Toray Automotive

Future Trends for High Performance Materials in Structural Components for Existing and Alternative Propulsion Systems

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Toray Automotive
Director of Business Development, Volker Plehn
Sr. Technical Engineer, Jeffrey Satterwhite
Agenda

- Introduction: Toray
- The Automotive Environment
- High Performance Material: PPS
- High Performance Material: Polymers for Powertrain
- Target Applications
- High Performance Fibers
- Advanced Rapid Cure Prepreg
- Outlook
About TORAY

- **Established:** January 1926
- **Employees:** 45,839 (Japan: 17,743 / Overseas: 28,096)
- **Subsidiaries:** 254 (Domestic: 100 / Overseas: 154)

### Business Segments

<table>
<thead>
<tr>
<th>Business Segments</th>
<th>Net Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foundation Businesses</strong></td>
<td></td>
</tr>
<tr>
<td>Fibers &amp; Textiles</td>
<td>$1,036</td>
</tr>
<tr>
<td>Plastics &amp; Chemicals</td>
<td>(65%)</td>
</tr>
<tr>
<td><strong>Strategically Expanding Businesses</strong></td>
<td></td>
</tr>
<tr>
<td>IT-related Products</td>
<td>$313</td>
</tr>
<tr>
<td>Carbon Fiber Composite Materials</td>
<td>(19%)</td>
</tr>
<tr>
<td><strong>Strategically Developing Businesses</strong></td>
<td></td>
</tr>
<tr>
<td>Environment &amp; Engineering</td>
<td>$239</td>
</tr>
<tr>
<td>Life Science &amp; Other Businesses</td>
<td>(16%)</td>
</tr>
</tbody>
</table>

Millions/USD (JPY100/USD), as of March 31, 2016

Total: 21,044
The Automotive Environment

Other Conditions

- Thermal Shock
- Thermal Cycle (1000 Cycles or More)
- Power Spikes
- Low Temperature (-40° C)
- Mechanical Shock
- Mechanical Vibration (up to 10Grms)
- Voltage Spikes
- Electromagnetic Interference
- Electrostatic Discharge
- Altitude
- Salt Spray
- High Humidity
- Break Fluid
- Transmission Fluid
- Oxides of Nitrogen
- Engine Coolant
- Gasoline
- Oil
- Water Immersion

Engine Compartment
- Close to Engine: 120° C
- Remote from Engine: 105° C

Exterior
- Accessible to Splash, etc.: 70° C

Wheel-Mounted Components
- Up to 250° C

Engine Oil
- 148° C

Transmission Oil
- 148° C

Ignition Surface
- 129° C

Alternator Surface
- 150° C

Passenger Compartment
- 85° C

Exhaust System
- 587° C

Engine 140° C

Road Surface
- 66° C
Polymers Evolution

CO² Reduction
(e.g. Solar Power and Cells)

Levers for reducing CO² emissions

- Energy Recuperation
- Demand-controlled Energy Supply (Energy Management)
- Transport of Energy Without Losses (Focus: Efficiency)
- Optimization of Overall Power Economy by Reducing Energy Consumption & Kinetic Losses (Reduced Spending & Drag Elimination)

Energy Flow

- Electrification
  Battery Systems
  Predictive Energy Management

- Thermal Management
  Stop-Start, Predictive Energy Management, Demand-controlled Actuation

- Combustion
  Turbocharging, Hybridization, Electrification

- Weight
  Rolling Resistance, Aerodynamics

Sources
Left: International Engine Conference
Right: ATZ 11/2011 Thermal Management Solutions
toray products (brand names in brackets)
Properties of Linear and Cross-link PPS

- **Tensile Strength**  Linear = Cross-link
- **Anti-Creep**  Linear < Cross-link
- **Stiffness**  Linear < Cross-link
- **Out Gas**  Linear > Cross-link
- **Weld Strength**  Linear > Cross-link
- **Toughness**  Linear > Cross-link
Comparison of Heat Resistance of Resins

![Comparison of Heat Resistance of Resins](image-url)
Target Applications in Automotive

