HEXION™
Responsible Chemistry

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

February 18, 2021

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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

Borden Chemical

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

1950s
Primarily a dairy company, Borden expands into industrial products, chemicals and petroleum.

1981
First Space Shuttle launches using Borden phenolic resin in its engine nozzle to resist heat and fire

2001
Borden divests its dairy and food divisions and focuses on its chemicals business — renames itself Borden Chemical Inc.

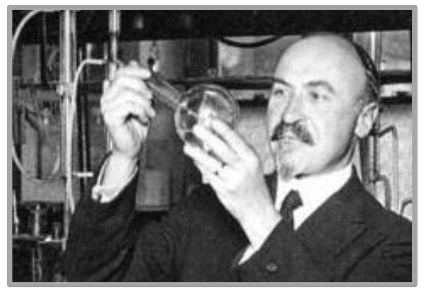
Bakelite AG

1910
Leo Baekeland develops one of the first synthetic plastic, 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

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



Shell

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

2000
Resolution Performance Products (RPP) formed from Apollo Management Acquisition of Shell's epoxy and Versatics 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

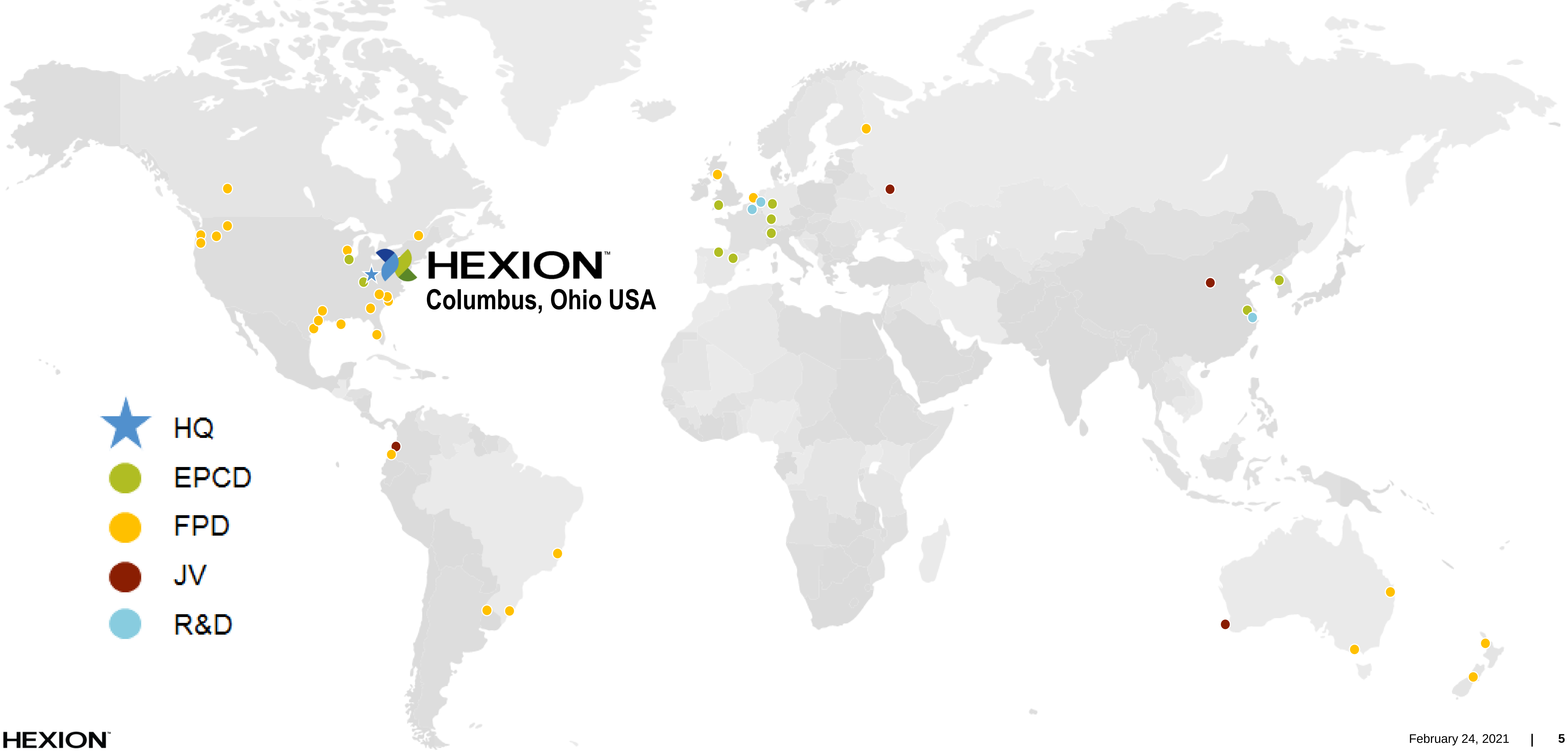
2015-2017
Major facility expansions including increased capacity in China, wax production in Brazil, formaldehyde in U.S. and resin production in Canada

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

Base Epoxy Resins & Coatings

Forest Product Resins

Specialty Epoxy Resins

Phenolic Specialty Resins

Versatic™ Acids & Derivatives

HEXION™

Hexion at a Glance

- 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

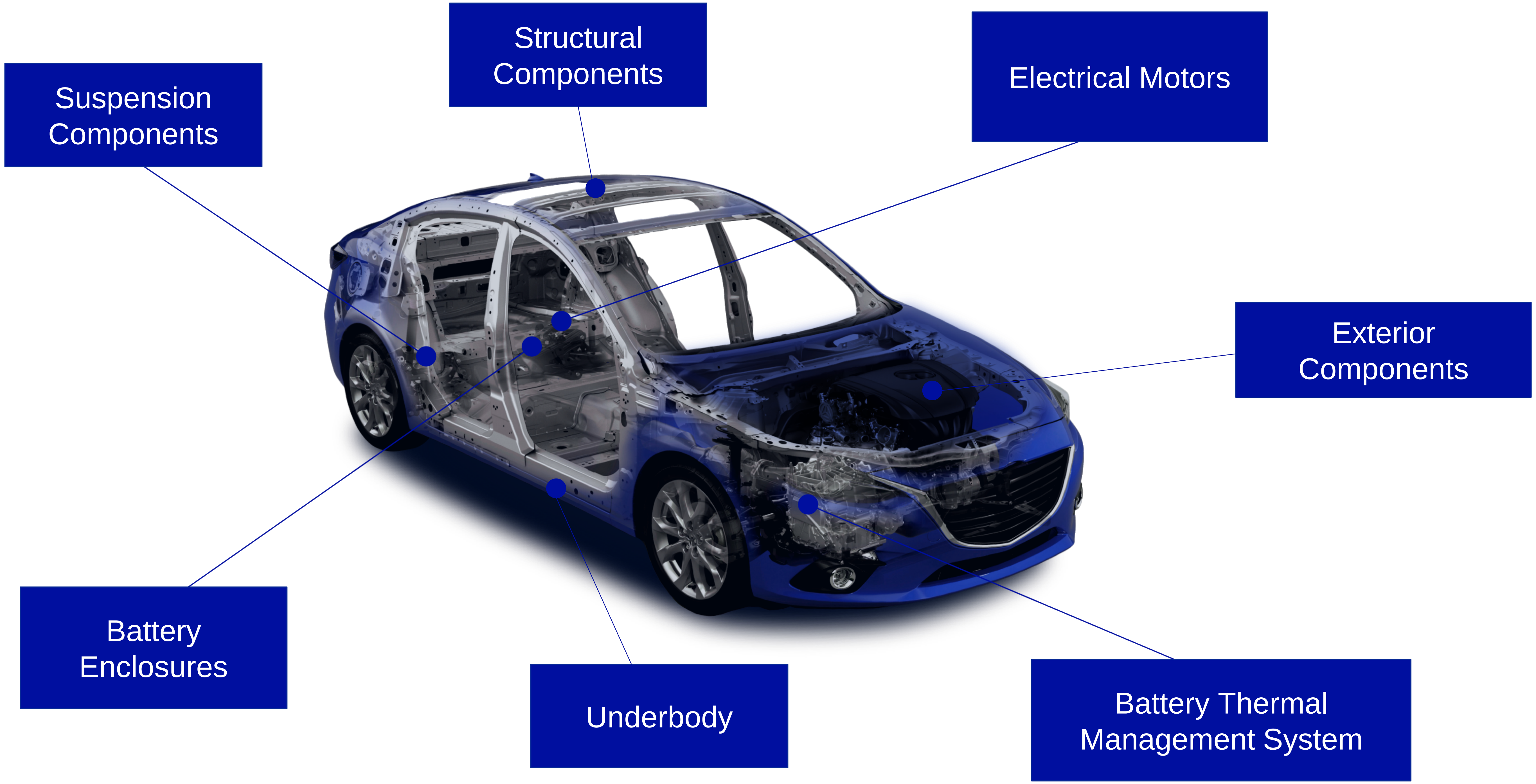
Primary Technologies:

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

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
- https://www.hexion.com/en-US/company/responsibility/sustainability/

Hexion thermoset solutions for EV Applications



EV Battery Enclosures Requirements and Current Trends

Innovative fire retardant material solutions are needed

Battery enclosures ensure passenger safety

Internal: “Thermal Runaway”

