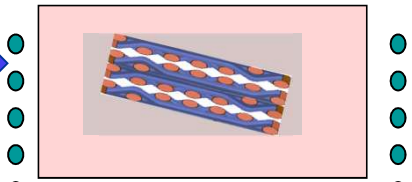
Reactor

Hybrid matrix combines CVI and PIP processing

Partial CVI



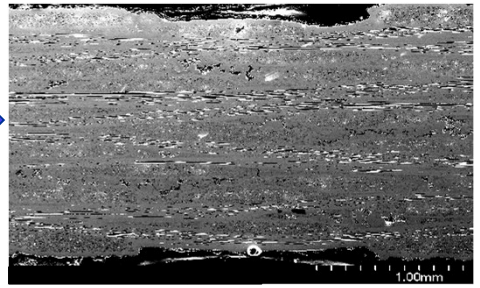
Porous



PIP

PIP – Polymer impregnation pyrolysis

Dense, Si-free composite

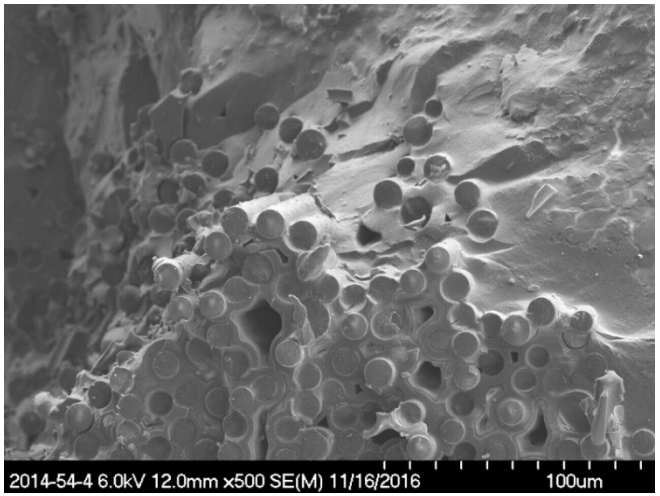


Contact: Ramakrishna.T.Bhatt@nasa.gov

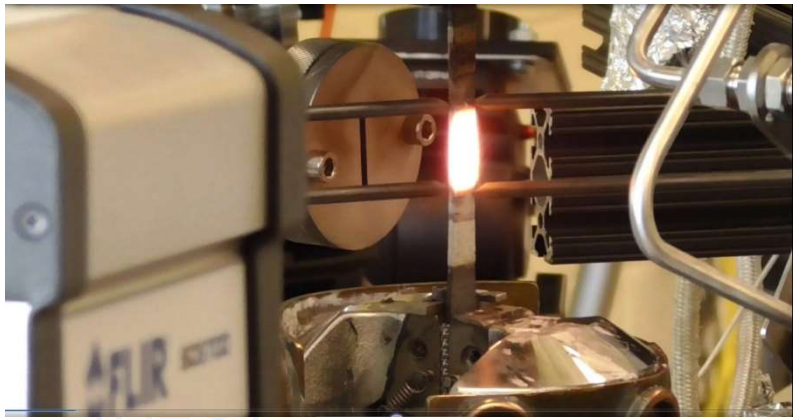
Durability Assessment of 2700°F CMC/EBC in Progress

Test rig generates through-thickness thermal gradient

- Laser heating with backside air cooling
- Surface temp up to 3000°F, measured with pyrometers and IR camera
- Coated 3D CVI/PIP CMC demonstrated 487 hour life under mechanical fatigue (10 ksi max stress) and constant thermal gradient (2700°F max temp)

