Development of Particle-Core Compression Molding

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MITSUBISHI RAYON CO., LTD.
PCM Technology

- High cycle process based on compression molding
- Rapid curing prepreg
  - 2 minutes cure at 150 °C (302°F)
- Developed for high volume Carbon Fiber Reinforced Plastic (CFRP) applications

**PCM (Prepreg Compression Molding)**

Near net shape preform made of rapid curing prepreg is cured in heated steel tool. Short mold cycle time.
Hollow section effectively stiffens structure of part without increasing weight.

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Hallow</th>
<th>Core included</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EI [N mm²]</strong></td>
<td>4.17E+10</td>
<td>4.19E+10</td>
<td>4.19E+10</td>
</tr>
<tr>
<td><strong>Weight [g]</strong></td>
<td>400</td>
<td>166.4</td>
<td>179.4</td>
</tr>
<tr>
<td><strong>Weight ratio [-]</strong></td>
<td>1.00</td>
<td>0.42</td>
<td>0.45</td>
</tr>
</tbody>
</table>

**CFRP:**

- **Modules [GPa]:** 80
- **Density [g/cm³]:** 1.6
- **Core:**
  - **Modules [GPa]:** 0.07
  - **Density [g/cm³]:** 0.05
Molding Processes of Hollow Section

- Joining two open sections
  - Additional bonding time
  - Joint design is necessary, such as flange

- Bladder molding
  - High molding pressure cannot be used
  - Part design limitation

- Molding with core material
  - Conventional soluble core
  - No internal pressure from core side

**Particle Core Compression Molding**
- High cycle compression molding
- Internal pressure can be applied
- Design flexibility
Particle-Core Compression Molding

- **Removable core**
  - Plastic inner shell filled up with particle
  - Particle is reusable

- **Prepreg compression molding**
  - Net shape preform made of prepreg and removable core
  - After compression molding, particle is removed from molded parts, forming hollow section.
### Advantages of Particle Core Molding

<table>
<thead>
<tr>
<th>Advantage of Particle Core Molding vs.</th>
<th>Bonding</th>
<th>Bladder Molding</th>
<th>Soluble Core</th>
<th>Conventional Core</th>
</tr>
</thead>
</table>
| **Bonding**                           | ✓ Lower cost (Bonding cost is expensive)  
    | ✓ Shorter process time (Bonding is extra process)  
    | ✓ Higher reliability (Lower strength at bonded area) |              |                   |
| **Bladder Molding**                   |         | ✓ Better appearance and properties (Bladder molding pressure is low)  
    |         | ✓ More freedom for parts design (Restriction due to insertion of bladder tube) |              |                   |
| **Soluble Core**                      |         |                 | ✓ Better appearance and properties (Internal pressure cannot be used)  
    |         |                 | ✓ Dimensional stability (Internal pressure cannot be used) |              |                   |
| **Conventional Core**                 |         |                 |              | ✓ Lighter weight (Core is heavier)  
    |         |                 |              | ✓ Lower cost (Core material is expensive)  
    |         |                 |              | ✓ More design flexibility (Restriction for parts design) |
Compression Molding Process

- Particles can move inside plastic inner shell by compression force
  - Particles push prepreg from inside and fits it to tool cavity
  - Uniform pressure can be applied on prepreg, even on vertical wall

Particle moves and pressurizes inside of cavity evenly, even at vertical wall
Internal Pressure with Plunger

- Applying internal pressure with plunger
  - Pressurize more evenly from inside of core
  - Eliminate fiber distortion in the vertical wall
  - Eliminate resin accumulation at the sharp corners

Resin rich area in corners
Fiber distortion at vertical wall

Compress
Pressurize from inside of core by plunger
**Heat Transfer Rate**

- **Internal pressure application with plunger prevents resin accumulation**

**Without Internal Pressure**
- Compress
- Resin Accumulation

**With Internal Pressure**
- Compress

Press pressure: 8MPa
Plunger pressure: 4MPa
Plastic Inner Shell

- Plastic inner shell can be made by blow molding thermoplastic
  - Common thermoplastic such as polyamide or polypropylene can be used
    - Appropriate mechanical property at 140 - 150 °C

