Zwick Roell EXPO October 2022

Large Fireproof Battery Enclosure for electric truck

Filava-Polysiloxane resin

Motivation

- Freight accounts for 20% of road vehicle emissions
  - Substantial interest in zero emission trucks to meet net zero targets
- Trucks need large, heavy batteries and range is limited
  - Volta Zero, 1.44T of batteries, range 90-125 miles
- Lithium ion batteries (LIBs) present a substantial fire risk
  - Thermal runaway caused by overheating, short circuits, impacts etc.
  - Temperatures can reach 800-1000°C
  - High risk of large truck batteries e.g. in urban areas, hazardous cargo
- Current 'lightweight' battery enclosure materials are not ideal
  - Aluminium and carbon fibre composites cannot withstand the temperatures and also conduct electricity
  - Nextel ceramic fibre composites and Ti64 alloy are too expensive

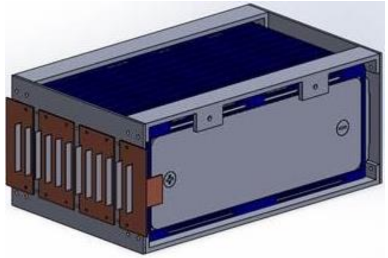
Reserach Approach

- Develop new lightweight, high temperature composite suitable for large battery enclosures
  - Polysiloxane resin reinforced with enriched mineral fibres – can withstand up to 950°C
  - Lighter and safer than current solutions
  - Impact resistant, electrically insulating, vibration absorbing, corrosion resistant, low embodied CO_2
- Design, develop and test a novel battery module prototype
  - Lightweight power cells, embedded cooling and electronics, high C-rate capability
  - Designed specifically for large battery systems in electric or hybrid trucks
- Exploitation, leading to increased sales revenue for the 3 SME partners, job creation
  - Benefits to wider UK supply chain and high potential for exports

Key Outputs/Deliverables

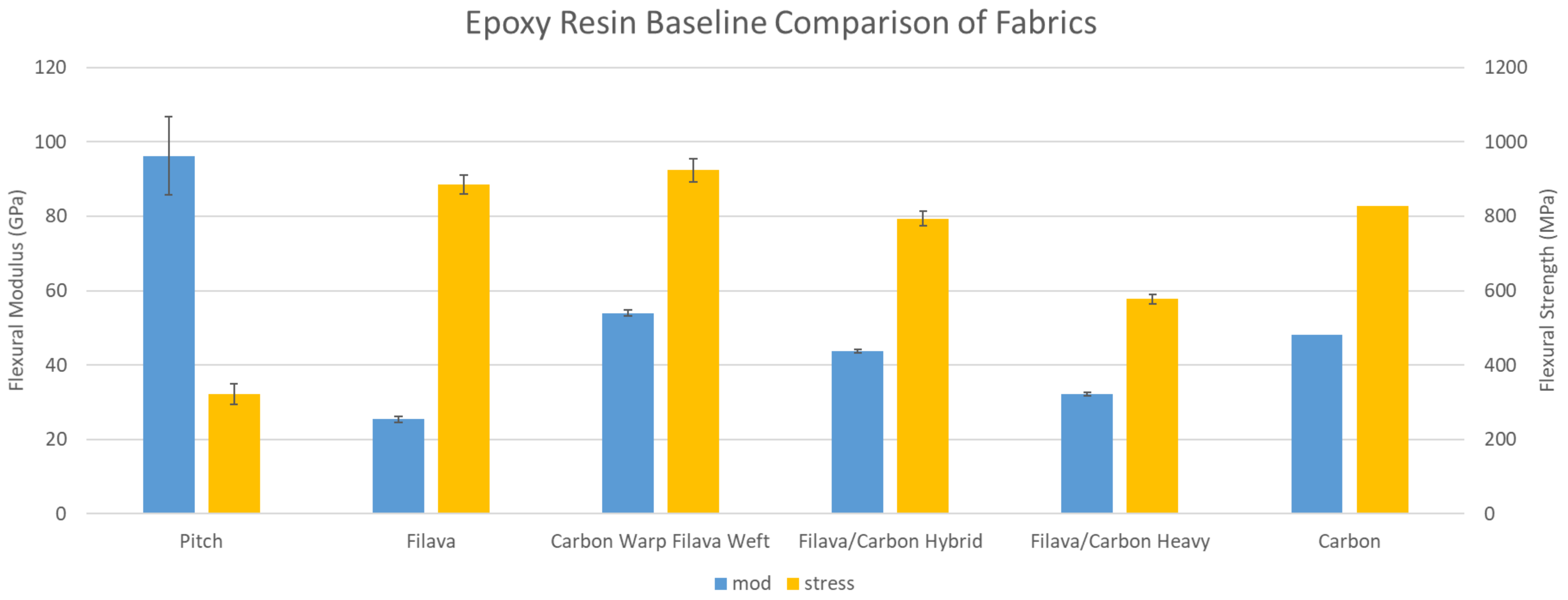
- Commercial and technical targets, customer engagement (MEP/All)
- Temperature resistant fabrics (Carr)
- High temperature resin and prepreg (CompEvo)
- High temperature composite enclosure and tooling (UoW)
- Prototype battery module (MEP)
- Exploitation plan (CompEvo/All)



