IR&D Studies of Light Weight Ablator for Future Reentry Capsule Heatshield

IHI AEROSPACE Co., Ltd.
Kenichi HIRAI
2012.6.21

JAXA
Yuichi ISHIDA, Toshio OGASAWARA, Takuya AOKI, Tetsuya YAMADA, Kazuhisa FUJITA, Toshiyuki SUZUKI
1. Objective of this study

HAYABUSA
(300MJ/m², 53%)

Reduction to 1/3 is required
Development of new LWA

Mars Viking
Pioneer Venus
MER
MPF
Stardust
Apollo
Galileo

HAYABUSA
Successfully returned to Earth in June 2010
HAYABUSA-2
To be launched in 2014

CFRP is derived from SRM nozzle material
Reliable but heavy!

The Possible Future Directions

<table>
<thead>
<tr>
<th>Reentry Capsule Size (DIA)</th>
<th>Peak Heat Flux (MW/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4m</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>2m</td>
<td>5~10</td>
</tr>
<tr>
<td>1m</td>
<td>10~20</td>
</tr>
<tr>
<td>0.5m</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

### Large Capsule Tiled LWA
- **HTV-R 2017**
- **LWA 0.3~0.4**
- **MSL 2013**
- **CEV 2011**
- **GENESIS 2004**
- **PICA 0.3**
- **AVCOAT 0.5**
- **Post-HAYABUSA-2? >2015**
- **Marco-Polo 2018**
- **STARDUST 2006**
- **HAYABUSA-2 2015**
- **ASTERM 0.3**
- **PICA 0.3**
- **CFRP 1.3**
- **LWA 0.3~0.4**

### Small Capsule One-Piece CFRP
- **HAYABUSA-2 ? >2015**
- **PICA 0.3**
- **CFRP 1.3**
2. Our Strategy (1/2)

Carbon Preform (0.15<\(\rho\)<0.3)
- CBCF (Carbon Bonded Carbon Fiber)
- RVC (Reticulated Vitreous Carbon)
  - FIBERFORM
  - CALCARB
  - Grafoam
  - JFOAM

1. Issues of Imported preforms
- Expensive
- Long Delivery Time (EL)
- Sustainability

2. Pursuit of unique LWA
- Unique Preforms (RVC)
  I don’t want to imitate PICA

3. Preform microstructure Tailoring for successful JAXA PI impregnation

Resin Impregnation
- Phenolic SC-1008
- Polyimide JAXA Original

LWA (0.25<\(\rho\)<0.4)

Development of Domestic RVC JFOAM
2. Our Strategy (2/2)

Imported Preform
- CBCF
- RVC

Resin Impregnation
- Phenolic
- Polyimide

Domestic Preform
- RVC

Resin Impregnation
- Polyimide

LWA

Process is good?

2nd Step (22cm×22cm×5cm)

3rd Step (12cm×12cm×5cm)

Arcjet Test

Hopefully improve

Same Process

F/B

F/B
3. Overview (1/3)  
candidate carbon preforms

**CBCF**  
Carbon Bonded Carbon Fiber  
Chop/Milled Fibers Connected by Phenolic Resin

**RVC**  
Reticulated Vitreous Carbon


Carbon Preform ($\rho < 0.2$)

Grafoam ($\rho = 0.16$) SEM photo
3. Overview (2/3)

**JAXA Polyimide Resin Impregnation**

- **s-BPDA / BAFL / DMAc Solution**
  - Stir
  - 60-80°C

- **Gellant**
  - RT

- **Resin Solution**

**Gelation at RT!**
**Reliable Process!**

**s-BPDA**

**BAFL**

**Cure**

- **240°C, air**

**LWA**

**Remove Solvent**

- **50-200°C vacuum**

**After Gelation**

**Gelation**

- **RT, air**

**Resin Impregnation**

- **vacuum**

**sufficiently long gel time (several Hrs)**
3. Overview (3/3)
JAXA Polyimide Raw Material Cost

JAXA/PI
In the Past

JAXA/PI
Expected in 2012?

Phenolic
SC-1008

Raw Material Cost for
□25cm×5cm Panel Fabrication
(10,000Yen)

JAXA/PI Price will be comparative to SC-1008!
### 4. Validation of Resin Impregnation Process

**Imported Preform based LWA Fabrication (1/6)**

<table>
<thead>
<tr>
<th>Candidate Carbon Preforms</th>
<th>Bulk Density [g/cm³]</th>
<th>Fabrication Matrix of LWA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RVC</strong></td>
<td></td>
<td>Polyimide Resin</td>
</tr>
<tr>
<td>Imported RVC (Grafoam FPA-10)</td>
<td>0.18</td>
<td>NA</td>
</tr>
<tr>
<td>Imported CBCF (CALCARB 18-2000)</td>
<td>0.19</td>
<td>○</td>
</tr>
<tr>
<td>Domestic RVC (JFOAM-1, -2, -3)</td>
<td>0.15, 0.21, 0.28</td>
<td>○</td>
</tr>
<tr>
<td>Domestic CBCF</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**RVC**: Reticulated Vitreous Carbon

**CBCF**: Carbon Bonded Carbon Fiber

**LWA**: Low Weight Ablator
### CBCF/Preform

<table>
<thead>
<tr>
<th>Size</th>
<th>22cm × 22cm × 5cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>473.4g</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>0.196g/cm³</td>
</tr>
</tbody>
</table>

### CBCF/PI LWA

<table>
<thead>
<tr>
<th>Size</th>
<th>21.98cm × 21.99cm × 4.65cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>799.7g</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>0.356g/cm³</td>
</tr>
</tbody>
</table>
4. Validation of Resin Impregnation Process
Imported Preform based LWA Fabrication (3/6)

Data Scatter < ±3%!

