Metal Matrix Composites for Rocket Engine Applications

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Rocketdyne
Propulsion & Power
• Need for Advanced Materials
• Components and Weights
• Materials Selection Criteria
• Metal Matrix Composites
• Technical Issues
• Conclusions and Recommendations
• AF Integrated High-Payoff Rocket Propulsion (IHPRPT) Goals for Year 2010 for “Boost and Orbit Transfer” Propulsion
  
  *Double Thrust to Weight*
  
  *Reduce Hardware Costs by 35%*

• NASA Goal 9  Low-Cost Space Access
  
  “Reduce the payload cost to low-Earth orbit by an order of magnitude, from $10,000 to $1,000 per pound within 10 years, and..”
SSME Engine Weight Distribution
(7037 lbs)

- HOUSINGS 75%
- OX. PUMPS
- DUCTS/LINES
- AVIONICS
- INJECTOR
- MCC
- MANIFOLD
- PREBURNERS
- VALVES
- MISC.

- ROTATING HARDWARE 17%
- ATTACHING HARDWARE 2%
- BOOST PUMP 8%
• Properties Over Operating Temperature

• High Specific Strength

• Compatibility

• Fuel

• Oxidizer

• Combustion Products

• Affordable and Producible
Inlet pressure 5647 psia
Exit pressure 4441 psia
Coolant inlet -366°F
Max wall temp 1000°F

Pressure 425 psia
Temperature 420°F

Inlet pressure 5624 psia
Exit pressure 5420 psia
Max wall temp 950°F

Inlet Pressure 422 psia
Inlet Temp -272°F
Exit Pressure 4300 psia
Turbine Speed 28120 rpm
• Tailored Properties

![Graph showing coefficient of thermal expansion vs. volume % SiC in aluminium.](image)

Clyne & Withers, An Intro, to MMCs, 1993, p. 458

![Graph showing tensile yield stress vs. fiber volume fraction.](image)

Taya & Arsenault, MMCs Thermo-mechanical Behavior, 1989, p. 181

Fig. 3.9 Tensile yield stress of a continuous tungsten fiber/copper composite as a function of fiber volume fraction, $V_f$ (%).
FIBER PREFORM

PREHEAT TOOLING & MELT ALLOY

Molten Alloy

Preform

Mold

VACUUM ATMOSPHERE

INfiltration

Pressure

MMC COMPONENT
Selected Component: Reusable Turbopump Housing

Requirements:
- High Specific Strength, Stiffness
- Oxygen Compatibility
- Contain High Pressure
- Good Toughness
- Fatigue Resistant
- Producible, Affordable
Solutions

Use High Strength Alloys with Coatings

Use Low Strength, Compatible Alloys

Develop High Strength, Compatible Materials

Issues

Maintainability
Reliability

Weight Penalty

Development

Producibility

Joining
Alloy Selection

- Cu Base for Burn Resistance
- Alloying Elements
  - Al for Oxidation Resistance
  - Zn, Ge, or Mn for Melting Temperature Reduction
- Ti, Si, or Cr for Wetting and Bonding

Fiber/Matrix Interaction Studies

- Bonding and Wetting
- Grain Size Refinement
• Define and Manufacture Subelements
• Integrate Preforms for Single Infiltration

Advanced Composites Inc., 2000

Engineering Materials Handbook Vol.1: Composites,
- Demonstrate Propellant Compatibility
- Design to Optimize Fiber Orientation and Anisotropy
- Develop Preform Manufacturing Technology
- Minimize Processing Damage to Fibers
- Establish Mechanical Properties Database
- Demonstrate Attachment Schemes
- Validate Processing Techniques and Producibility
- Verify Inspection Methods
• Industry Goals Call for Engine Weight Reduction
• MMCs Offer Several Potential Benefits
  • High Specific Strength
  • Tailored Properties
  • Producibility
• Turbopump Housings Targeted for MMC Development
• Several Technical Challenges Remain
• MMC Technology Development Provides Potential for Weight Savings in Other Engine Components