



הטכניון - מכון טכנולוגי לישראל
מוסד הטכניון למחקר ופיתוח - מכון המתכות הישראלי

SiC/SiC Ceramic Matrix Composites (CMC) for jet engine applications

state of the art

Dr. Alex Katz

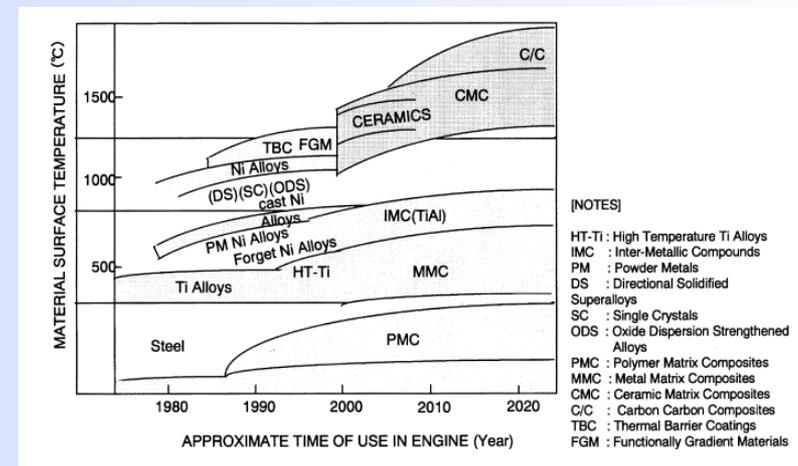
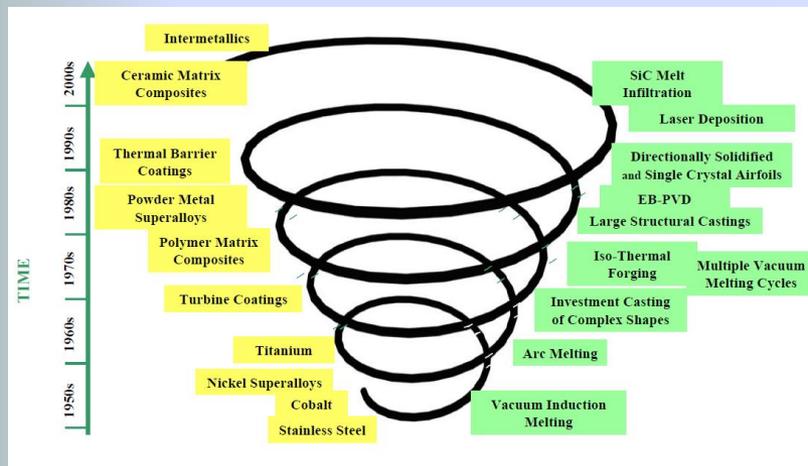
Israel Institute of Metals, TRDF, Technion

**15th ISRAELI SYMPOSIUM ON JET ENGINES & GAS TURBINES,
Faculty of Aerospace Engineering, Technion, Haifa, Israel
November 17 2016**



Materials and production processes for jet engine blades

Endurance of materials in high temperature is a limiting property in many engineering applications. In the case of jet engines, the technical potential in increasing the thermal endurance is immense and is directing many R&D funds towards new material solutions.

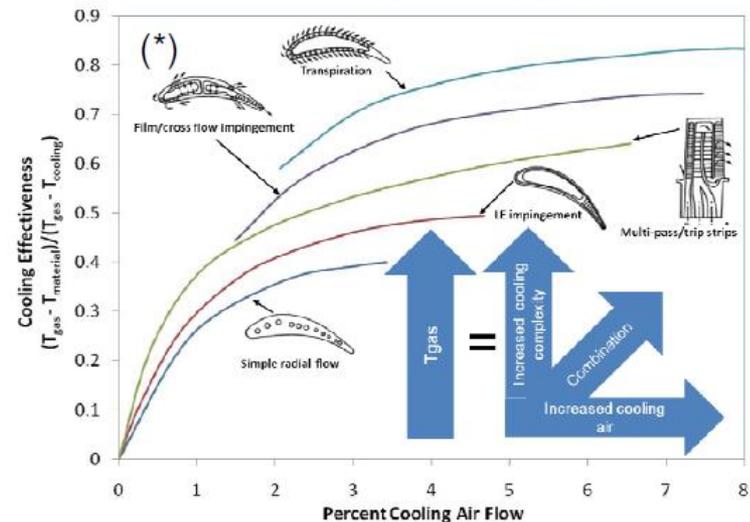
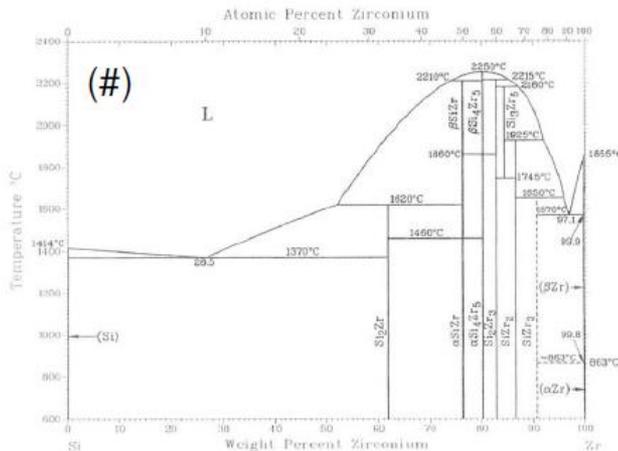
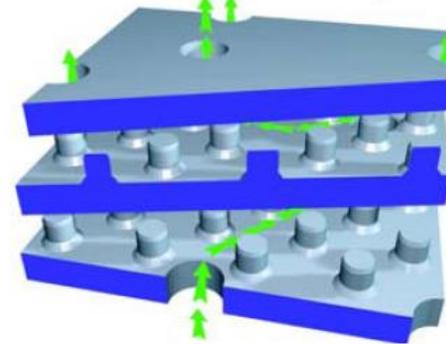


