Ceramics at Hypersonic Limits

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Difference between Airbreathing and Non-Airbreathing

Take off Weight	Aircraft (%)	Rocket (%)
Payload	15	4
Fuel	30	24
Oxygen	0	65
Vechicle	55	7

What are the regimes of flight speed

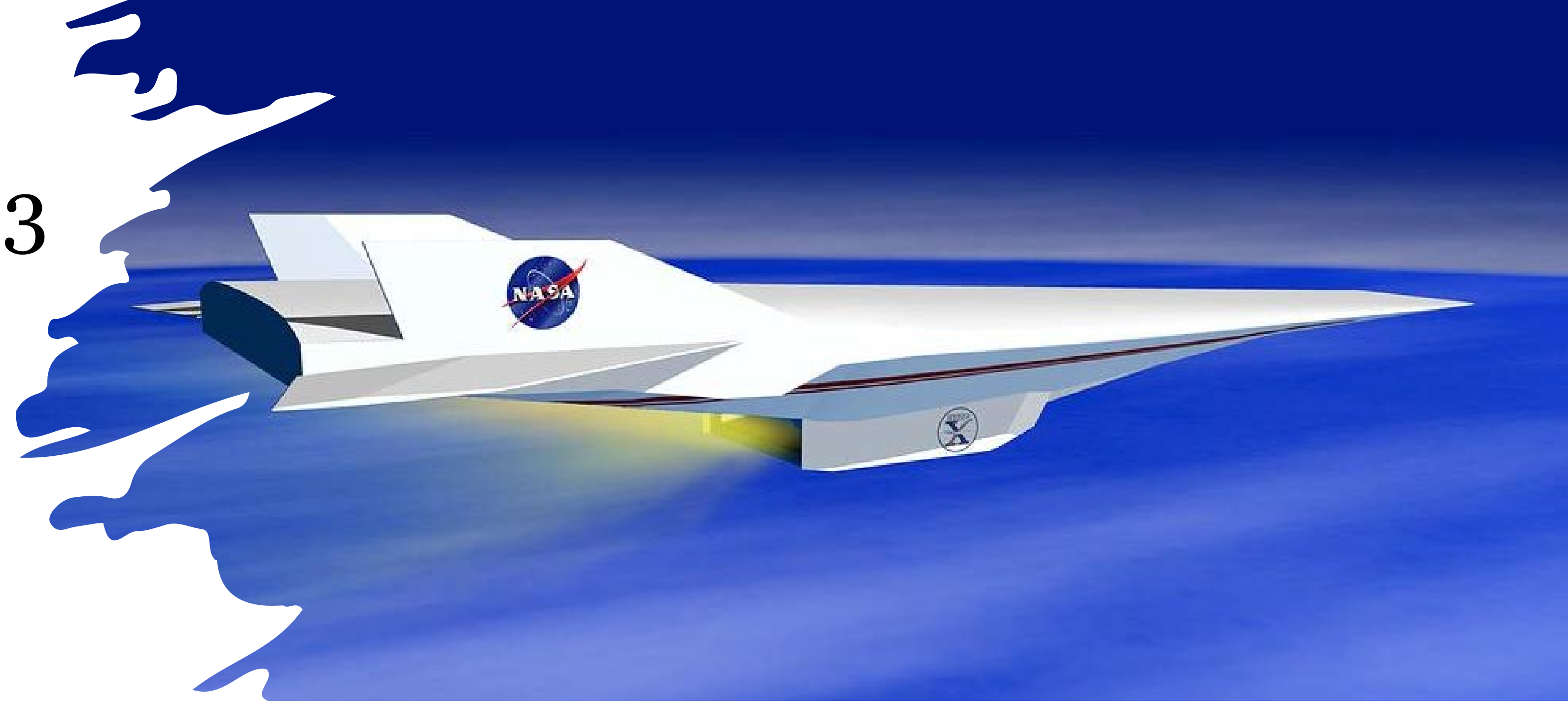
What is a Mach number M?

