CMC Research at NASA Glenn in 2014: Recent Progress and Plans

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for the 38th Annual Conference
on Composites, Materials and Structures
January 27-30, 2014 in Cocoa Beach, FL

National Aeronautics and Space Administration

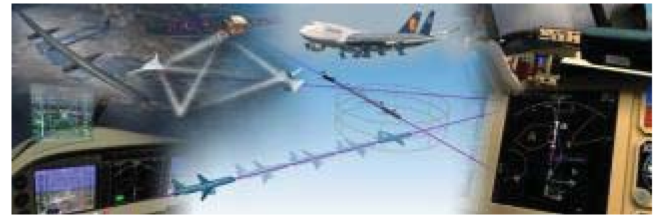
NASA Aeronautics Programs

Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

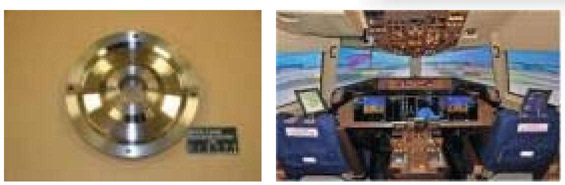
Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



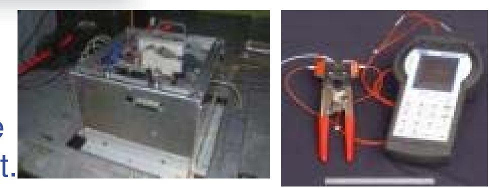
Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.



Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.

2013 Accomplishments

CMC Development & Characterization

- Fabricated and characterized 2700°F SiC / SiC CMC
  - 3D fiber arch. with *Sylramic-iBN* fiber and Hybrid (CVI+PIP) matrix
- Demonstrated matrix modifications for toughening SiC/SiC CMC

Fiber Development & Characterization

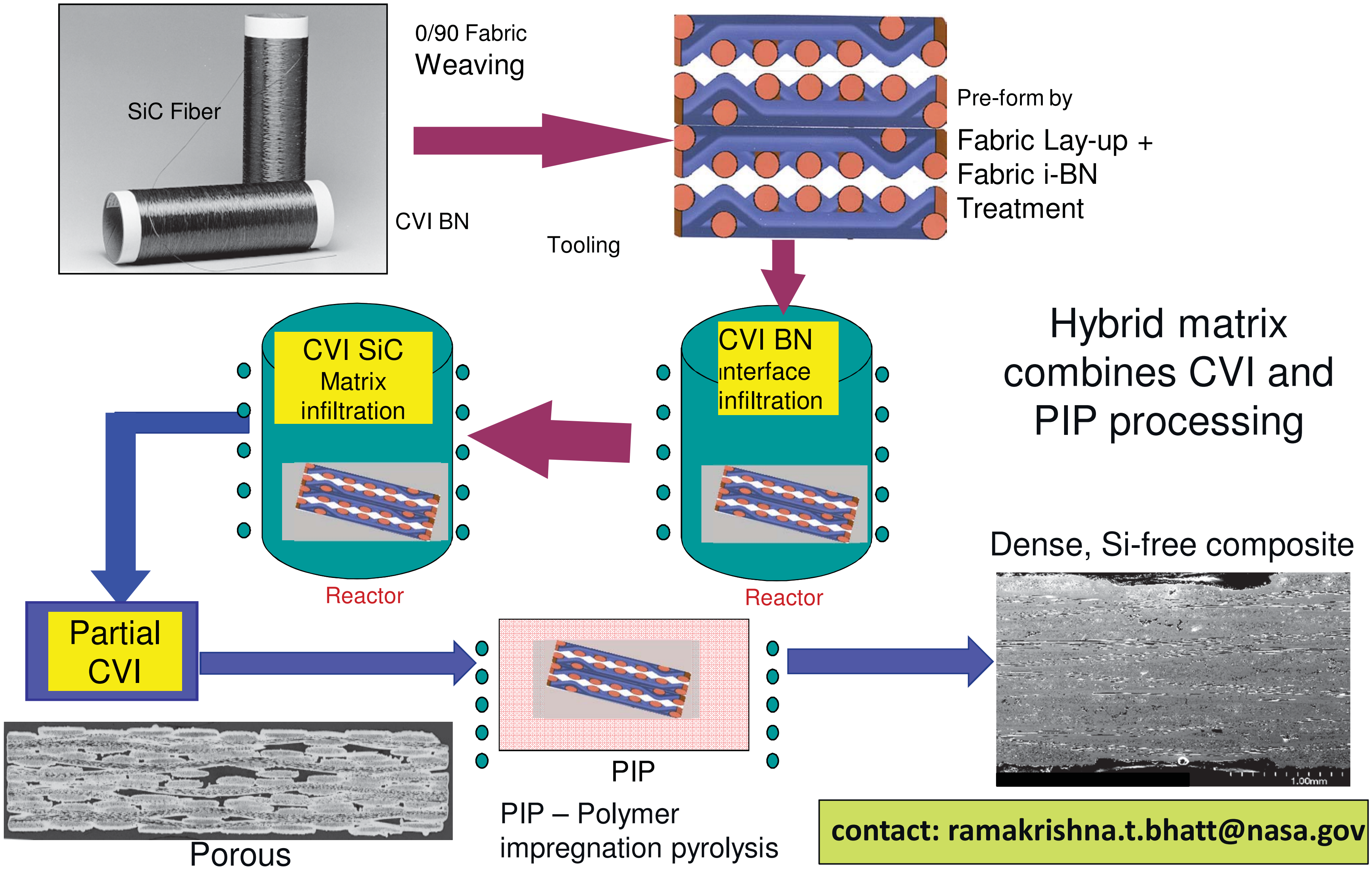
- Re-established *Super Sylramic-iBN* SiC fiber with improved creep resistance
- Developed and validated fiber creep-rupture models in SiC/SiC CMC
- Developed a processing approach for SiC "fuzzy fibers" with BN nanotubes