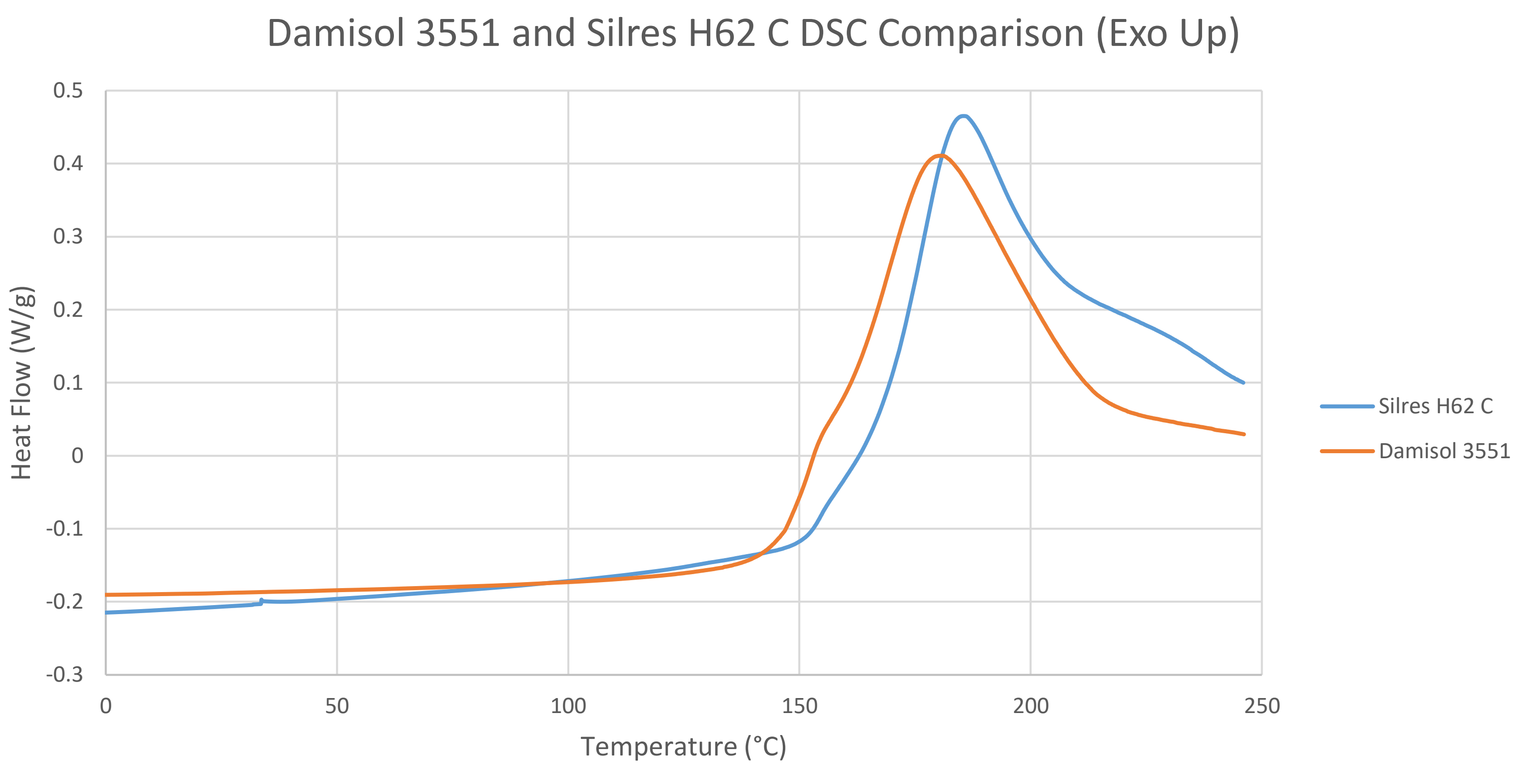
Baseline Testing with Epoxy Resin inc. Pitch Carbon

