Center for Automotive Research
Hexion Fire Resistant Material Solutions for EV Battery Enclosures

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Today’s Seminar Goals

• To provide an overview of Hexion’s material solutions for safer and lightweight EV battery enclosures
  • Fire resistant
  • Lightweight
  • Easily integrated with proven technologies and design approaches
  • Cost effective
Who is Hexion?

Hexion is one of the world’s largest producers of thermosetting resins and a leading producer of coatings, adhesives and specialty resins.

Our specialty chemicals are critical components in most paints, coatings, binders and other adhesives that serve a diverse range of industries and provide valuable performance characteristics of durability, gloss, heat resistance, adhesion or strength of the final product.
Hexion’s Business Heritage

A history of firsts in the chemicals industry and continued growth spanning more than a century

1899
Gail Borden Jr. and Company is founded, offering first process for condensed milk

1910s
Casein, a byproduct of Borden’s milk production process, is first used as an adhesive for wood products such as plywood

1910
Leo Baekeland develops one of the first synthetic plastics, spawning the Bakelite Company

1920s
Bakelite, marketed as “The Material of a Thousand Uses,” experiences rapid growth

1940s
Commercial plywood and particleboard become common, using Borden and Bakelite products as glues

1942
Dr. S.O. Greenlee at Jones-Dabney Paint (which is eventually purchased by Celanese) synthesizes the first epoxy resins in the U.S., using Shell epichlorohydrin

1952
Shell begins the first commercial production of epoxy resins

1980’s
Celanese chemists help develop the first waterborne epoxy resins, reducing emissions from flooring, adhesives, coatings and textiles.

1993
Shell acquires Jones Dabney and Celanese Resin legacy businesses

1978
First modern wind turbine is built utilizing specialty epoxy resins from a Bakelite company

2000
Resolution Performance Products (RPP) formed from Apollo Management Acquisition of Shell’s epoxy and Versatic businesses

2005
Hexion Specialty Chemical formed by merger of Borden Chemical, Bakelite AG, RPP and Resolution Specialty Materials (formed from Apollo’s purchase of Eastman Chemical’s coatings, adhesives and polymers businesses.)

2006
Hexion launches EcoBind ultra-low emitting resin technology for plywood, particleboard and other engineered wood

2012
The Advanced Applications Development Center opens to fast track development of lightweight automotive composite materials

2015-2017
Major facility expansions including increased capacity in China, wax production in Brazil, formaldehyde in U.S. and resin production in Canada

2018
Resonance™ brand of polyols launched into foam, tire and other industries, improving fire resistance and strength

2019
EPON™ FlameX epoxy system takes center stage at JEC in Paris. The resin system has low fire, smoke and toxicity properties.
A Strong Global Presence Serving Customers Worldwide

Forty-seven (47) Production Sites Around the World in 85 Countries
A leading global specialty materials supplier

Based in Columbus, Ohio USA

2019 Global Sales of US$3.8 Billion

Nearly 50 facilities globally

Approximately 4,000 employees

More than 3,000 customers across various end-use markets

More than 800 active patent files and over 800 trademark files

Primary Technologies:

- Amino Resins
- Epoxy Resins
- Phenolic Resins
- Polyols
- Versatic™ Acids & Derivatives

Hexion at a Glance
Sustainability Mindset

- UL 880 Certified (Standard for Sustainability for Manufacturing Organizations)
- Founding member of American Chemistry Council Responsible Care® Program
- EPA and REACH compliance for all products
- Product Risk Prioritization Handling Strategy
Hexion thermoset solutions for EV Applications

- Suspension Components
- Structural Components
- Electrical Motors
- Exterior Components
- Battery Thermal Management System
- Battery Enclosures
- Underbody
- Structural Components
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- Exterior Components
- Battery Enclosures
- Underbody
- Suspension Components
- Structural Components
- Electrical Motors
- Exterior Components
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EV Battery Enclosures
Requirements and Current Trends
Innovative fire retardant material solutions are needed
Battery enclosures ensure passenger safety

External: “Bonfire”
Internal: “Thermal Runaway”

