Novel Ceramic Matrix Composites (SiC/ SiC) for High Temperature Use up to 1500°C and Issues for Practical Application

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Examples of Envisioned Aerospace Applications

Scramjet engine (Mach 6-12)

Turbine engine or rocket engine (Mach -6)

SiC Composite Nozzle

Courtesy: HHTC

 Courtesy: JAXA
Direction of Aerospace Material

- Ti alloy to CFRP
- Ni alloy to Ti alloy, TiAl, CMCs
- Ni alloy to TiAl

Blade: Ni alloy to TiAl, silicide, CMCs
Disc: Large scale Ni-base superalloy

Improve thermal efficiency: Few % - 20%
CO₂ reduction: 50,000 ton
Silicon Carbide Composites

Silicon carbide composites
- Consist with
  - Silicon carbide fiber
  - Silicon carbide matrix
  - Fiber/matrix interphase (typically C or BN)
- Very Low Radio activation
- Very High Temperature Use
Comparison of Oxidation of Particle Dispersion SiC Composites and Conventional SiC Composites

- **Oxidation of fiber through interphase**
- **Degradation of strength**
- **Oxidation from C and BN**
- **Retaining strength**
- **Oxidation of just surface**
Tensile Properties and Microstructure of BN Particle Dispersion SiC Matrix Composites Exposed at High Temperature Air

UD-SiCf/SiC+BN Composites

As-received
Exposed temperature 1500°C

UD2-No.2
(As-received) 208.6MPa
UD2-No.2
(1500) 223.9MPa

<table>
<thead>
<tr>
<th>UD2-No.2</th>
<th>Stress (MPa)</th>
</tr>
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<tbody>
<tr>
<td>As-received</td>
<td>208.6</td>
</tr>
<tr>
<td>1500°C</td>
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</tbody>
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# Particle Dispersion SiC Composites - Comparison with Conventional SiC Composites -

<table>
<thead>
<tr>
<th>Method</th>
<th>Strength</th>
<th>Heat resist.</th>
<th>Cost</th>
<th>Development Stage</th>
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<tbody>
<tr>
<td>GE (ref.)</td>
<td></td>
<td>1200C Oxidation</td>
<td>-</td>
<td>-</td>
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</table>

| Company A       |          | ≈GE          | >GE  | databasing       |
|                 |          | ≈GE          |      | · verification    |

| Company B       | <GE      | ≈GE          | >GE  | Material development |

| Kyoto Univ.     | ≈GE      | >GE 1500C    | <GE  | Material development |

- GE: General Electric
- CVI: Chemical Vapour Infiltration
- MI: Melt Infiltration
- Pre-preg: Pre-impregnated
- LPS: Laser Powder Injection
Promising seeds

- The novel CMCs were developed at Kyoto University. The high temperature strength are excellent and the material cost is low compared with conventional CMCs.

Huge markets but huge efforts required

- The CMCs have excellent potential due to high temperature strength beyond metals.
- However, the material cost is much higher than that for metals. Fracture behavior is completely different from metals and ceramics. It requires significant efforts for practical application including designing materials and establishment of supply chain.

Risk

- It’s very difficult for most companies to take a big risk for a big business even for a big company.
- It’s required to decrease the risk.
Risk Control for Practical Application

CMC parts maker risk
- Large cost for material development
- Long term development
- Limited application due to high material cost at this moment and depending on engine maker

Pre-preg maker (between law material and CMCs)
- The Pre-preg consists with fibers and matrix slurry.
- Kyoto University contracted the CMCs license with the pre-preg maker.
- The pre-preg can be distributed to CMCs parts makers for any CMC parts.
CMC Supply Chain

Raw materials
- NGS (SiC fiber)
- Ube (SiC fiber)
- Company A (SiC powder)
- Company B (SiC powder)
- Company C (SiC powder)
- Company D (BN powder)

Fiber weave
- Company E
- Company F
- Company G

CMC parts
- GE/GE Aviation
- Snecma
- Rolls-Royce
- HyperThermo
- Pratt & Whitney
- UTC Aero Space (Goodrich)
- IHI
- KHI
- MHI

Engine
- Company A (Pre-preg)
- CMC license

Airplane
- Airbus
- Boeing

Characterization
- Company I (Mechanical properties)
- Company J (Mechanical properties)

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Concluding Remarks for Practical Application

- R&D at Universities are relatively long term, high risk and high return.
- There is a large gap between seeds at universities and practical application.
- It’s required to fill the gap. Otherwise only low risk and low return R&D can be utilized for practical application. It’ should not be the R&D motivation for universities in particular for Kyoto University.
- Some organizations and coordinators are required to fill the gap and plan the business model utilizing license. Faculty can play the role.
- Long term vision are expected for industries to create prosperity 10 years later or 100 years later.