GB 38031-2020

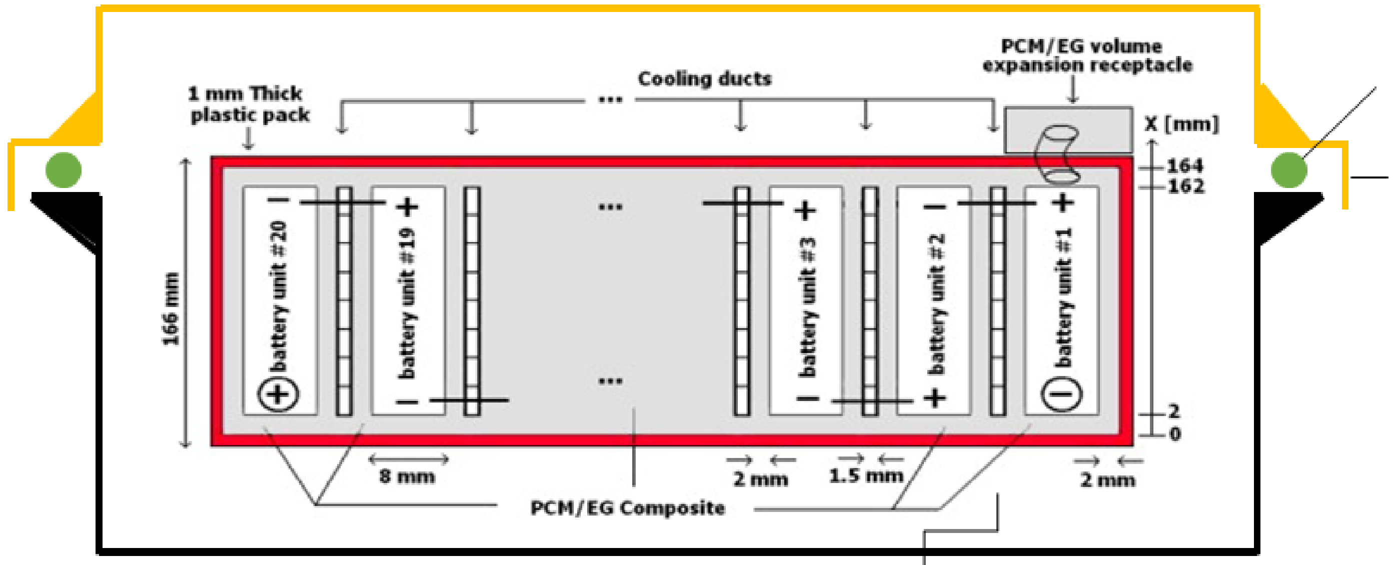
External: “Bonfire”

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



Seal

Sealing Flange

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

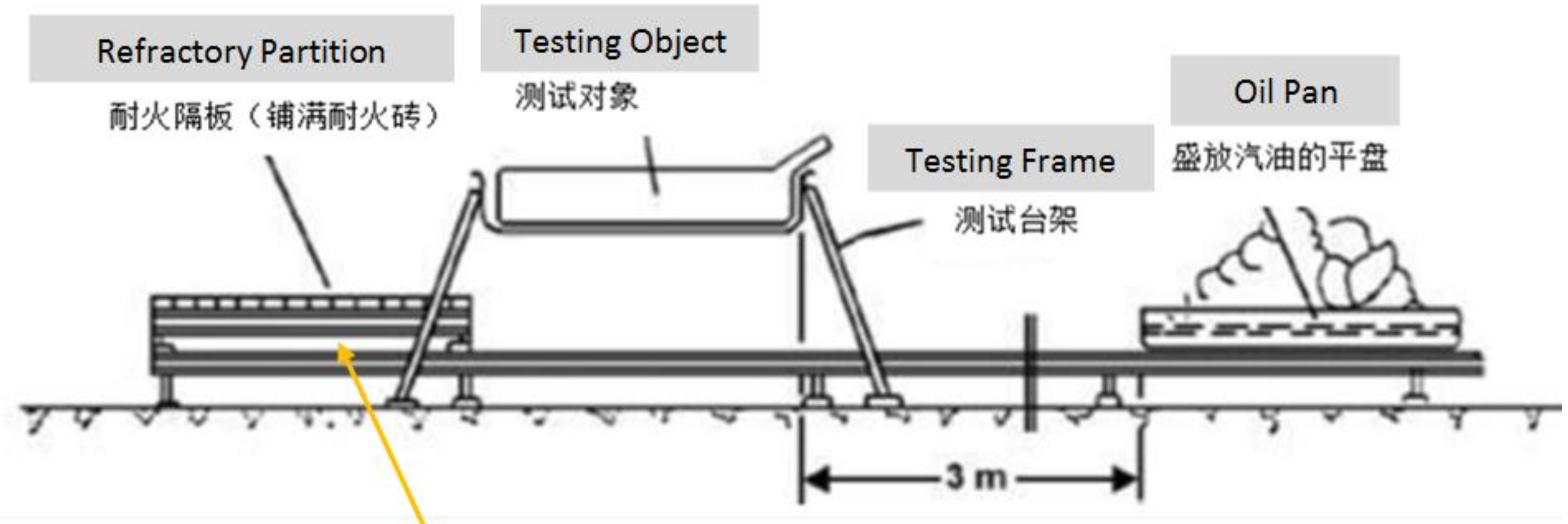
Battery Enclosure Fire Safety Requirements 2021 and Beyond

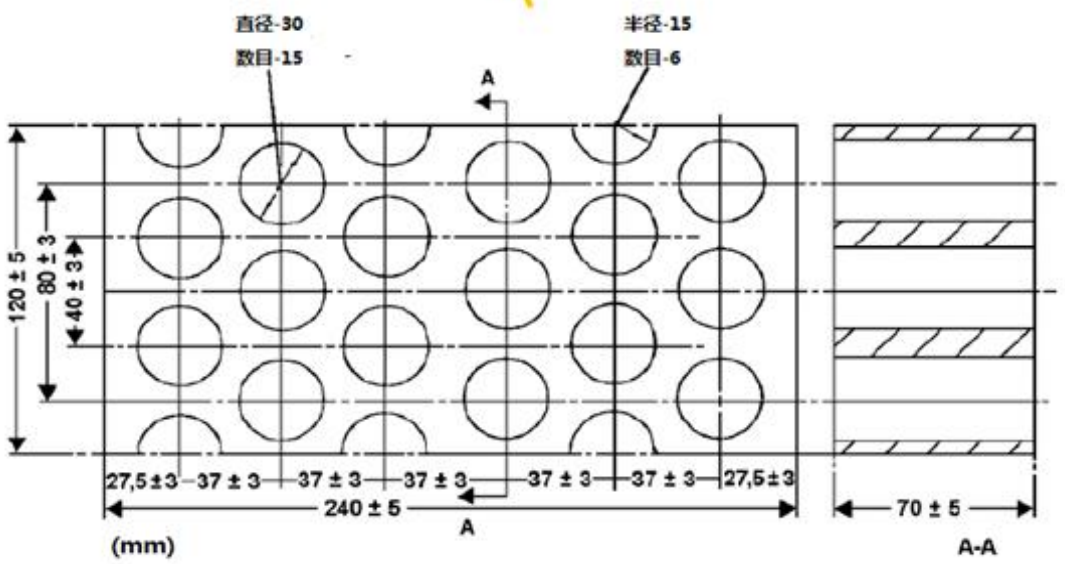
Regulatory Trends Becoming More Demanding (2019-2020)

	China	EU	US
FST Required	• 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
FST Not Required			

GB/T 31467.3 & GB 38031 Test Overview

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





Fire Resistance：SK 30；
Component：30-33% Al_2O_3；
Density：1900-2000kg/m^3；
Effective hole area：44.18%；
Aperture Ratio：20-22% by volume；

Key Requirements for EV Battery Enclosures

Source: Nissan Leaf

- **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

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)

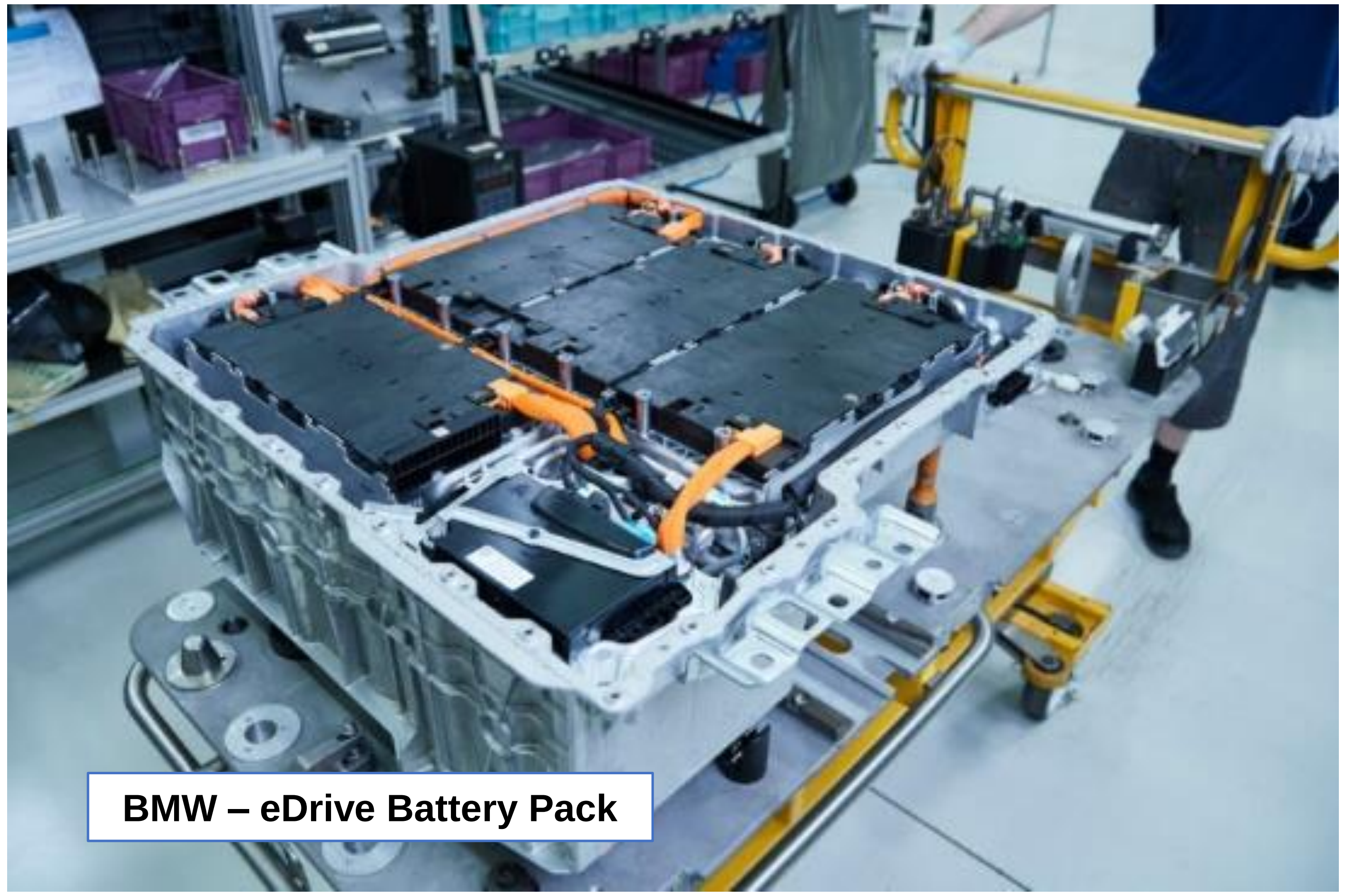
Example of a 3D cover / deep draw

Passenger sits – literally – on top of the battery cover
Importance of Fire protection is evident

