Automotive Composites ‘Crash Box’
for Mass Production

14th Annual Society of Plastics Engineers
Automotive Composites Conference & Exhibition
Novi, Michigan USA

Damien Guillon
Matthieu Kneveler

Alain Leroy
Jean Philippe Sauvaget
Roman Hillermeier
Advances in Automotive Composite Processes for Thermosets

Continuous Fiber Technologies

- HP-RTM
- LCM

New Faster Cure Epoxy Systems

- Fast Cure Prepregs
- Liquid Molding Technologies

New Automated Processing / Equipment Systems

- Pre-form Binders

Advanced Molding Compounds

- Short and Long Fiber Hybrid Technologies

SMC

Non-Structural
Semi-Structural

Unit Cost

Performance
Advances in Epoxy Resin Cure Time Development

Automotive Industry Target
= 1.0 minute
Crash-box Definition

- **Key Requirements: passenger survival + repairability**
  - To absorb significant energy in case of frontal or 15-degree off-axis crash at 65 km/h without acceleration peak
  - To keep the front end module linked to the car

- **Constraint**
  - To be easily joinable to the body in white
  - To be produced at 1000 part/day
  - To be cost competitive against steel design

- **Localization:**
  - Between a body in white (assumed in steel) and a front end module
  - In a box of 200 mm length and 100 mm diameter

*Image: Audi AG*
Patented CETIM Solution

• A very easy-to-produce shape:
  – A cone with total axial symmetry and no specificity
  – A crash triggering mechanism in the shape of the cone
  – Preform that can be braided or weaved directly in shape and continuously

• Optimized process
  – No dry fiber manipulation
  – Fast curing Epoxy resin systems for HP-RTM molding process
  – No step between molding and final assembly

• Simple mechanical assembly (patented):
  – Cost-effective: large manufacturing tolerance, low-cost interface parts, easy (dis)mounting
  – Performance: bending resistance, no localized weakness, keep the link with the front end module
Preform Braiding

• Continuous braiding:
  – Preform are braided on mandrel introduced in row in the center of the braiding machine
  – After braid cutting, mandrel are put directly in the injection mold

• Productivity
  – 4 layers with a 96 spools + UD braiding machine ==> 
  – One meter/minute braiding 
    (including reloading and mandrel switch): 
    36 seconds per parts, 1000 parts/day in 10 hours

• Cost estimation < 8€ per preform
  – 250 g of carbon fiber + 5% lost at 20€ / kg
  – 40 seconds of a worker
  – 40 seconds of a braiding machine 
    costing 250 k€ to invest
Molding

• Reactive RTM process:
  – Established for years as state of the art production process for high quality and performance parts
  – Use of highly reactive Epoxy resin systems allowing 2 to 5 minutes total cycle with opening and loading/removing of parts
  – Use of multiple parts mold (9 parts/mold needed to produce 1000 parts in 10 hours like braiding → mold dimension 500mm*500mm is enough)

• Cost estimation <2€ per injection
  – 150 g of epoxy resin + 10% lost
  – 40 seconds of a workers
  – 40 seconds of a injection machine + mold
  costing 200k€ + 100k€ to invest
Thermolatent, Fast Curing HP-RTM Epoxy Systems

- Reference Systems Used:
  - EPIKOTE Resin 05475 & EPIKURE Curing Agent 05500 & HELOXY Additive 112 (2min cure time)
  - EPIKOTE Resin 05475 & EPIKURE Curing Agent 05443 & HELOXY Additive 112 (5min cure time)
- Low viscosity (< 50mPa.s) during system injection
  - Ensure good mold filling
  - Ensure low in-mold pressure (no fiber distortion)
  - Ensure proper fiber wetting
  - Ensure good coupling between fiber and matrix
- Fast reaction after thermal activation
  - High conversion rate – X linking density:
    - => 2 or 5 minutes cycle time @ 120° C
  - Fast Tg development: Tg > 115 °C
  - VOC emission close to zero
  - 2015 REACH compliant
- Easy de-moulding with HELOXY 112 internal mould release agent
Part Molding + RTM Process Cycle for > 1000 parts / day

**Transfer preform into mold:**
- 5-10 sec.

**Mold closing & Resin Injection:**
- 10-20 sec.

**Curing:**
- 110 sec. (120°C)
- 90 sec. (130°C)

**Opening & Demolding:**
- 5-10 sec.

**Total Cycle Time:** 120-180 sec.

*Additional cycle-time reduction possible by replacing part of the in-mold cure by a postcure.*
Experimental Results

Crushing tests were carried out by using a drop-weight tower. A 319 kg mass fall from a height up to 3.4 m for a maximum energy of 10650 J

Conical crashbox is fitted on a fixture representative of the patented automotive solution.
Experimental Results

