Progress beyond

The Interdependency of Design, Materials, and Manufacturing to Optimize a Composite Battery Solution

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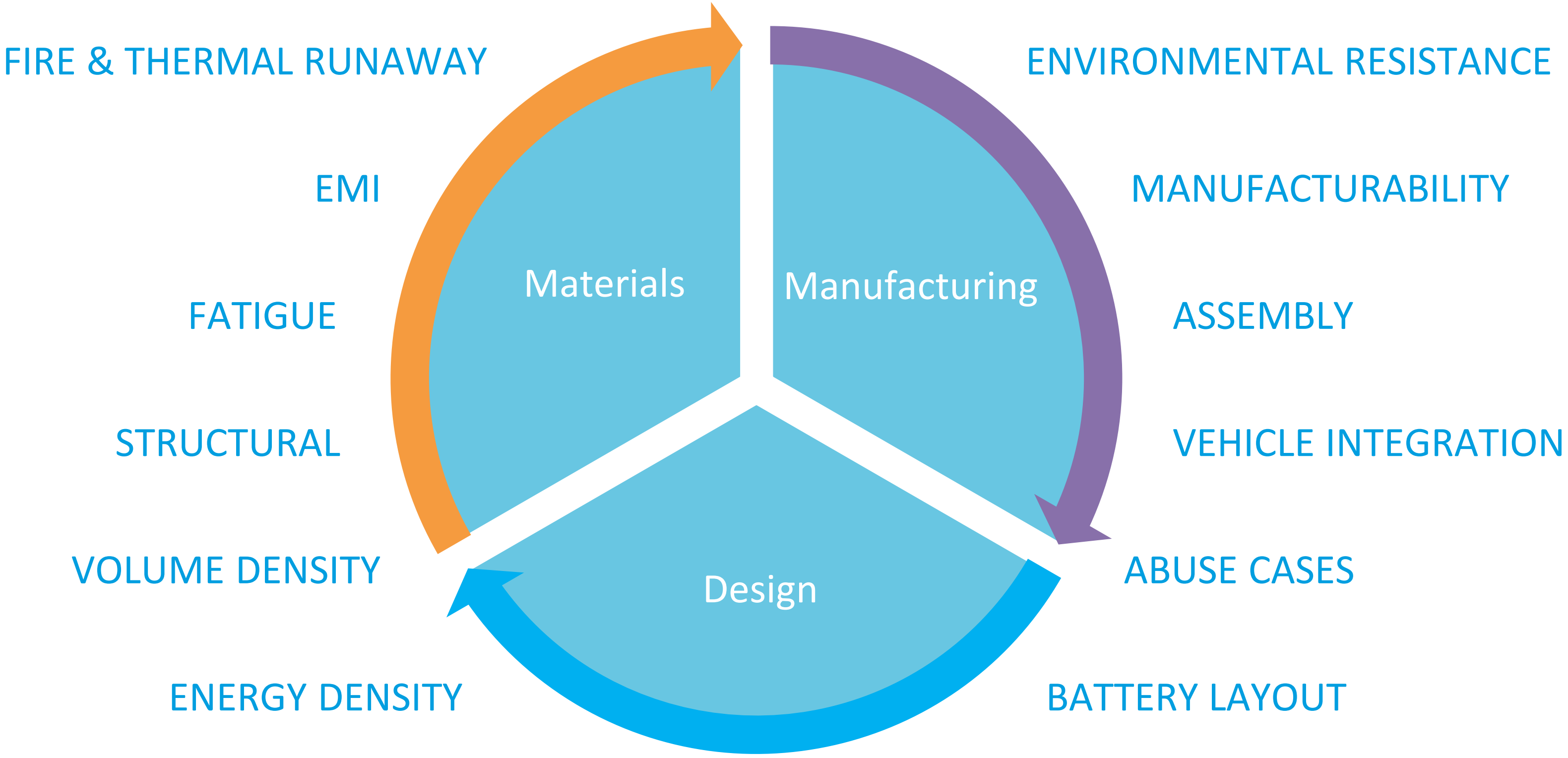
A Simple Question – A Complex Answer

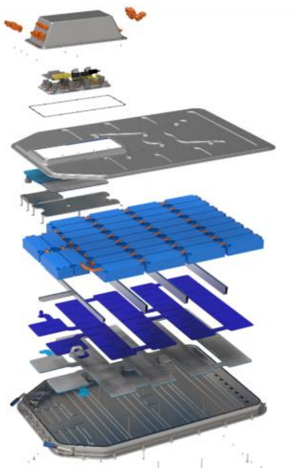
Why are composite materials not more widely used for battery enclosures?



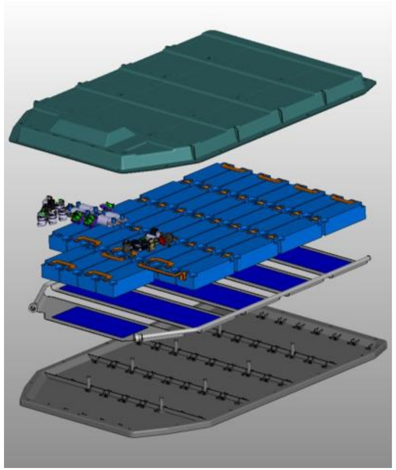
Composite Design Solution – Developed with Ricardo

- Virtual composite design project developed in two phases with Ricardo PLC
- Complete composite solution - tray, cover and cross members
- Focus on improving volumetric and mass energy density
- Full structural loading simulations completed with composite design exceeding all requirements