GB 38031-2020
GB/T 31467.3 & ECE R100
Battery Enclosure Typical Construction and Main Functions

- Semi-structural part
- Seal and protect battery from water, dirt/dust, fire, ...
- Protect the passenger compartment in case of thermal run-away in battery cell / pack

Cover

3D box structure can be provided by either the Tray or the Cover
Requirements and design vary by OEM and region

Tray

Battery Pack Configuration

- Structural part, optionally part of BIW.
- Carries the (heavy) battery
- Protects the battery against intrusion risk during crash or other adverse situations.
- Provide fire protection towards open fire under the vehicle
## Battery Enclosure Fire Safety Requirements 2021 and Beyond

Regulatory Trends Becoming More Demanding (2019-2020)

<table>
<thead>
<tr>
<th>FST Required</th>
<th>FST Not Required</th>
</tr>
</thead>
</table>
| • BEV/PHEV mandatory  
• Clear push to high-end offering (drive range and battery technology)  
• Toughest FST requirements on complete enclosure starting January 2021 | • EU OEMs, have a strong stake in China  
• CO2 emission targets getting more stringent than expected spur shift to NEV  
• Regional FST requirements are focused on battery cover; tend to lag CN by 1-2 years |

|  |  | Ford/GM have important stake in China need to meet FST requirements  
• Tesla expanding production in CN  
• EV implementation less fast or extensive  
• Regional FST requirements are limited  
• OEMs starting shift toward FST evaluation |
# GB/T 31467.3 & GB 38031 Test Overview

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GB/T 31467.3 External Fire</strong></td>
<td></td>
</tr>
<tr>
<td>Battery unit</td>
<td>70 seconds direct</td>
</tr>
<tr>
<td>Battery cover</td>
<td>60 seconds direct or indirect</td>
</tr>
<tr>
<td>Petrol level to test object</td>
<td>50 cm</td>
</tr>
<tr>
<td>Criteria</td>
<td>No explosion or fire Self-extinguishing</td>
</tr>
<tr>
<td><strong>GB 38031 Internal Fire/Smoke</strong></td>
<td></td>
</tr>
<tr>
<td>Fire spread rate</td>
<td>Time from alarm signal to fire spread beyond enclosure should be &gt; 5 minutes</td>
</tr>
<tr>
<td>Smoke diffusion rate</td>
<td>Time from alarm signal to smoke spread into passenger compartment should be &gt; 5 minutes</td>
</tr>
</tbody>
</table>

**GB/T 31467.3 & GB 38031 Test Diagram**

**Fire Resistance**: SK 30; Component: 30-33% Al₂O₃; Density: 1900-2000 kg/m³; Effective hole area: 44.18%; Aperture Ratio: 20-22% by volume.
Key Requirements for EV Battery Enclosures

- **Fire resistant**
- Package protection
  - Knee loads
  - Impact, 15 g impulse
  - Survive 30° offset barrier
  - Puncture-proof
  - Impermeable to 1m water, dust
- **Corrosion resistant**
- **Lightweight**
- Easy to assemble and service
- Non-conductive
- Provide thermal regulation
- Electromagnetic Interference / Electromagnetic Compatibility

Source: Nissan Leaf
Battery Cover Examples

- Semi-structural part
- Seals and protects battery from fire, water, etc.
- Provides fire protection towards the passenger in case of run-away event (dependent on regional regulation)

Importance of Fire protection is evident

• Semi-structural part
• Seals and protects battery from fire, water, etc.
• Provides fire protection towards the passenger in case of run-away event (dependent on regional regulation)
Battery Tray Examples

- Structural part, optionally part of BIW.
- Carries the (heavy) weight battery
- Protects the battery against intrusion risk during crash or other adverse situations.
- Also requires FST protection

Example of 3D Cast aluminum tray and cooling system

Daimler’s dedicated architecture for EV
Fire Resistant Material System for EV Battery Enclosures
Two primary material and process formats for thermoset composite EV battery enclosure components …