Materials and production processes for jet engine blades

Future material needs

- **Increased temperature capability**
 - Small improvements can have a big impact
 - Additional reductions in cooling air
 - Removal or simplification of cooling schemes
 - Reduces thermal gradients
 - Reduces manufacturing cost
 - Increased insertion opportunities
- **Potential solutions exist**
 - CVI or PIP SiC/SiC
 - New MI systems

Metals can utilize cooling technologies that are not available to CMCs (Lamilloy®)





Materials and production processes for jet engine blades

Currently used materials

- ✓ nickel based super alloys (such as the Mar M247)
- ✓ single crystal (SC) based nickel super alloys

Advantages

- ✓ high temperature strength
- ✓ corrosion resistance
- ✓ oxidation resistance

Disadvantages

- ✓ requirement of use of Rhenium in order to achieve improved creep strength and fatigue resistance
- ✓ hard to machining with, due to their strength
- ✓ highly expensive



Materials and production processes for jet engine blades

Future development in the field of metallic alloys for blades application

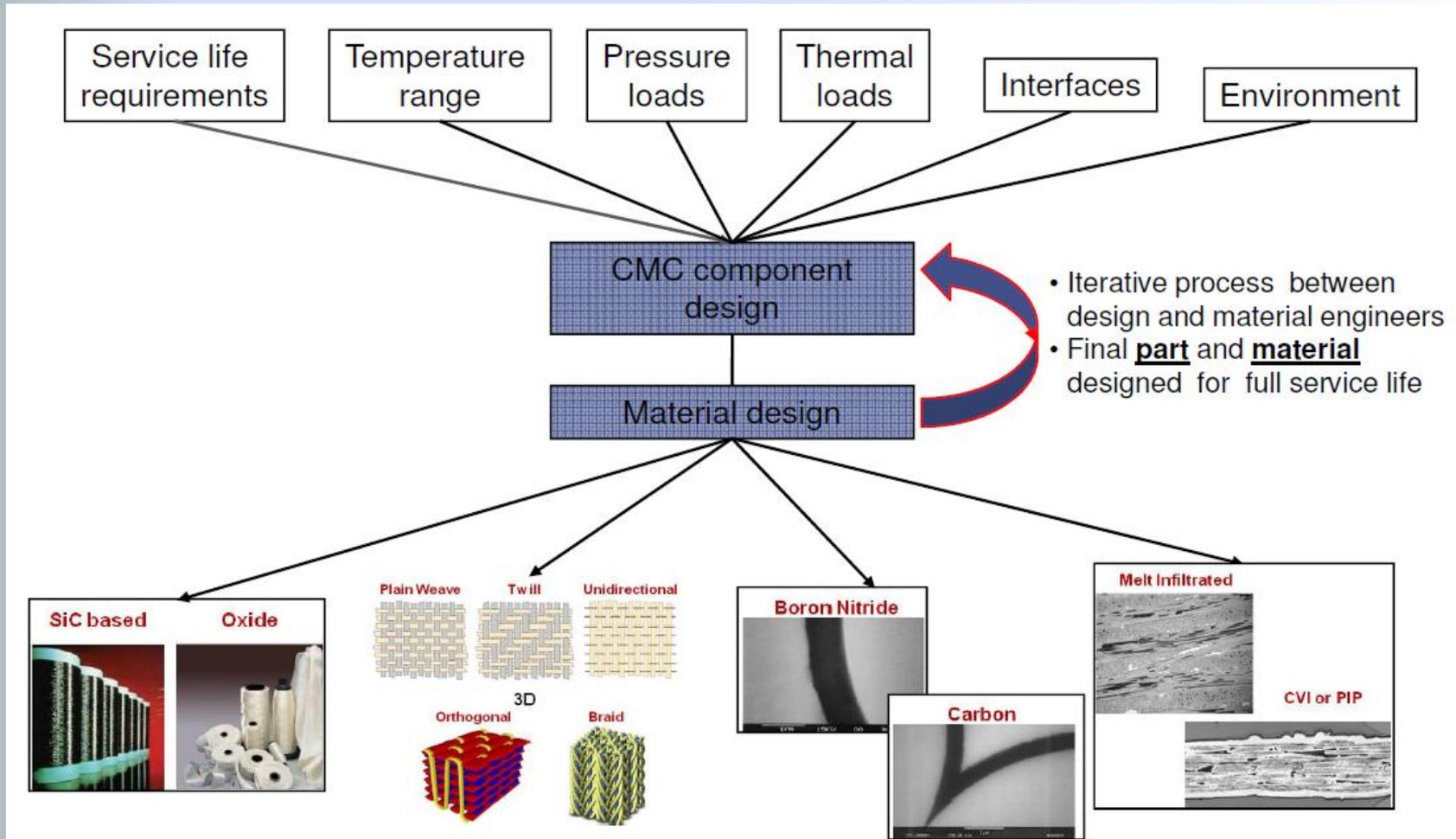
- ✓ BCC High Entropy alloys (HEA) should provide a cost efficient solution to replace the SC blades