- ISO14125 (Results normalized to 50%Vf)



Alternative Resins: Damisol 3551 - Resin Analysis

- Alternative Polysiloxane resin produced by Von Roll
- Initial sample received from UoW and 20kg received from Carr
- Initial DSC suggested similar cure profile to Silres H62 C



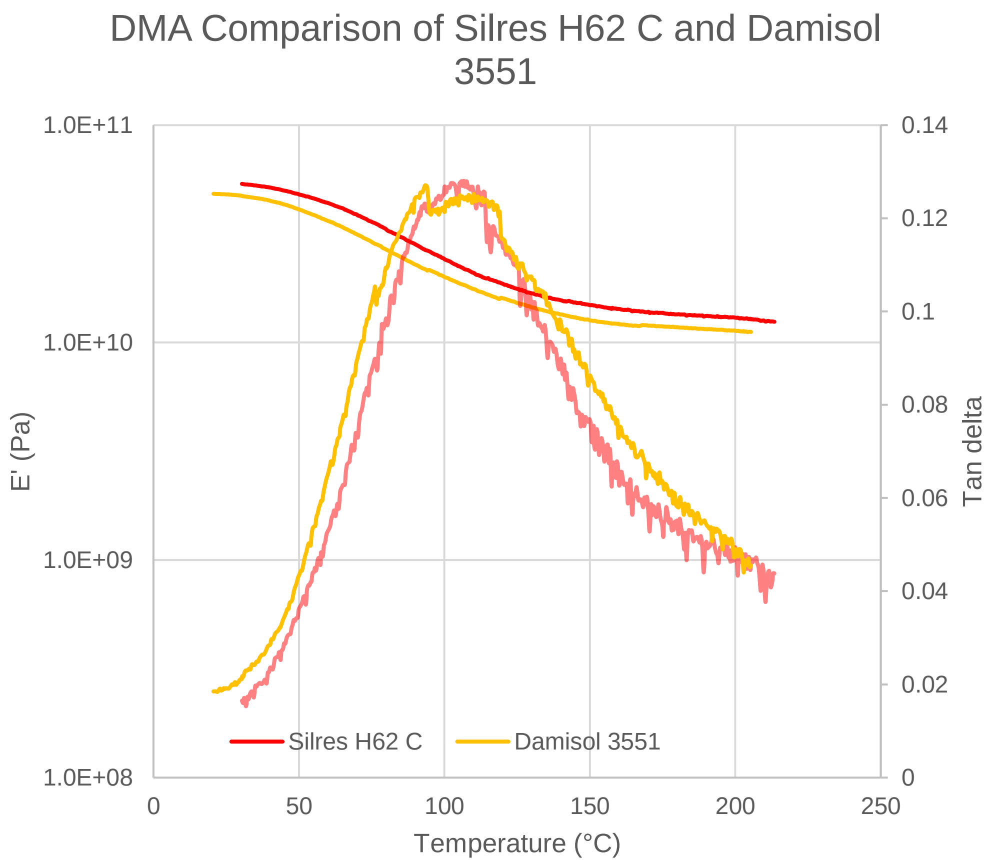
- Thermal staging trials found that Damisol staged at a similar temperature, but gave more consistency and achieved a good viscosity in shorter times