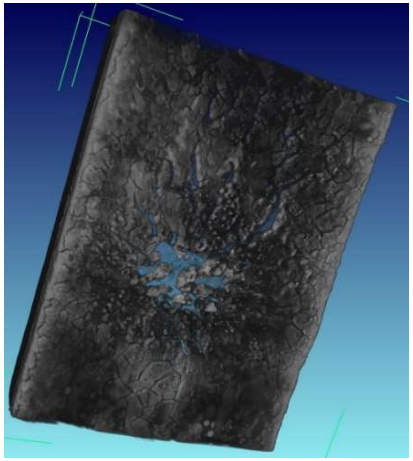


SEM images show failure location



Laser rig produces thermal gradient in CMC

X-Ray CT shows EBC damage after 487 hours



Further testing will evaluate effects of steam environment under isothermal and thermal gradient conditions

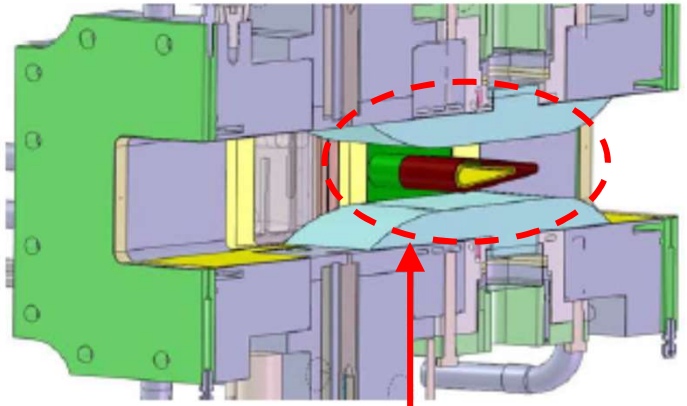
Contact: Sreeramesh.Kalluri-1@nasa.gov

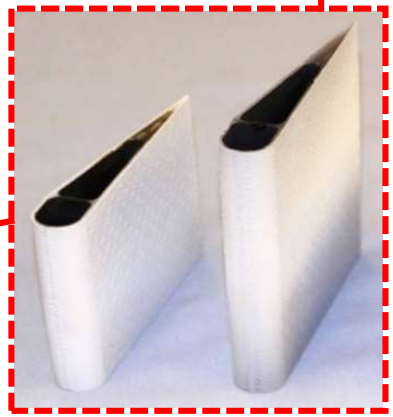
TRL 5 rig test planned for 2017

CMC subelement will be used to evaluate material capabilities in a simulated turbine environment

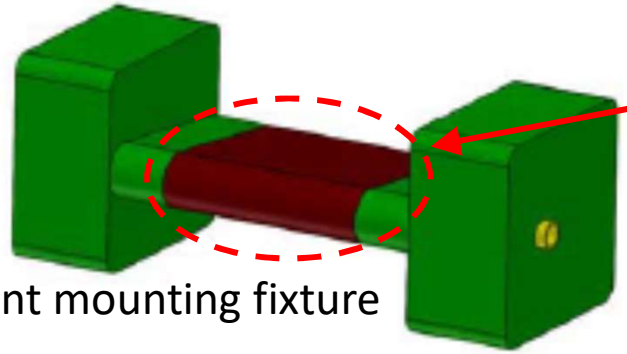
- Airfoil-shaped test article, 3x3 inches
- Air temperature up to 3600°F
- Mach No. 0.2 < M < 0.8 in test section
- 1.5 lb/s airflow at 220 psia
- Internal specimen cooling allows for a tunable through-thickness temperature gradient
- Thermocouples, pyrometers and IR camera monitor material temperatures
- NASA / P&W / UTRC collaboration

UTRC JBTS test rig





airfoil subelements



subelement mounting fixture

Contact: Joseph.E.Grady@nasa.gov

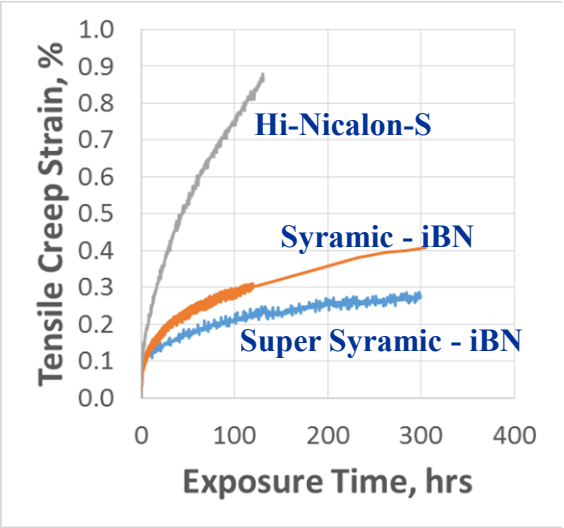
Measured Fiber Effect on 2700ºF CMC Durability

