Development of Preforming Process in PCM* Technology

* Prepreg Compression Molding

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MITSUBISHI RAYON CO., LTD.
PCM Technology

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

PCM (Prepreg Compression Molding)

Newly developed rapid curing prepreg is preformed, and then cured in heated steel tool. Short mold cycle times.

Laminate → Heat → Prefoming → Charge → Compression → De-molding

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# Prepreg for PCM

## Resin Properties

<table>
<thead>
<tr>
<th>Resin Formulation</th>
<th>R 02</th>
<th>R 03</th>
<th>R 05</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resin type</strong></td>
<td>Bisphenol A type Epoxy resin</td>
<td>Bisphenol A type Epoxy resin</td>
<td>Bisphenol A type Epoxy resin</td>
</tr>
<tr>
<td><strong>Gel time @ 140 °C min.</strong></td>
<td>2.0</td>
<td>1.3</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Minimum cure time @140 °C min.</strong></td>
<td>5.0</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>G'-Tg</strong> °C</td>
<td>125</td>
<td>165</td>
<td>167</td>
</tr>
<tr>
<td><strong>tanδ</strong> °C</td>
<td>154</td>
<td>186</td>
<td>190</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>Good Surface</td>
<td>High Tg</td>
<td>Good Surface High Tg</td>
</tr>
</tbody>
</table>

## Prepreg Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Ttypical grade</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CF reinforcement</strong></td>
<td>UD</td>
</tr>
<tr>
<td><strong>FAW</strong> g/m²</td>
<td>250 or 125</td>
</tr>
<tr>
<td><strong>Resin Content</strong> wt%</td>
<td>30.0</td>
</tr>
<tr>
<td><strong>CF Vf</strong> vol%</td>
<td>59</td>
</tr>
<tr>
<td><strong>Specific Gravity</strong></td>
<td>1.54</td>
</tr>
</tbody>
</table>

[^1]: TR50S carbon fiber from Mitsubishi Rayon Co., Ltd. is used for all prepregs

[^2]: Tensile strength; 4900 MPa, Modulus; 240 GPa, Elongation; 2.0%

[^2]: Plain, twill and Satin fabric can be used.
Automotive Body Panels

- Class A surface is achievable with UD prepreg
- Body panels can be produced by bonding PCM outer panel and CF-SMC inner panel

Outer Panel
- PCM
- Part size: 600X600X1.1mm

Inner Panel
- CF-SMC
- Part size: 600X600X1.5mm

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Automotive Structural Parts

- PCM process application on floor part
  - Molded parts have high mechanical properties due to continuous fiber material
  - Co-molding of prepreg and CF-SMC allows complex three dimensional shapes
Rapid Curing Material

- Prepreg compression molding significantly reduces time to convert PREPREG to COMPOSITE

Traditional Process
Cycle time: 240 minutes

High Cycle Process
Cycle time: 5 Minutes
Rapid Preforming Process

- Conventional preforming process is inefficient compared to high-cycle PCM process

Conventional Preforming

- Manual lay-up
  - Very slow
- Large variation
- Human error

Advanced Preforming Process

- Fast enough for PCM
- Consistent
- Less manual labor
- Automated

Preforming process for PCM must be...
Rapid Preforming Process

- Pattern cutting, preforming and compression molding are consecutive processes.
- Cycle times of each process must match for high capacity production.
Development of Rapid Preforming Process

- Preforming large and complex shapes
  - Deep drawn shapes
  - Shapes that cannot be preformed by stretching material
  - Three dimensional shapes such as ribs and bosses

- Optimization of preforming parameters
  - Heating temperature and time, press pressure, etc.

- Automated process for rapid preforming system
Prepreg Curing Analysis

- Temperature of prepreg quickly rises after charged on heated steel tool
- Curing reaction starts immediately after prepreg is heated to tool temperature.

Preforming cannot be done with compression molding tool.

Exothermal behavior of prepreg

Temperature at the center of prepreg was measured by a thermocouple.

(Measuring Condition)
Material: R05 UD prepreg, cross ply
Thickness of prepreg: 4mm (2mmX2sets)
Tool temperature: 140 °C
Preforming with Press

- Heating temperature must be below 80 °C during press-preforming process.
  - Resin viscosity decreases by heating and prepreg becomes flexible and drapable
  - Curing occurs when temperature is over 80 °C

**Temperature Dependence of Resin Viscosity**

**Stability of Resin at Elevated Temperature**

- Resin formulation; R02
- Measured by TA Instruments AR-G2 Rheometer
- Temperature ramp up rate; 2°C/min

Resin formulation; R02
Measured by TA Instruments AR-G2 Rheometer
**Preforming with Press**

- Thicker laminates need longer heating time.
  - Longer time is needed for inside to reach to appropriate temperature (50-75°C)
  - Low heater output allows longest working time.

**IR Heater output; Low (11mA)**
**Material; R05 (Thickness of Laminate: 1, 2, 3mm)**

- Good temperature range
- Working range (Preform is possible)

**Thermocouple**
- Top
- Middle
- Bottom

**About 15cm**
Preforming with Press

- Higher heater output shortens heating time, but working time is shorter.