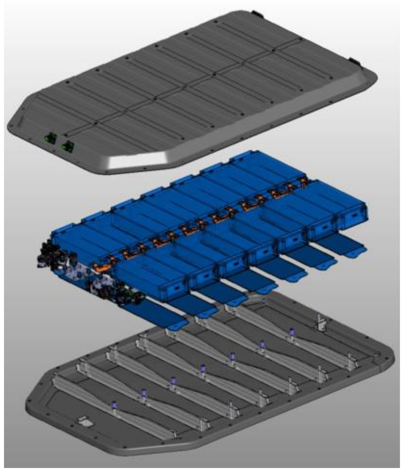
Incumbent Metallic Design



Composite Phase 1 Design



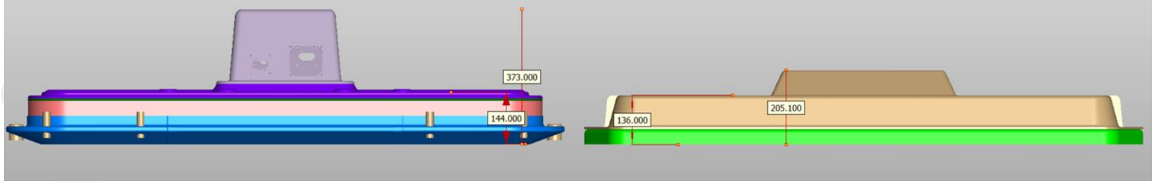
Composite Phase 2 Design



Phase One Results Comparison

Presented at 2022 SPE ACCE

FuVA Metallic Design	Pack Specification	Concept Composite Design
428	Volume of Enclosure* (l)	349 (-18%)
220	Volume Density (Wh/l)	270 (+23%)
141	Mass (kg)	66 (-53%)
141	Mass Density (Wh/kg)	161 (+14%)
22	Structural Parts	2 (-90%)
373 144	Z-Height (mm)	205 (-45%) 136 (-6%)



MAJOR BENEFITS

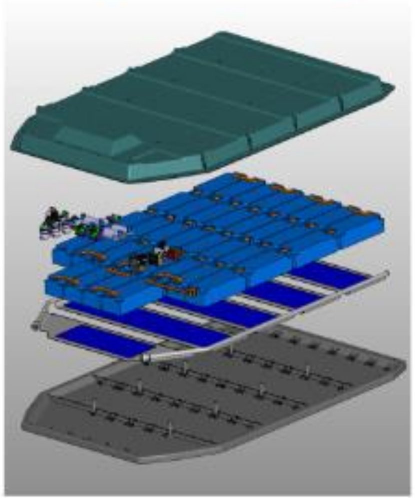
- **Volumetric energy density improvement** - **<u>improve vehicle range</u>**
- **Vehicle packaging benefit**
  - more packaging space for batteries modules without decreasing vehicle interior space
  - reduced height and exterior volume improves the occupant/booth space
- **Easier pack assembly and reduced number of seals** - greatly reduced numbers of parts, potentially improved safety and durability
- **Weight reduction (-75kgs)**

*Volume of space taken up by the battery pack enclosure - exterior volume minus interior volume.

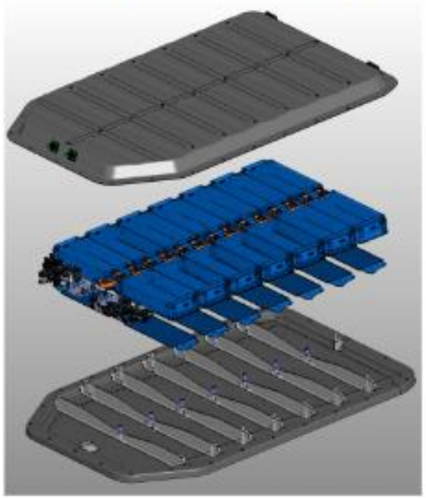
Phase 2 Simulation/Analysis

- Improved module layout to increase power
  - Phase 1: 36 Modules
  - Phase 2: 14 Modules
- Analyzed Manufacturing (Draping) to optim cover design
- Updated Structural Analysis
  - Enclosure Pole Crash
  - Modal
  - Module Retention and Clamping
  - Endcap Side Pole Crash
  - Abuse Jacking
- EMI Shielding
  - Material Testing
- Thermal Runaway
  - Simulation
  - Material Testing