OBJECTIVE

Measure the effect of fiber on CMC mechanical properties and durability

APPROACH

- Fabricate SiC / SiC CMC's with 2700ºF hybrid matrix composition and 3D fiber architecture.
- Compare creep performance of CMC's with 3 different high temperature fibers



2700ºF creep strain at 15 ksi stress

CMC with 3D HNS fiber architecture

SIGNIFICANCE

Compared 2700ºF creep and fatigue behavior of SiC/SiC CMC reinforced with:

- Sylramic-iBN
- Super Sylramic-iBN
- Hi-Nicalon-S

Contact: Ramakrishna.T.Bhatt@nasa.gov

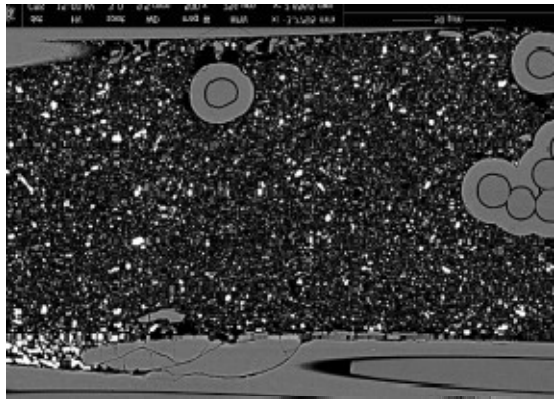
Engineered matrix under development for 2700ºF CMC

OBJECTIVE

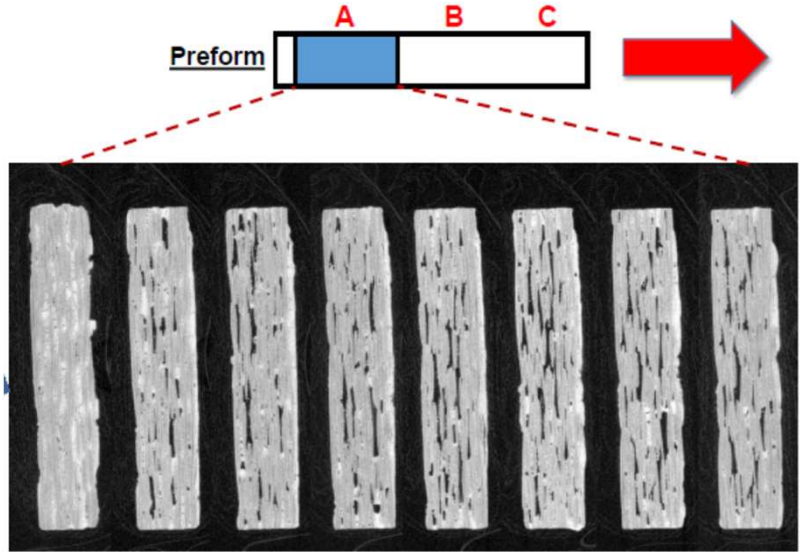
Develop a durable matrix material for CVI SiC/SiC preforms with improved toughness, fatigue life and self-healing properties

APPROACH

- Formulate engineered matrix compositions for evaluation
- Optimize slurry infiltration and melt infiltration processes to densify CVI SiC/SiC preforms
- Identify optimal matrix composition based on toughness, fatigue life and self-healing properties