1. **SMC**
   - Sheet Molding Compound
   - Chopped fiber format
   - Excellent moldability for complex shapes
   - Lower mechanical properties
   - Can incorporate continuous fiber reinforcements

2. **RTM / LCM**
   - Resin Transfer Molding / Liquid Compression Molding
   - Continuous fiber format
   - Excellent mechanical properties
   - RTM capable of molding complex geometries - preforming required
   - LCM compatible for simple geometries - no preforming required
SMC: A Versatile and Cost-Efficient Process Format

- Offers significant design freedom
- Very good mechanical properties
- Flexible resin chemistries and fiber types
- Low scrap rate compared to other formats
- Established global supply chains
- Large and scalable industrial capacity
Hexion’s New EPONOL™ TRAC 06921 SMC Resin System

- No FR additives: inherently resistant
- No styrene, ultra-low formaldehyde
- Globally available
- Processes on standard SMC equipment
- Pass automotive FST test requirements
- Excellent mechanical properties
- 2 – 3 minute total cure time

All materials are REACH compliant; composite meets EU directives for recyclability.
Hexion Eponol™ Resin TRAC 06921 System: A Unique Value Proposition for EV Battery Enclosures

- Lower density vs. aluminum
- Lower replacement tooling expense (vs. cast aluminum)
- Greater design flexibility
  - Package-constrained HEV designs
  - Integrated cooling concepts
  - One-piece designs prevent dust/water intrusion
- Inherent electrical and thermal insulation properties
- Corrosion resistant

Eponol™ Resin TRAC 06921 Black Pigmented System
Battery Box “Bonfire Test” Using EPONOL™ TRAC 06921 SMC
GB/T 31467.3 Test Protocol

https://youtu.be/3eQcW GnJk_g
Excellent Property Retention Even After a Fire Event …

EPONOL 06921 SMC retains >65% of its strength and impact resistance even after full fire exposure.

Tested according to DIN EN ISO 6603-2
Thermal Runaway using EPONOL™ TRAC 06921 SMC

GB 38031 Test Protocol

https://www.youtube.com/watch?v=t7rMzMLsVN8
Protocol B: combined thermal / mechanical load

Phenolic SMC
3.08 mm
1.78 g/cm³
# cycles: 6

50% ATH SMC
2.94 mm
1.89 g/cm³
# cycles: 2

60% ATH SMC
3.24 mm
1.94 g/cm³
# cycles: 3

6016-T6
1.5 mm
2.71 g/cm³
# cycles: 1
# Best-in-class Mechanical Performance

<table>
<thead>
<tr>
<th></th>
<th>PF SMC</th>
<th>PF UD [0]</th>
<th>PF UD [90]</th>
<th>Comm. #1 (50% ATH)</th>
<th>Comm. #2 (60% ATH)</th>
<th>AA365</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Phenolic</td>
<td>Phenolic</td>
<td>Phenolic</td>
<td>Polyester</td>
<td>PE / VE blend</td>
<td>Aluminum</td>
</tr>
<tr>
<td><strong>Glass content (%wt)</strong></td>
<td>60</td>
<td>70</td>
<td>70</td>
<td>20</td>
<td>20</td>
<td>--</td>
</tr>
<tr>
<td><strong>Density (g/cm³)</strong></td>
<td>1.78</td>
<td>1.90</td>
<td>1.90</td>
<td>1.89</td>
<td>1.95</td>
<td>2.71</td>
</tr>
<tr>
<td><strong>Tensile Strength (MPa)</strong></td>
<td>262</td>
<td>474</td>
<td>34</td>
<td>48</td>
<td>55</td>
<td>185</td>
</tr>
<tr>
<td><strong>Tensile Modulus (GPa)</strong></td>
<td>17</td>
<td>47</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>75</td>
</tr>
<tr>
<td><strong>Flexure Strength (MPa)</strong></td>
<td>459</td>
<td>820</td>
<td>107</td>
<td>116</td>
<td>129</td>
<td>359</td>
</tr>
<tr>
<td><strong>Flexure Modulus (GPa)</strong></td>
<td>21</td>
<td>33.8</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td><strong>Notched Charpy (kJ/m²)</strong></td>
<td>154</td>
<td>48</td>
<td>101</td>
<td>142</td>
<td></td>
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</tr>
</tbody>
</table>

Expect ~30% weight saving over traditional materials.
Two primary material and process formats for thermoset composite EV battery enclosure components ...