Characterized durability of CMC/EBC systems with new test methods

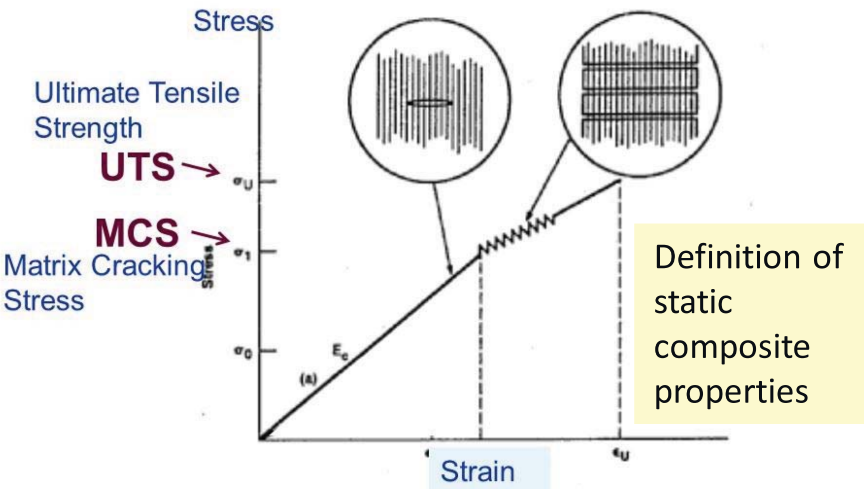
- Characterized CMC/EBC damage development in subcomponent rig tests
- Evaluated vibration response in rig test of CMC exhaust nozzle mixer
- Developed new REABOND joining technique for SiC / SiC structural joints
- Characterized CMAS / EBC interaction in burner rig tests