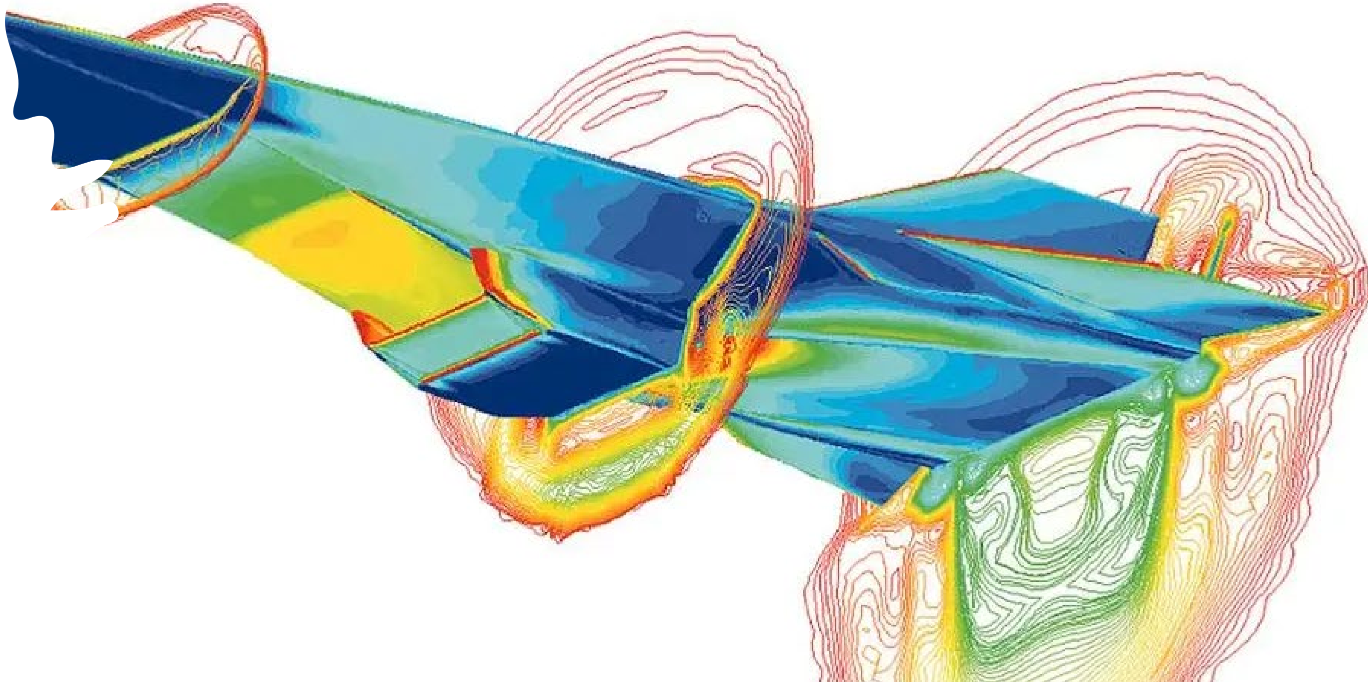
Dimensionless Ratio = Vehicle Speed /Speed of Sound at Sea Level 668 mph

New York to Paris

Subsonic	33 hours Ryan NYP (C. Lindberg)
Sonic M1	7 hours Boeing 767 (0.8Mach)
Supersonic M2	3 hours Concorde
Hypersonic M5	1 hour
Re-entry Speed M39	(90 minutes Orion- Artemis II- any where on Earth)

NASA's X-43





Hypersonic Flight Conditions

At Mach 5 calculations predict the heating on leading edges at 1000 ^{o}C

Current High Temperature Materials

Reinforced Carbon-Carbon – Space Shuttle leading edge at 1650 ^{o}C

Silicon Carbide Composites 1200 ^{o}C

(While important, Ablatives don't apply here (Orion))

For hypersonic service we need repeatable exposures

- High temperature durability above 1500 ^{o}C
- Resistance to:
  - Thermal Shock
  - Impingement and erosion
  - Reactive ionized gases