Composite Phase 1 Design

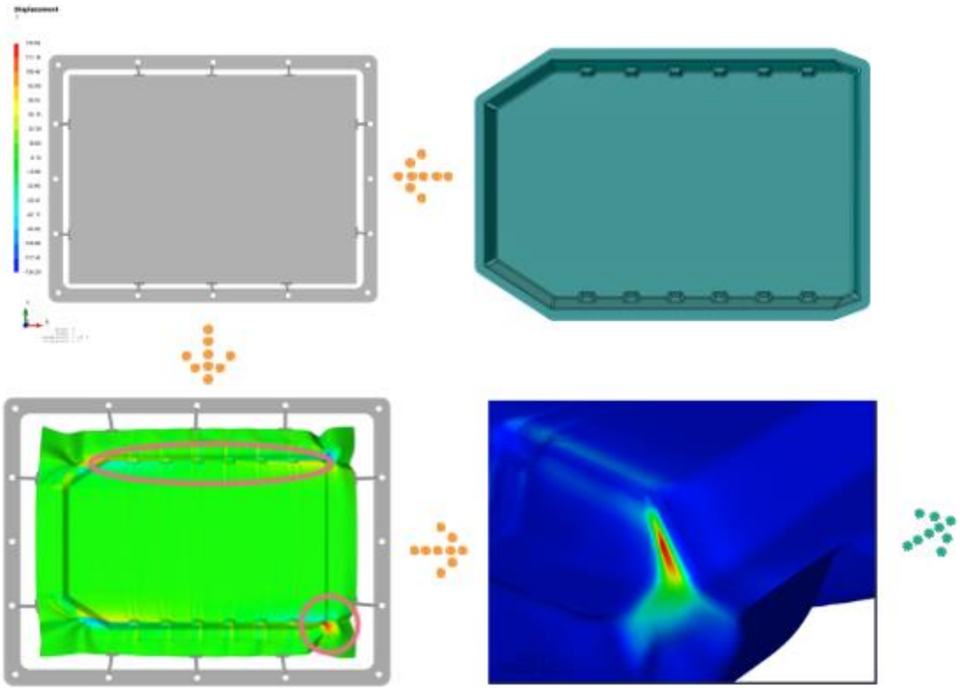


Composite Phase 2 Design

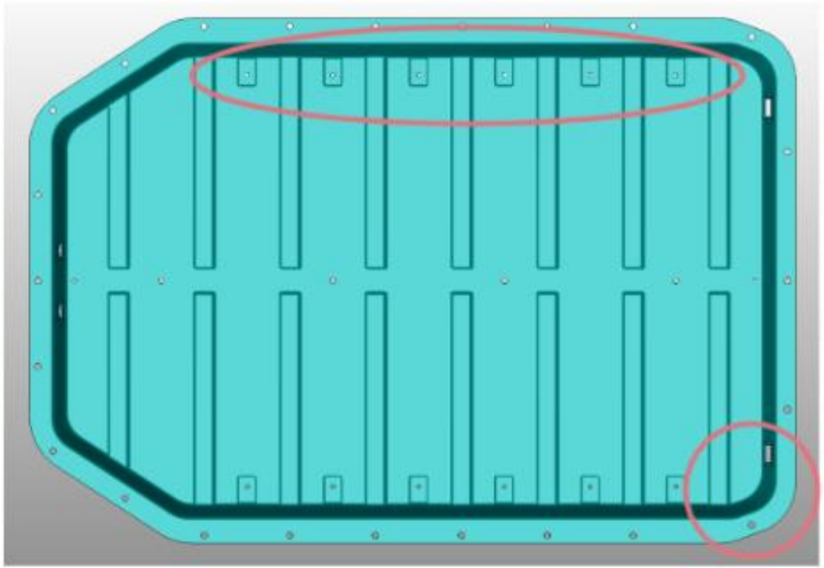


Manufacturing Simulation – Eliminate Sharp Corners

Draping Simulations - Top Cover Example



Final Design - Optimized for Manufacturing

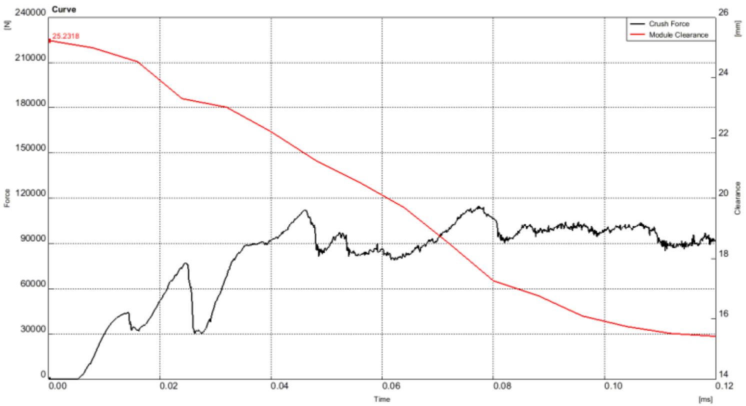


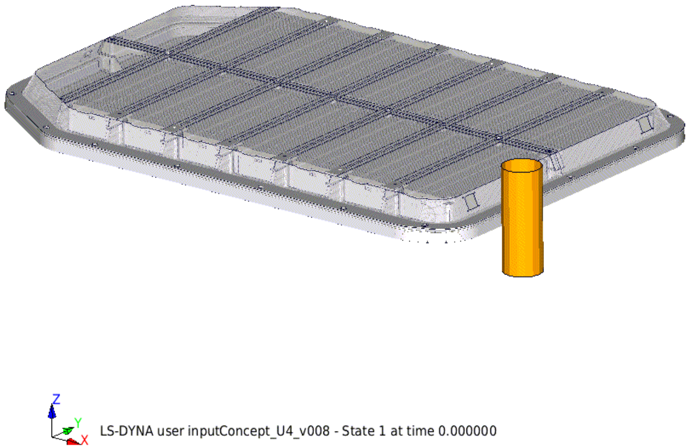
Structural Simulation

Most severe structural requirements at pack and vehicle level were met in simulation. Standards are a mix of international, regional and OEM. Generally the most difficult requirement was used as the target for each.