NASA / AFRL Collaboration



Computed Tomography assessment of slurry infiltration effectiveness

RESULTS

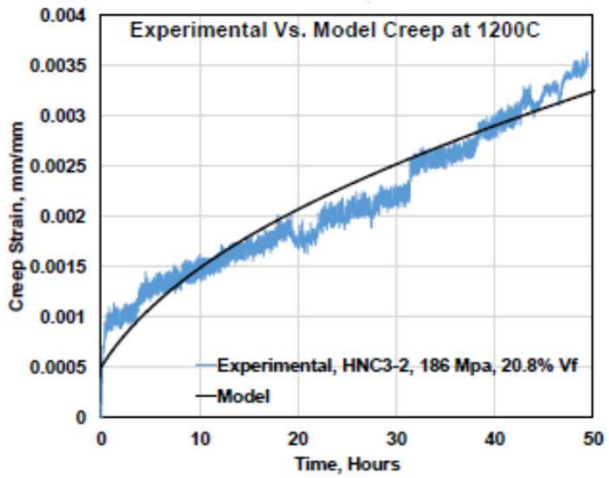
- Weave architecture affects extent of matrix infiltration
- Computed Tomography is useful in evaluation of the infiltration process & reduces the need for destructive inspection techniques
- Summary of the initial slurry infiltration trials with Hi-Nic-S and Tyranno SA3 fiber preforms to be reported at Cocoa Beach conference

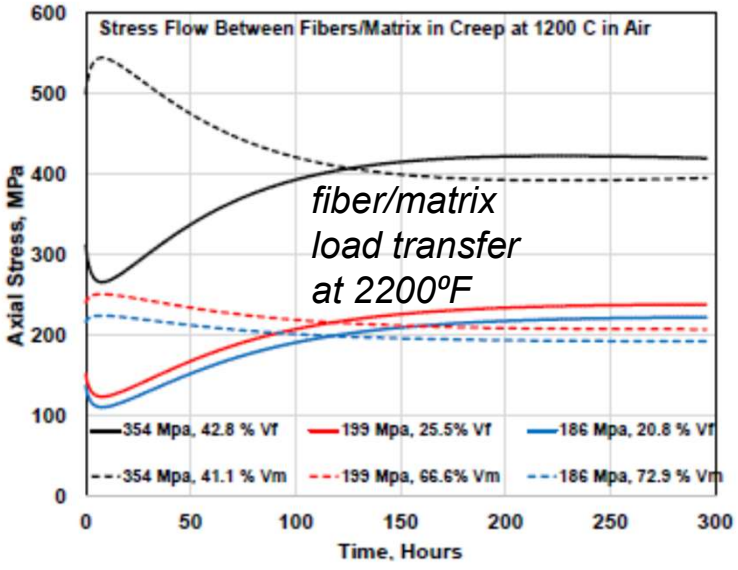
Contact: Sai.V.Raj@nasa.gov

CMC / EBC Durability Modeling & Validation

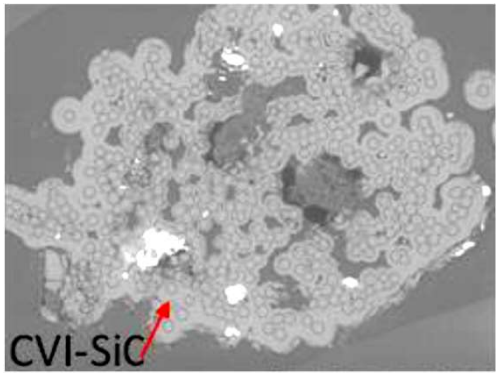
Mini-Composites used for Validation of CMC Creep Model

- Micromechanics-based creep model shows fiber/matrix load transfer during creep deformation
- 2200ºF model will be extended to 2700ºF for Sylramic and HNS composites





