Changing the Future of Carbon Fiber Reinforced Thermoplastic Composites

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Application Development Manager
Teijin Advanced Composites America
Outline of Teijin Group

Business Group Structure

- Pharmaceutical products
- Home healthcare products (Oxygen generator, CPAP)
- Pet, PC, etc.
- Film, Resin, etc.
- Trading of chemicals, industrial materials, etc.
- Apparel business

- Major supplier of Carbon & Aramid Fiber in the world
- Materials for battery cells
- Printable electronics materials
- IT system for healthcare
- ERP
- Contents business for smartphones

Carbon Fibers & Composites BU
High Performance Fibers BU
Advanced Fibers & Composites BG
New Business Development BU
Healthcare BG
Electric Materials & Performance Polymer Products BG
Resin & Plastic Processing BU
Products Converting BG
IT BG
Outline of Teijin Group

Global Network

Number of Group Companies
- Europe: 15
- Americas: 26
- Asia: 53
- Japan: 58
Total 152
(As of March 31, 2015)

Consolidated Net Sales by Region
- Europe: 8.2%
- Americas: 7.2%
- Asia: 25.5%
- Japan: 59.2%
Total 786.2 billion yen
(Fiscal 2014)

Teijin Limited, Regional Headquarter Company
Advanced Fibers & Composites Business
Healthcare Business
Electric Materials & Performance Polymer Products Business
Products Converting Business
IT Business
New Business, Others
Teijin's Carbon Fiber Business

- Broad portfolio of materials & technologies
- Wide range of applications ranging from sporting goods to automotive and aerospace.
In order to apply CFRP to mass-produced cars, shorter takt time (1 min) & superior mechanical property matched for primary structure is key
Newly Developed CFRTP Technology

- Maximize Carbon Fiber Performance by Fiber Configuration Control & Sizing
  - Controlled highly planar & isotropic fiber orientation for complex load cases
  - Sizing technology

- 1 min takt Time Molding Technology with Keeping Superior Fiber Configuration

- Assembly Technique to Meet "Mass Production takt Time"

- Dimension Control Technique for Qualified Automotive Parts

- Predictability of Performance by CAE for Practical Parts Design

Innovative Technology Which Provides
- High mechanical property for structural usage
- 1 min takt time for mass production
- Recyclability

Save the earth, revolutionary & evolutionally carbon
### Maximize Carbon Fiber Performance

#### (1) Compare with metallic materials

<table>
<thead>
<tr>
<th></th>
<th>Sereebo® I-series</th>
<th>AL (6061T6)</th>
<th>Steel (590 MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [kg/m³]</td>
<td>1380</td>
<td>2700</td>
<td>7900</td>
</tr>
<tr>
<td>Tensile Modulus [GPa]</td>
<td>26</td>
<td>71</td>
<td>206</td>
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<tr>
<td>Yield Strength [MPa]</td>
<td>(350)</td>
<td>275</td>
<td>350-450</td>
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<tr>
<td>Tensile Strength [MPa]</td>
<td>350</td>
<td>310</td>
<td>590-710</td>
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</tbody>
</table>

#### (2) Compare with composite materials

<table>
<thead>
<tr>
<th></th>
<th>Sereebo® I-series</th>
<th>CF-SMC (Chopped)</th>
<th>CF-RTM (Chopped)</th>
<th>CF-AC (Woven)</th>
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</thead>
<tbody>
<tr>
<td>Fiber Vol [%]</td>
<td>35</td>
<td>40</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Density [kg/m³]</td>
<td>1380</td>
<td>1460</td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>Tensile Modulus [GPa]</td>
<td>26</td>
<td>33</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td>Tensile Strength [MPa]</td>
<td>350</td>
<td>150</td>
<td>400</td>
<td>840</td>
</tr>
<tr>
<td>Bending Modulus [GPa]</td>
<td>26</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bending Strength [MPa]</td>
<td>480</td>
<td>300</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

These values are not isotropic but orthotropic. Estimated quasi-isotropic value would be:
- Modulus: 41 GPa
- Tensile Strength: 630 MPa

Controlling fiber configuration gives superior strength & reasonable stiffness.
Superior specific property especially for strength

=> Good for "Weight Reduction" of Strength Driven Structural Application
Fully automated molding cell are available. 2000 ton in Japan (Ehime) and 4000 ton in USA (Auburn Hills, MI). Video shows 2000 ton cell.
Excellent Mold-ability

- Good behavior of heated blank material to maintain isotropic fiber orientation during molding
- Complex shaping with absorbing wrinkles during molding
- High-flow molding (like SMC / GMT) is also available

Less-flow 3D complex molding

Wrinkle-free deep drawing

Complex feature with high-flow molding
Uneven Thickness in One Parts

"Local & Global Thickening / Thinning" will help optimize parts design

Front Bulkhead Panel (Teijin's Concept Car)

Thickness data by 3D scanning

\[ t = 2.0 \text{ mm} \]
\[ t = 4.5 \text{ mm} \]
Hole in Mold Technology

Hole in Mold give holes having accurate diameter & location suitable for locator. Not only circular holes but also rectangular or other shape can be available.
### Applicable Technique for Assembly