Enclosure Crush - 4 Positions Assessed
GB/T 31485 - 150mm pole - >100kN

✓

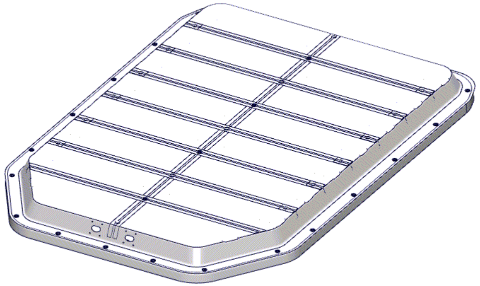




Structural Simulation - Modal Analysis

Modal Stiffness
11 Modes Assessed

Mode 1 - 73.3 Hz

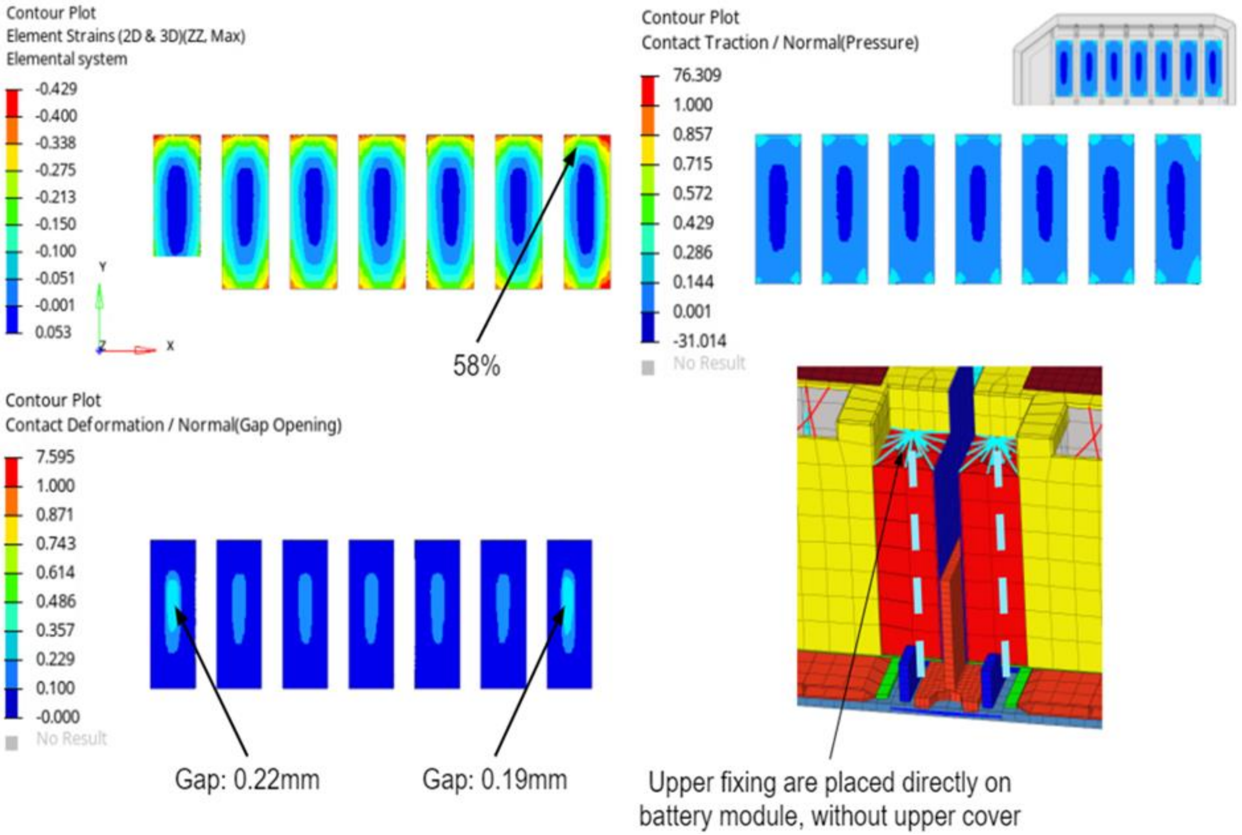


Mode 11 - 89.3 Hz

Typical Mode 1 Requirement: >35 Hz. 50 Hz considered good. ✓

Structural Simulation – Module Retention and Clamping

Target: Gap Pad Compressive strain >15% on 80% of interface with module and <40%



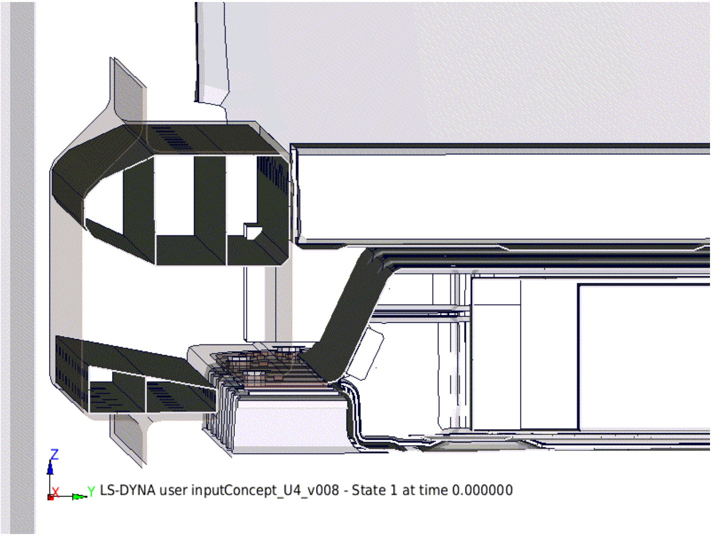
✓

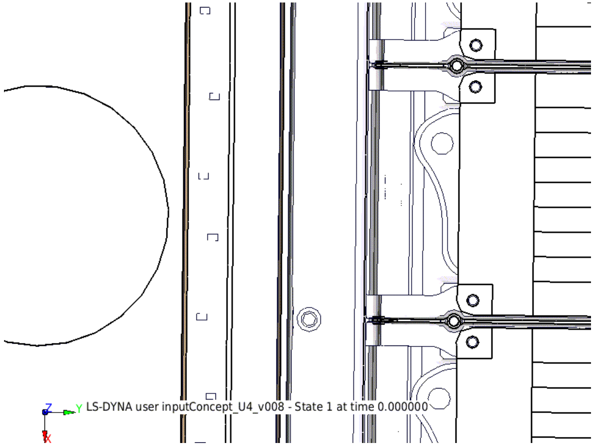
Abuse Case Simulation

- Most severe structural requirements at pack and vehicle level were met in simulation.
- Standards are a mix of international, regional and OEM.
- Generally the most difficult requirement was used as the target for each.

NCAP Side Pole Crash
13.8kJ absorbed by pack - 16mm clearence to modules

✓



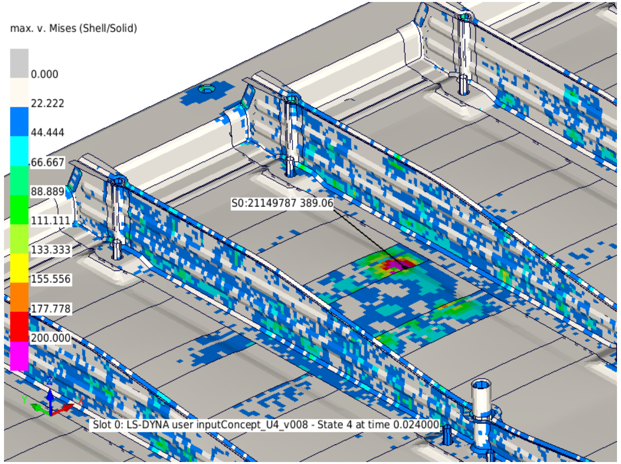


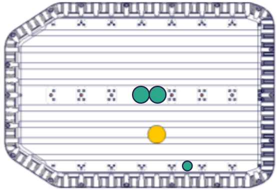
Abuse Case Simulation

- Most severe structural requirements at pack and vehicle level were met in simulation.
- Standards are a mix of international, regional and OEM.
- Generally the most difficult requirement was used as the target for each.