1. **SMC**
   - Sheet Molding Compound
   - Chopped fiber format
   - Excellent moldability for complex shapes
   - Lower mechanical properties
   - Can incorporate continuous fiber reinforcements

2. **RTM / LCM**
   - Resin Transfer Molding / Liquid Compression Molding
   - Continuous fiber format
   - Excellent mechanical properties
   - RTM capable of molding complex geometries - preforming required
   - LCM compatible for simple geometries - no preforming required
One manufacturing cell - two manufacturing processes ...
One manufacturing cell – two manufacturing processes …

HP-RTM

Resin Flow/Fiber Impregnation (during Injection)

LCM

Resin Flow/Fiber Impregnation (during Mold Closure)

Cycle time < 60s for Hexion's EPIKOTE™ Resin/EPIKURE™ Curing Agent TRAC 06170

Cycle time (s)

Molding temp (°C)
EPIKOTE/EPIKURE TRAC 06170 ATH or liquid FR additive

RTM/LCM Epoxy for EV Battery Enclosure

- ATH-filled system compatible with LCM
- Liquid FR Filled system for LCM and RTM process
- Tailored additive loading to match specific FR requirements of application
- 2 – 3 minute cure time
- Excellent mechanical performance – flexural, tensile, compression, fracture toughness
- Minimal impact on $T_g$ performance
Application Areas

Underbody:
- Skid Plates
- Aerodynamic Closures
- Battery box protection (EV)
  - Fabrics: Glass Fiber, Carbon Fiber, Hybrid
  - Resin: Epoxy

EV Battery Enclosure:
- Cover (primarily SMC based)
- Tray (RTM/LCM)
- Materials:
  - Fabrics: Glass Fiber, Carbon Fiber, Hybrid
  - Resin: Epoxy, Phenolic
# Underbody Application

<table>
<thead>
<tr>
<th>OEM/Molder</th>
<th>Daimler / Multimatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>AMG GT-R (EU)</td>
</tr>
<tr>
<td>Application</td>
<td>Midsection/driveshaft underbody aerodynamic/torsional reinforcement panel</td>
</tr>
<tr>
<td>Materials</td>
<td>High $T_g$ EP resin, Tailored Fiber Placement CF laminate - 7mm thickness</td>
</tr>
<tr>
<td>Manufacturing Process</td>
<td>Liquid Compression Molding</td>
</tr>
</tbody>
</table>

- Multimatic currently produces an LCM CFRP underbody torsional reinforcement panel approximately 1.2m x .5m x 7mm thickness – being supplied to Daimler for the AMG GT platform.
- Production rates fluctuate between 100-400 parts per month.
- The CF fabric preform comes in the form of a tailored fabric placement ‘blank’ made from continuous roving. The part utilizes a high $T_g$ epoxy resin and is LCM molded.
Design and Integration of Composites
Lightweight Fire Resistant Battery Box Concept

Original Metal Concept (~20 pc Assembly)

Multi-Material Composite Concept (simplified)

- Phenolic SMC Cover
- Aluminum/Composite Extrusion Frame Structure
- Continuous Fiber LCM/RTM Structural Tray
Composite Materials for EV Battery Box Enclosures

RTM/LCM
- Continuous fiber format
- Excellent mechanical properties
- LCM compatible for simple geometries/no preforming required

Most suitable for Battery Trays

SMC
- Chopped fiber format
- Lower mechanical properties
- Excellent moldability/complex shapes
- Can incorporate continuous fiber reinforcements

Most suitable for Battery Covers
Key takeaways

Phenolic resin technology:
Withstands even the toughest automotive FST requirements

Best-in-class material performance:
FR Epoxy and phenolic systems for optimized design and performance

Hexion Expertise:
Globally positioned; full-scale technical partner