Practical disadvantage

- ✓ Development status of these materials remains quite far from industrial application

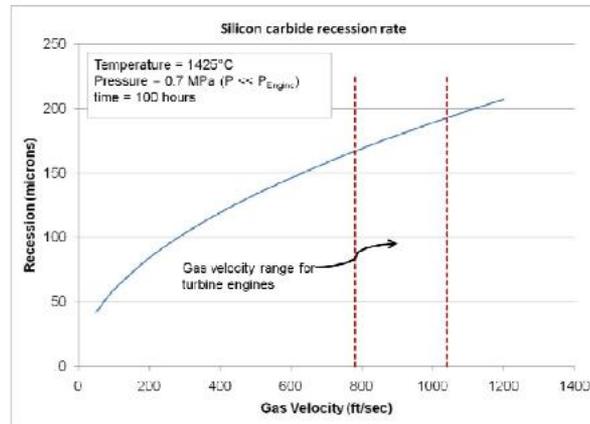


Ceramic Matrix Composites (CMCs) as an alternative material and component design

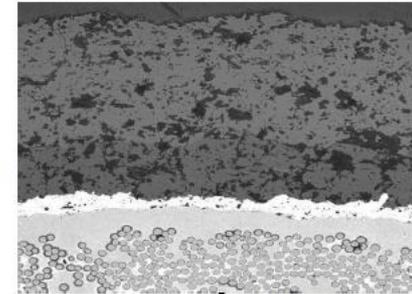




Ceramic Matrix Composites (CMCs) as an alternative *environmental stability*

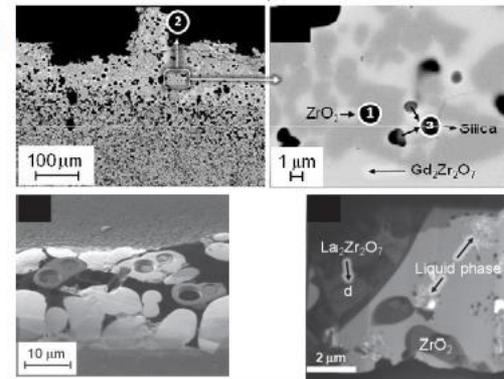


Environmental barrier coatings

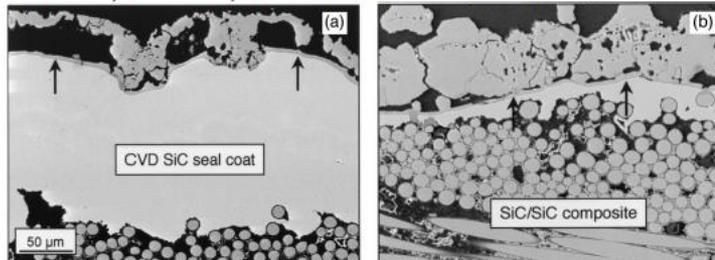


Future Solution?