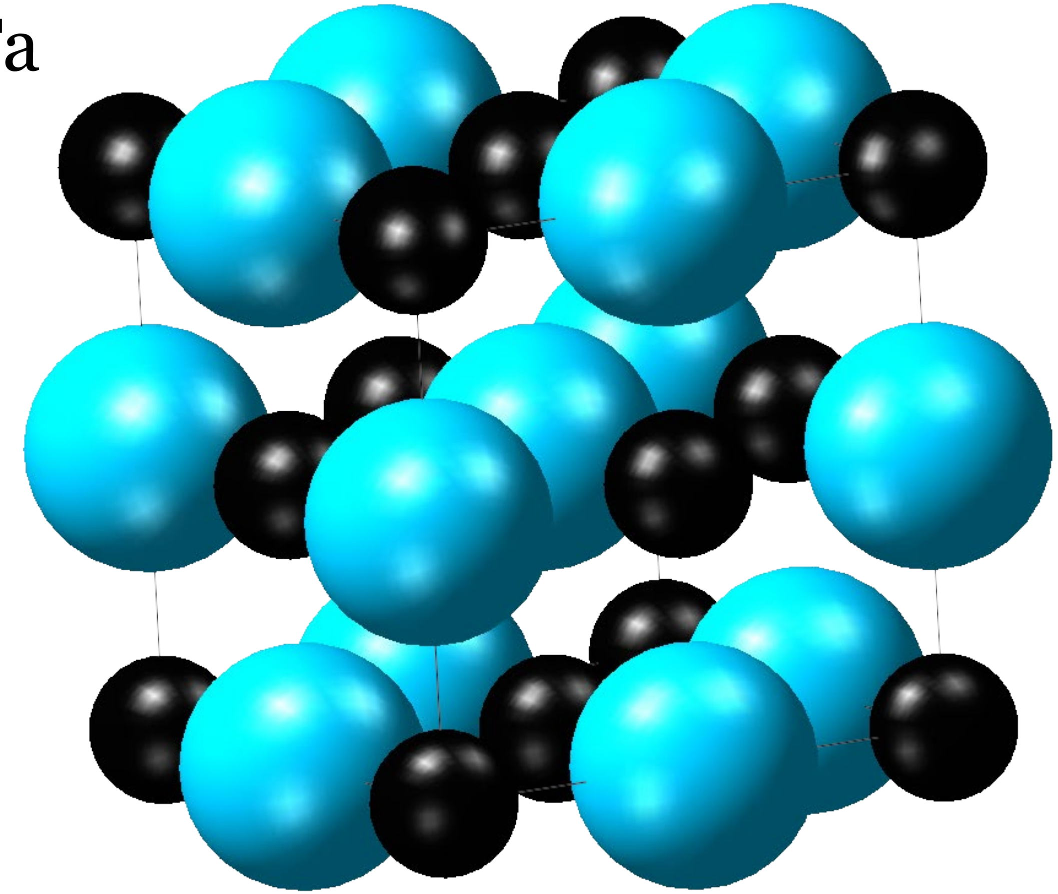
What are Ultra High Temperature Ceramics (UHTC) ?

Refractory Transition Metals Carbides and Borides

Non-oxide- Use temperatures 1800 ^{o}C

MC and MB2

M= Zr, Hf, Nb, Ta



Processing Temperatures 2000 ^{o}C

Covalently Bonded Compounds

Melt Temperature ~ 3000 ^{o}C

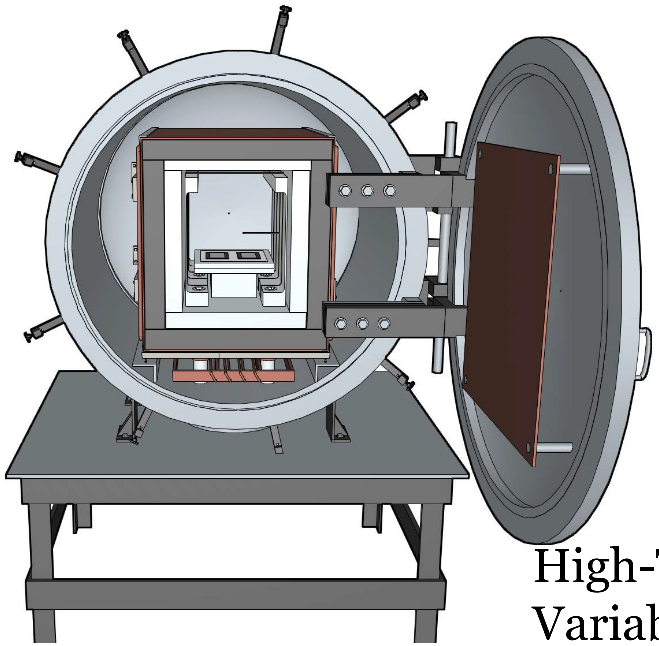
Non sintering techniques

-Chemical Vapor Disposition (CVD, CVI)

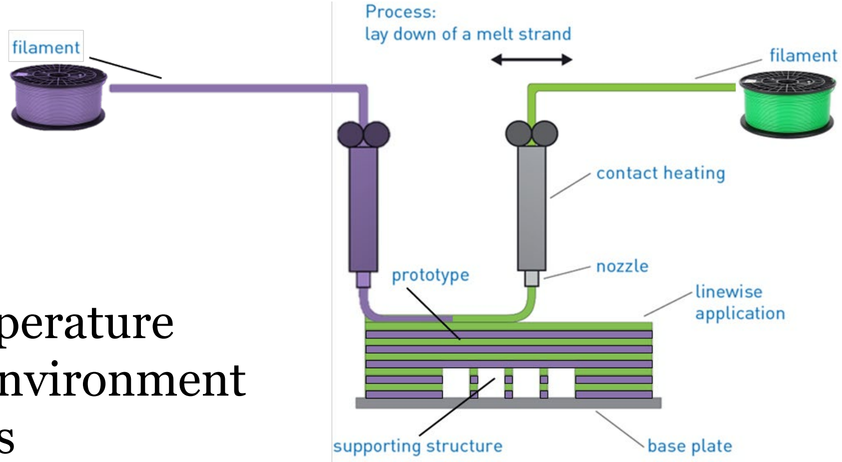
-Reactive Melt Infiltration (MI)