Material: R05 (Thickness of Laminate: 1, 2, 3mm)

Thickness: 1mm

Thickness: 2mm

Thickness: 3mm

Heater; Middle

Heater; High

Material: R05 (Thickness of Laminate: 1, 2, 3mm)
Typical Preforming Process

- Near net shape preform can be produced at low temperature and low pressure.
  - Low cost equipment can be used (chemical wood tool, air cylinder driven press, IR heater, etc.)

1) Lay up several prepreg sheets
2) Debulk for 2 minutes by vacuum
3) Cut patterns

1) Heat laminate to 70 °C
   ex) 30 seconds by IR heater for 1mm thick
2) Press for 1 minute to cool down
   Typical pressure is lower than 0.1 MPa (1 bar)
3) Debulk for 1 minute by vacuum
   (if necessary)
Preforming Demonstration Unit

- Preforming demonstration unit was built
  - Pressing by tool stretches prepreg like manual lay-up in few minutes.
Preforming Process

PREPREG COMPRESSION MOLDING
PATTERN CUTTING
Preforming of Complex Shape

- Advanced procedures to produce near net shape preform for complex shape
  - **Apply tension to stretch laminate.**
    - Optimal for forming round or deep drawn shape
  - **Divide into smaller sections.**
    - Preform each section with press.
    - Sections are combined into an integrated near net shape preform
    - Overall short process time.
  - **Combine prepreg and CF-SMC for three dimensional complex shape.**
    - Prepreg based design for mechanical properties with CF-SMC only for three dimensional complex shape.
    - CF-SMC based design for design flexibility with prepreg as local reinforcement.
1/2 Scale Seat Back Demonstration

- Complex deep drawn shape
  - Normally preformed manually by skilled operator

![Diagram of seat back with dimensions: 400mm (15.7"), 300mm (11.8"), 85mm (3.3")]
Fiber distortion was observed in simple press-preforming by matched tool.

**3K Plain Fabric PP ; 0/90**

Shear deformation angle:
- B; 0-15° Possible
- Y; 15-30° Difficult
- R; over 30° Impossible

**Fiber Direction; 0/90**

**3K Plain Fabric PP ; 45/-45**

Shear deformation angle:
- B; 0-15° Possible
- Y; 15-30° Difficult
- R; over 30° Impossible

**Fiber Direction; 45/-45**
Preforming Deep Drawn Shapes

- Apply tension to stretch material and fit on tool surface without fiber distortion.
- Jigs are used to simulate manual lay-up

Jigs for press preforming
- Apply tension during preforming
- 10 minutes

Traditional Manual Preforming
- Heat and stretch by hand
- 60 minutes

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**Tension Application**

- **Automatic chucking unit applies tension and stretches prepreg during preforming**

![Preforming Unit](image1.png)
![Chucking unit](image2.png)
![Heating unit](image3.png)
![Press unit](image4.png)
![Trim](image5.png)

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*By Courtesy of Challenge*

*By Courtesy of Mitsubishi Rayon Co., Ltd.*
Automatic System for Complex Shape

By Courtesy of

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Sectional Preforming Process

- Divide large complex shape to smaller sections.
  - Each section can be preformed by press in only a few minutes.
Sectional Preforming Process

- Design sections so their edges are not at the same position and do not overlap.
  - Section edges must not be where significant load is applied, as mechanical strength is lower.
Sectional Preforming Process

- Preformed sections are merged into a net shape preform.
- Each section is stacked, layer by layer
Sectional Preforming Process

- A near net shape preform is debulked by vacuum.
  - Debulking is completed in a few minutes
  - Ready to mold by compression molding

Two each of Layer A and B are stacked alternately

Debulk by vacuum for 3 minutes

Three dimensional net Shape preform
Sectional Preforming Process

- High cycle preforming is also possible for large complex shaped part by automated process.
Hybrid Molding of Prepreg and CF-SMC

- Prepreg for mechanical properties and CF-SMC for complex shapes
  - Curing properties of both materials were matched for co-molding
  - CF-SMC flows in the tool cavity and molds into complex structures

CF-SMC was charged on the net shape preform

Molded part
Summary

- Automated preforming process for PCM technology has been developed.
  - Short preforming process by press matches compression molding of rapid cure prepreg.

- Large complex shape also can be preformed quickly by using following procedures.
  - Apply tension to stretch prepreg and fit to parts shape.
  - Divide part to several smaller sections.
    - Sections can be preformed by press
    - They are consolidated and form a near net shape preform ready for compression molding.

- PCM/CF-SMC hybrid molding
  - Co-molding of prepreg and CF-SMC can provide high mechanical properties with three dimensional complex shape
To a world standard.

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Our driving force is our integrated production system - raw material to finished product - which enables us to respond quickly to changing market needs.
Our new range of P330 carbon fibres is an example of this response in action with a fibre that offers high strength and resilience plus volume production.
The standards set by Mitsubishi are endorsed by customers throughout the world.

Thank you
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