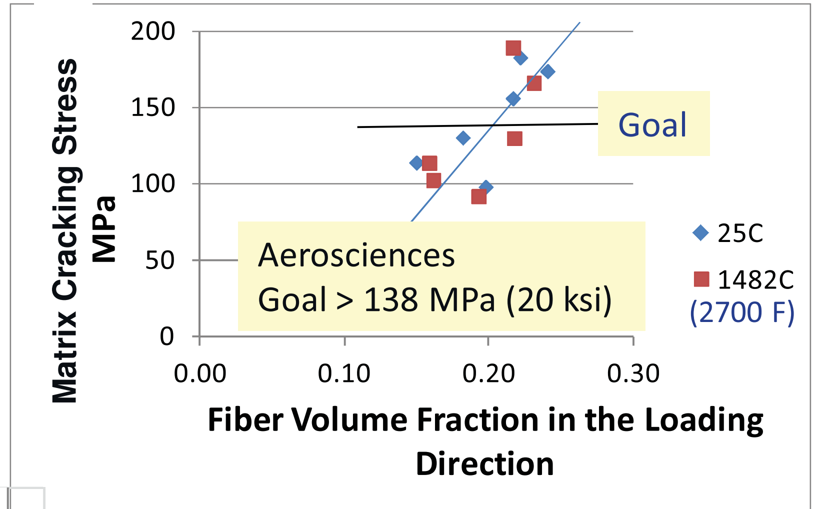
CMC Development

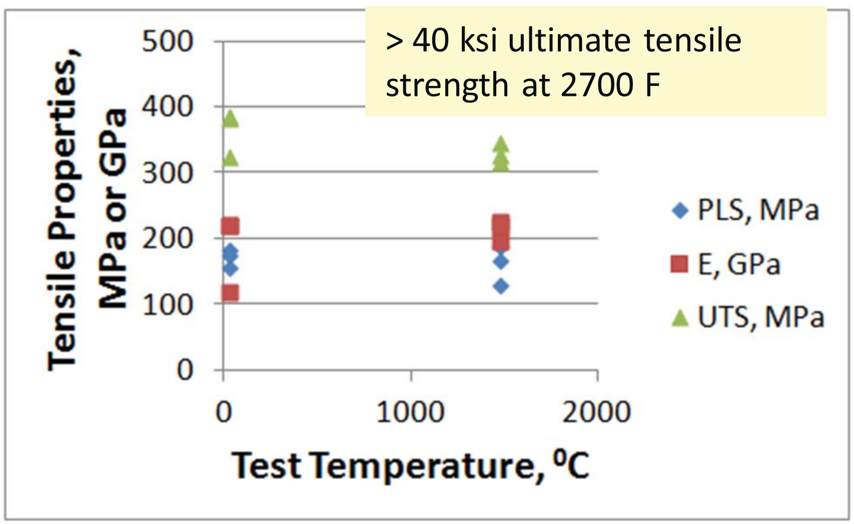
Hybrid Process for Dense SiC / SiC Composites

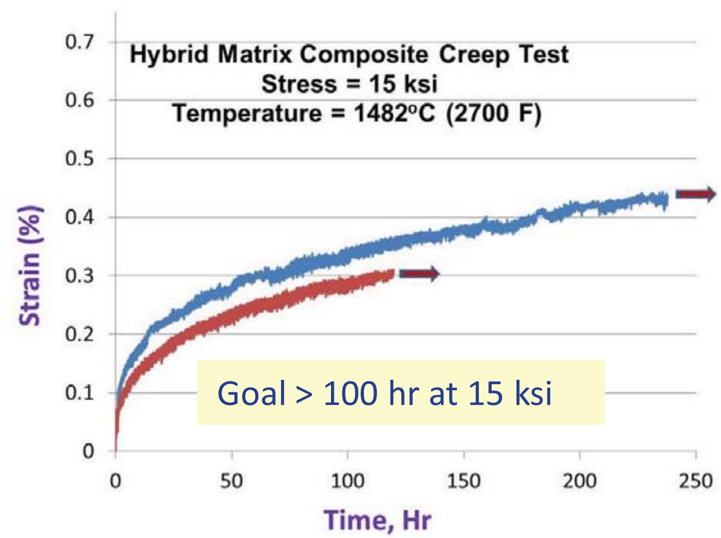


2700°F Property Goals Achieved



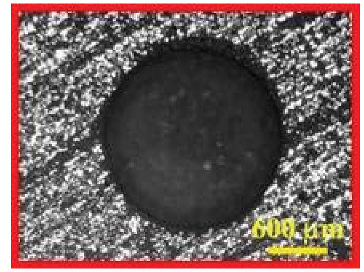




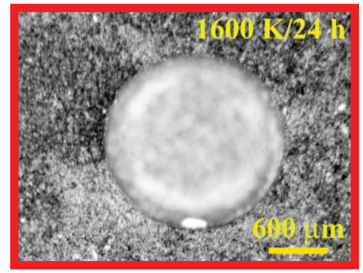


Static strength and stiffness of hybrid matrix CMC meets turbine requirements at 2700°F