-Precursor Infiltration and Pyrolysis (PIP)

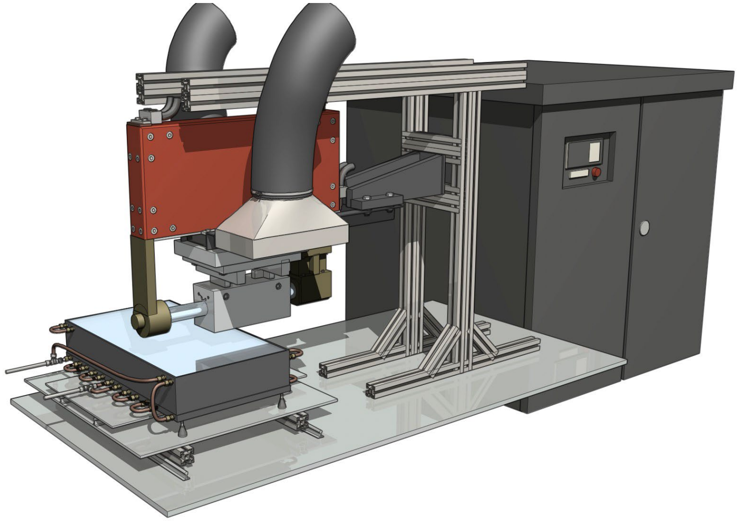
Composite Processing



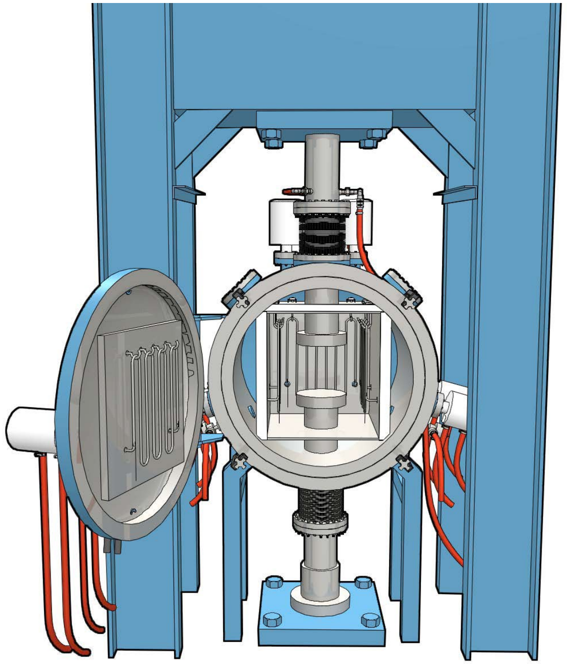
High-Temperature
Variable Environment
Autoclaves