Alternative Resins: Damisol 3551 – Prepreg Analysis

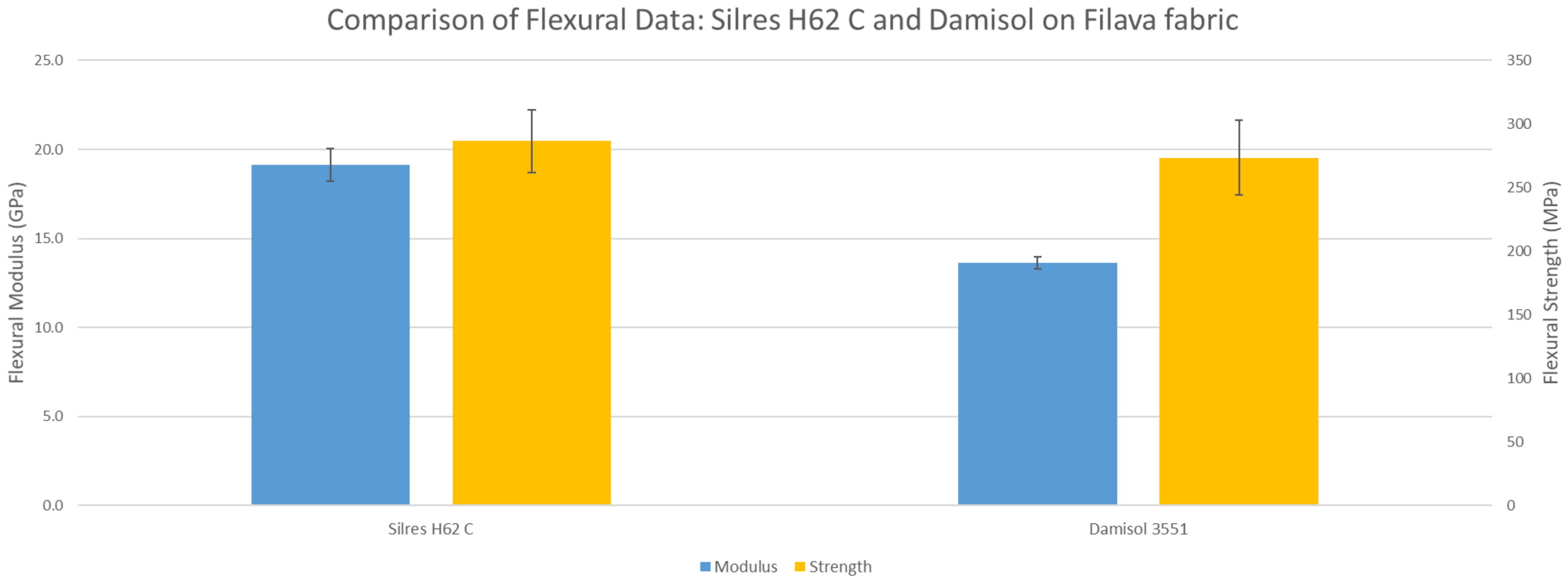
- A small amount of Damisol 3551 prepreg was made with the staged resin (~7m) on two different fabrics (Filava and Bi-directional Filava/Carbon hybrid) on the pilot line