<table>
<thead>
<tr>
<th>Methods</th>
<th>Welding</th>
<th>Staking</th>
<th>Adhesion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vibration</td>
<td>Ultrasonic (spot)</td>
<td>Staking</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>★☆☆</td>
<td>★☆</td>
<td>★☆☆☆</td>
</tr>
<tr>
<td>takt time</td>
<td>★★★☆</td>
<td>★☆</td>
<td>★☆</td>
</tr>
<tr>
<td>Cost</td>
<td>$</td>
<td>$$</td>
<td>$$</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>- One step</th>
<th>- Simple</th>
<th>- Molded in</th>
<th>- Light</th>
<th>- Multi Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Large area</td>
<td>- Flexible</td>
<td>- Dimension</td>
<td>- Flexible</td>
<td>- Tolerance</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>- Limited shape</td>
<td>- Many points</td>
<td>- Hole needed</td>
<td>- Hole needed</td>
<td>- Long takt</td>
</tr>
<tr>
<td></td>
<td>- Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outline</th>
<th><img src="#" alt="Image" /></th>
<th><img src="#" alt="Image" /></th>
<th><img src="#" alt="Image" /></th>
<th><img src="#" alt="Image" /></th>
<th><img src="#" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>★★★☆</td>
<td>⇔</td>
<td>★☆</td>
<td>Poor</td>
<td></td>
</tr>
</tbody>
</table>

Wide variety of well-known joining methods are available.
Assembly (Ultrasonic Welding)

Automatic continuous robotic welding video

Stable welded mark & size

Joining technology is also very important to achieve mass production takt times. Ultrasonic welding (and vibration welding) has great potential to achieve this.
CAE material card for Sereebo-I has been developed.
- As a validation trial, corrugated plaque was molded and cut.
- 2 different boundary conditions have been validated.
CAE modeling & Validation

Normal Position

Upside Down Position

CAE & experimental result show reasonably good match. Load-displacement curves & peak loads of 10 different specimens are fairly constant.
Warpage Prediction Technology

Dimensional control of parts is quite important for automotive parts.
- In case of thermoplastic, cooling fixture is not effective.
- Warpage prediction method for Sereebo-1 has been successfully developed.

Deviation between nominal parts shape & 3D measurement data.

Deviation between 3D measurement and CAE data.

Tooling design in expectation of warpage gives superior dimension control of parts.
Tooling design in expectation of warpage works well for large size complex panel
Potential Application - Body Structure -

**Design concept for mass-production CFRP cars**
- Double-deck
- Welding (vibration / ultrasonic)
- Combine Anisotropy & Isotropy

**Concept car**
- Composite Parts made of Sereebo (Small metal insert parts)
- 47 kg body weight (no crash structure)

**CAE Analysis**
- Equivalent bending / torsion stiffness
- Not include crash management

**Patent No.**
- WO 2012105389 A1
- WO 2012105716 A1
Potential Application - Crash Structure -

<table>
<thead>
<tr>
<th></th>
<th>Sereebo® I-series</th>
<th>Steel (SPFC590)</th>
<th>Aluminum (A6061)</th>
<th>CFRP (Vf60 %, Woven)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>2.0 mm</td>
<td>0.8 mm</td>
<td>1.0 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>144 g</td>
<td>324 g</td>
<td>138 g</td>
<td>141 g</td>
</tr>
<tr>
<td>Weight ratio</td>
<td>1</td>
<td>2.25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Joint method</td>
<td>Vibration weld</td>
<td>Spot weld</td>
<td>Spot weld</td>
<td>Adhesive</td>
</tr>
</tbody>
</table>

Energy Absorption:
- Sereebo-I 70 J/g
- A6061 20 J/g
- CFRP 59 J/g
- SPFC590 16 J/g

Superior fiber configuration gives great energy absorption in compression mode
Potential Application - Crash Structure -

Sereebo-I has superior energy absorption in compression mode.
Still keeping more than 50J/g under Hot-Wet condition (worst case). Except Hot-Wet condition, energy absorption behavior seems stable.
No Element Deletion  |  Element Deletion

Control of Element Deletion is still a challenge, but simple shell modeling with isotropic/elastic-plastic material cards gives acceptable predictions. => Share-rate dependency of compression strength should be considered.
Conclusion

Teijin has been developing "New CFRTP Technology which offers;

- Great material property with **Keeping Isotropy** during molding
- "**CAE Friendly Material**" for effective parts design
- **Superior Dimension Control** with predictability of warpage
- **Excellent Energy Absorption** performance in compression mode
- **1 min takt Time** molding to match with automotive production
APPENDIX
Teijin's Composites Technology

**Pultrusion (Thermoset)**
- Constant cross-section
- Hollow tube section without flange
- Constant curvature available
- Continuous fiber / Designed anisotropy
- Effective continuous process
- Middle to Large number of production

**RTM - Parts via Preform - (Thermoset)**
- Near net shape with
- Designed anisotropy with Random & UD
- Low scrap rate (<10 %)
- Good appearance
- Low to Middle number of production

**Structural Panel (incl. Semi)**
- Complex panel shape
- HTS steel
- Sheet metal forming / (Hot stamp)

**Injection Molding (Thermoplastic)**
- Injection molding
- Longer fiber than conventional one
- Better stiffness / strength
- Good appearance
- Medium to large number of production

**Compression Molding (Thermoplastic)**
- 1 min takt
- Isotropic Random fiber in parts
- Complex & large integrated shape
- Damage tolerant / Energy Absorption
- Recyclable
- Middle to large number of production

**Semi structural parts**
- Complex solid shape
- Al / Mg
- Die-cast Forming

**Structural Member (incl. Semi)**
- Simple tube shape
- UHTS steel
- Hot stamp / Hydro form

**Semi structural parts**
- Complex solid shape
- Al / Mg
- Die-cast Forming