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

state of the art

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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

- Iterative process between design and material engineers
- Final part and material designed for full service life
Ceramic Matrix Composites (CMCs) as an alternative environmental stability

- ZrO$_2$ stable in H$_2$O
- Are zirconates stable in H$_2$O?
- Can you incorporate this into a fiber composite?
Ceramic Matrix Composites (CMCs) as an alternative testing and analysis

CMC testing with monitoring
- Local strain measurements
- NDE (IR, x-ray)
- Acoustic measurements

Accurate design inputs
- Elastic constants
- Elastic inputs vs. load
- Statistical variation

Proper FEA definition
- Mesh size
- Global vs. local

Understanding of damage progression
- Initiation and growth
- Life limiting features

CMC component design
 ✓ Optimized design for weight
 ✓ Robust design for life
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
NASA development - obtained properties

Turbines
1482 °C, 138 MPa, 300 hrs

- Full CVI SiC/SiC (2D balance, 18 vol %)
- Full CVI SiC/SiC (2D biased, 26 vol %)
- NASA CVI SiC/SiC (3D biased, 22 vol %)

Larson-Miller Parameter: q = T(\log(t)+22) \times 10^{-3}

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

As-produced
After 300 hrs creep test at 1482 °C/138 MPa
After 300 hrs SPLCF test at 1482 °C/138 MPa

Modified Angle Interlock fiber architecture
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 SiCf/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.

Contact: roy.m.sullivan@nasa.gov
GE development - production scheme

Preform Fabrication

Melt Infiltration
GE development - microstructure of Prepreg MI Composites

- Fibers Homogeneously Distributed; Vf = ~25%
- Separated Fibers and Fiber Coatings
- ~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

\[
\text{SiO}_2 + \text{H}_2\text{O} \rightarrow \text{Si(OH)}_x \text{ (gas)}
\]

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

9. A. Chamberlain and J. Lane, SiC/SiC ceramic matrix composites: A turbine engine perspective.