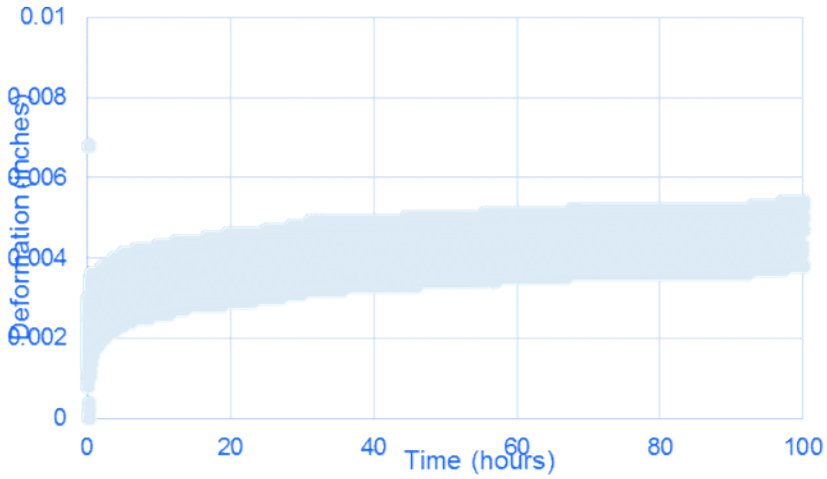
Hi-Nicalon-S single fiber tow minicomposite



Single fiber tow minicomposites allow quick experimental model validation

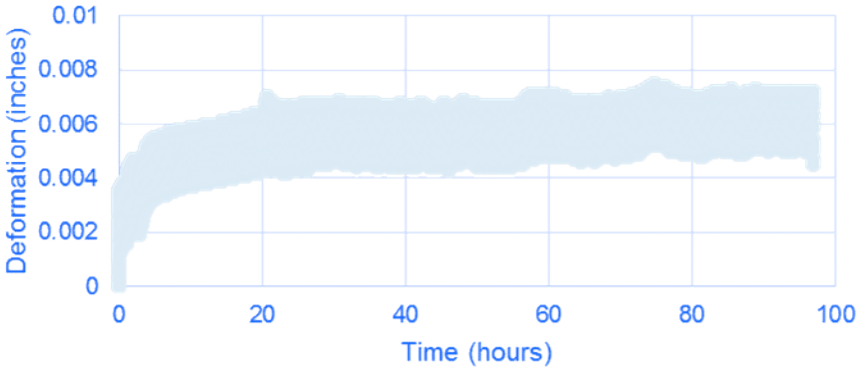
Contact: Amjad.S.Almansour@nasa.gov

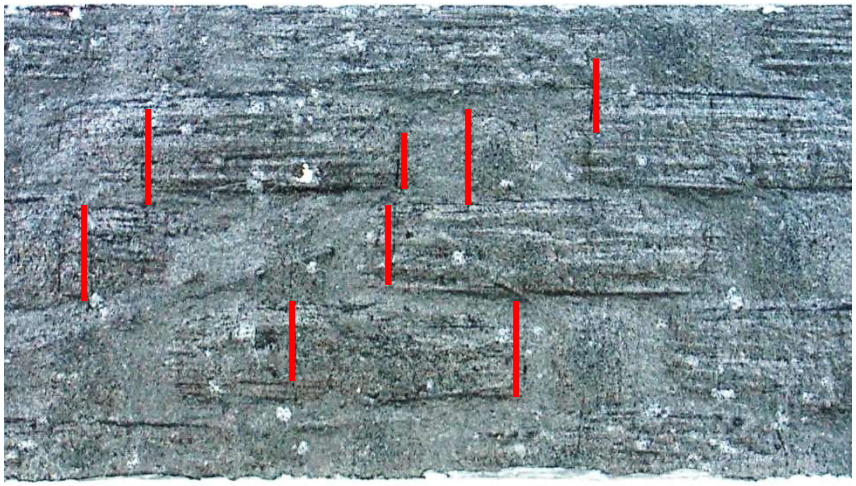
Steam environment accelerates matrix cracking in flexural fatigue at 2200ºF



Dry Air

uncoated SMI-CVI SiC/SiC





tensile side

50% H_2O

Matrix cracking increases flexural compliance after 100 hours (3000 LCF cycles)