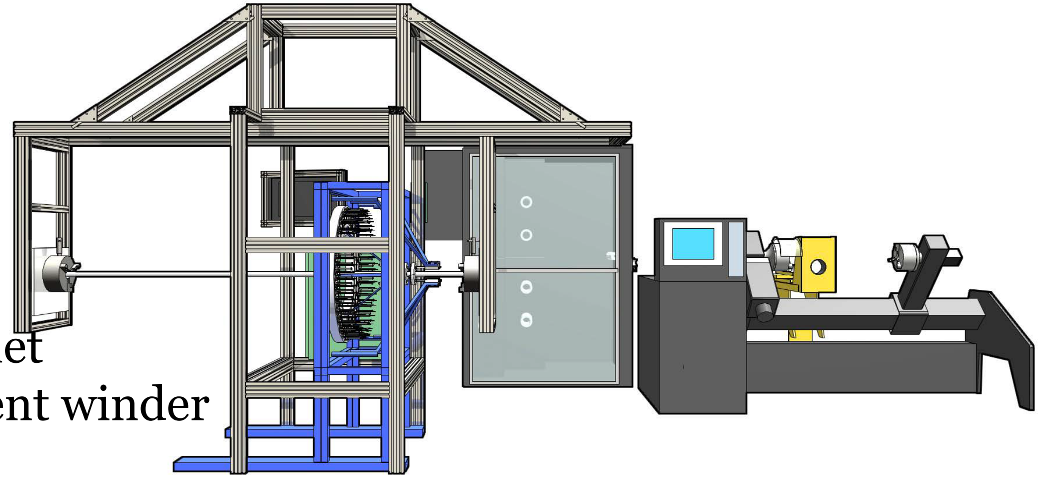
Additive Manufacturing



Vortex High heat flux arc-lamp

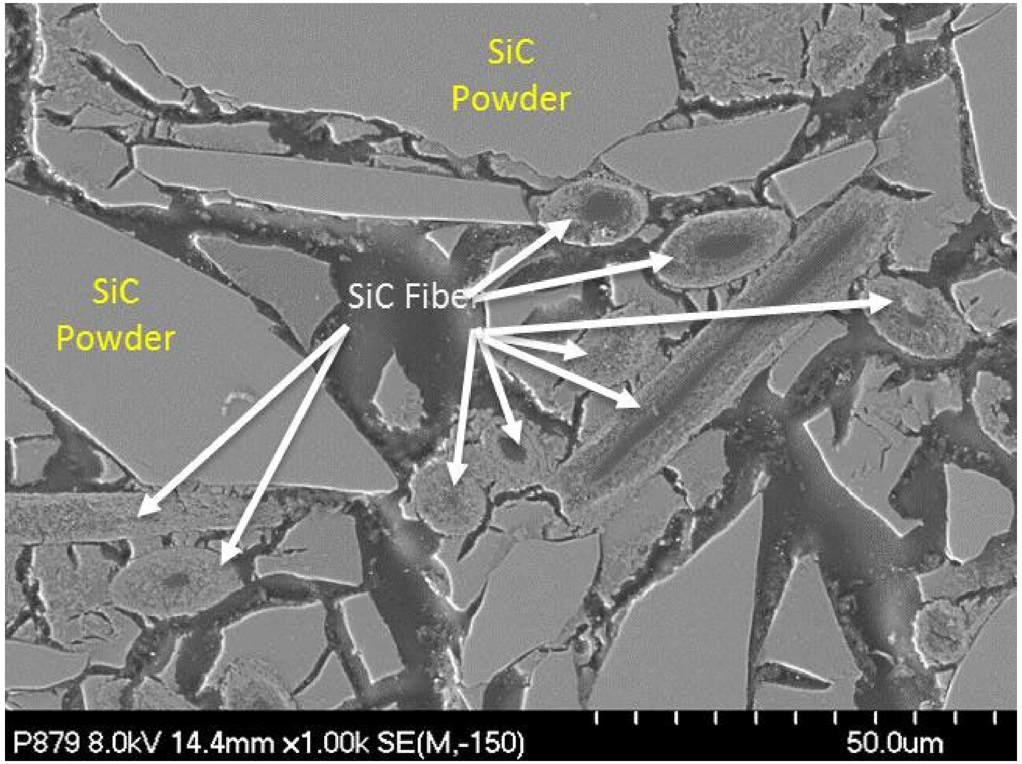


AVS 100-ton large capacity
2000 °C hot press



Wardwell Composite Braider
McClean Anderson Super Hornet
four axis CNC controlled filament winder

Material Forms Monolithic and Composites



Chopped fiber reinforced ceramic matrix composite

Composite Types

-Two Phase Materials Structure

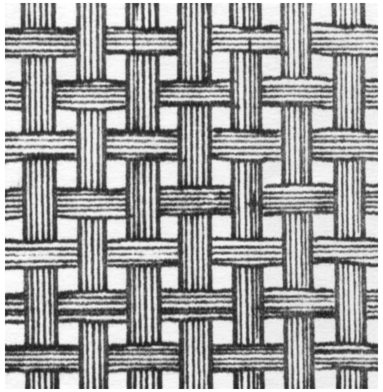
- Matrix + Particulate
- Matrix + Chopped Fibers
- Matrix + Continuous Fibers (Textiles)

Carbon Fiber Reinforced CMC by CVI :

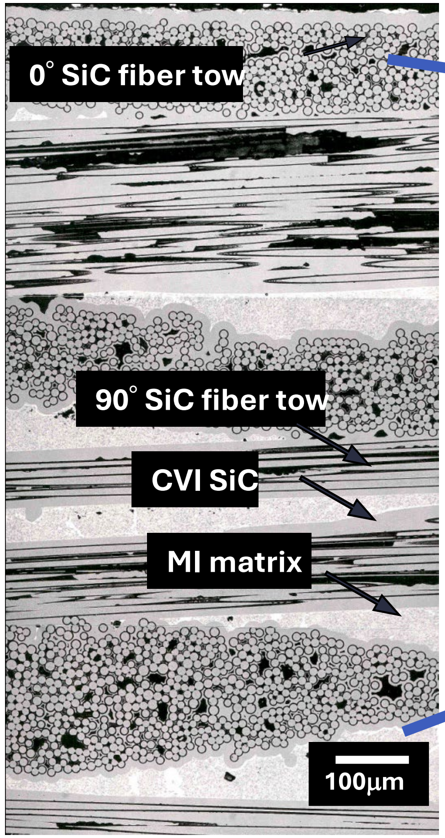
$HfCl_4$ + Methane + Hydrogen   produces HfC + Hydrogen Chloride