1. Radiator Tank
2. Engine
   - Engine cover
   - Intake manifold
   - Engine mount
   - Oil strainer
   - Water pump
   - Turbo duct
3. Wire Harness
4. ECU
   - ECU case
   - Semiconductor
5. PCU
   - Inverter
   - DC/DC converter
   - Connector
6. Battery Charger
Applications for Reciprocating Engine vehicle

**Power train & Engine Parts**
- Intake manifold, Engine cover,
  Turbo duct, Ignition coil

**Electric Parts**
- Lever combination switch, ECU case,
  Wire harness connector

**Cooling Parts**
- Radiator tank, Cooling fan,
  Water treatment module

**Interior & Exterior Parts**
- Head lamp, Door lock, Power window
Advantages

- Dimensional stability
- Long life coolant (LLC) resistance
- High mechanical properties
- Achievement of parts integration
- Metal replacement for weight reduction
- Design freedom

Torelina® PPS is currently used by European OEM

- Water Pump
- Water Pump Impeller
- Thermostat
- Thermostat Housing
Applications for HEV, PHEV, EV, FCV

Target Applications

Drive / Generator
Motor insulator
(Insulator, Bus ring)

Battery
(Spacer, End plate, Case)

E-water pump
E-compressor

Invertor
(Power module, Capacitor, E-sensor, DC-DC convertor)
Turbo System: Materials for Turbo Ducts

Down-sized Engine & Turbo System

Turbo Housing

Intercooler

Turbo Duct
Toray Fuel Cell Technology

Toyota Motor MIRAI

- Carbon fiber composite material (CFRTP/CFRP) developed for automobile structural components
- Carbon paper for fuel cell stack electrode base material
- High-strength carbon fiber for high-pressure hydrogen tanks
- Toray carbon fiber material used in Toyota MIRAI
Low Density
Small Linear Expansion
High Strength & Modulus
Excellent Wear & Abrasion Resistance
Low Creep Behavior
Better Fatigue Performance
Excellent Electrical Conductivity
Excellent Electromagnetic Shielding

## TORAYCA® Carbon Fiber Reinforced Thermo Plastics

<table>
<thead>
<tr>
<th>BASE RESIN</th>
<th>PP</th>
<th>ABS (AS)</th>
<th>PC</th>
<th>PBT (PET)</th>
<th>PA</th>
<th>PPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td>Low Cost</td>
<td>Low Specific Gravity</td>
<td>Good Moldability</td>
<td>Low Cost</td>
<td>Good Dimension</td>
<td>Accuracy of Impact Property</td>
</tr>
<tr>
<td>Fiber Content (30%)</td>
<td>GF</td>
<td>CF</td>
<td>GF</td>
<td>CF</td>
<td>GF</td>
<td>CF</td>
</tr>
<tr>
<td>Gravity (g/cm3)</td>
<td>1.22</td>
<td>1.06</td>
<td>1.26</td>
<td>1.18</td>
<td>1.45</td>
<td>1.31</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>90</td>
<td>115</td>
<td>115</td>
<td>145</td>
<td>125</td>
<td>160</td>
</tr>
<tr>
<td>Bending Elastic Modulus (GPa)</td>
<td>6.2</td>
<td>15.0</td>
<td>8.5</td>
<td>18.5</td>
<td>7.2</td>
<td>16.0</td>
</tr>
<tr>
<td>Application</td>
<td>Automotive Structure</td>
<td>Electric Component</td>
<td>Exterior Components</td>
<td>Air Conditioner Parts</td>
<td>Body Tube for Camera</td>
<td>PC-Package IC-Tray</td>
</tr>
</tbody>
</table>

### Graphs

**Specific Gravity** vs **Tensile Yield Strength**

**Specific Gravity** vs **Flexural Modulus**

**Specific Gravity** vs **Electromagnetic Shielding Performance**

**Al**, **Mg**, **GFRT**

**CFRT**
CFRP Propulsion Shaft

- 40% weight reduction vs. aluminum construction
- Less revolutionary mass results in reduced resistance/ friction wear
- Increased RPM responsiveness
- Handles extreme torque loads
Rapid Cure Prepreg For Automotive Applications
Outline

- Introduction
- Motivation
- Objective
- Resin development
- New resin candidate
- Variability of cure cycle
- Properties of new resin system
- Conclusion
Need for Thermal Resistance

The typical finishes for the automobile are shown above.