Abuse Jacking – >13.7kN
4 Positions Assessed, 150mm & 50mm

✓





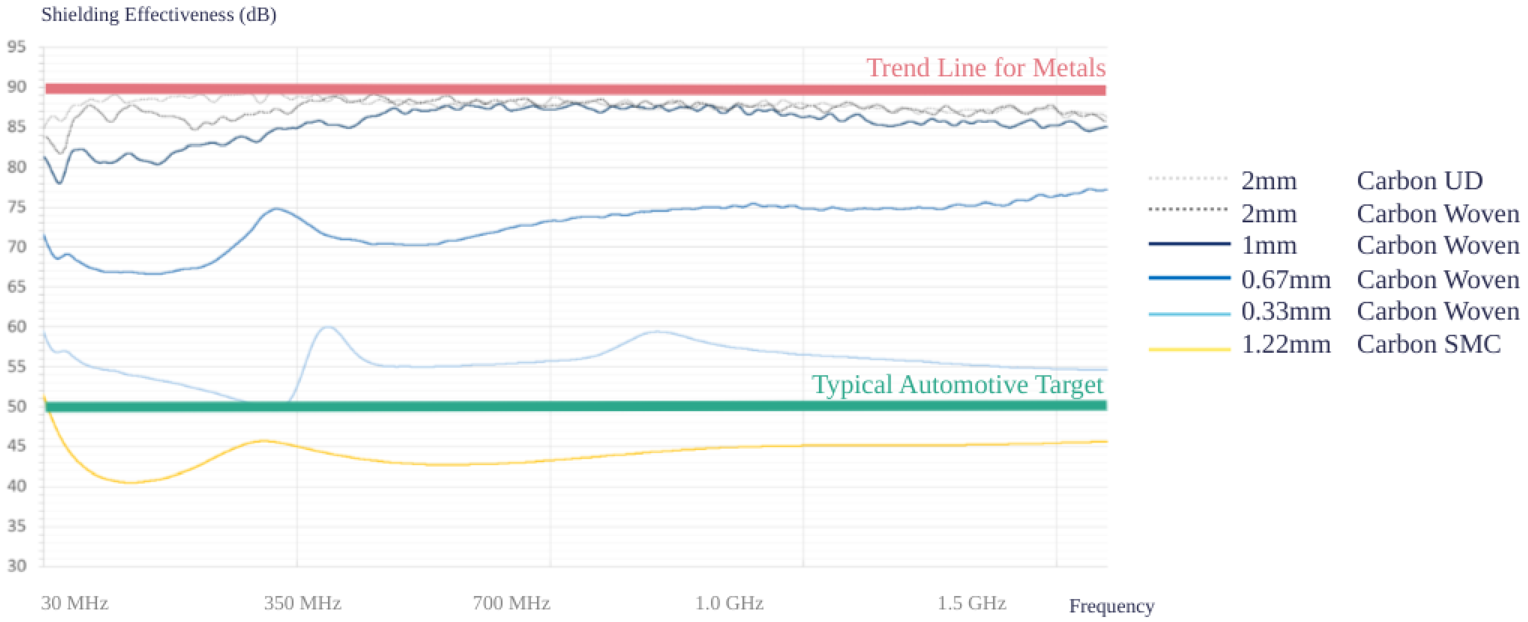
Phase 2 Improvements

Pack Specification	Metal Design	Composite Design Phase 1	Composite Design Phase 2
Power (kWh)	94	94	104
Total Pack Mass (kg)	668	585	567
Number of Modules	36	36	14
Volume of Enclosure (L)	428	349 (-18%)	328 (-23%)
Volumetric Density (Wh/L)	220	270 (+23%)	317 (+40%)
Enclosure Mass (kg)	141	66 (-53%)	85 (-40%)
Mass Density (Wh/kg)	141	161 (+14%)	184 (+30%)

Major Benefits

- Volumetric energy density improvement
- Vehicle packaging benefit
  - more packaging space for batteries modules without decreasing vehicle interior space
  - reduced height and exterior volume improves the occupant/booth space
- Easier pack assembly and reduced number of seals
- Weight reduction
- Potential corrosion resistance and thermal management advantage

EMI Shielding - Internal Test per ASTM D4935

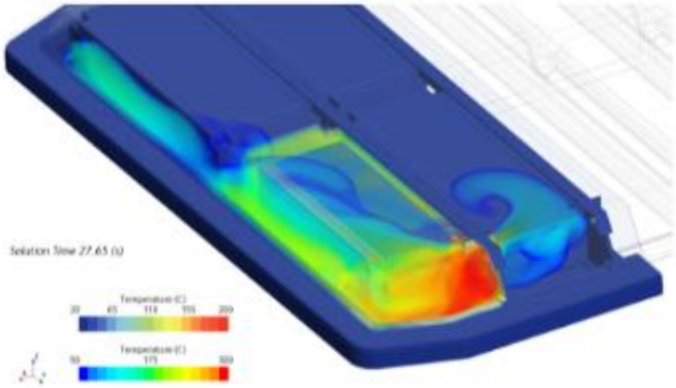


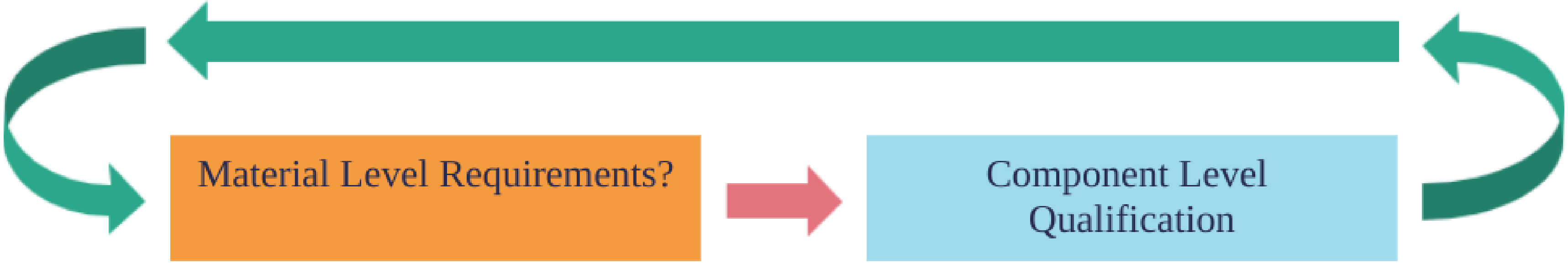
Continuous Carbon Fiber >> Discontinuous Reinforcement (SMC)