(*)



1200°C, 10 atm, 500 hrs 1200°C, 10 atm, 3500 hrs

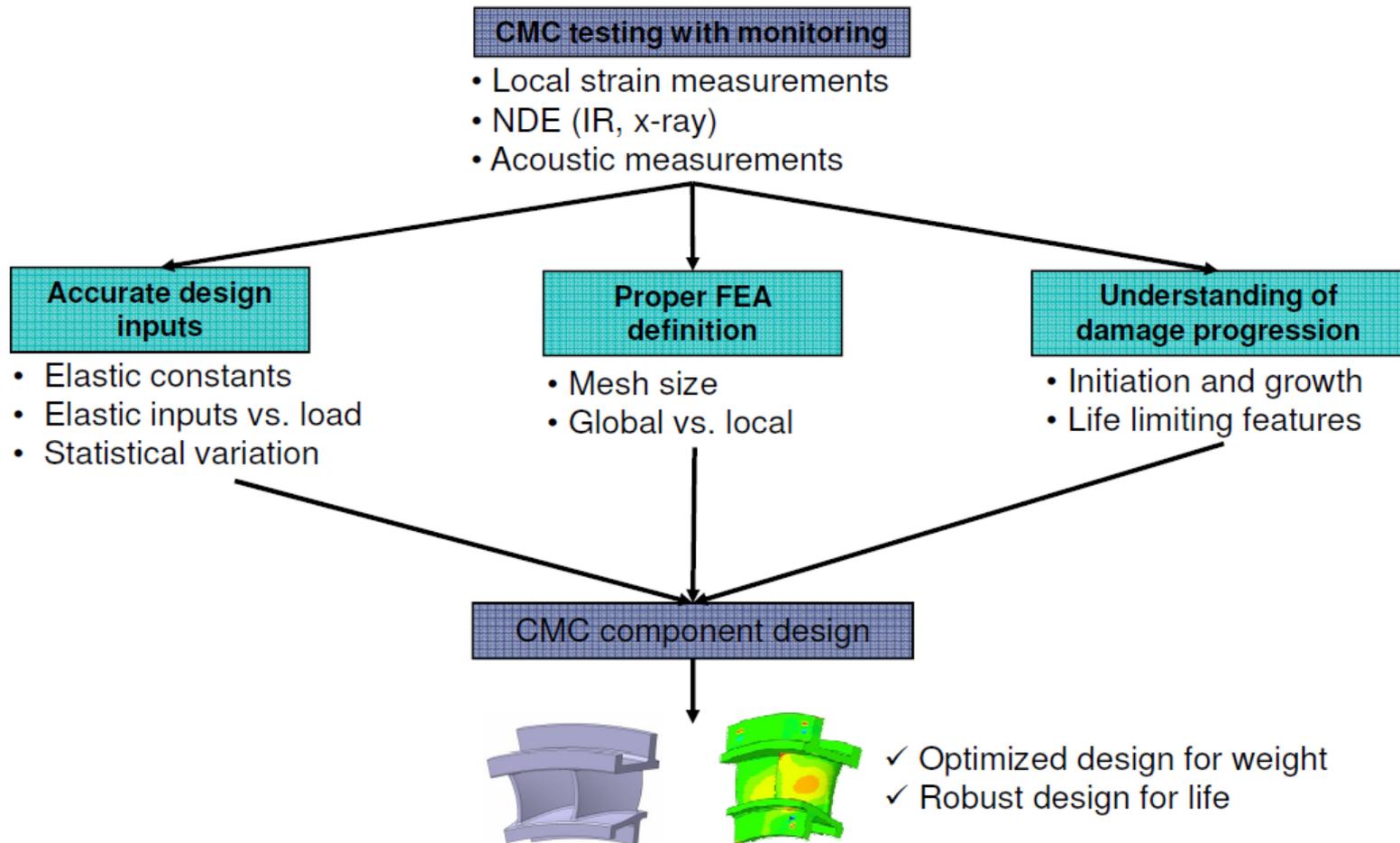


Images from: P. Tortorelli and K. More, "Effects of High Water-Vapor Pressure on Oxidation of Silicon Carbide at 1200°C," J. Am. Ceram. Soc, 86 [8] 1249-55 (2003)

- ZrO_2 stable in H_2O
- Are zirconates stable in H_2O ?
- Can you incorporate this into a fiber composite?