Plastic Inner Shell

Filling up the shell with particle

Filled up with particle
Thermal Conductivity

- Particles must not absorb much heat
  - Low thermal conductivity
    - Low heat absorption to maintain high prepreg temperature for rapid curing

<table>
<thead>
<tr>
<th></th>
<th>Thermal Conductivity (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Nitride (AN216A)</td>
<td>150</td>
</tr>
<tr>
<td>Silicone Carbide (SC211)</td>
<td>60</td>
</tr>
<tr>
<td>Alumina (A479M)</td>
<td>32</td>
</tr>
<tr>
<td>Silicone Nitride (SN220)</td>
<td>20</td>
</tr>
<tr>
<td>Zirconia (Z201N)</td>
<td>3</td>
</tr>
<tr>
<td>Cemented Carbide WC-Co</td>
<td>85</td>
</tr>
<tr>
<td>Steel (Carbon Steel)</td>
<td>41</td>
</tr>
</tbody>
</table>

Fine Ceramics

Metal

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Friction on Particle Surface

- Particles must move smoothly in shell
  - Low friction coefficient
    - Prevent pressure loss
  - Combination of different particle sizes

\[ F_p = F_0 - f \times n \]

- \( f \): friction
- \( n \): number of particle

Pressure loss is larger as position from plunger is farther.
Size of Particle

- Size of particle is important
  - Smaller particles compress prepreg more evenly, however does not flow smoothly
  - Larger particles move and transfer pressure easily, which minimizes pressure loss by friction
  - Combination of different particle sizes balances efficiency of pressure transfer and uniformity

![Diagram showing small and large particles in a press]

Example: 1mmφ
Press Pressure: 8MPa
Plunger Pressure: 4MPa

Example: 10mmφ
Pressure Chart

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Compression Molding Process

- **Particles must move smoothly and not absorb heat**
  - Low friction coefficient
    - Preparing pressure loss
  - Low heat transfer coefficient
    - Minimal heat absorption to maintain temperature for curing material

- **Selection of particle size is important**
  - Smaller particles apply more uniform pressure
  - Larger particles lose less pressure by friction
  - Combination of different particle sizes balances pressure transfer efficiency and uniformity
Preforming with Core No.1

- **Polyamide Inner Shell**
- **Core; Inner Shell filled with Ceramic Particle**
- **Sectional Preform; Core Wrapped with Prepreg**
- **Near Net Shape Preform; All Sectional Preforms Assembled**
Preforming with Core No.2

Near Net Shape Preform; All Sectional Preforms Assembled

Near Net Shape Preform; Outside Wrapped with Fabric Prepreg

Near Net Shape Preform

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Tool for Wheel Demonstration

<Upper Mold>

<Near Net Shape Preform; Outside Wrapped with Fabric Prepreg>

<Lower Mold>

Plunger

Upper Mold

Ring

Lower Mold
Molding of Wheel Demonstrator

- Charge a net shape preform made with particle core into the tool
  - Tool Temperature; 140℃
  - Molding pressure; 4MPa

- Close the tool
  - Upper tool pushes ring on lower tool
  - Vertical wall of a preform is compressed by ring and plunger on upper tool

- Plunger compress preform after upper tool close completely
  - Plunger compress particle core and generate internal pressure

- Parts is de-molded after curing completes
  - Eject all the particles from core
Molding Process Demonstration of Wheel

**Molding Parameters**
- Tool Temp: 140 °C
- Cure time: 600 sec.
- Molding Pressure: 8 MPa
- Plunger Pressure: 3.3 MPa
- Plunger Insert: 1.5 mm

**Steps:**
1. **Charging Near Net Shape Preform**
2. **Curing Complete**
3. **Finished Part**
4. **De-molding**
5. **De-flushing**
   - Removing particles

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Miniature Floor Demonstration

- Demonstration floor part with hollow section was developed
  - Corrugate structure
  - Hollow section by particle core molding
  - Hybrid molding of prepreg and CF-SMC

**Structural floor model**
Size: 500X500mm
To a world standard.

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