Thermal Runaway Requirements

Example: GB/T 38031 2020

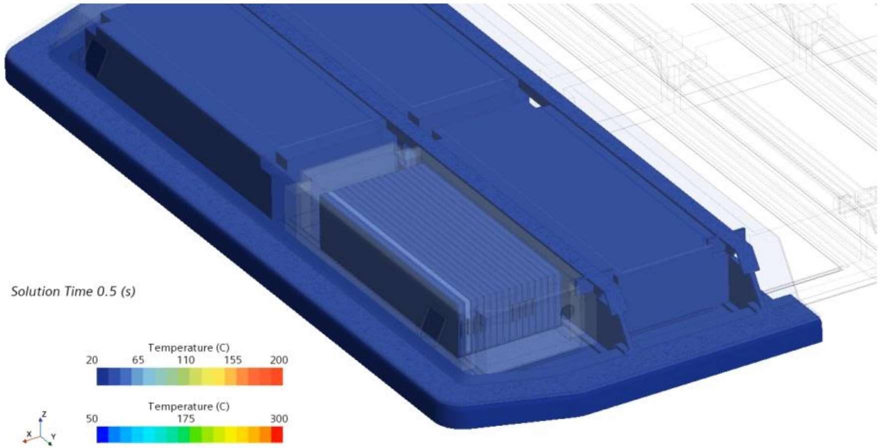
- Protection of passengers primary concern
  - 5 min to allow for safe escape from vehicle
- Open to OEM interpretation.
- Battery layout and design specific

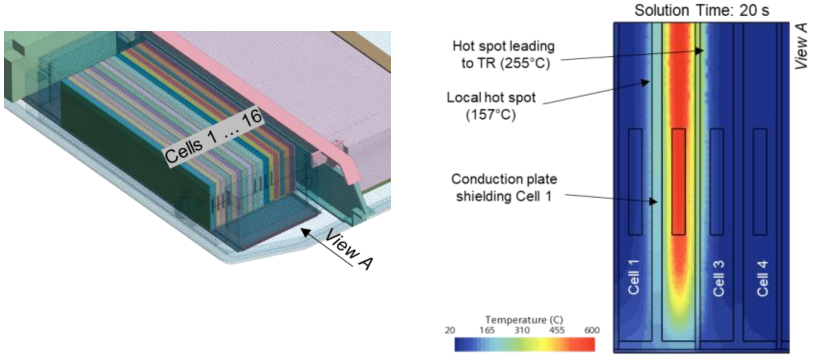


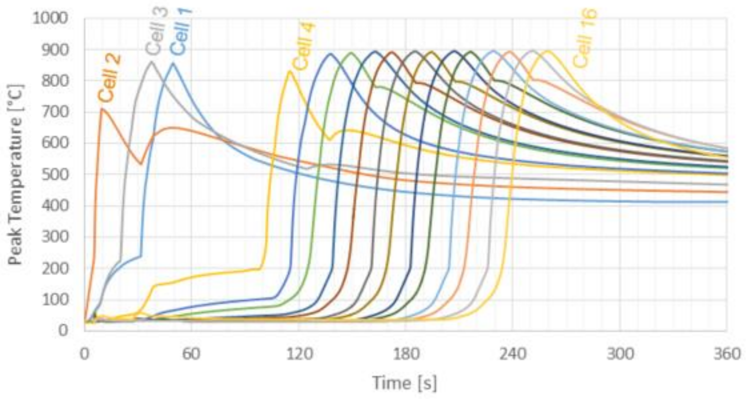


Thermal Runaway Simulation

Basic TR simulation carried out – no dynamic loading or break down of materials simulated

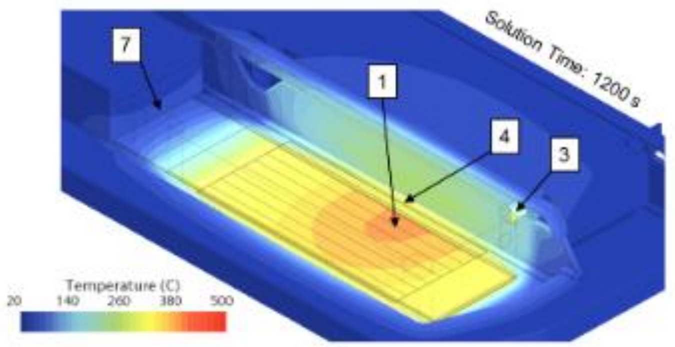


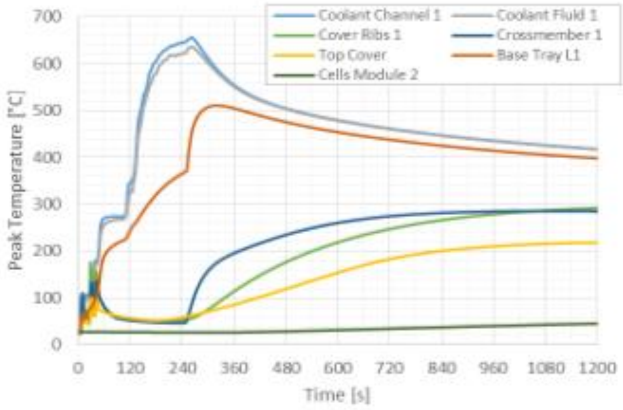




Thermal Runaway Simulation

Basic simulation - no dynamic loading or material degradation was simulated





	Component	Peak Temp, °C
1	Coolant Channel	655.8
2	Coolant Fluid	635.6
3	Cover Ribs	292.0
4	Cross Members	285.7
5	Top Cover	218.6
6	Base Tray	510.9
7	Adjacent Cells Module 2	45.7

