Ceramics and Ceramic Matrix Composites in Aerospace Applications - An Overview

Suraj Rawal
Technical Fellow, Advanced Technology Center
Lockheed Martin Space Systems Company

Ceramics Expo 2017
April 25, 2017
Outline

• Lockheed Martin Space Systems Company
• Use of Ceramics and CMCs
  – Aero-entry Systems
    • Space Shuttle and other Entry, Descent and Landing Missions
  – UHTCs, Insulations and Coatings
  – Propulsion Subsystems
  – High Temp. Radiators
• Concluding Remarks
  – Also Following
    • Industry Standards: Uniform reproducible standard products!
    • CMC Behavior and Life Prediction Tools, Time Dependent Damage Progression
    • Role of Additive Manufacturing
Aeronautics
• Tactical Fighters
• Tactical /Strategic Airlift
• Advanced Development
• Sustainment Operations

Missiles and Fire Control
• Air and Missile Defense
• Tactical Missiles
• Fire Control
• Combat Maneuver Systems
• Energy

Rotary and Mission Systems
• Naval Combat Systems
• Radar and Surveillance Systems
• Aviation Systems
• Training and Logistics Solutions
• DOD Cyber Security

Space Systems
• Surveillance and Navigation
• Global Communications
• Human Space Flight
• Strategic and Defensive Systems
• Strategic / Operational Command & Control Systems
Shuttle Tile Insulation Invented at Palo Alto Labs of Lockheed

- 04/79 – LMSC delivered 24,000 Silica Tiles for the First Shuttle Launch
- 04/12/81 – First Columbia Launch (STS-1)
- 04/04/83 – First Challenger Launch (STS-6)
- 8/30/84 – First Discovery Launch (STS-41)
- 10/03/85 – First Atlantis Launch (STS-51-J)
- 01/28/86 – Challenger Disaster (STS-51-L)
- 05/07/92 – First Endeavour Launch (STS-49)
- 01/11/96 – Endeavor Launch (STS-72)**
- 01/12/97 – Atlantis Launch (STS-81)**
- 02/01/03 – Columbia Disaster (STS-107)
- 7/8-21/11 – Final Launch and Return of Atlantis (STS-135)
- 2012 Atlantis Shuttle Retired
LI-900 Randomly Oriented Fibers

- 99.9% pure silica fibers
- 94% air by volume
- Overall density is 9pcf
- Fiber diameters range in sizes less than 10 μm
- Fiber lengths range from 10’s to several 100 μm
- Fibers are “unbonded”
- CTE = 0.5 ppm/°C
- Tmax = 1250° C / 2280° F
- Coating not bonded to substrate

- LI-2200 (22pcf) used in high-stress areas such as landing gear doors and windows
RCG-Coating on LI-900 Tile

• Glass frit milled with silicon tetraboride and binder in ethanol
• Ball mill 24 hours
• Measure slurry properties
• Apply slurry to tile in continuous, consistent path traces to predetermined weight (density)
• Dry overnight
• Fuse at 1200°C for 90 minutes

Tiles (also) on the backshell of Orion
Space Shuttle: RCC at LM Facility

- Reinforced Carbon-Carbon (RCC) Developed and Manufactured at LM facility for Space Shuttle Missions
Ultra High Temperature Ceramics (UHTCs)

- Collaborated with NASA ARC in the development of UHTCs for Leading Edge applications.
  - In-House Developments in Conventional and Eutectic UHTCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Crystal Structure</th>
<th>Density (gm/cc)</th>
<th>Melting Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HfB₂</td>
<td>Hexagonal</td>
<td>11.2</td>
<td>3380</td>
</tr>
<tr>
<td>HfC</td>
<td>Face-Centered Cubic</td>
<td>12.76</td>
<td>3900</td>
</tr>
<tr>
<td>HfN</td>
<td>Face-Centered Cubic</td>
<td>13.9</td>
<td>3385</td>
</tr>
<tr>
<td>ZrB₂</td>
<td>Hexagonal</td>
<td>6.1</td>
<td>3245</td>
</tr>
<tr>
<td>ZrC</td>
<td>Face-Centered Cubic</td>
<td>6.56</td>
<td>3400</td>
</tr>
<tr>
<td>ZrN</td>
<td>Face-Centered Cubic</td>
<td>7.29</td>
<td>2950</td>
</tr>
<tr>
<td>TiB₂</td>
<td>Hexagonal</td>
<td>4.52</td>
<td>3225</td>
</tr>
<tr>
<td>TaB₂</td>
<td>Hexagonal</td>
<td>12.54</td>
<td>3040</td>
</tr>
<tr>
<td>TaC</td>
<td>Cubic</td>
<td>14.5</td>
<td>3800</td>
</tr>
<tr>
<td>TaN</td>
<td>Cubic</td>
<td>14.3</td>
<td>2700</td>
</tr>
<tr>
<td>SiC</td>
<td>Polymorph</td>
<td>3.21</td>
<td>Dissociates 2545</td>
</tr>
</tbody>
</table>