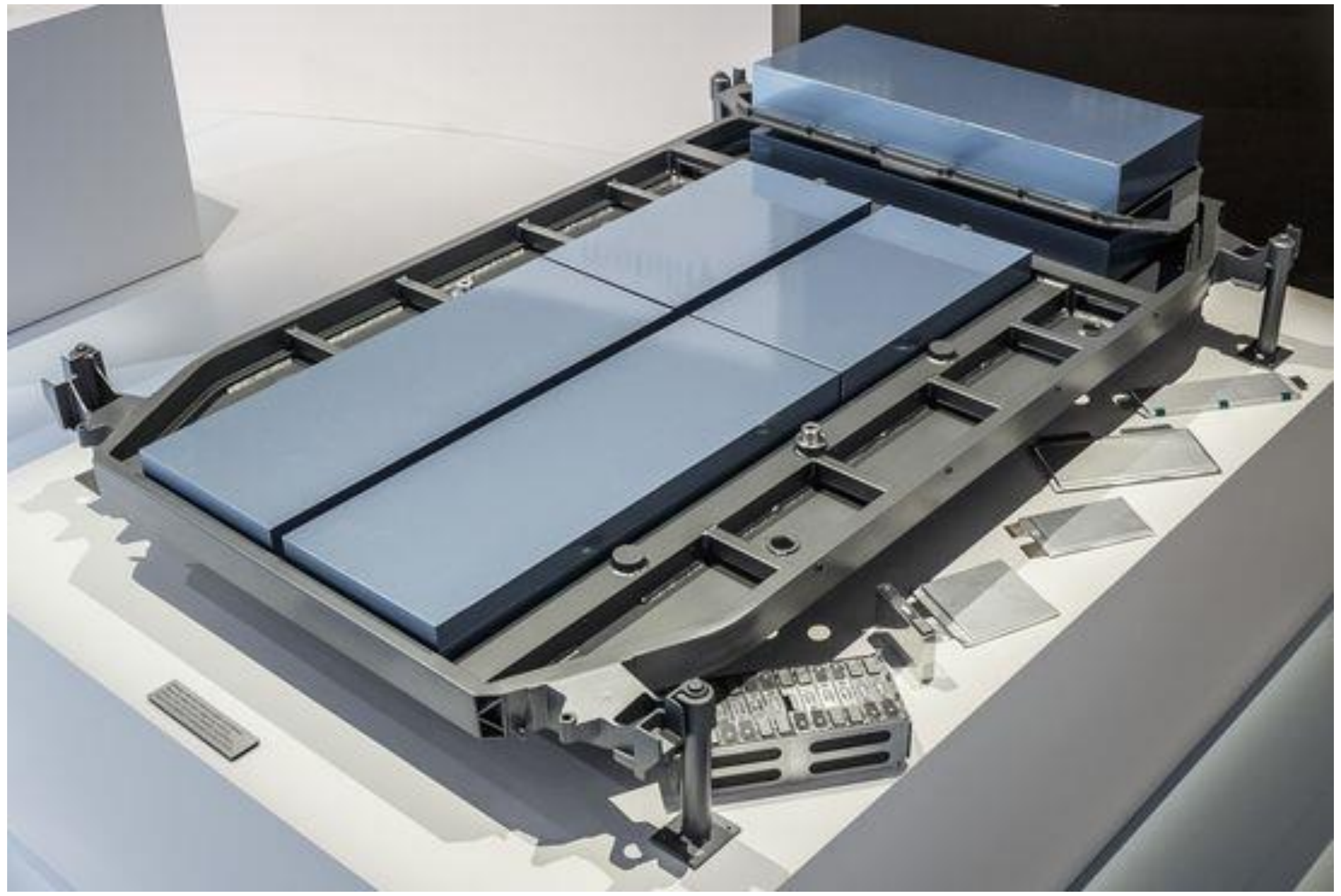
Example of a 2D cover / shallow draw

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

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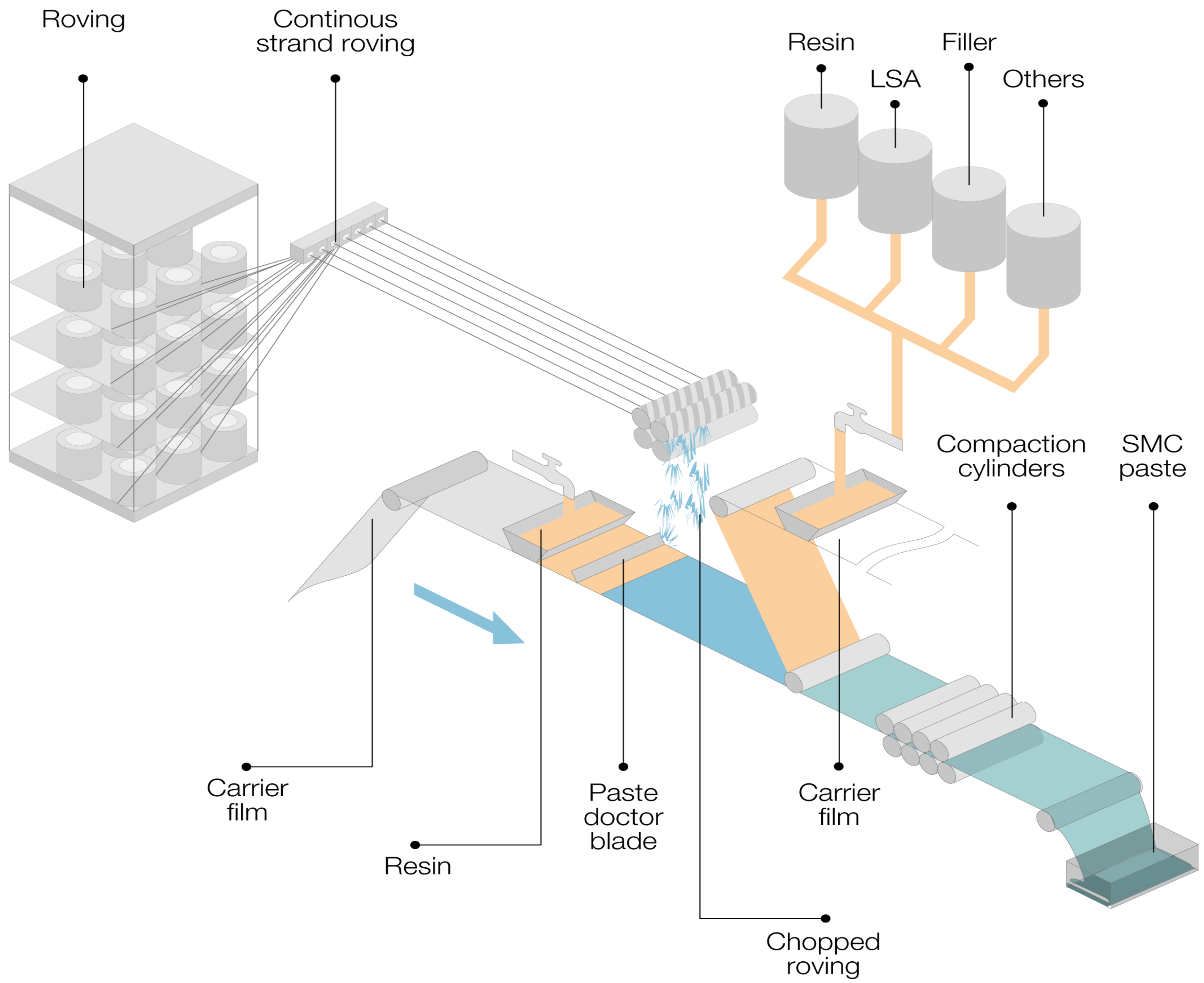
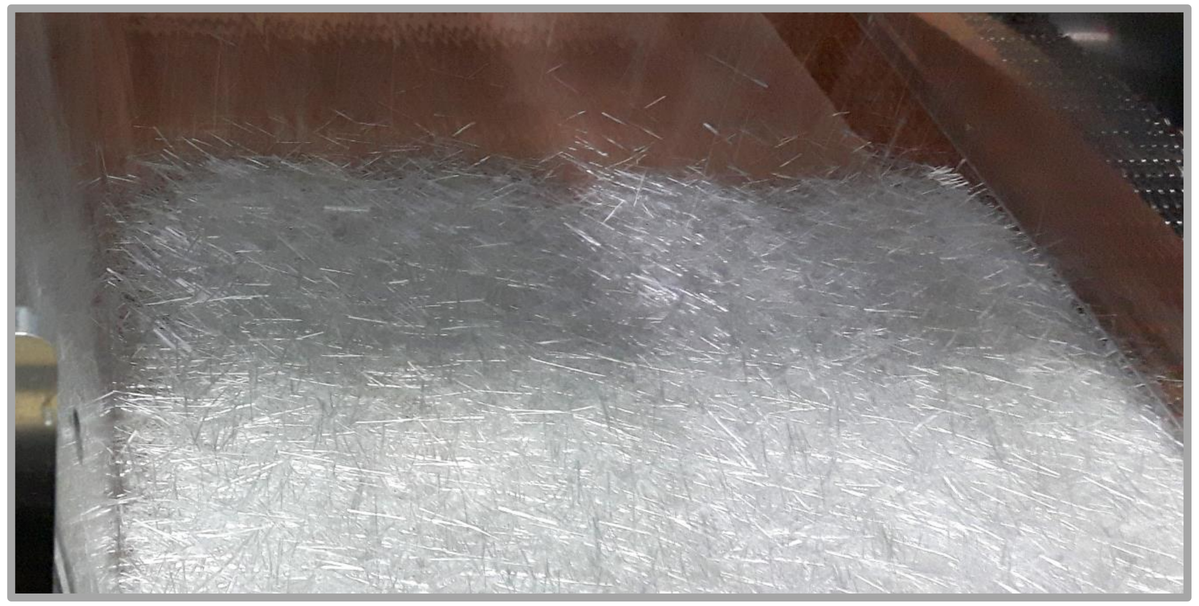
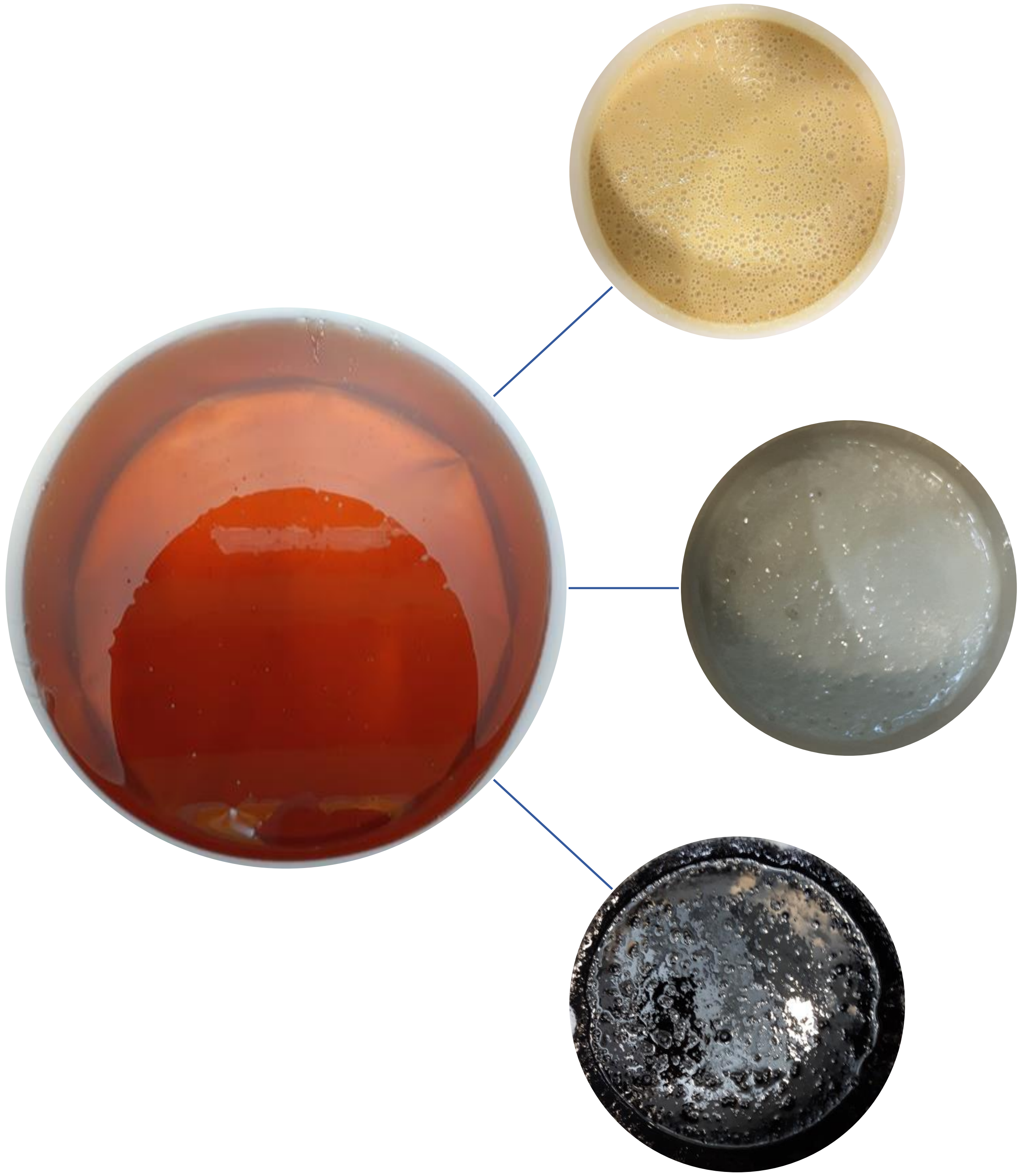