Fire and Thermal Runaway Testing

Solvay Material Characterization for Thermal Runaway Resistance

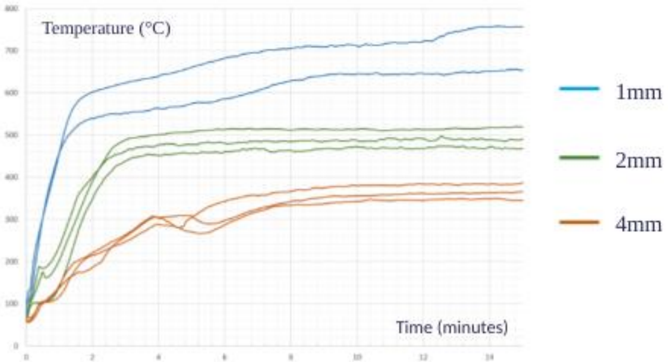
Burn Through Torch Test

Test carried out in house at Solvay

Typical temperature 1100°C

Variable Torch Output 0.5kW – 4kW

Tracks cold face temperature



Under Development Fire Resistance Underload

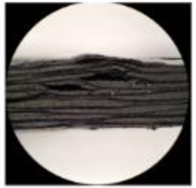
New tests under development by Solvay

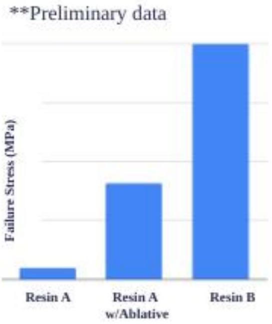
1. Flexural performance (cantilever) <u>during</u> flame impingement.

2. Residual compressive strength <u>after</u> flame impingement.

Resin A w/ablative

Resin B

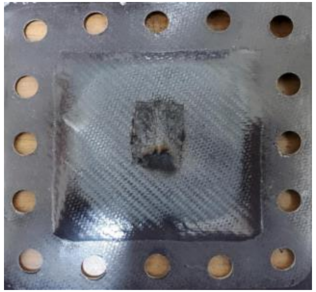




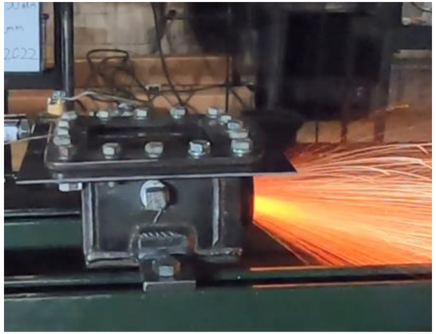
Thermal Runaway Testing

UL2596 – Test Method for Thermal and Mechanical Performance of Battery Enclosure Materials

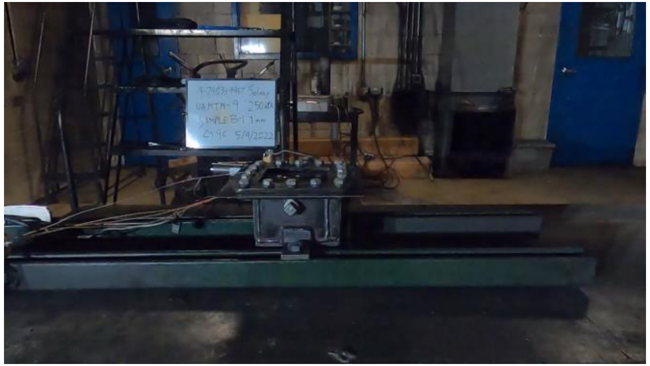
FR Epoxy GF - 2mm Thickness



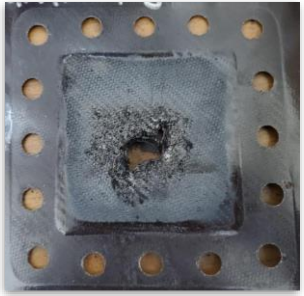
No Rupture



No Rupture



FR Epoxy GF - 1mm Thickness



Large Rupture Damage

Aggressive Rupture

Solvay Composite Solution meets the Market Needs for Thermal Runaway Protection and EMI Shielding

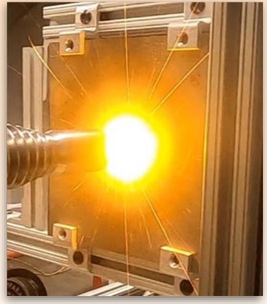
Flame & Thermal Runaway Resistance

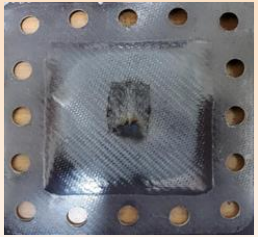
Fire Penetration & Cold Face

- ➢Cold-face temperature measurement vs time
- ➢Unloaded impingement tested
- ➢Loaded impingement under dvp

Abrasion & Flame (UL 2596)

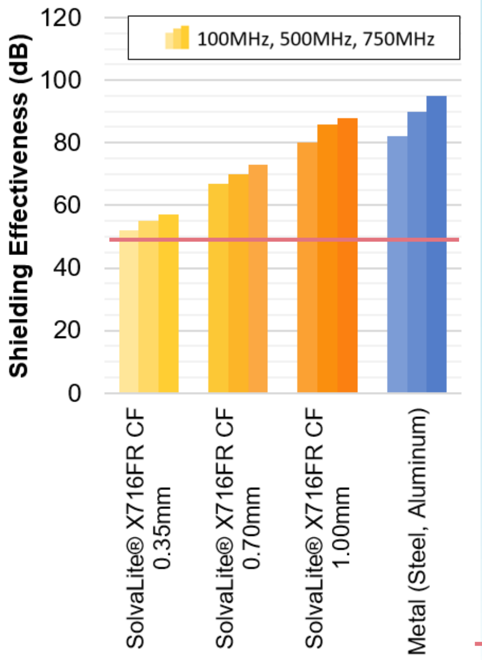
- ➢Torch & Grit (TaG)
- ➢Box Test (25 cells induced in thermal runaway under test coupon)





SolvaLite® 716FR (@2mm) passed successfully all the tests

Electromagnetic Compatibility (EMC)