Optimized SiC CMC matrix under development



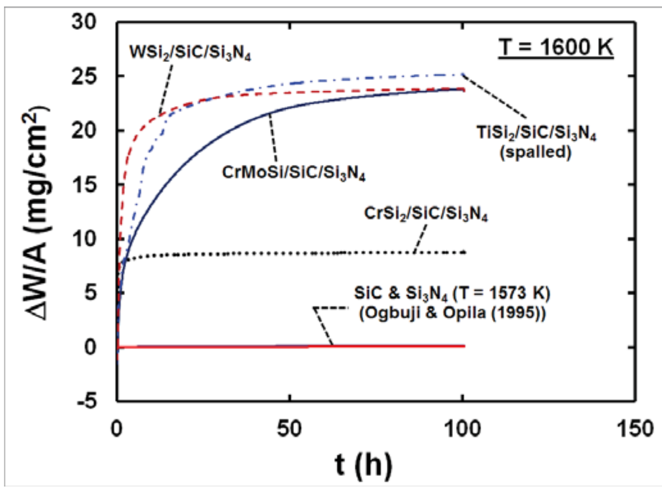
Before Oxidation



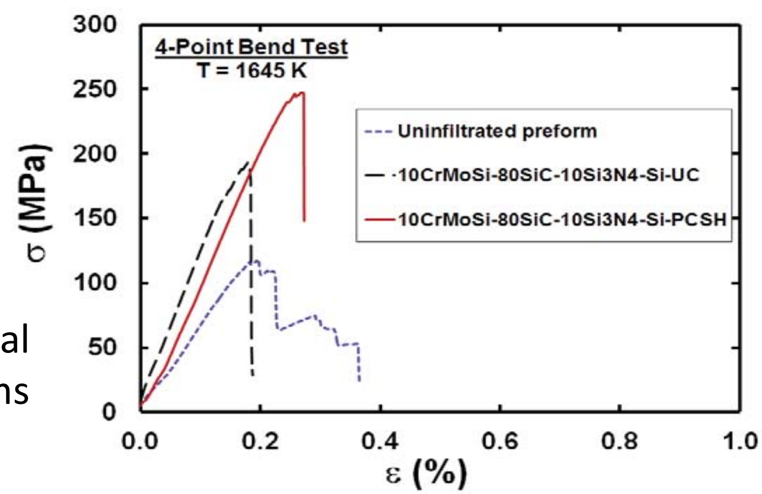
After Oxidation

Desired matrix properties:

- Increased toughness for improved durability
- Dense matrix for high thermal conductivity



Isothermal oxidation of candidate matrix systems



4-pt bend data for initial composite systems

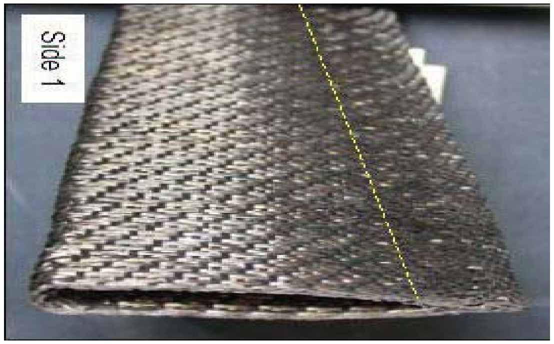
$CrSi_2$ / SiC / Si_3N_4 and CrMoSi / SiC / Si_3N_4 had the best bend and oxidation properties

contact: sai.v.raj@nasa.gov

Fiber Development

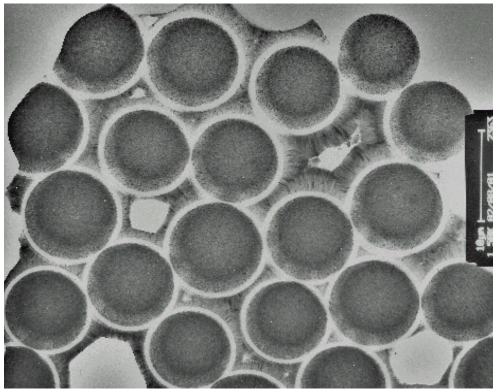
Fabrication Process for 2700°F Fiber

Boron-Sintered SiC Fiber Preform (formed from commercial "Sylramic" Fiber) → **Preform Treatment in High-Pressure N_2** (Boron removal for SOA creep-rupture resistance) → **Super Sylramic-iBN Preform** (in-situ grown BN surface layer on each fiber for environmental protection)