SMC: A Versatile and Cost-Efficient Process Format



- 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/3eQcWGnJk_g

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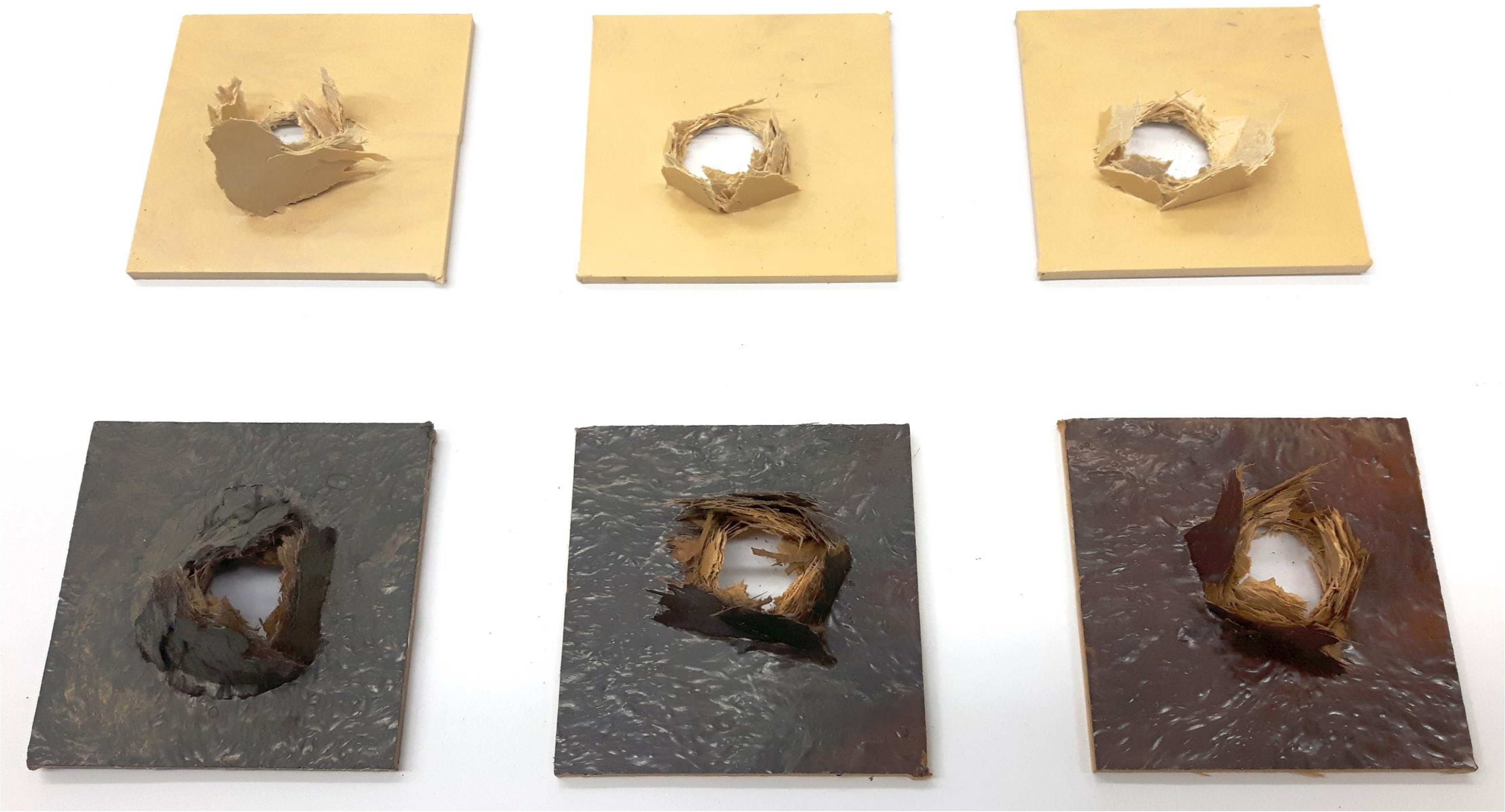
Excellent Property Retention Even After a Fire Event …