ASTM D4935 testing capability in Solvay

Initial results on carbon fabric show very promising shielding effects

1mm allows to achieve SE > 80dB in the range 30-1000MHz

Virtual Engineering work initiated to support understanding

50dB = typical automotive target

Moving Forward - BEMA Project

Solvay working in collaboration with Airborne to demonstrate the complete understanding of Materials, Manufacturing and Design

Real testing of composite battery enclosure to corrolate virtual/physical attributes

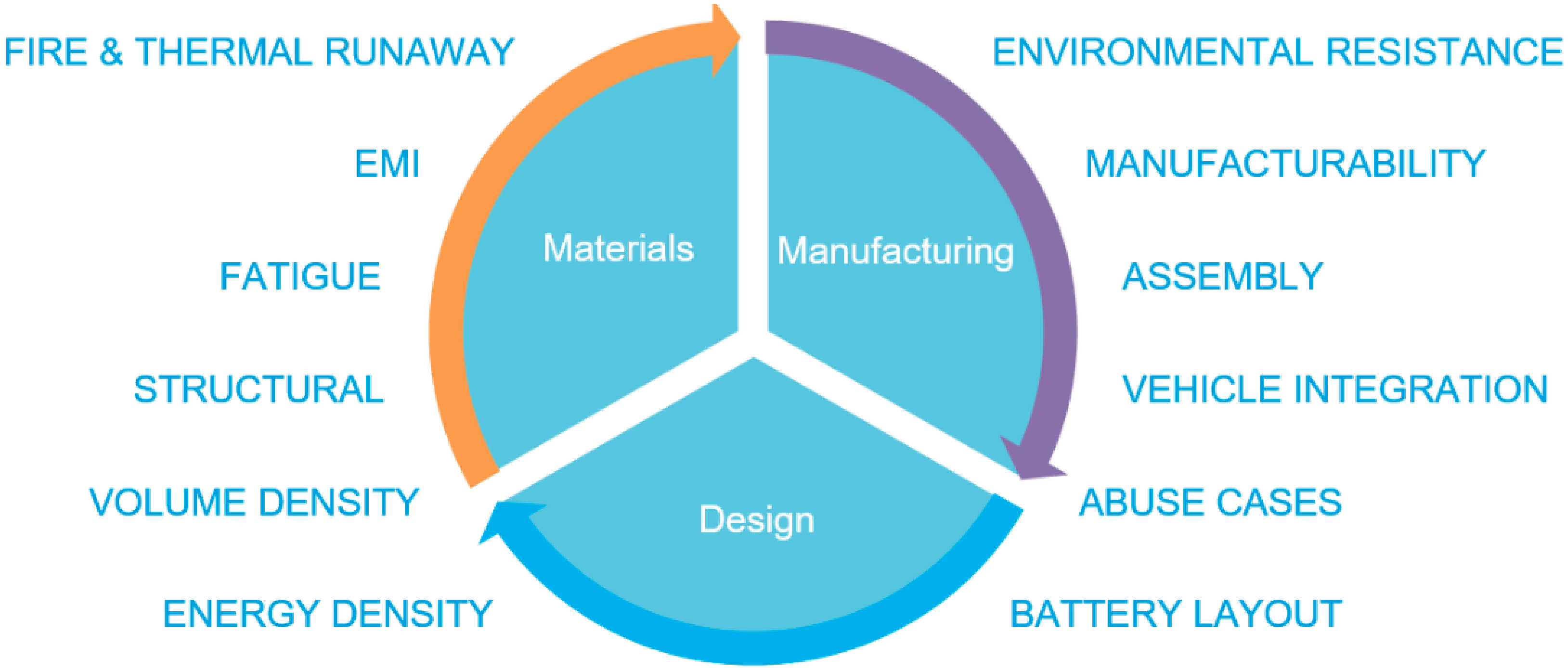
- Fire Protection
- Thermal Runaway
- EMI

Develop Design for Manufacture guidelines

Integrate Manufacturing automation with business process automation

Complete assessment of cost and environmental impact

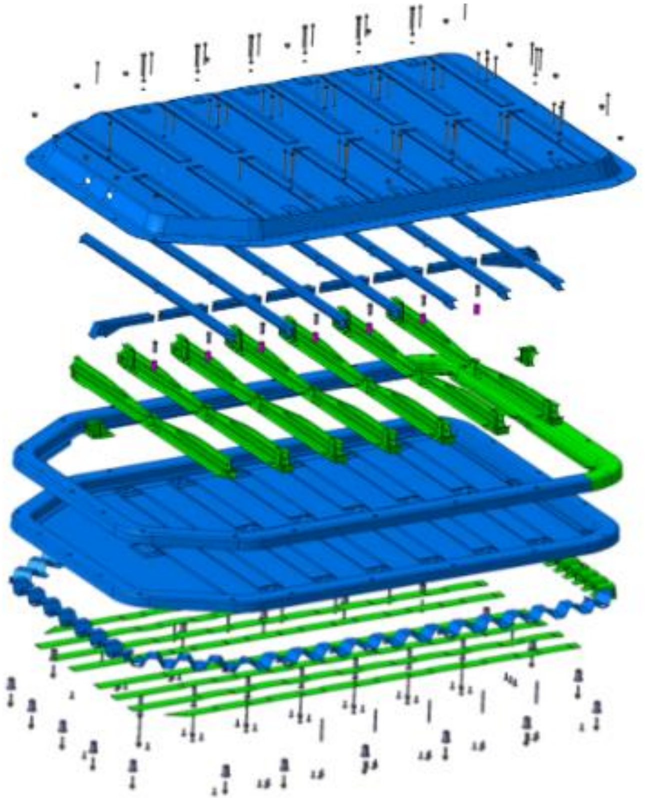
What Happened when We Considered the Complexity of Design/Materials/Manufacturing?



Composite Design Solution

A balanced solution providing market leading performance

- Meets many typical Industry requirements
  - Structural loads
  - Abuse cases
  - Environmental and fatigue
  - Fire protection
  - Thermal runaway
  - EMI
- Design Improvement via Manufacturing Optimization
- 40% weight saving vs steel equivalent
- 30% increase in energy density (Wh/kg)



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