Blade Preform

Preform Treatment Furnace



iBN coating between every fiber

Heat treatment in high-pressure N_2 improves creep resistance of Sylramic iBN fiber

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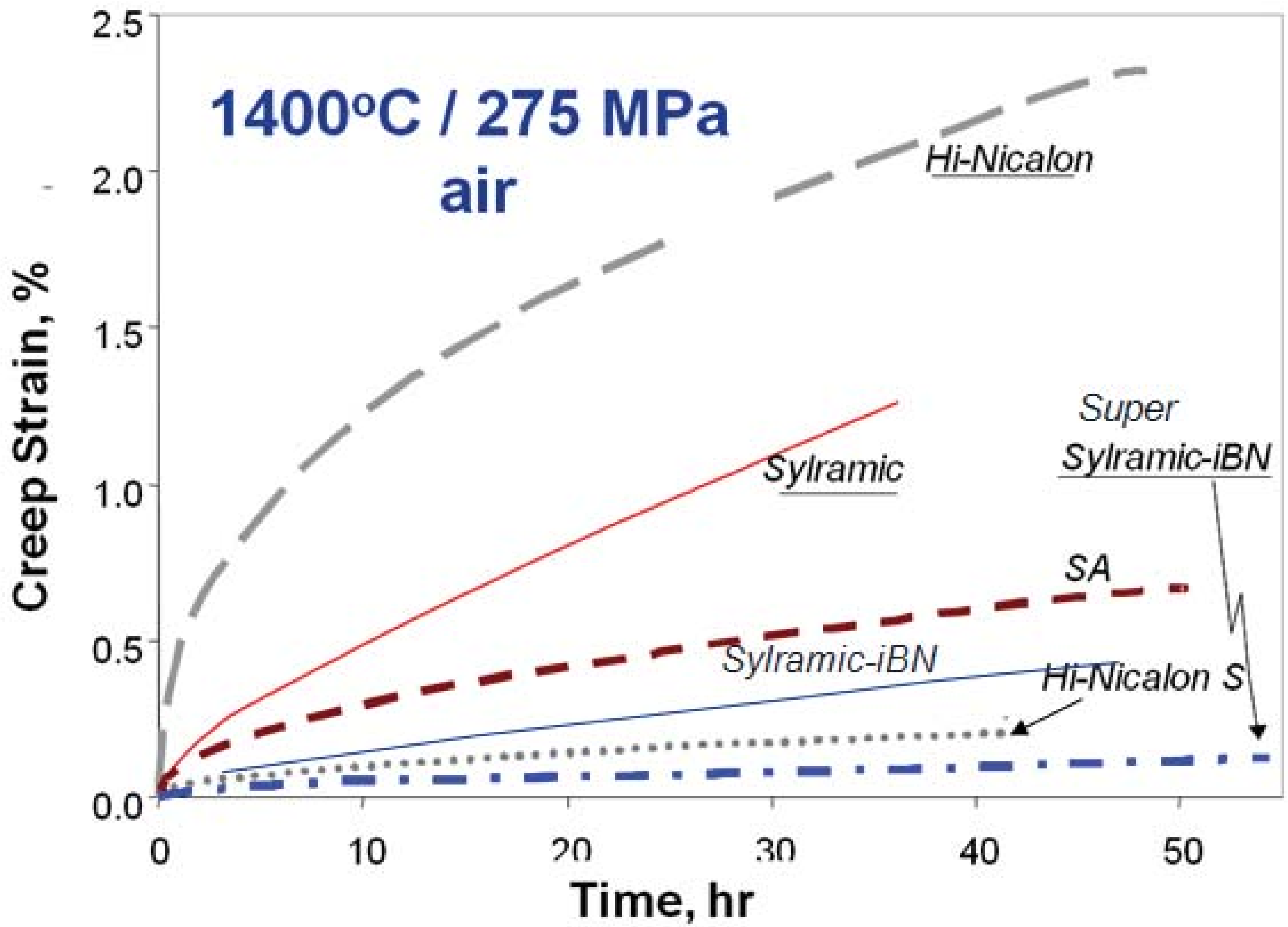
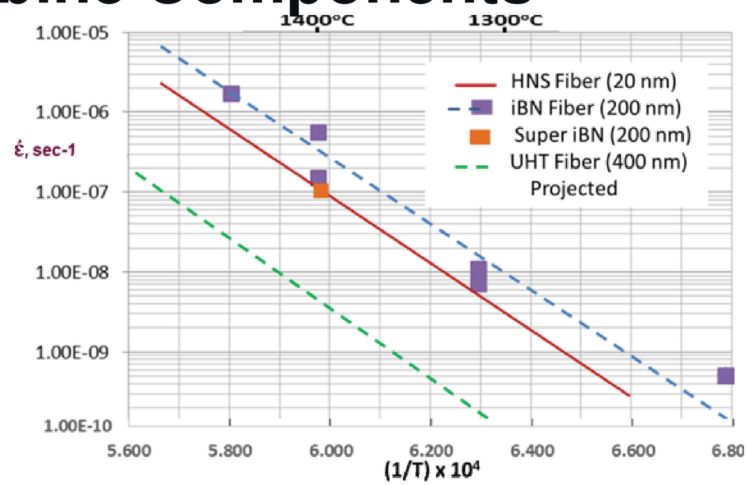
US Patent 7,687,016: *Methods for Producing SiC Architectural Preforms*