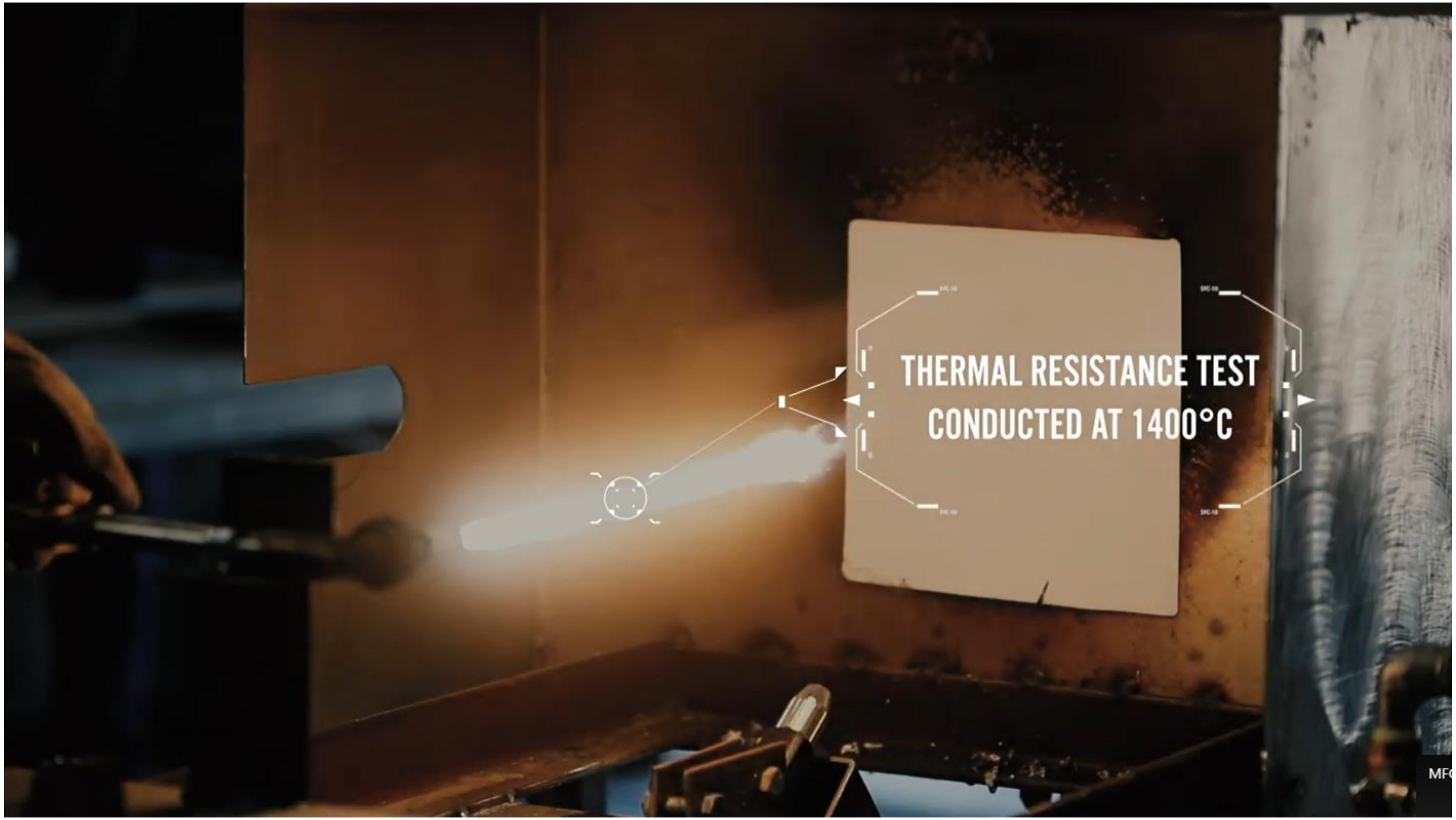


Tested according to DIN EN ISO 6603-2

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

Thermal Runaway using EPONOL™ TRAC 06921 SMC

GB 38031 Test Protocol



https://www.youtube.com/watch?v=t7rM2MLsVN8

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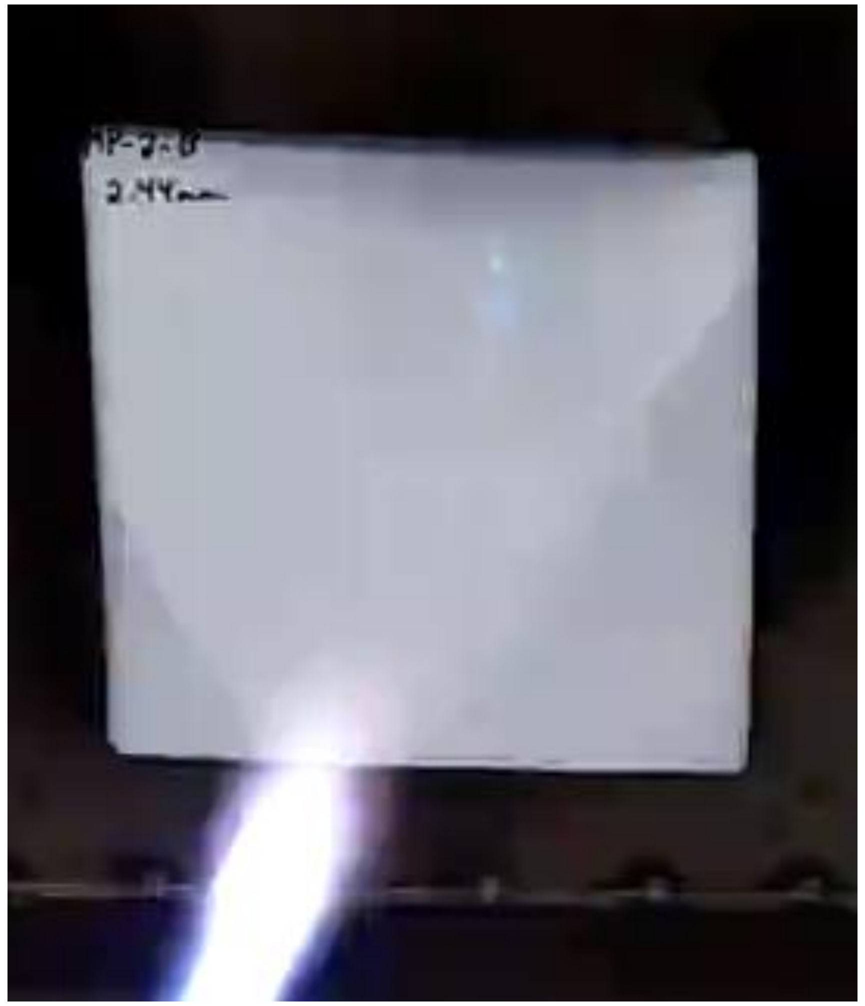
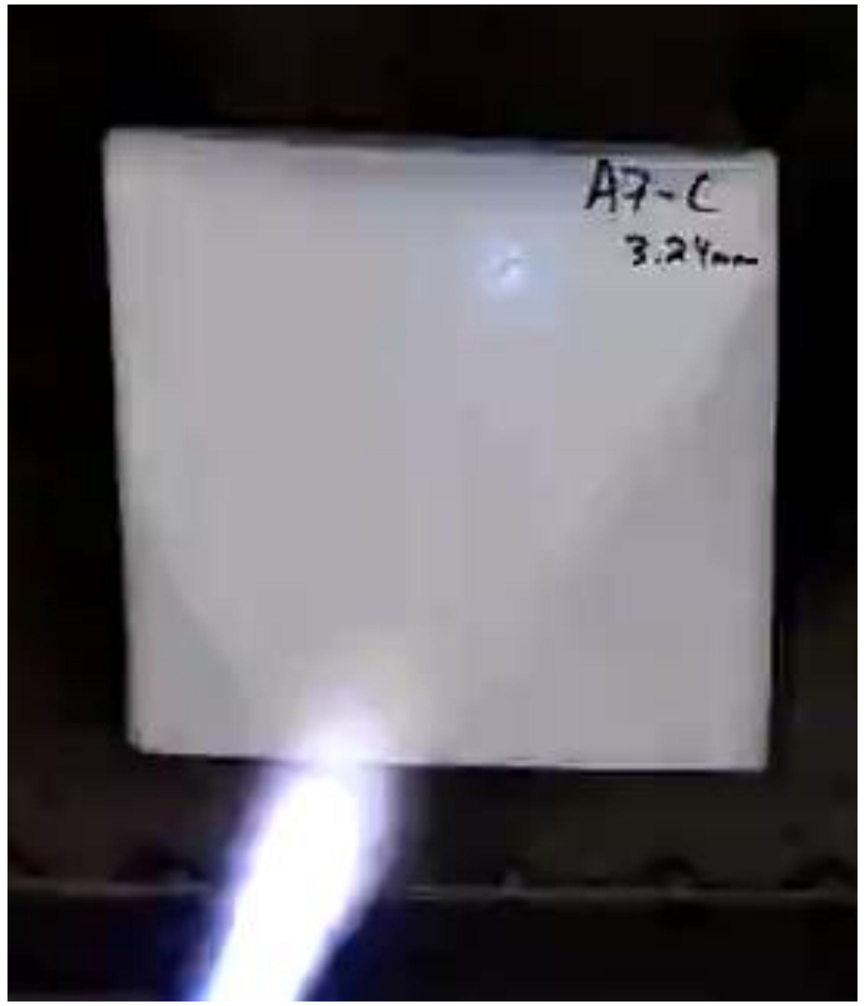
Protocol B: combined thermal / mechanical load

Phenolic SMC
3.08 mm
1.78 g/cm^3
cycles: 6



50% ATH SMC
2.94 mm
1.89 g/cm^3
cycles: 2



60% ATH SMC
3.24 mm
1.94 g/cm^3
cycles: 3

6016-T6
1.5 mm
2.71 g/cm^3
cycles: 1

Best-in-class Mechanical Performance

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

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

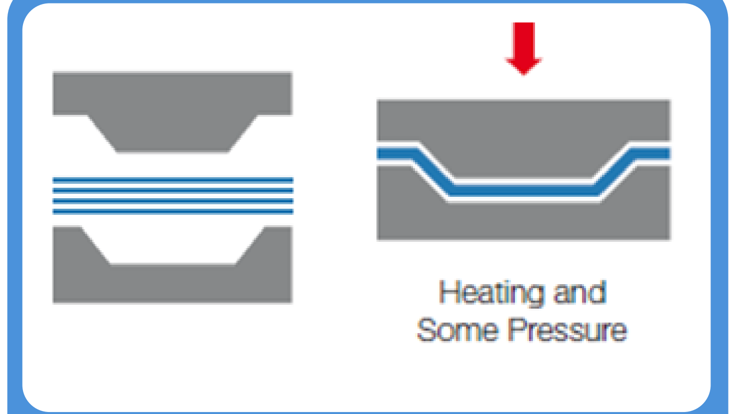
- Continuous fiber format
- Excellent mechanical properties
- RTM capable of molding complex geometries - preforming required
- LCM compatible for simple geometries - no preforming required