Ceramic Matrix Composites (CMCs) as an alternative *testing and analysis*





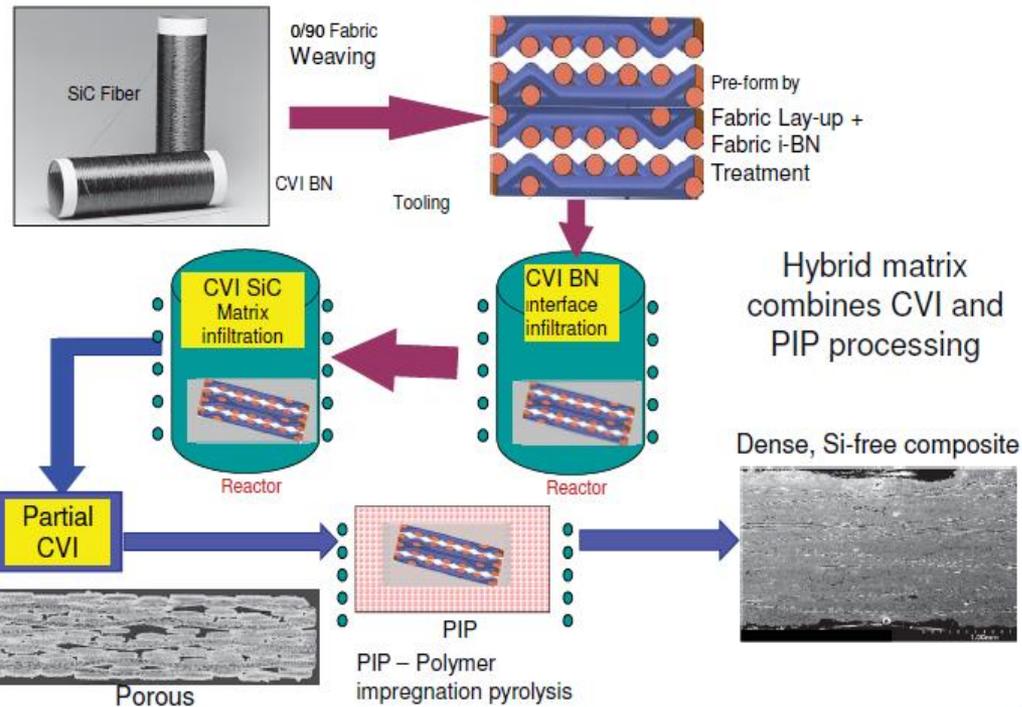
SiC/SiC composites as an alternative to metallic alloys

- SiC/SiC ceramic matrix composites (CMC) are not only significantly lighter than the Ni-based superalloys, but also possesses a much higher temperature resistance making it a big technological opportunity for materials resistance in high-temperature applications.
- While ceramics have been known for quite a while for their superior thermal stability, the lack of ductility have prevented the use of these in airborne applications or any other applications where safety aspects demand ductility prior to failure of a component. In order to provide some (0.1%-0.5%) elongation the SiC/SiC CMCs are made by embedding SiC fibers inside a SiC matrix.
- Exists a possibility to produce SiC/SiC composites by means of Additive Manufacturing (AM) technology.