Contact: Martha.H.Jaskowiak@nasa.gov

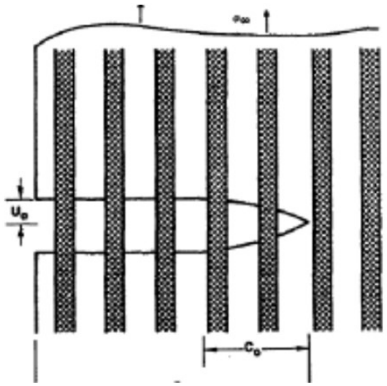
CMC NDE Technique Extended to 2400ºF Applications

OBJECTIVE

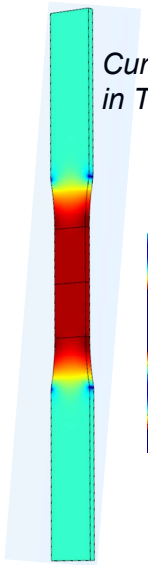
Non-Destructive Evaluation of CMC's is needed at high temperatures to detect matrix cracks that lead to failure

APPROACH

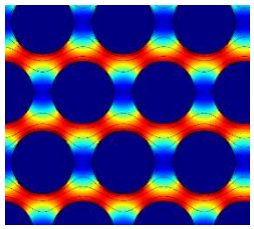
- Conduct long-term tests at 1500ºF and 2400ºF while monitoring electrical resistance .
- Relate changes in electrical resistance to CMC damage and microstructural changes.



CMC electrical resistance was measured while matrix cracks formed during long term tests



Current Density in Tensile Specimen



Resistivity of SiC matrix

SUMMARY & RESULTS

- 6,881 hours of long-term tests were conducted
- Changes in electrical resistance at 1500ºF were directly related to the density of matrix cracks in the CMC
- At 2400ºF, electrical resistance measurements were less sensitive to damage by an order of magnitude

Multi-physics computational model will relate CMC damage modes to electrical resistance measurements

Contact: Craig.E.Smith@nasa.gov

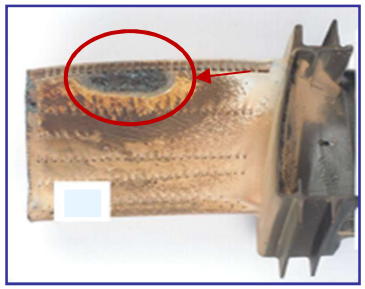
CMAS Effects on CMC / EBC Durability

Overview:

Operating temperature of future engines ~1500ºC

Environmental Barrier Coatings protect CMC's but are susceptible to attack by molten Calcium-Magnesium-AluminoSilicate (CMAS)

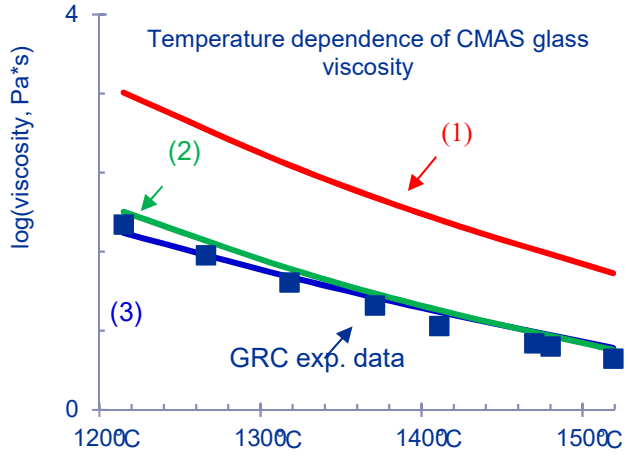
- Thermochemical interactions lead to spallation
- EBC infiltration due to low CMAS viscosity above 1200ºC



Turbine blade damaged by CMAS

Accomplishments:

- Measured viscosity of CMAS at 1200 - 1500ºC
- Evaluated current CMAS viscosity models



Significance:

- CMAS effects on EBC properties will impact durability of CMC aircraft engine components
- Durability in CMAS environment is required for advanced EBC