One manufacturing cell - two manufacturing processes …

HP-RTM

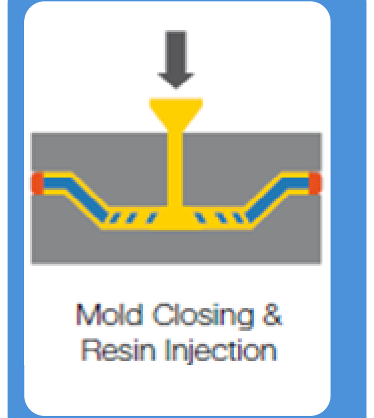
Two-stage Process:
Preforming and Molding

Binder Stabilized Fabrics



Preform tool

Press



Injection

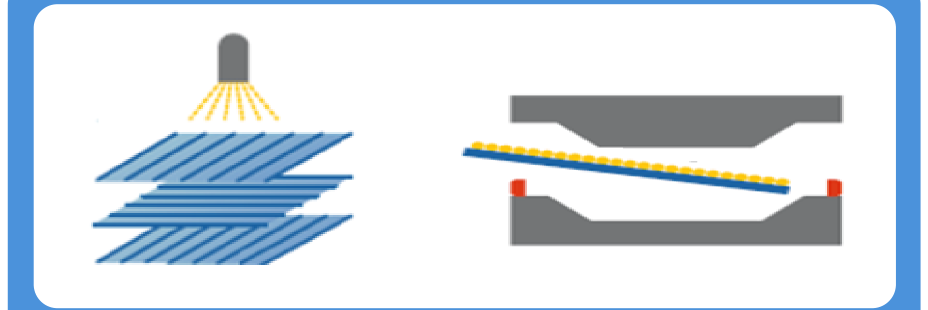
Curing

Opening & de-moulding

LCM

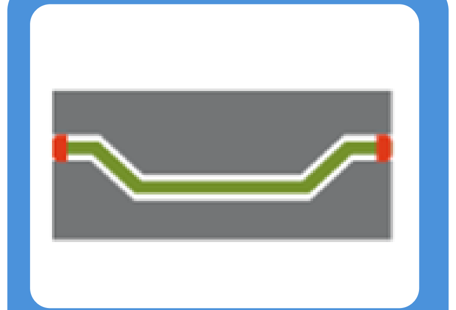
One-stage Process:
Molding

Mould closing & resin injection

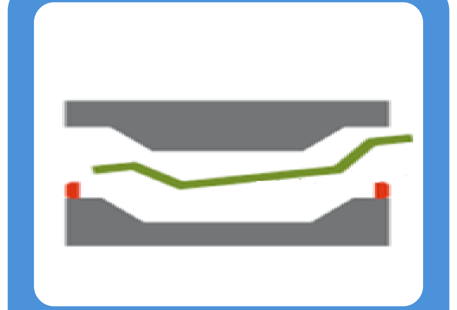


Liquid resin application

Transfer wet lay-up into mould



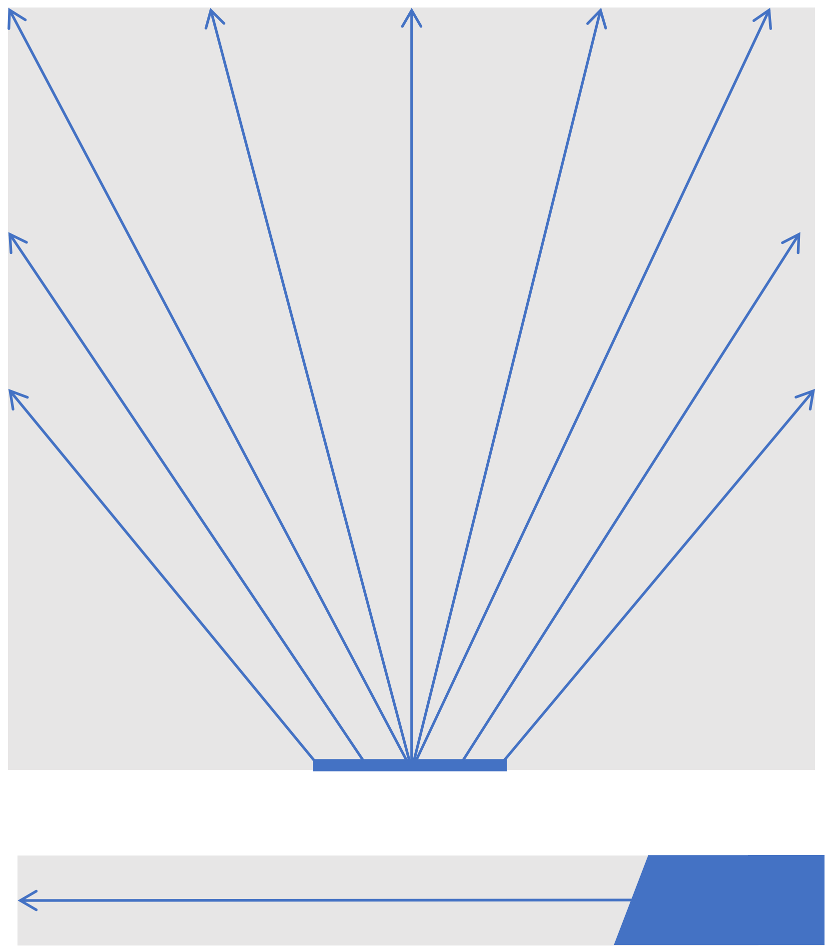
Curing



Opening & de-moulding

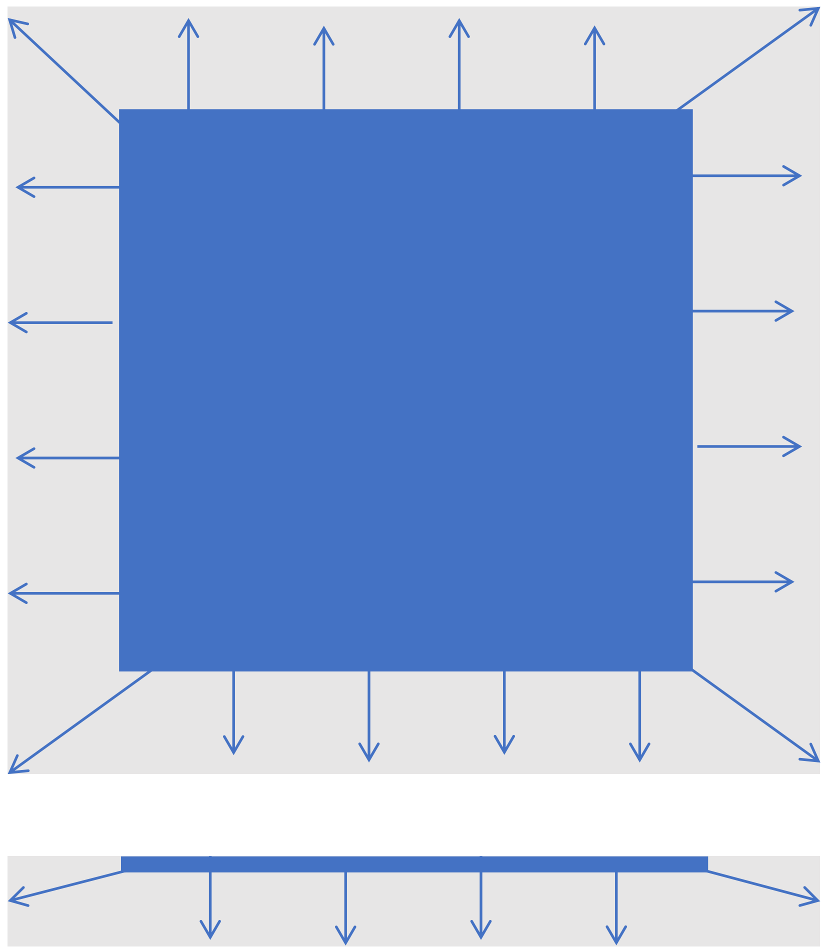
One manufacturing cell – two manufacturing processes …