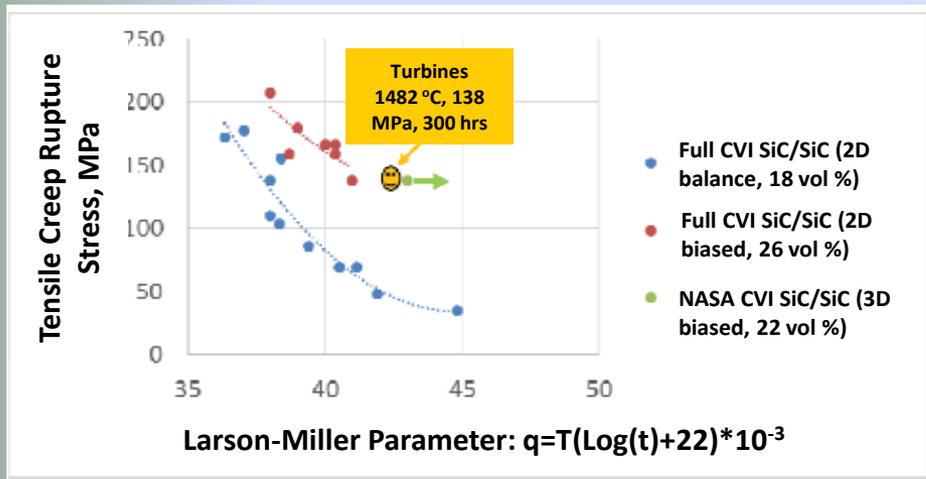
NASA development - production scheme

Hybrid Process for Dense SiC / SiC Composites

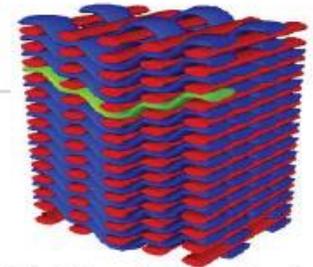
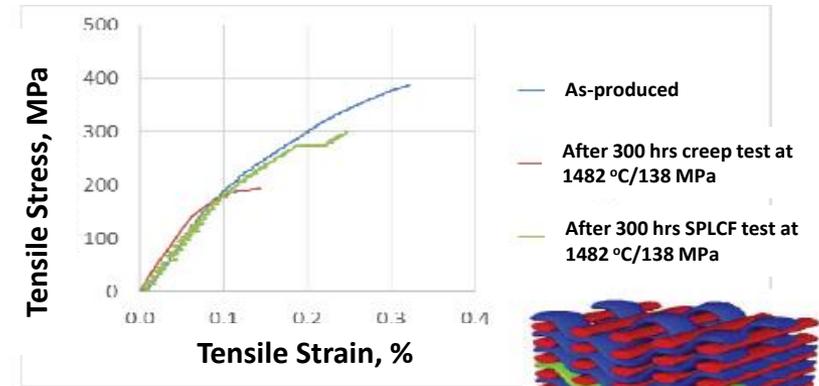




NASA development - obtained properties



Generation 1 CMC has >300 hrs life at 1482 °C at 1380 MPa



Modified Angle Interlock fiber architecture



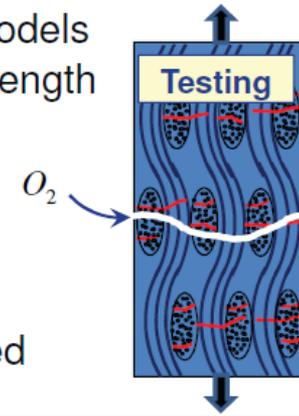
NASA - modeling environmental effects on SiC/SiC CMCs

Modeling Supported by Characterization of Degradation Mechanisms

Objective: Determine oxidation mechanisms and develop models for the mechanical-oxidation-creep interactions that affect strength and life of SiC_f/BN/SiC CMCs

Approach:

- Perform parallel and correlative *experimental* and *numerical analysis* studies.
- Build on the numerical solution methodology developed previously for the oxidation of C/SiC CMCs.



Testing

and

Characterization

iterate

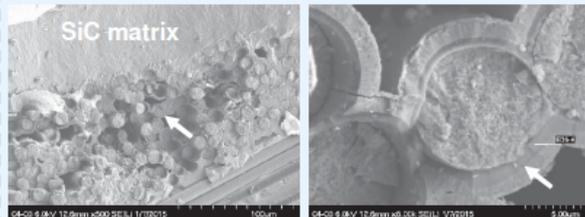
Modeling and Validation

Notched CVI SiC/SiC Sample:

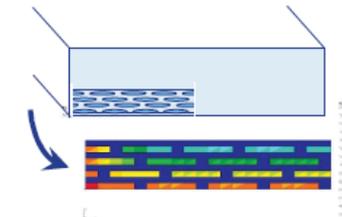
- Pre-cracked to 250 MPa
- Held 300 h, 815°C (air), 172 MPa



contact: roy.m.sullivan@nasa.gov



Fracture surface: oxidation of BN interphase near surface of specimen

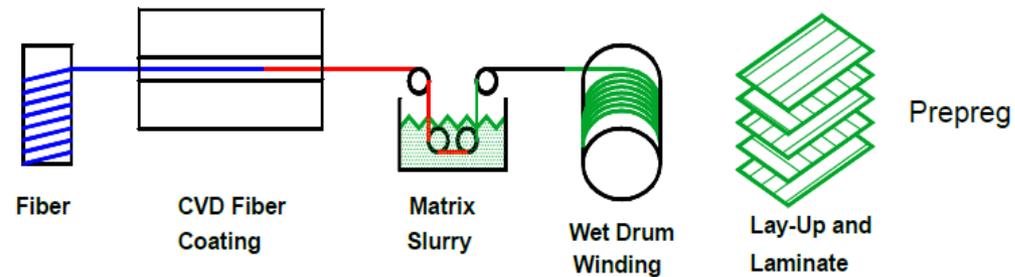


Prediction of BN oxidation patterns at 30 h, 815°C (air)