Super Sylramic-iBN fiber has lowest total creep at 1400℃

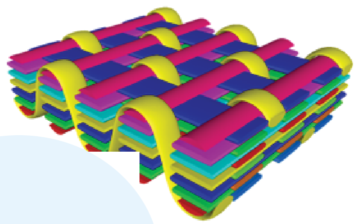


SiC Fiber Modeling and Development for High-Temperature CMC Turbine Components

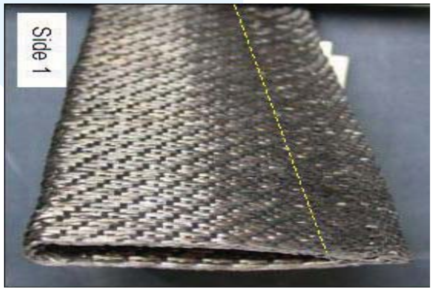


Mechanistic Modeling of Creep-Rupture Behavior of Current SiC Fibers. ISSUES: Impurities, Small Grains, and Non-Uniform Grain Size Distribution

Process and Property Modeling of 3D SiC Fiber Architectures for Improved Multi-Directional CMC Durability.



FY14 PLANS: Application of Models for Process Development of Advanced SiC Fibers within 3D Architectures that significantly enhance the Thermo-Structural Capability of SiC/SiC Components.



PROGRESS: Demonstrated 3D-reinforced SiC/SiC components, and 3D optimized test panels.

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SiC “Fuzzy Fibers” with Boron Nitride Nanotubes

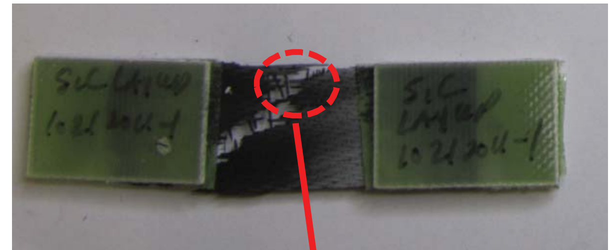
Objectives: Demonstrate the feasibility of boron nitride nanotube (BNNT) coated SiC tows in improving SiC/SiC properties. Fabricate “minicomposites” from coated tows to measure mechanical property improvements.

Approach: Coat SiC tows and woven fabric with BNNT to create a fuzzy fiber-matrix interface that can improve interlaminar strength and other CMC properties

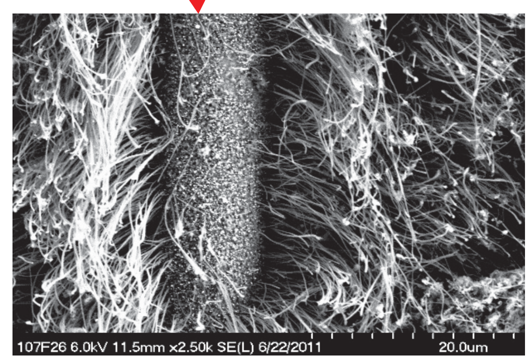
Accomplishments:

- Demonstrated in-situ grown BNNT can infiltrate SiC tows
- Fabricated and tested BNNT/SiC/SiC composites.
- Demonstrated improved tensile strength