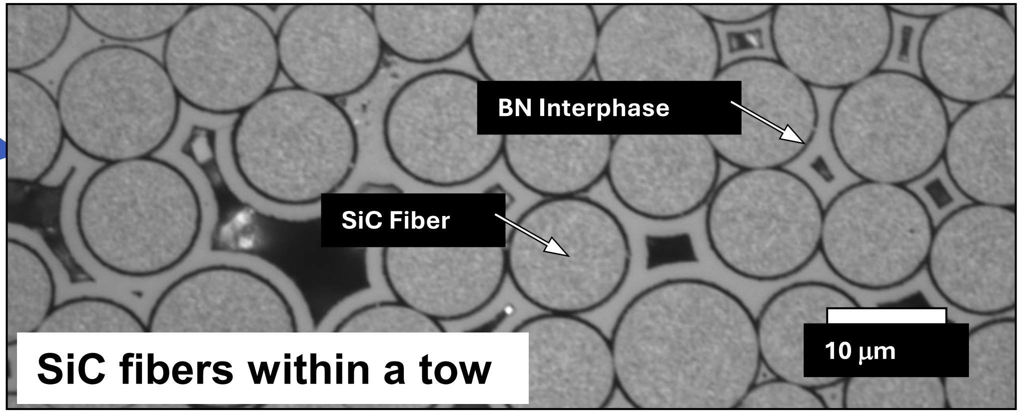
Conventional CMC Materials – Hybrid CVI and Melt Infiltrated (MI) SiC/SiC