Batch no.	Fabric	Resin Weight	Tack	Outlife	DMA	
					Extrapolated Onset (°C)	Tan(δ) peak max (°C)
BS-22T-2107	DW0743 – Pure Filava	39.6%	1/1	Ongoing – 1 month	45.0	91.9

- Laminates made and tested (results on next slide)
- Overall – Damisol 3551 appears to be a viable alternative to Silres H62 C



Alternative Resins: Damisol 3551 - Laminate Analysis



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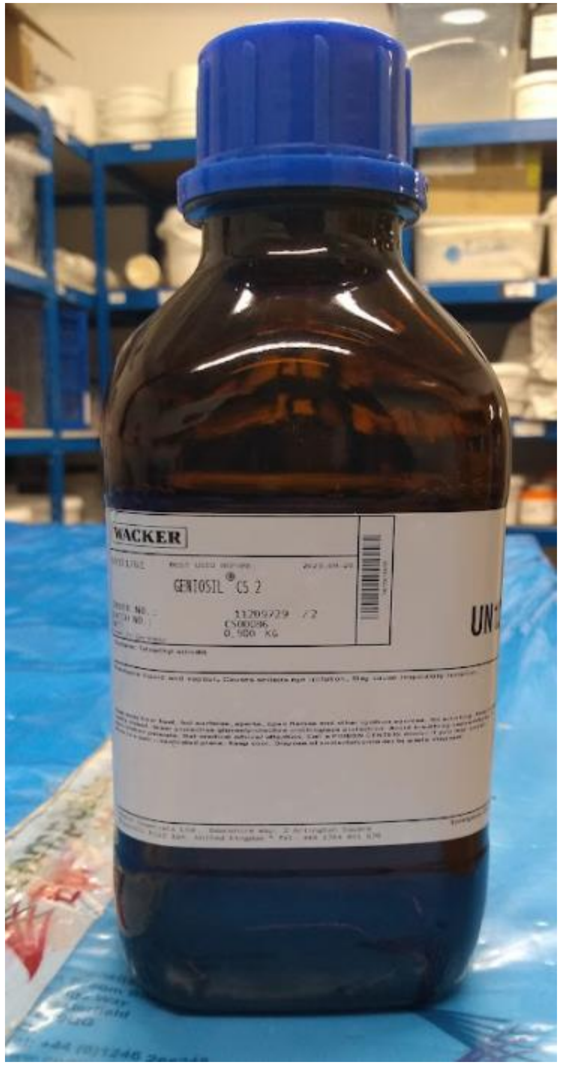
Silres H62 C – Resin/Prepreg Development



- Geniosil CS 2 additive
  - Designed for mechanical improvement, added at ~7% (suggested by UoW)
  - Hand-preg made and cure analysed using DMA and DSC
  - These suggested that initial cure rates are similar, but is slowed down by the additive after that initial period
  - For further investigation, a pilot line trial would be required
- Silres H62 prepreg outlife testing
  - Unchanged after 8 months (many prepregs go dry and stiff after 1 month)

Silres H62 C – High Temperature Post-Curing

- Filava/Silres H62 C laminate samples were post-cured at high temperatures to examine the effect on mechanical properties