2014 Research Focus: mechanical property measurement with “minicomposites” fabricated from BNNT-coated fiber tows



Graceful failure for SiC/SiC composite with fuzzy fibers



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CMC / EBC Subelement Testing and Characterization

Rig tests evaluate durability of CMC turbine vane subelements in simulated engine environments

21 hours

31 hours

70 hours

CVI SiC/SiC vane after burner rig testing

at 2500°F coating temperature

240 m/s gas velocity at 10 atm

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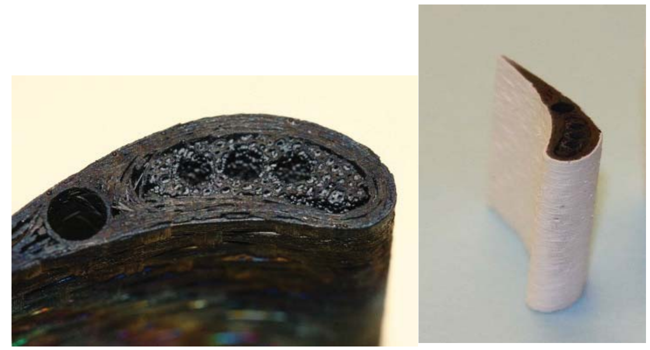
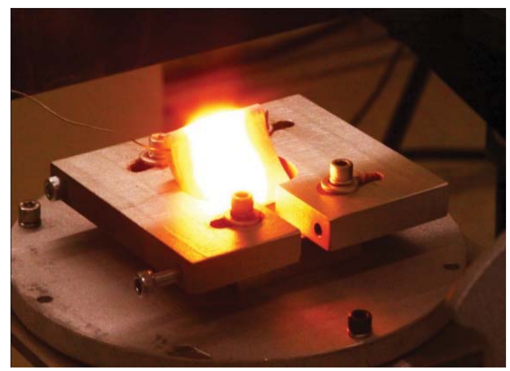


CVI SiC with Sylramic iBN

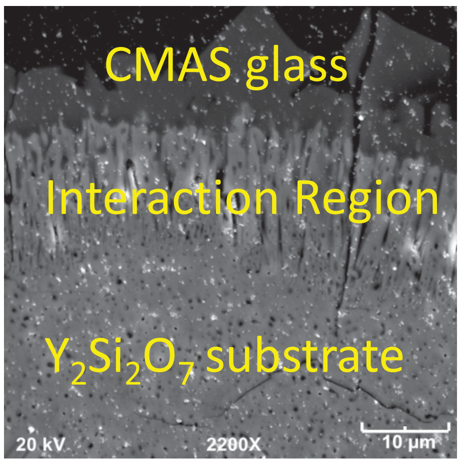


Laser Heat Flux
Thermal Gradient Test

- Completed 1000, 1-hour cycles with 2660°F T_{LE}
- Observed minor damage to leading-edge EBC at 350 cycles

EBC interactions with CMAS characterized

Ingested sand particles can form molten glassy deposits of calcium-magnesium-aluminosilicate (CMAS) on engine components, which react with environmental barrier coatings at high temperatures



CMAS reacted more extensively with hafnium silicate ($HfSiO_4$) EBC compositions than yttrium disilicate ($Y_2Si_2O_7$)

Sand ingestion

CMAS formed a ~20µm interaction region with yttrium disilicate after 20 hour / 1200°C exposure

$HfSiO_4$ formed a glassy phase near areas of CMAS contact > 1300°C

2014 PLANS

- Investigate CMAS interactions with EBC at 1200-1500 °C
- Study effects of CMAS on EBC stability

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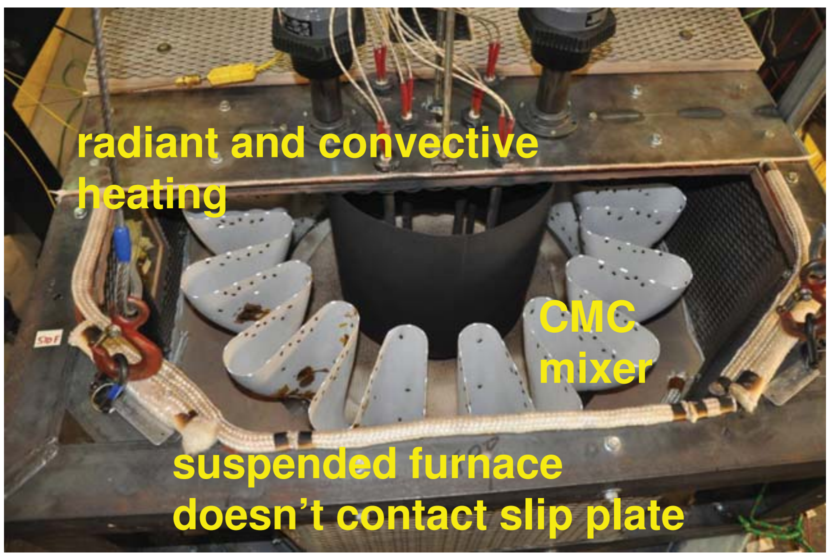
Hot vibration test of CMC exhaust mixer approximates engine operating conditions