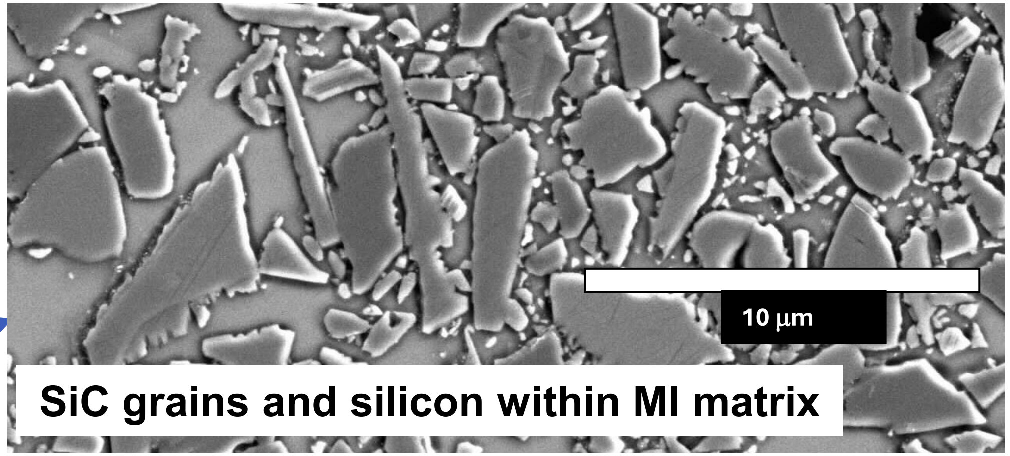
0-90 Plain Fiber Tow Weave



Composite Cross-Section



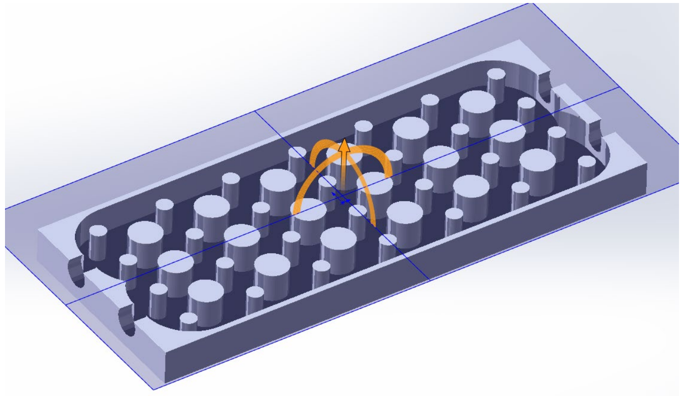




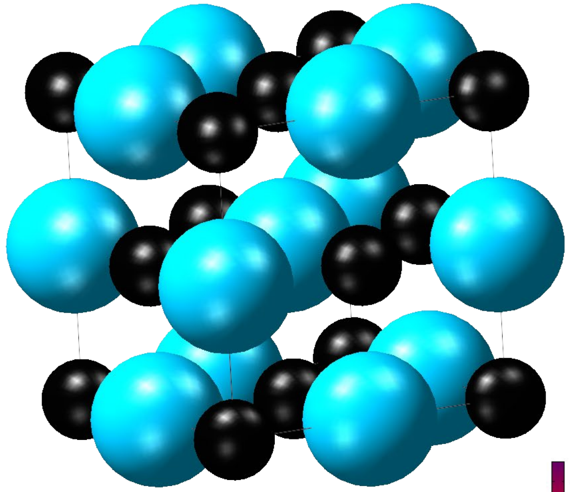
CMC properties:
- **High thermal conductivity matrix**
- **Elimination of interlaminar porosity**
- **No matrix micro cracking**
- **Continuous fibers and high fracture toughness**
- **High strength and temp. capable**

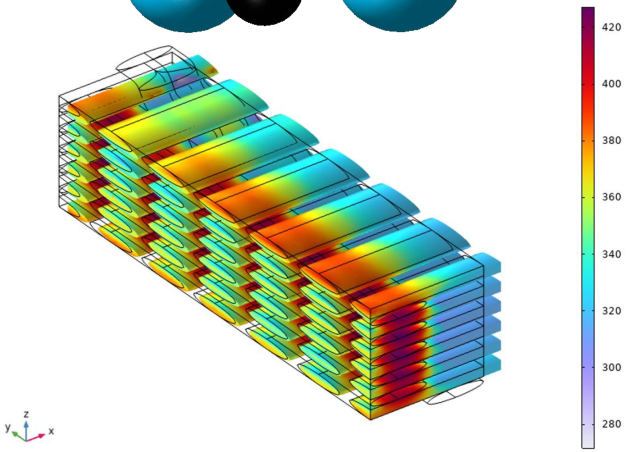
Benefits of CMCs in high temperature, structural aerospace applications:
- Higher temp. capability and reduced cooling and weight than for metals.
- Increased fuel efficiency, performance, range, and payload,
- Lower emissions and lower operation costs.

Ceramic Technologies

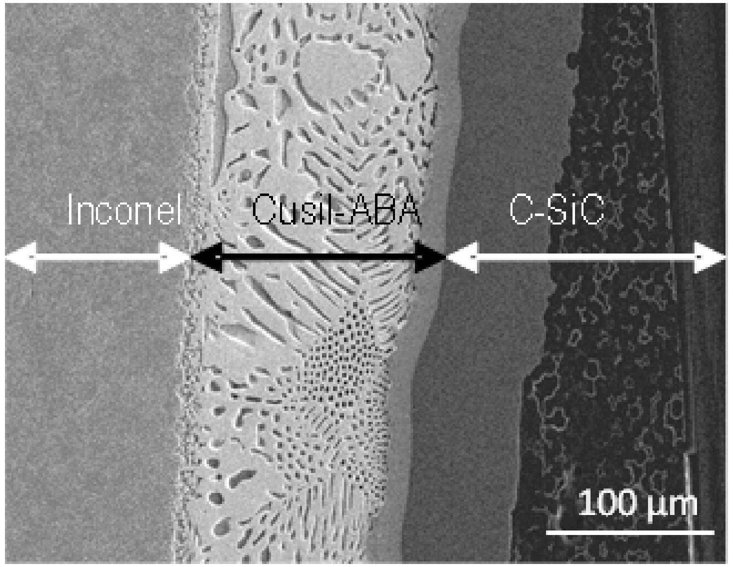


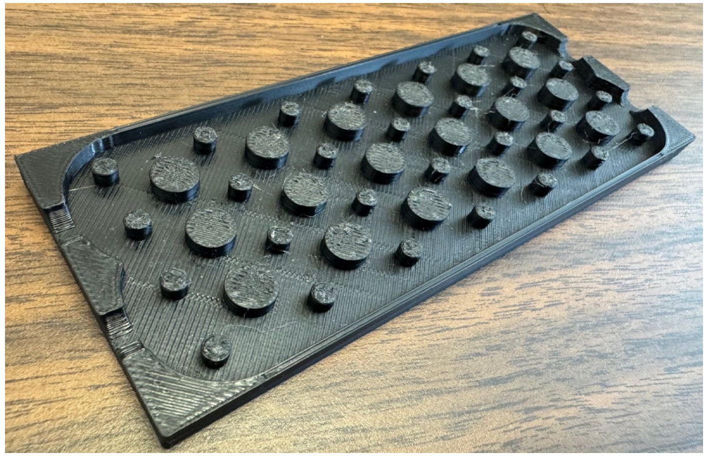
Computational Material Sciences:
Density Functional Theory
Finite Element Analysis
Fiber Architecture Design