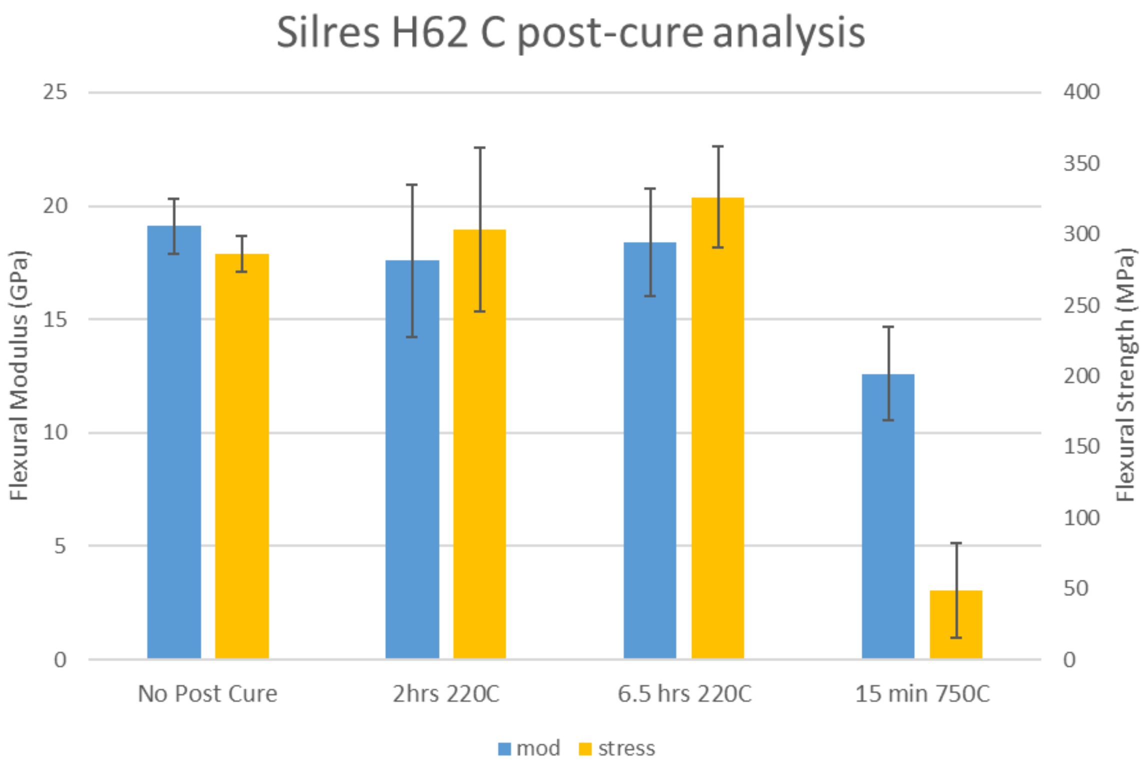
- Samples were cured at 200°C for 2 hours

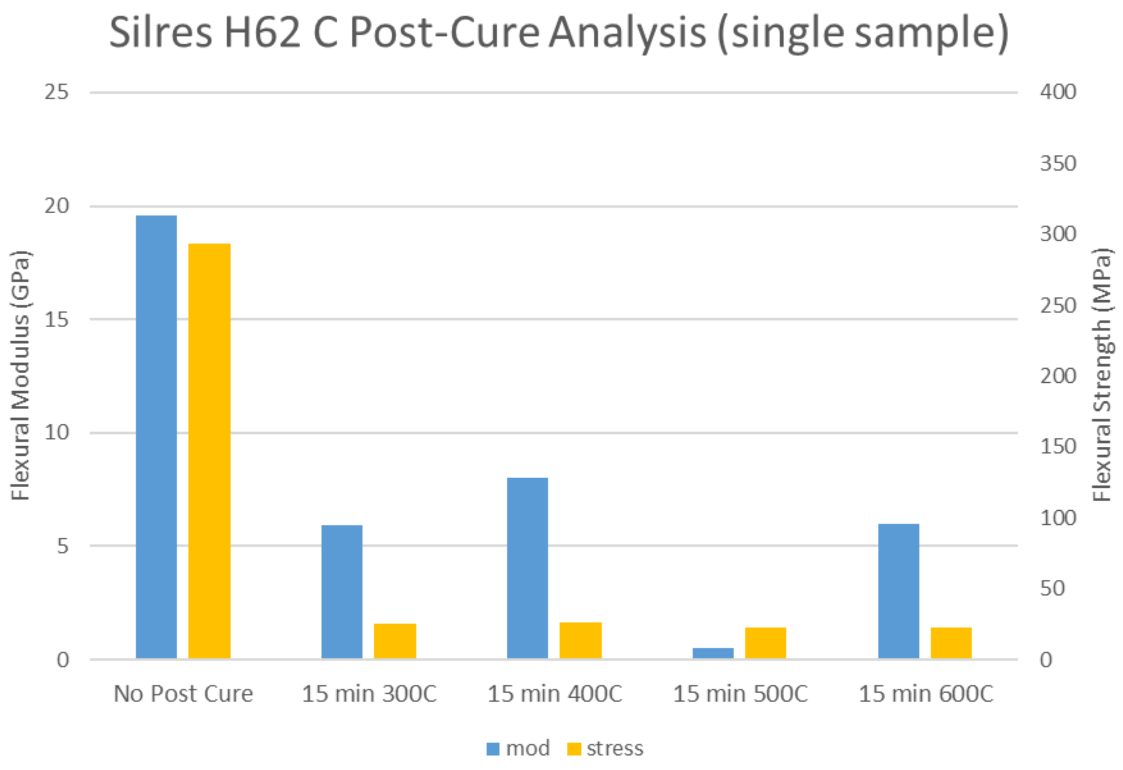
- Oven post cures: 2 hours 220°C, 6.5 hours 220°C
  Furnace post cures: 15 min 300°C, 15 min 400°C, 15 min 500°C, 15 min 600°C