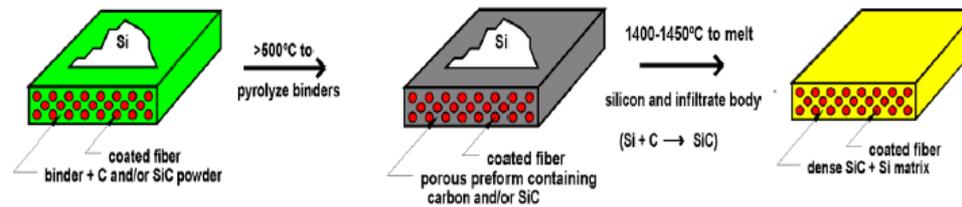


GE development - production scheme

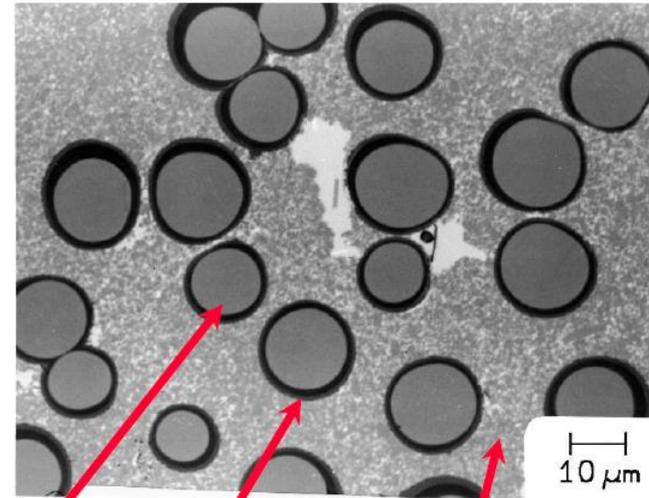
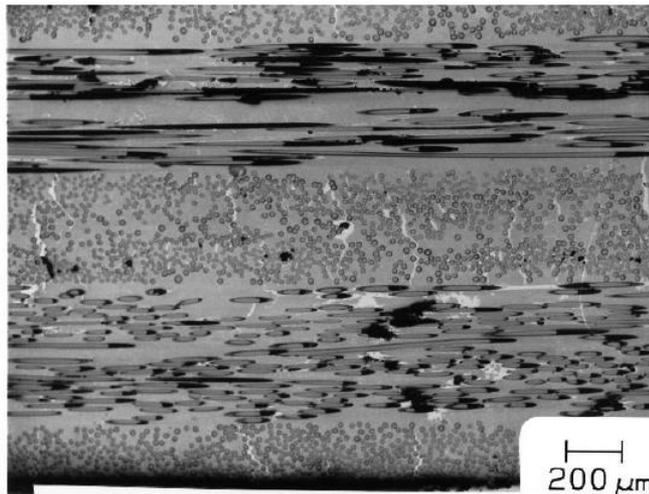
Preform Fabrication



Melt Infiltration



GE development - microstructure of Prepreg MI Composites



Fiber

Fiber
Coating

SiC-Si
Matrix

- Fibers Homogeneously Distributed; $V_f = \sim 25\%$
- Separated Fibers and Fiber Coatings
- $\sim 2-3\%$ Matrix Porosity

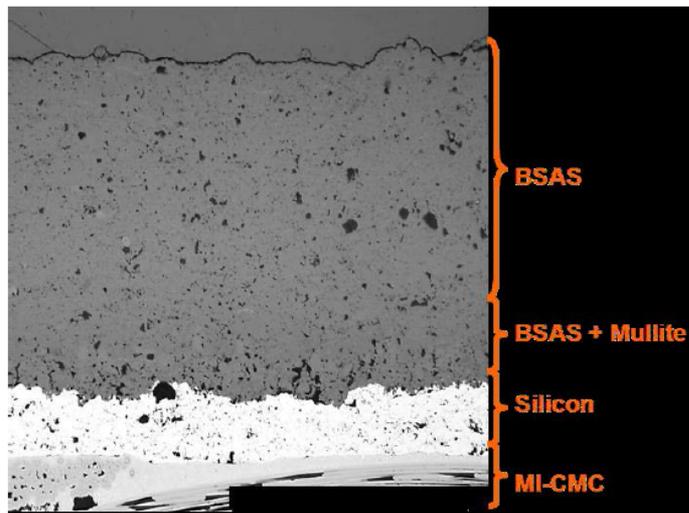


GE development - Environmental Barrier Coating (EBS)

EBS needed for turbine applications to prevent silica volatilization and surface recession from water vapor in combustion gas



