Flight Performance of a Functionally Gradient Material, TUFI, on Shuttle Orbiter

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Outline

• Introduction
  – Ames Research Center Contributions
  – Coating/Insulation Materials
  – Performance Comparison
• Initial TUFI Flight Experiment
• Performance of TUFI in Other Selected Areas
• Current Status
• Summary
Ames Developed Thermal Protection Materials Adopted to Date on Shuttle

- TUF/AETB Tile
- AIM-22 Tile
- AFRSI Blanket
- FRCA-12 Tile
- RCG Coating
- Gap Fillers

AETB Tile Fabrication Process

- Alumina (1-3) μ
- Silica (1-3) μ
- Aluminoborosilicate 8 μ
- Calcining Furnace
- Silicon Carbide Ammonia
- Blender
- Drying Oven
- Furnace
- Finished Billet
Reaction Cured Glass (RCG) Coating

- High Emittance $\varepsilon > 0.8$
- 0.38 mm thick
- Compatible with silica tiles
  - no devitrification
  - match tiles C\''E
- RCG coating sits on top of tile surface
  - particle size too large to infiltrate
- Dense coating
  - initial moisture barrier
- Poor impact resistance.
TUFIFabrication Process

- Emittance Agent
- Ethanol
- Ball Milling
- Spraying
- Drying
- Mixing
- Sintering
- Finished Tile

Toughened Uni-Piece Fibrous Insulation (TUFIF)

- High Emittance $\varepsilon > 0.8$
- 2.5 mm thick
- Compatible with tile
  - no devitrification
- Porous coating
- Material penetrates into the tile
  - smaller particle size
- Significantly improved impact resistance
- MoSi$_2$ acts as emissivity agent
  - also increases CTE so it matches that of AETB tiles.
Microstructure of TUFI System

- TUFI is applied as three separate coats.
- Results in a graded coating system that is denser near the surface.
- Two scales of porosity
  - regions that appear deficient in glass
  - denser regions also have a smaller scale porosity

Impact Resistance Comparison of Tile Coating Systems

- SHUTTLE TECHNOLOGY, 1978
- CURRENT TECHNOLOGY

**DAMAGE RESISTANCE AS A FUNCTION OF AREAL WEIGHT**

**IMPACT = 1.8 \times 10^{10} \text{ ft-lb}**

**AREAL WEIGHT, \text{lb/ft}^2**

**RELATIVE DAMAGE RESISTANCE**

<table>
<thead>
<tr>
<th>AREAL WEIGHT, \text{lb/ft}^2</th>
<th>RELATIVE DAMAGE RESISTANCE</th>
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<tbody>
<tr>
<td>0.015 in.</td>
<td>0</td>
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<tr>
<td>0.1 in.</td>
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<td>10</td>
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<tr>
<td>0.2 in.</td>
<td>100</td>
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<tr>
<td>0.25 in.</td>
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**TUF1**

**RCG**

**THERMAL PROTECTION MATERIALS AND SYSTEMS BRANCH**
Location of TUFI/FRCI-12 Tiles on Base Heatshield Panel

6 TUFI-coated FRCI-12 tiles

57 Door
Located between SSME #2 & #3 above body flap

Base Heat Shield Upper Body Flap Overall

LH OMS
RH OMS
Base Heat Shield
Body Flap
TUFI/FRCI-12 Panel After First Flight

TUFI/AETB-8 Tiles
Undamaged After Three Flights

Shuttle Base Heat Shield Flight Testing of TUFI on AETB Tile Substrate, STS-59
TUFIAETB-8 Tiles Adopted on all Orbiters for
Base Heat Shield, Upper Body Flap and Other
High Damage Locations

TUFIAETB-8 Tiles
Now in Use for All
Base Heat Shields

Base Heat Shield Pre/Post
TUF1

Degraded Repairs and Damage
Undamaged TUF1 Tile

Thermal Protection Materials and Systems Branch
TUFI Tiles Installed in Base Heat Shield (All Orbiters)

Upper Body Flap: Lost Tile \(\rightarrow\) RTV \(\rightarrow\) TUFi
Installed TUFI Tiles – Upper

Body Flap

- OV-102 (12 Tiles)
- OV-103 & OV-104 (136 Tiles)
- OV-102 (148 Tiles)

Total = 432

TUFI Tiles on OMS (Orbital Maneuvering System) Pods

- Pod 15 (15 Tiles)
- Pod 25 (15 Tiles)
- Pod 13 (2 Tiles)
- Pod 24 (1 Tile)

Total = 35
OV-102 TUF1 Tile Damage

OV-105 Tile Chatter Damage
(~ 1.0"L x .7" W x .1" D)

Chatter damage area
Summary

- An order of magnitude improvement in flight performance has been demonstrated in TUFI, a graded porous surface treatment for RSI when compared on the Shuttle Orbiter to the baseline RCG, a fully dense glass surface coating.
- 766 TUFI tiles have been applied and flown in various locations on all 4 Orbiters.
- Usage has expanded into high damage areas on an attrition basis as funding has become available and the financial benefits can be demonstrated.