ρ = 0.36
ρ = 0.28

CALCARB / polyimide

Grafoam / phenolic

Density Dispersion %

ρ = 0.36
ρ = 0.28

1 cm cubic
LWA test specimen
Validation of Resin Impregnation Process
Imported Preform based LWA Fabrication (4/6)

Residual carbon ratio [%] within impregnated “resin + solvent”

\[
\text{Residual carbon ratio} = \frac{W_{\text{final}} - W_{\text{preform}}}{W_{\text{initial}} - W_{\text{preform}}}
\]

Charred Resin
Resin + Solvent

Data Scatter is small, so resin impregnation process is judged reliable

65% : Same as genuine PI

35% : lower than genuine Ph

Residual carbon ratio [%]

A1  A2  A3  B1  B2  B3  C1  C2  C3

CALCARB / polyimide

Grafoam / phenolic
4. Validation of Resin Impregnation Process
Imported Preform based LWA Fabrication (5/6)

- Same behavior as genuine PI
- Low BP solvent Is much contained?
4. Validation of Resin Impregnation Process
Imported Preform based LWA Fabrication (6/6)

4. Validation of Resin Impregnation Process
Imported Preform based LWA Fabrication (7/7)

Temperature Response of CALCARB/PI LWA

Temperature responses of LWA’s are well predicted by the present tentative ablation calculation!

Repeatability of LWA Temperature responses is fairly good!
5. Domestic RVC based LWA Development

Development of JFOAM (1/5)

Grafoam

CALCARB

JFOAM-1

SEM Photographs of various kinds of lightweight carbon preforms
(Our RVC’s are designated as JFOAM-1 (density=0.16g/cm³))

Current microstructure of JFOAM is much coarser than existing imported CBCF/RVC!
5. Domestic RVC based LWA Development
Development of JFOAM (1/5)

Similar Properties as Existing Carbon Preforms

- Bulk Density (g/cm³)
- Thermal Conductivity (W/m/K)
- Open Porosity (%)

*Imported CALCARB_18-2000
*Imported Grafoam_FPA-10
*Domestic JFOAM
5. Domestic RVC based LWA Development

Development of JFOAM (1/5)

JFOAM bulk density vs thermal conductivity

Fiberform ($\rho_{0.17}$)

Fiberform ($\rho_{0.14}$)

JFOAM bulk density vs thermal conductivity

### Test Conditions of Arcjet Experiments

<table>
<thead>
<tr>
<th></th>
<th>CW Heat Flux [MW/m²]</th>
<th>Impact Pressure [KPa]</th>
<th>Heating Time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.8</td>
<td>4.4</td>
<td>30</td>
</tr>
<tr>
<td>#2</td>
<td>3.4</td>
<td>13.7</td>
<td>30</td>
</tr>
<tr>
<td>#3</td>
<td>6.0</td>
<td>19.6</td>
<td>30</td>
</tr>
</tbody>
</table>

- **LWA Specimen**
- **Flat Faced Specimen**
- **Bakelite Holder**
- **T/C φ0.2mm Type-K**
- **65mm**
- **50mm**

**5. Arcjet Tests of LWA (1/6)**
5. Arcjet Tests of LWA(2/6)

JFOAM/PI
Before Test

JFOAM-3/PI
After Test: 3.4MW/m² x 30s

JFOAM-3/PI
After Test: 6MW/m² x 30s
5. Arcjet Tests of LWA (3/6)

JAXA/ISAS
Arcjet Tests Photographs
By Digital Camera

CALCARB / PI
6MW/m²x 30s
Spallation by Smaller Particles

JFOAM-1 / PI
6MW/m²x 30s
Spallation by Larger Particles
Empirical Expression for Surface Recession Rate of PICA

\[ Y = 0.2326X \]
\[ X = p^{0.33} \times \exp(-5.93/q^{0.25}) \]

Arcjet Data
- AHF271
- Computed (TITAN)

Recession Rate (mm/s)

P: pressure (KPa)
q: heat flux (W/cm²)

5. Arcjet Tests of LWA (5/6)
Recession of JFOAM/PI LWA

Our LWA’s surface recession rates are comparative to PICA, when the density values are around 0.36!
5. Arcjet Tests of LWA (6/6)
Recession of JFOAM/PI LWA

For the moment, char density values of RVC/LWA’s are somewhat ambiguous, however, recession mass flux values of RVC/LWA seem to be almost constant. Are they independent of the microstructures?
5. Conclusions & Future Works

- We are currently conducting IR&D activity towards domestic RVC/LWA with density 0.3-0.4g/cm³ for future reentry missions.
- From the experiences of fabricating LWA panels of 22cm x 22cm x 5cm and density measurements, we have confirmed that our resin-impregnation process for LWA is quite stable and reliable.
  - CALCARB/PI <±3%
  - Grafoam/Ph <±3%
- The insulative performance of current LWA’s is judged acceptable.
- But the Arcjet tests revealed signs of spallation-driven recession especially for our domestic RVC/LWA, which may be attributed to the coarse microstructures peculiar to our current RVC’s.
- Therefore, further modifications for our RVC are currently underway in order to improve recession resistance.
  - Fine Cell Structures
The Possible Future Directions
Fine Cell Structured JFOAM

Current JFOAM (ρ0.22)

Fine Cell Structure

Fine Cell Structured JFOAM (ρ0.20)
Thank You for Your Attention!

Any Questions?