- Specific energy absorption at 0°, SEA: 45 - 60 kJ/kg
- Validation of assembly concept at 0° and 15° off-axis crush
- Fast curing systems at the performance level of aerospace system
- Enhanced fast curing system: 20% Higher SEA

<table>
<thead>
<tr>
<th>Matrix: Aerospace Epoxy (Reference)</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>crash inclination: 0°</td>
<td>47.6 ±4.0</td>
</tr>
<tr>
<td>crash inclination: 15°</td>
<td>44.2 ±1.3</td>
</tr>
<tr>
<td>Matrix: Momentive fast cure epoxy</td>
<td></td>
</tr>
<tr>
<td>crash inclination: 0°</td>
<td>47.4 ±4.5</td>
</tr>
<tr>
<td>crash inclination: 15°</td>
<td>40.0 ±1.3</td>
</tr>
<tr>
<td>Matrix: Enhanced Momentive epoxy</td>
<td></td>
</tr>
<tr>
<td>crash inclination: 0°</td>
<td>57.8 ±1.2</td>
</tr>
</tbody>
</table>

Axial and Off-axis Composite Crashbox

- 0° axial crush
- 15° off-axis...
Experimental Results

Tested Parameters

- **Bias angle (with half of axial fiber in each case):** lower angle leads to better SEA in axial crush, but lower SEA for 15° off-axis crush.
- **Heavy tow leads to ~20% lower SEA:** to compare to cost decrease!
- **Twist of fiber doesn’t change the SEA:** A way for better productivity

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°</td>
<td>50,5 (2,3)</td>
</tr>
<tr>
<td>30°</td>
<td>48,6 (6,1)</td>
</tr>
<tr>
<td>45°</td>
<td>47,6 (4,0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>48,3 (4,3)</td>
</tr>
<tr>
<td>15°</td>
<td>37,8 (5,1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>48,1 (4,0)</td>
</tr>
<tr>
<td>15°</td>
<td>32,2 (3,3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>48,3 (4,3)</td>
</tr>
<tr>
<td>15°</td>
<td>37,8 (5,1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>39,6 (4,4)</td>
</tr>
<tr>
<td>15°</td>
<td>29,5 (2,3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>43,3 (7,6)</td>
</tr>
<tr>
<td>15°</td>
<td>31,0 (2,9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>39,6 (4,4)</td>
</tr>
<tr>
<td>15°</td>
<td>29,5 (2,3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>44,1 (4,0)</td>
</tr>
<tr>
<td>15°</td>
<td>32,2 (3,3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bias angle</th>
<th>Mean (SD) of SEA (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50K</td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>39,6 (4,4)</td>
</tr>
<tr>
<td>15°</td>
<td>29,5 (2,3)</td>
</tr>
</tbody>
</table>
Conclusion

• An opportunity to use composite materials (CFRP) at its “right place”
  – Crash performance of composite has been proven for years in sports car design
  – A design with regular shape and no stress concentration point well fitted for composite manufacturing and performance

• A concept allowing fast industrial implementation
  – Braiding and RTM are proven processes
  – Fast Cure RTM epoxy systems for mass production readily available (EPIKOTE/EPIKURE)
  – Assembly concept is suitable for mass production

• A concept with an economically attractive solution
  – An objective cost < 5 € per saved kilogram to be optimized by material choice (glass or low cost carbon fiber) or improved performance (100kJ/kg achievable goal)
  – Equivalent steel parts : 3,6€ for 1200g (assuming a Specific Energy Absorption of 17kJ/kg for steel again 51kJ/kg for composite, and a cost for steel parts of 3€/kg)
  – Tuning of crash scenario and reparability for optimized body in white design
Thank You!

14th Annual Society of Plastics Engineers
Automotive Composites Conference & Exhibition
Novi, Michigan USA

Damien Guillon
Matthieu Kneveler

Alain Leroy
Jean Philippe Sauvaget
Roman Hillermeier

[cetim logo]
[MOMENTIVE logo]
DISCLAIMER

The information provided herein was believed to be accurate at the time of preparation or prepared from sources believed to be reliable, but it is the responsibility of the user to investigate and understand other pertinent sources of information, to comply with all laws and procedures applicable to the safe handling and use of any product of Momentive Specialty Chemicals Inc. or Momentive Performance Materials Inc. and/or their respective subsidiaries (individually, and collectively, “Momentive”) and to determine the suitability of any Momentive product for its intended use. All products supplied by Momentive are subject to Momentive’s terms and conditions of sale. MOMENTIVE MAKES NO WARRANTY, EXPRESS OR IMPLIED, CONCERNING THE PRODUCT OR THE MERCHANTABILITY OR FITNESS THEREOF FOR ANY PURPOSE OR CONCERNING THE ACCURACY OF ANY INFORMATION PROVIDED BY MOMENTIVE, except that the product shall conform to Momentive’s specifications. Nothing contained herein constitutes an offer for the sale of any product.