- Rig test applied engine vibration spectrum at 700°F operating temperature
- AFRL used scanning laser vibrometry for vibration measurement




16-lobe mixer

- Full-scale Rolls-Royce AE 3007 CMC mixer fabricated by COIC
- 2D N610 / Aluminosilicate CMC

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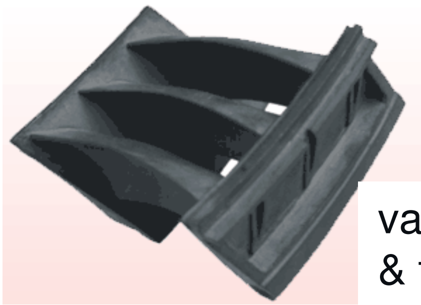
CMC Joining and Integration

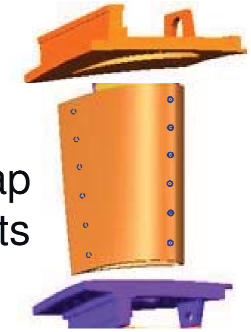
Objective: Develop joining and integration technologies to enable reduction in part count, seals, and leakage from fabrication of complex CMC components and integration with metals



vane doublets & triplets

vane airfoil sections

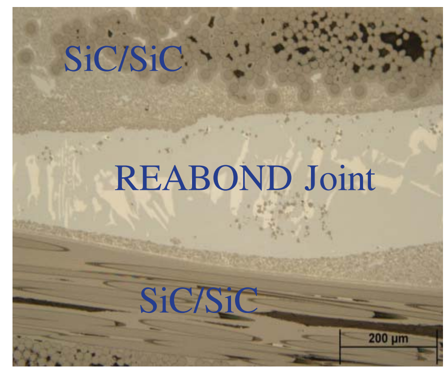
airfoil / endcap joints



Status:

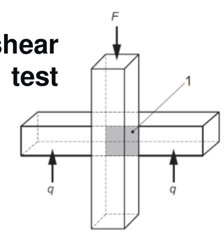
- REABOND technology successfully used to join CMCs
- Dense, crack free joints with stable reaction formed phases.
- Properties from single-lap offset shear tests of REABOND joints:

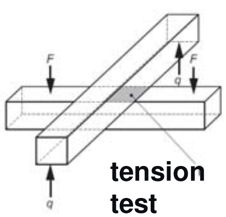
- 100 MPa at room temperature
- 70 MPa at 1382°F (750°C) and 2192°F (1200°C)
- good strength retention after creep test run out at 2192°F



SiC/SiC composite joint

shear test





tension test

2014 Focus:

- Nano-particle inter-layer toughening for improved joint properties
- Implement ISO 13124 tests for tension and shear strength

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NASA GRC Focus in FY14

Development and characterization of fiber, matrix and CMC

- Fabricate & characterize CMC with Hybrid (CVI + PIP) matrix and Super Sylramic-iBN Fiber (also Hybrid/Hi NiC-S)
- Measure "fuzzy fibers" effect on CMC mechanical properties

CMC characterization for validation of life prediction models

- Characterize durability and failure modes of hybrid matrix CMC at 2700°F
- Validate fiber and fiber architecture models in 3D CMC
- Validate model to predict environmental effects in cracked SiC/SiC CMC
- Identify CMAS interactions with CMC / EBC
- Analysis & durability characterization of SiC/SiC joining techniques

EBC constituents evaluated for turbine blade for 2700 F CMC

- Bondcoat developed for 2700 F durability
- Volatility and recession assessed for key phases of the top coat
- Combined effects of temperature, load, and environment quantified