Advanced Ceramic Materials for Future Aerospace Applications

Ajay Misra
NASA Glenn Research Center
Cleveland, OH

Presented at 39th International Conference and Exposition on Advanced Ceramics and Composites, Jan 25 – 30, Daytona Beach, Florida
Widespread Use of Ceramics in Multiple Aerospace Systems
Ceramic Materials in Gas Turbine Engines

CMC Combustor

Ni-base disk

Thermal Barrier Coatings

CMC Turbine Blade

CMC Turbine Vane
Thermal Barrier Coatings

Future challenges:
- Increased temperature capability
- Low thermal conductivity
- Erosion resistance
- Resistance to molten sand/glass deposit
CMCs for Gas Turbine Engine Hot Section

Environmental Barrier Coatings Required for CMCs

SiC/SiC CMC preferred
 Challenges for Increasing Temperature Capability of SiC/SiC CMCs for Gas Turbine Engines

2400°F Today 2700°F + Future

Advanced SiC Fiber

Dense, Si-free Matrix

Durable Environmental Barrier Coatings with 2700°F+ Capability

Recession Rate, mg/cm²·hr

- BSAS
- HPBR 1350°C (2462°F), 6 atm, 30 m/s
- Yb silicate
- HfResilicate
Increasing Use of CMCs in Aircraft

Boeing – CMC Exhaust Nozzle

NASA Environmentally Responsible Aviation Project – CMC Nozzle Demonstration

GE Passport Engine Exhaust Nozzle
Ceramic Matrix Composites for Hypersonic Vehicles

3000 F + temperature capability required

Benefit: Reduced weight

Ceramic Matrix Composites

Reentry TPS

Hypersonic Control Surfaces

Leading Edges

Exhaust-Washed Structure

Acreage TPS

Actively Cooled CMC Combustor

Control Surfaces
Cooled Ceramic Matrix Composite Structures in Hypersonic and Rocket Propulsion

NASA GRC

AFRL

EADS - Astrium
High Temperature Materials for Planetary Entry, Descent, and landing (EDL)

Thermal Barrier Seals

Outer Fabric
Aerogel Insulation
Gas Barrier

Woven SiC Fiber

High Temperature Ceramic Aerogel
High Temperature Thin Film Ceramic Sensors

SiC Pressure Sensor

Cr-doped GdAlO₃ Coating for Temperature Measurement

Multifunctional TaN-Based Sensors

Ceramic Sheath for 2400°C – Capable Temperature Probe
Ion and Hall Thrusters for In-Space Propulsion

- Provides higher exhaust velocity than chemical rockets – reduces propellant mass and reduction in launch mass

Life Limiting Mechanisms:
- Ion sputter erosion of electrodes and ceramics
- Erosion and depletion of cathode materials

Material Needs:
- High temperature sputter resistant electrodes and ceramics
- Long-life, low work function cathode (LaB<sub>6</sub> – ZrB<sub>2</sub> eutectic promising)
Superconducting Ceramics in Electric Propulsion

Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

Turboelectric Propulsion for Aircraft

High Power Density Superconducting Motor

Superconducting magnet for VASIMR

MgB$_2$ round wire - Small diameter to reduce ac loss

STATOR COILS (MUST BE NON-PLANAR TO CLEAR ROTOR)

MgB$_2$ round wire BSCCO or YBCO tape

ROTOR COILS (CAN BE PLANAR)
Mars Oxygen ISRU Experiment (MOXIE)

- Extract oxygen from the horrible Martian atmosphere by breaking down carbon dioxide.
- Enable a manned Mars mission to have oxygen ready and waiting when they arrived by sending remote oxygen generators to the surface ahead of time.
Glass Windows in Space Systems

- Rendezvous / Docking Windows (2) Silica/Silica/Acrylic
- Side Windows (2) Silica/Silica/Acrylic
- Docking Hatch Window Silica/Silica/Silica
- Hatch Window Silica/Silica/Acrylic

Crew Vehicles
- Ascent vehicles
- Habitations
- Rovers
- Laboratories
- Visors

ISS
Advanced Window Glass Materials for Space Systems

Damage of Glass Windows due to Micrometeoroid Impact

STS-84 Atlantis

Damaged Space Shuttle window

Damaged ISS window

Damage of Glass Windows due to Micrometeoroid Impact

Window Life, years

Window Mass, kg

Coarse spinels

Fine spinels

Fused Silica

AlON

5µm 25µm 280µm
Application of Piezoceramic Materials

**AIRFRAME**

Piezoresistive Devices
- Embedded pressure sensors
- Embedded strain sensors

Piezoelectric Devices
- Energy harvesting
- Cabin noise suppression
- Active flow control
- Variable control surfaces

**ENGINES**

Piezoelectric Devices
- Energy harvesting
- Power amplification
- Vibration suppression
- Noise suppression

Challenges:
- High temperature capability (\(>> 300^\circ C\))
- Large displacement
- Integration with structure and durability of integrated structure
- Multifunctionality
Piezoceramic Patches for Controlling Vibration of PMC Fan Blades

Fan Blade with Piezo patches

Fan Blade with Piezo Patch in Test Rig

GE Blade Vibration Control

Blade Response (microstrain/excitation G)

Excitation Frequency (Hz)

No Control
Control
Demonstration of Smart Rotor for Helicopters Using Piezoceramic Materials

- Smart rotor incorporates cutting edge changes to MD900 baseline rotor
  - Trailing edge control flap
  - Piezo-electric “smart” material actuators
- Effectiveness of flap for noise and vibration control demonstrated
- Closed-loop feedback control applied for first time to full-scale active rotor
- Initial demonstration of blade displacement technique
Power Conversion and Energy Storage System

Hybrid Electric Aircraft

Long-Duration EVA

Landers, Rovers, Habitats

High Energy Density Batteries

- Need 2 – 4X increase in energy density of batteries
- Need > 5X increase in power density of fuel cell for electric aircraft

High Power Density Solid Oxide Fuel Cell

All oxide ceramic components

Multifunctional systems with structural load bearing capability ??

SiC Power Electronics for High Power Density and Radiation Tolerant Power Processing System

Ceramic electrolyte for solid state batteries

Ceramic cathode
Ceramics in Satellite Communication

- Ceramic dielectric materials with engineered properties for microwave, millimeter wave communication system
- Dielectric ceramics as resonators, filters, oscillators
- Miniaturization continuing trend

Piezoceramic materials
- Change in shape of reflector to improve signal quality
- Vibration control
- Positioning control
Use of Ceramics in Space Telescope Mirror

Hubble Space Telescope
Glass mirror

Herschel Space Telescope
SiC mirror

James Webb Telescope,
electrostrictive ceramic actuator to control the shape of mirrors

Future requirements: Lower cost and increase in aerial density
Concluding Remarks

• Will see increasing use of CMCs in aircraft – challenge to increase temperature capability to > 2700°F; cost reduction required

• Goal of Durable 3000°F CMC system for hypersonics and rocket propulsion still remains a major challenge

• Increasing use of piezoceramic and dielectric type of materials
  – Multifunctional structures will be future
  – Integration with components without adversely impacting component performance is challenging
  – Miniaturization will be the trend

• For high power density and high energy density systems, engineered porous materials through advanced manufacturing processes will be required
  – Additive manufacturing likely to play a role
  – Increasing use of nanomaterials

• Significant potential for improving ceramic materials for in-space propulsion