Material Crystal Structure Density (gm/cc) Melting Temp. (°C)
HfB₂ Hexagonal 11.2 3380
HfC Face-Centered Cubic 12.76 3900
HfN Face-Centered Cubic 13.9 3385
ZrB₂ Hexagonal 6.1 3245
ZrC Face-Centered Cubic 6.56 3400
ZrN Face-Centered Cubic 7.29 2950
TiB₂ Hexagonal 4.52 3225
TaB₂ Hexagonal 12.54 3040
TaC Cubic 14.5 3800
TaN Cubic 14.3 2700
SiC Polymorph 3.21 Dissociates 2545
Coatings, Insulations, and Machinable Ceramics

• Evaluated the Family of Damage-Tolerant Ceramic Materials (Drexel Univ.)
  Based on 312, 211 and Other Stoichiometries:
  ➢ 312: Ti$_3$SiC$_2$,
  ➢ 211: Ti$_2$AlC, Ti$_2$AlN

• Often Used Machinable Ceramic Macor for Insulation Interfaces.

• High Temperature Oxidation Resistant Coatings on Refractory Composites and Metals
  • UHTC Family Type
  • SiC / TEOS (Space Shuttle Heritage)
Entry Descent Landing

Extensive History in Entry Systems

SLA: Superlight Ablator
PICA: Phenolic Impregnated Carbon Ablator
C-C: Carbon-Carbon
Typical EDL Materials

**Heatshield:**
- Sandwich Construct
- Gr/Pcn Facesheets
- Aluminum Core
- SLA-561V Ablator

**Parachute Cone:**
- Aluminum Skin Stringer
- SLA-220 & SLA-561M Ablator

**Seals:**
- HS To BS
- Thrusters
- Sep Fittings
- Vent

**Backshell:**
- Sandwich Construct
- Gr/Pcn Facesheets
- Aluminum Core
- SLA-561S Ablator
- White Paint

**Heatshield:**
- Sandwich Construct
- Gr/Pcn Facesheets
- Aluminum Core
- SLA-561S Ablator
- PICA Tile Ablator
Propulsion SubSystems:

• Ion Propulsion: Ions created and accelerated in an Electrostatic Field

• Hall Current Thrusters

  • Cathode must be efficient Electron Source
  • Anode must be an efficient Electron Sink
  • Insulator/Walls: Must maintain Properties (mechanical, electrical, thermal), Erosion Resistance
Warm Gas Thruster: Multifunctional Plenum Radiator

**Description:**
- Cost Effective and Robust Warm Gas Radiator for Multiple Small Spacecraft
- Improved Propulsion (2X) Performance for Microspacecraft Attitude Control
- 2X Reduction in Weight (Compared to Baseline)
- M&P Validation of Critical Interfaces (Foam/Metal, Foam/ Facesheet, and Foam/Foam)
- C-Foam Core Design: an Enabling Technology Solution for Plenum Radiator
- High Thermal Conductivity C-Foam Provides Lightweight and Efficient Thermal Performance
- Low Conductivity C-Foams at Mounting Sites

**Benefits to (XSS-11 Type) spacecraft:**
- Improved Propulsion (2X) Performance for Microspacecraft Attitude Control
- 2X Reduction in Weight (Compared to Baseline)
- M&P Validation of Critical Interfaces (Foam/Metal, Foam/ Facesheet, and Foam/Foam)

**Technology Transition:**
- Transitioned to XSS-11, GRAIL, and others
Electrostatic Propulsion:Ion Engine Thrusters

Accomplishments:
• Successfully Designed, Fabricated and Tested 8 cm, 20 cm, and 30 cm C-C Grids.
• Precision Laser Machining.
• Performed Random Vibration Tests (@20Grms) 8 cm grids: No Damage, Perveance Performance Identical to NSTAR-DS1 Mo-Grids.

Objective:
Develop and Demonstrate C-C as a High-Performance, Cost-Effective, Erosion-Resistant Grid Material

Benefits:
• Significant increased life (7x)
• Improved ion beam extraction capabilities
• Ease of Alignment and Assembly
• Cost savings (≤15%)

Potential USER Systems:
Future High Power NASA Missions (NEXT, CBIO, NEXIS, JIMO, and NSI programs, and DoD programs)
TPS Panels For Structural Health Monitoring

TPS-NASP
C-C Panels
- 24” x 24”
- Vertical stiffeners
-- C/SiC Brackets

TPS-Modular CCAT Panel
-12” x 12”
-- Grid Stiffened
-- C/C Brackets

Incorporated Impact Damage Sensors
Concluding Remarks

- Lockheed Martin Uses Ceramics and CMCs in Different Subsystem Application
  - Aero-entry Systems
  - UHTCs, Insulations and Coatings
  - Propulsion Subsystems
  - Structures and High Temp. Radiators
- In Pace with the advancements in
  - Industry Standards: Uniform reproducible standard products!
  - Understanding CMC Behavior and Life Prediction Tools, Time Dependent Damage Progression
  - Additive Manufacturing of Ceramics and Challenges of Insertion
Thank You

LOCKHEED MARTIN

We never forget who we’re working for®
Acknowledgements

• Special Thanks to Fellow LMSSC colleagues:
  • Connie Henshall
  • Gautham Ramachandran
  • Scott Smith
  • Vadim Khayms
  • Dan Lichtin
  • Kevin Johnson
  • Bill Willcockson