Baseline System

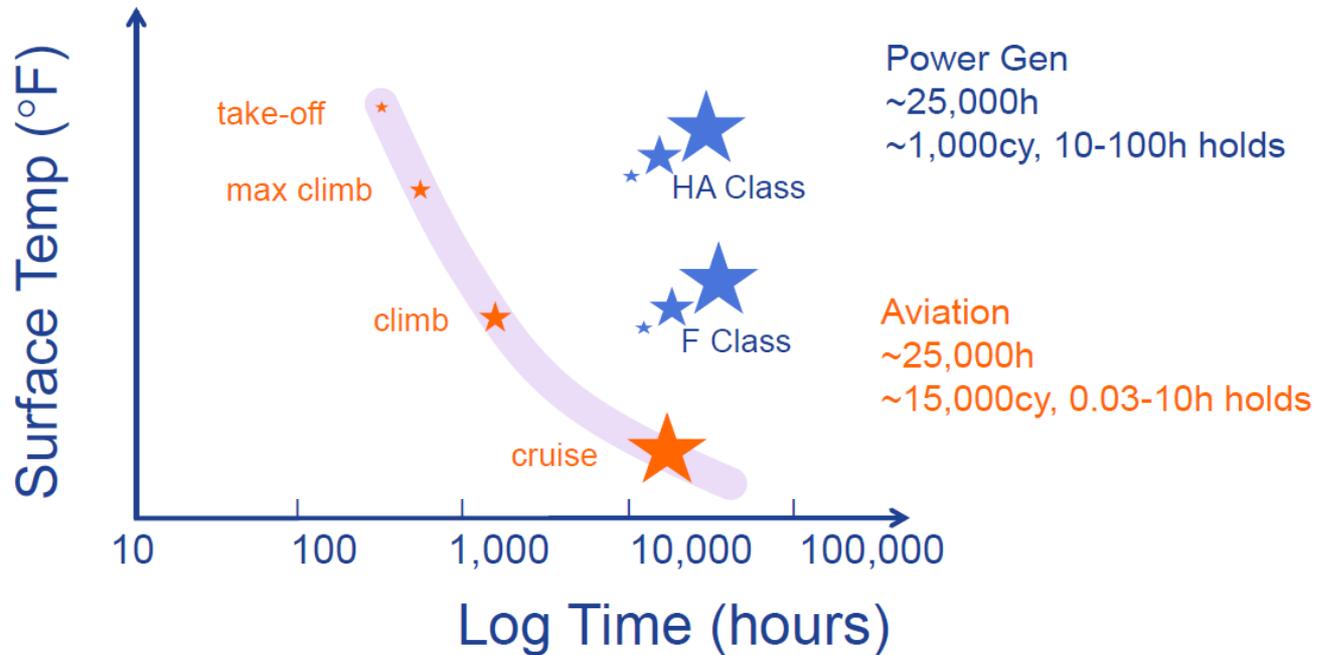


Advanced system

- Retain Si bond
- RE silicate layers
 - ✓ CTE match
 - ✓ recession resistance



GE development – Durability Challenge



Need to demonstrate capable designs



Summary

- CMCs have the opportunity to provide a step-change in engine technology
 - *Significant improvements in performance, emissions and fuel consumption*
- Insertion requires an understanding of all requirements
 - *Temperature range, service life, environment*
- Further improvement in material capability would increase insertion opportunities and further enhance performance
 - *Increased temperature stability*
- Optimized designs will need improved models that capture the local behavior after matrix cracking
 - *Critical for lifing attachment regions*
 - *Transition to more structural parts*



Israel Institute of Metals interest in SiC/SiC

IIM is interested to collaborate with Israeli companies as well as with academic institutions to study and to make use of industrial available infiltration capabilities to produce and optimize SiC/SiC and other CMC structures. This issue has a great technical-economical value and it might prove of key importance to Israeli jet propulsion capabilities.



References

1. Materials in Jet Engines - Past Present and Future by Robert Schafrik (GE Aircraft Engines).
2. <http://www.msm.cam.ac.uk/phase-trans/2003/Superalloys/SX/SX.html>
3. <https://www.secotools.com/en/Global/Segment-Solutions/Aerospace-Solutions/AS-Material-main/Heat-resistant-super-alloys/Inconel-71873/>
4. H. Ohnabe, S. Masaki, M. Onozuka, K. Miyahara and T. Sasa, *Potential application of ceramic matrix composites to aero-engine Components*, Composites: Part A 489–496 (1999).
5. J. E. Grady, *CMC Research at NASA Glenn in 2015: Recent Progress and Planes*, 39th annual conference on Composites, Materials and Structures, Florida 2015.
6. K. L. Luthra, *Melt Infiltrated (MI) SiC/SiC Composites for Gas Turbine Applications*, DER Peer Review for Microturbine & Industrial Gas Turbines Programs, March 14, 2002.
7. GE press release - http://www.geaviation.com/press/military/military_20150210.html
8. John Delvaux's (GE Technical Leader Ceramic Matrix Composites) presentation given on 2015.
9. A. Chamberlain and J. Lane, *SiC/SiC ceramic matrix composites: A turbine engine perspective*.
10. Engine perspective, presented at [Ultra-High Temperature Ceramics: Materials For Extreme Environmental Applications II](#) conference, May 13-18, 2012.