HP-RTM

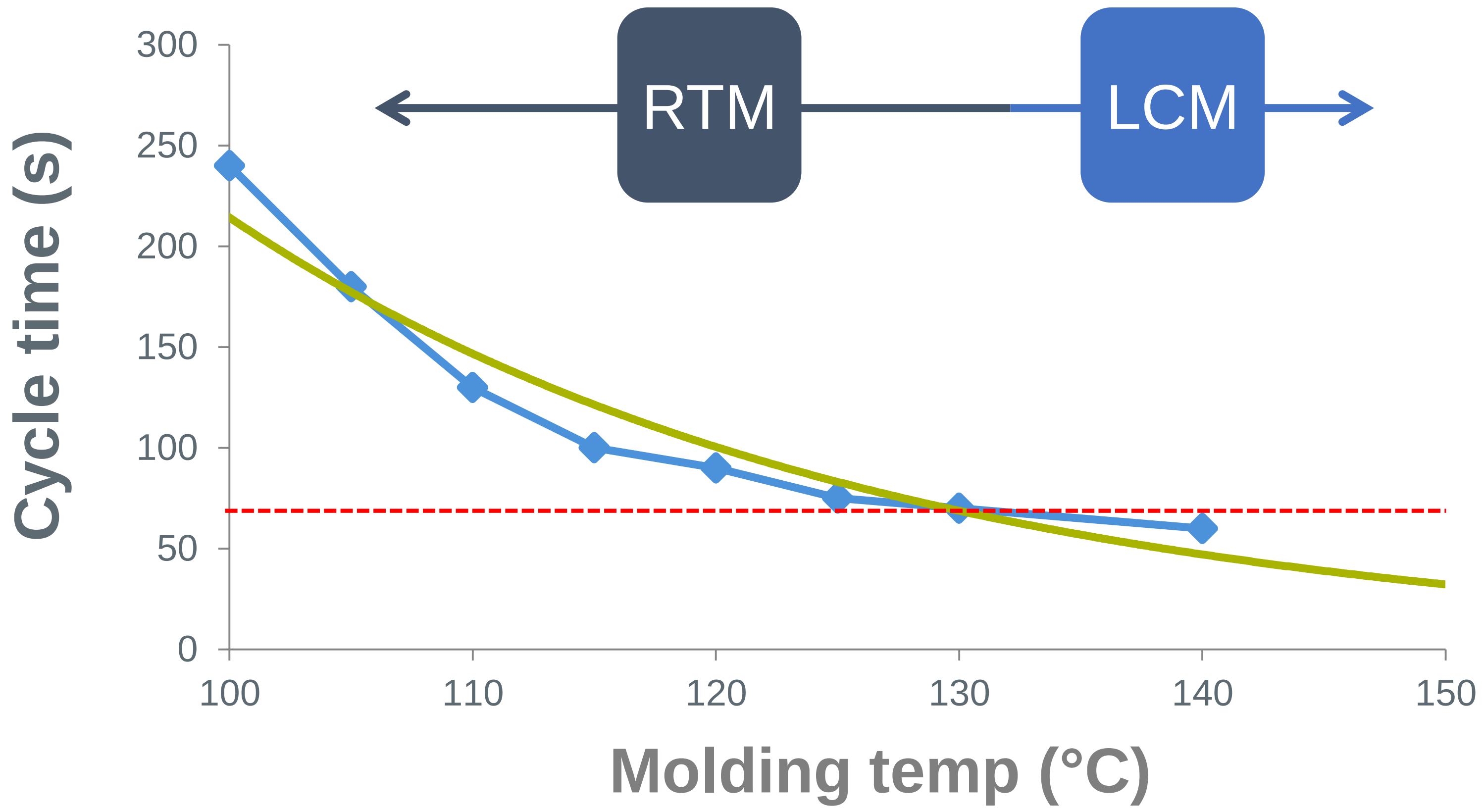


Resin Flow/Fiber Impregnation
(during Injection)

LCM



Resin Flow/Fiber Impregnation
(during Mold Closure)

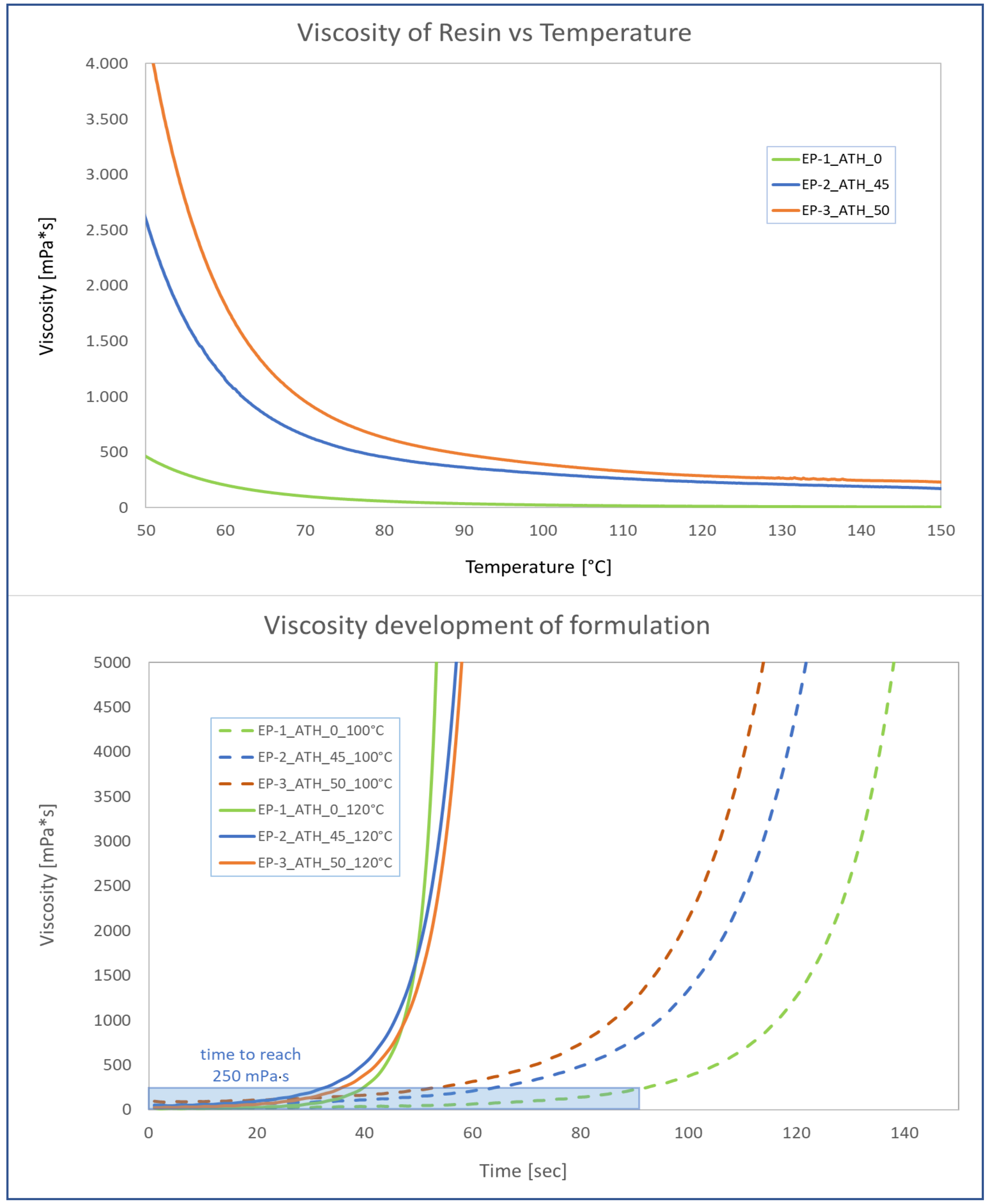


Cycle time < 60s for Hexion's EPIKOTE™
Resin/EPIKURE™ Curing Agent TRAC 06170

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

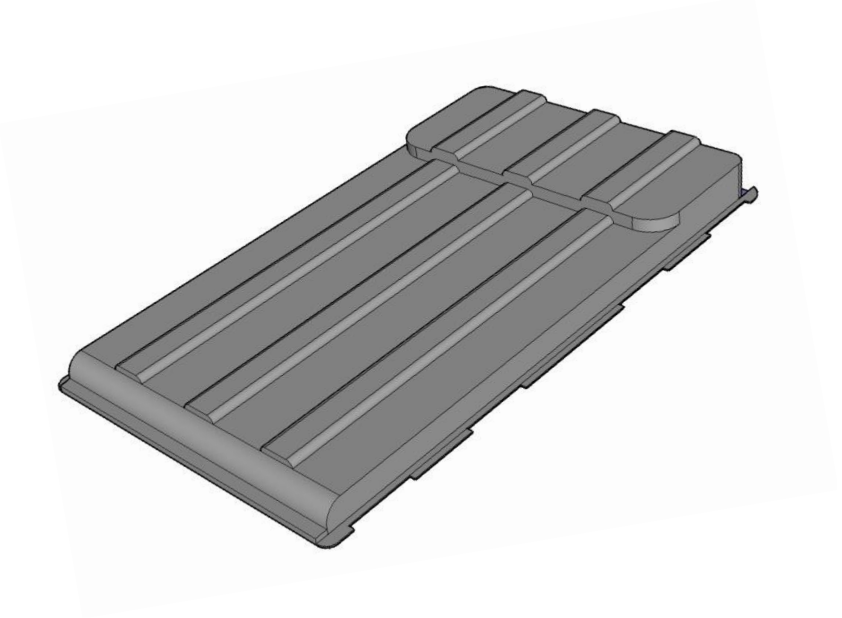
Underbody:

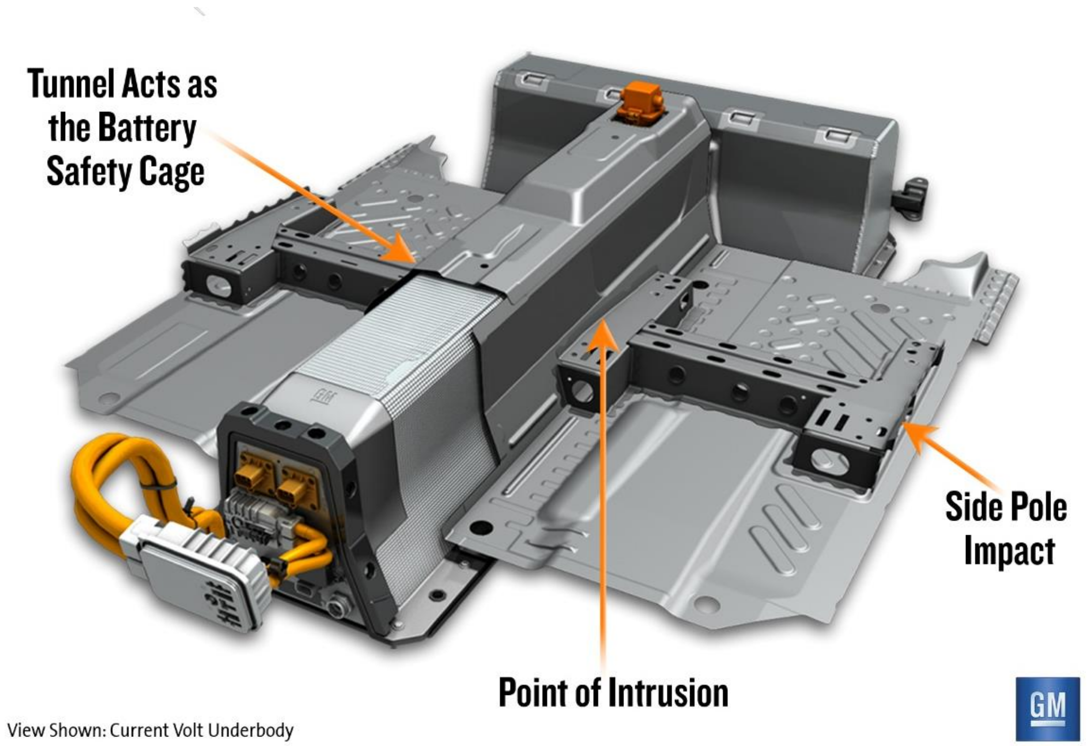
- Skid Plates
- Aerodynamic Closures
- Battery box protection (EV)
  - **Fabrics:** Glass Fiber, Carbon Fiber, Hybrid
  - **Resin:** Epoxy