- Each one of these coatings goes through a typical cure cycle of 180° C for 30min*.
- The E-coat currently has the highest temperature cure up to 200° C for up to 40 minutes.
- Materials need to be able to withstand these temperatures for the duration of the cure.

*http://support.fluke.com/datapaq/Download/Asset/9290093_ENG_A_W.PDF
Objective

Create a resin system that will be value added to the automotive industry and increase the use of carbon fiber

<table>
<thead>
<tr>
<th></th>
<th>Target</th>
<th>Current resin (G-83C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tg</strong>*</td>
<td>&gt;165°C</td>
<td>140°C</td>
</tr>
<tr>
<td><strong>Curability</strong></td>
<td>&gt;95% cure within 2 min of final dwell</td>
<td>~30 min for 95% of cure degree</td>
</tr>
<tr>
<td><strong>Viscosity Stability</strong></td>
<td>1.4 times for 150 min @ 65°C</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Surface Quality</strong></td>
<td>Equal or better than G-83C</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mechanical properties</strong></td>
<td>Equal or better than G-83C</td>
<td>-</td>
</tr>
</tbody>
</table>

*Cure cycle dependent*
Toray has created new resin system G-85 to meet objectives of automotive manufacturers designing for rapid curability in press-cure molding application.

<table>
<thead>
<tr>
<th></th>
<th>G-83C</th>
<th>G-85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg</td>
<td>140° C</td>
<td>165° C</td>
</tr>
<tr>
<td>Curability</td>
<td>~30 min for 95% of cure degree</td>
<td>&gt;95% cure After 5min Cure @ 163° C</td>
</tr>
<tr>
<td>Use</td>
<td>Designed for PCM</td>
<td>Designed for PCM</td>
</tr>
<tr>
<td>Surface Quality</td>
<td>Class A</td>
<td>Equal or better than G-83C</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Legacy material</td>
<td>Equal or better than G-83C</td>
</tr>
</tbody>
</table>
- G-85 systems show a longer induction time and lower viscosity compared to G-83C
- This long induction time at lower viscosities will allow the resin to flow faster and longer improving processing characteristics
G85 shows excellent curability behavior with a 5 minute cure and no primary dwell

- New G-85 resin shows good latency at the lower temperatures allowing for good resin flow
Variability of Cure Cycle

- G-85 resin system was evaluated for various cure temperature vs. time patterns to determine suitable minimum curing times.
- Curability in as low as 3-4 minutes, maximum performance within 9 minutes at 325°F.
- System shows suitable degree of cure for demolding as low as 225°F with mechanical performance achieved by post-cure.
Variability of Cure Cycle

- Curability known over a broad range of temperatures, cure cycles adaptable to customer needs
G85 Series resins exceed all mechanical properties of the previous snap cure material’s target mechanical properties

Additional properties are being tested for possible use in structure

**Mechanical Properties**

* Cure Cycle = Ramp 5° C/min to 163° C Dwell 10 minutes

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<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>G-85 / T300B-3K 2x2 (FAW 204, WR 42%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMA Tg</td>
<td>°C</td>
<td>177</td>
</tr>
<tr>
<td>0° TS</td>
<td>ksi</td>
<td>88</td>
</tr>
<tr>
<td>0° TM</td>
<td>msi</td>
<td>8.2</td>
</tr>
<tr>
<td>90° TS</td>
<td>ksi</td>
<td>87</td>
</tr>
<tr>
<td>90° TM</td>
<td>msi</td>
<td>8.2</td>
</tr>
<tr>
<td>V-notch IPS</td>
<td>ksi</td>
<td>13</td>
</tr>
<tr>
<td>ILSS</td>
<td>ksi</td>
<td>12</td>
</tr>
<tr>
<td>Flex. Mod.</td>
<td>msi</td>
<td>8.4</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>-</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Conclusion

- Need for CFRP lightweighting is increasing to meet CAFE standards, but requiring high Tg and rapid curability for CFRP to be applied to high volume automobiles.

- G85 resin was designed for these needs, and shows improved curability rate and suitability for a variety of curing means from press cure to autoclave molding and providing high ultimate Tg with full oven post-cure.
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