Joining and Integration of Composites to Metals for Applications in Hypersonic Systems





Testing Environment Hierarchy

Room Temperature Properties

Intrinsic

- Composition
- Density
- Microstructure
- Stiffness (Elastic Constant)
- Thermal Conductivity

Performance in Environment

Temperature

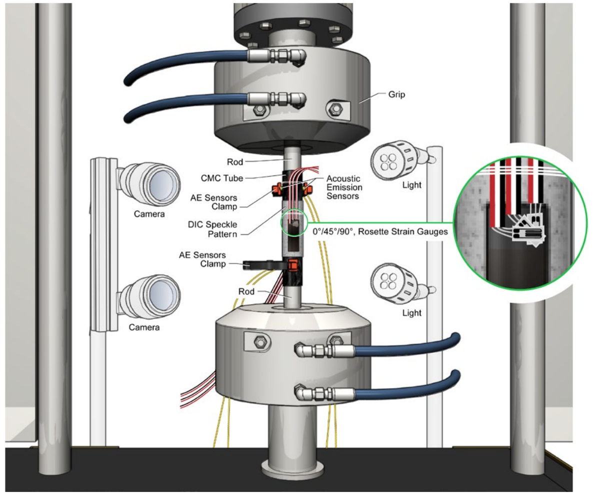
Environment (Steam, air, sand, etc.)

Arc Jet testing

Test Flight

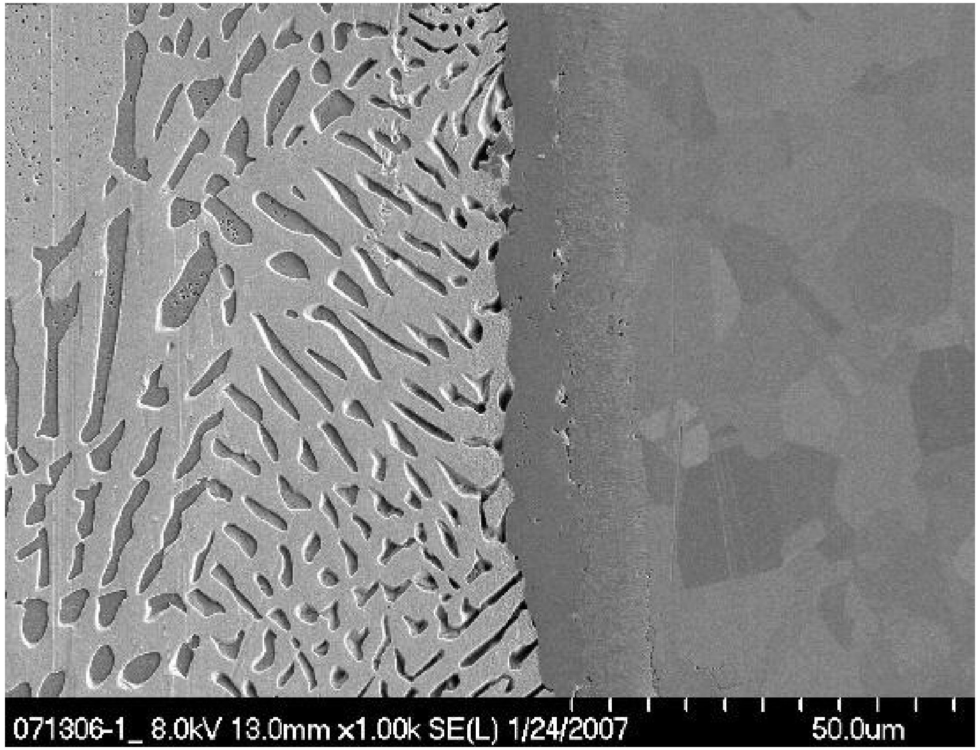
Testing Hierarchy

- Coupons
- Elements
- Details
- Sub- Components
- Components



Challenges

- Design
- Fabrication
- Large Scale Fabrication
- Joining, Repair
- Long Term Durability
- Modeling and Simulations



Brazing of Ceramic to Ceramic and Ceramic to Metal Systems