VIPR test of volcanic ash injestion

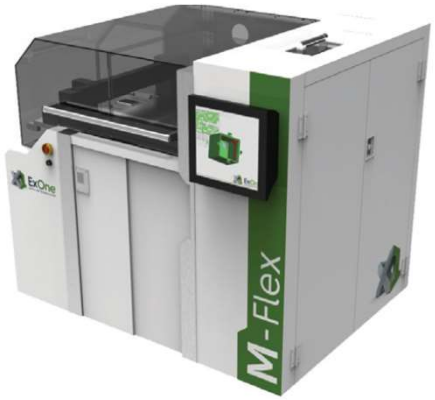
Next Steps:

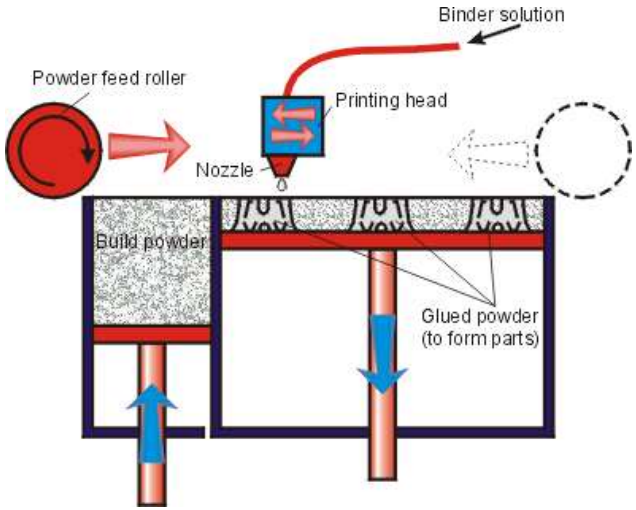
- Validate viscosity models for other CMAS Compositions:
  - Trace oxide effects
  - Volcanic ash
- Modify erosion burner rig to simulate CMAS exposure
- Develop CMAS-resistant EBCs

Contact: Valerie.L.Wiesner@nasa.gov

Additive Manufacturing for CMCs

Additive Manufacturing: GRC Composites Research



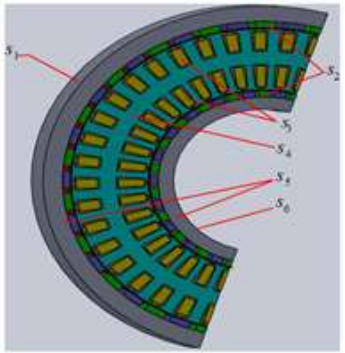


ExOne M-Flex Binder Jet machine:

Powder bed process with *tailored binders* and *chopped fibers* for CMC fabrication

n-Scrypt direct printing machine:

- Multi-material systems
- Ceramic pastes, electronic pastes, adhesives, solders, plastics



Multi-material stator for high power density electric motor

Contact: Michael.C.Halbig@nasa.gov

NASA GRC Focus in 2017

CMC Development & Characterization

- Evaluate durability of 2700°F CMC in TRL 4-5 rig tests
- Measure effect of cooling holes on durability of cooled CMC
- Compare fiber creep properties measured in air vs. inert environment
- Apply heat treatment process for improved Hi-Nicalon-S creep resistance
- Develop slurry infiltration process for CMC preform infiltration with advanced matrix

CMC / EBC Durability Modeling & Validation

- Measure effect of steam environment on CMC/EBC durability and failure modes
- Validate CMC creep model with mini-composite testing at 2400-2700ºF
- Determine how CMAS/EBC interaction affects mechanical properties
- Develop analytical model to relate matrix cracking to electrical resistance
- Validate SiC fiber crack growth model for CMC stress rupture prediction

Additive Manufacturing

- Optimize “binder jet” process for improved properties of chopped-fiber CMC’s

Support for our CMC research in 2016-17 comes from these NASA programs:

Transformative Aeronautics Concepts Program

- Transformational Tools & Technologies Project
- Convergent Aeronautics Solutions Project

Advanced Air Vehicles Program

- Advanced Air Transport Technology Project