Source: Nissan

EV Battery Enclosure:

- Cover (primarily SMC based)
- Tray (RTM/LCM)
- Materials:
  - **Fabrics:** Glass Fiber, Carbon Fiber, Hybrid
  - **Resin:** Epoxy, Phenolic





Volt Composite Battery Cover: Continental Structural Plastics

Underbody Application

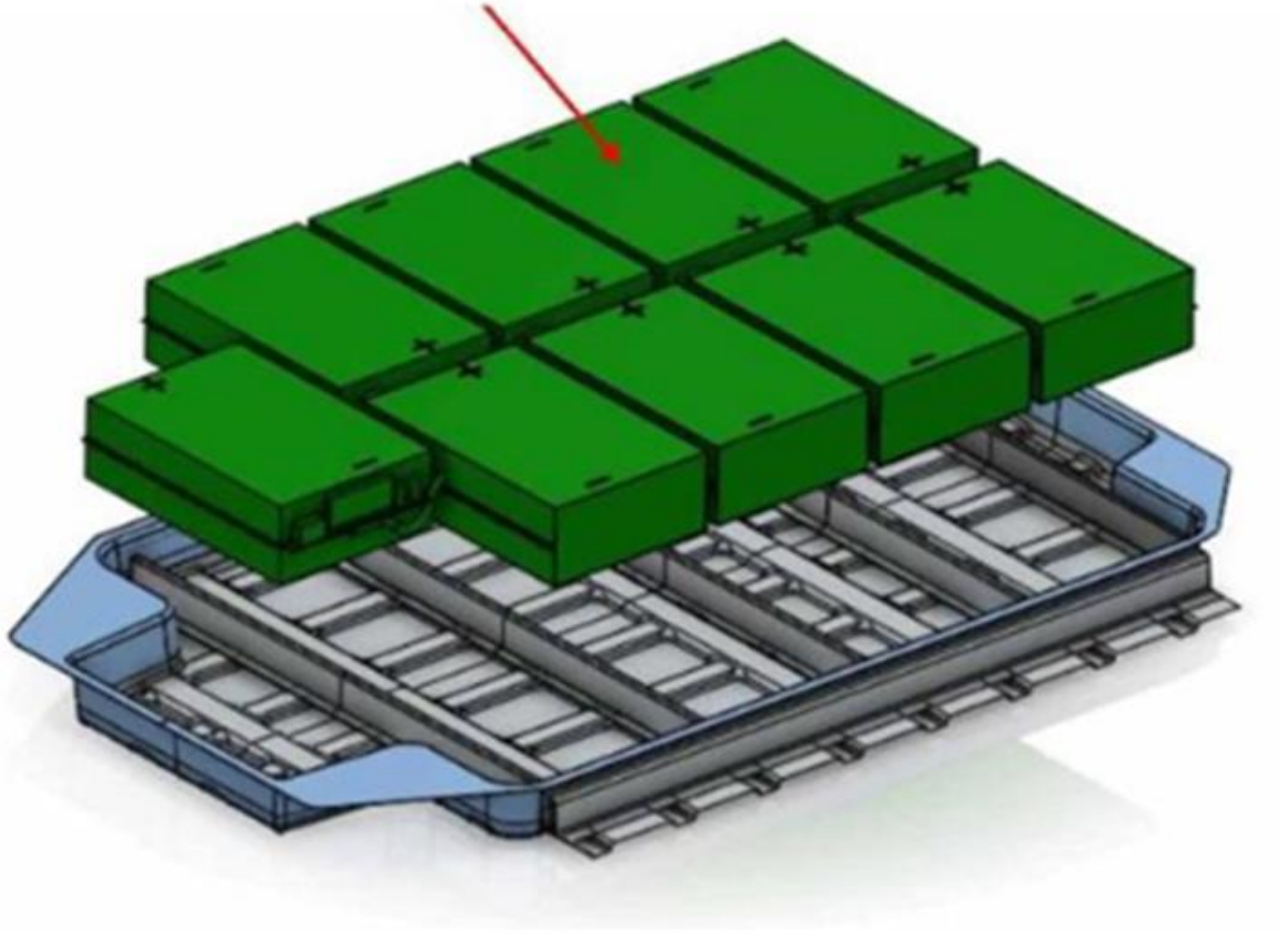
OEM/Molder	Daimler / Multimatic
Vehicle	AMG GT-R (EU)
Application	Midsection/driveshaft underbody aerodynamic/torsional reinforcement panel
Materials	High T_g EP resin, Tailored Fiber Placement CF laminate - 7mm thickness
Manufacturing Process	Liquid Compression Molding

- 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

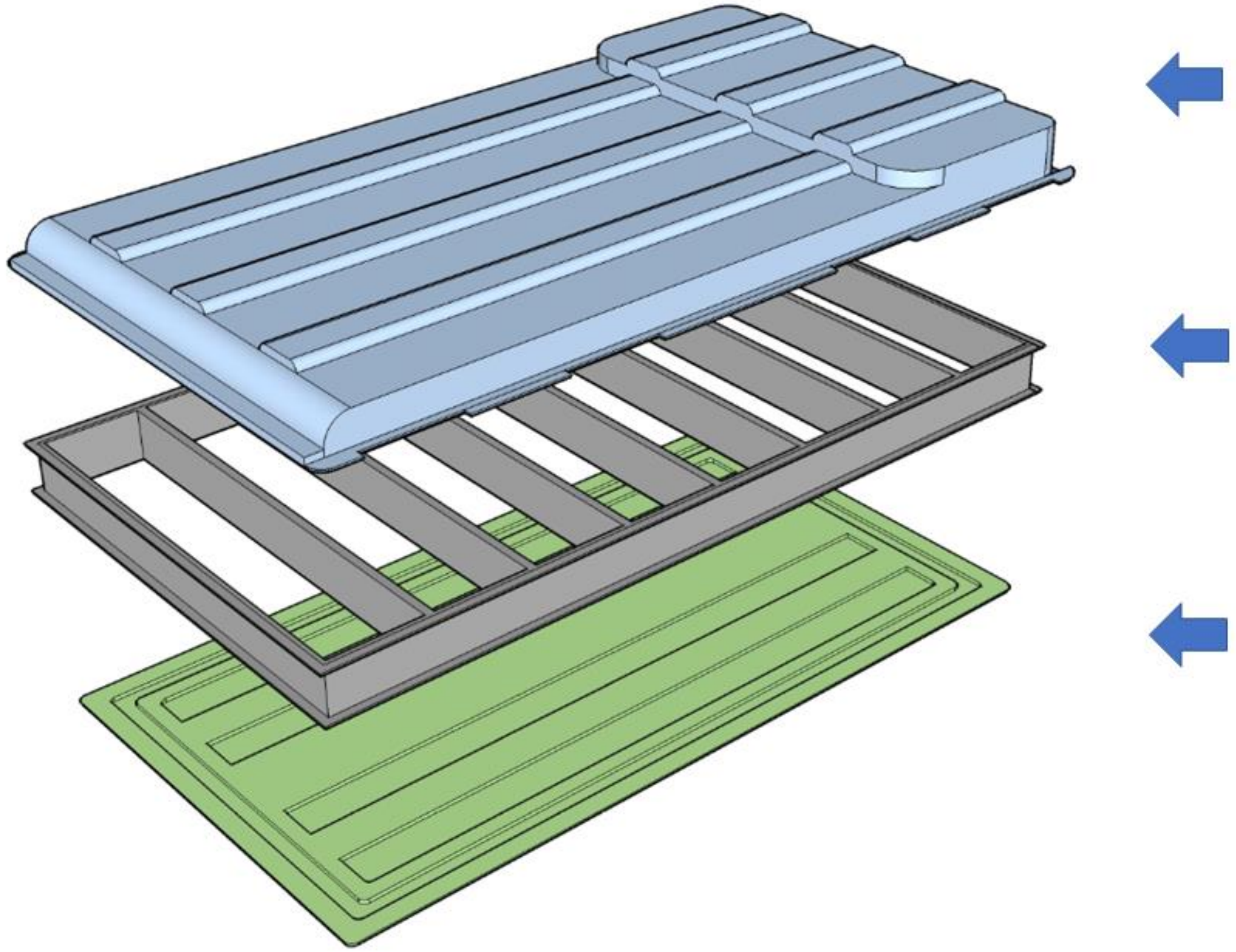
Design and Integration of Composites

Lightweight Fire Resistant Battery Box Concept

Original Metal Concept
(~20 pc Assembly)



Multi-Material Composite
Concept (simplified)



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

Dr. Ian Swentek
Senior Application Development Engineer
Ian.Swentek@Hexion.com

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Thank You!