- Samples then underwent flexural testing (ISO 14125)

Silres H62 C - Laminate Post-Cure Flexural Data

- ISO14125 (Results normalized to 50% Vf)





Pilot Prepreg Production

- A further 50m of various Silres H62 prepregs were produced for UoW for demo enclosures
- Low viscosity and variable staging behaviour of Silres presents challenges for prepregging
  - Difficulties in achieving target resin content (some prepregs delivered were 'resin rich')
  - Prepreg relatively 'wet' and difficult to handle, difficult to release from paper/poly
- Discussions ongoing with supplier (Wacker) regarding improved resin for prepregging

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Our task

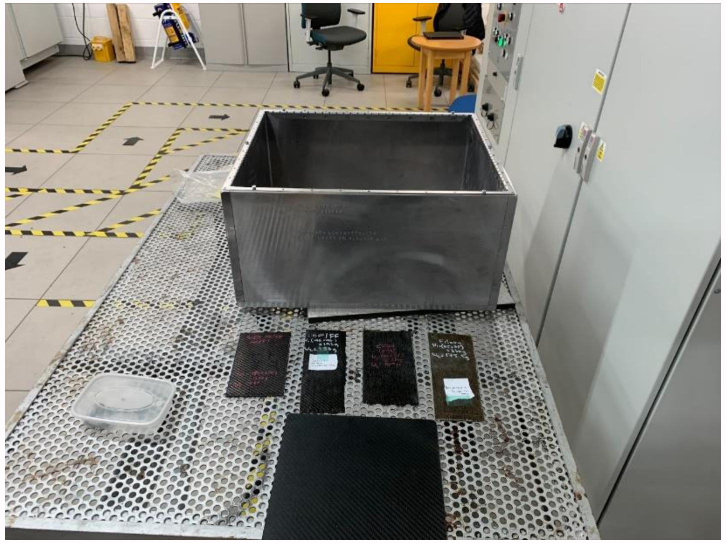
WP4, "High temperature composite enclosure development" (University of Wolverhampton, evaluation of laminates produced from the WP3 prepregs, followed by the design, manufacturing and testing of a prototype battery enclosure.

Our achievement

1. Design and manufactured stainless steel tool for the enclosure, lid and flange joint.
2. Manufactured 5 boxes from Filava-Silres H62, 1 CFRP and 1 HFRP
3. Mechanical and fire testing both in coupons form and physical assembly.

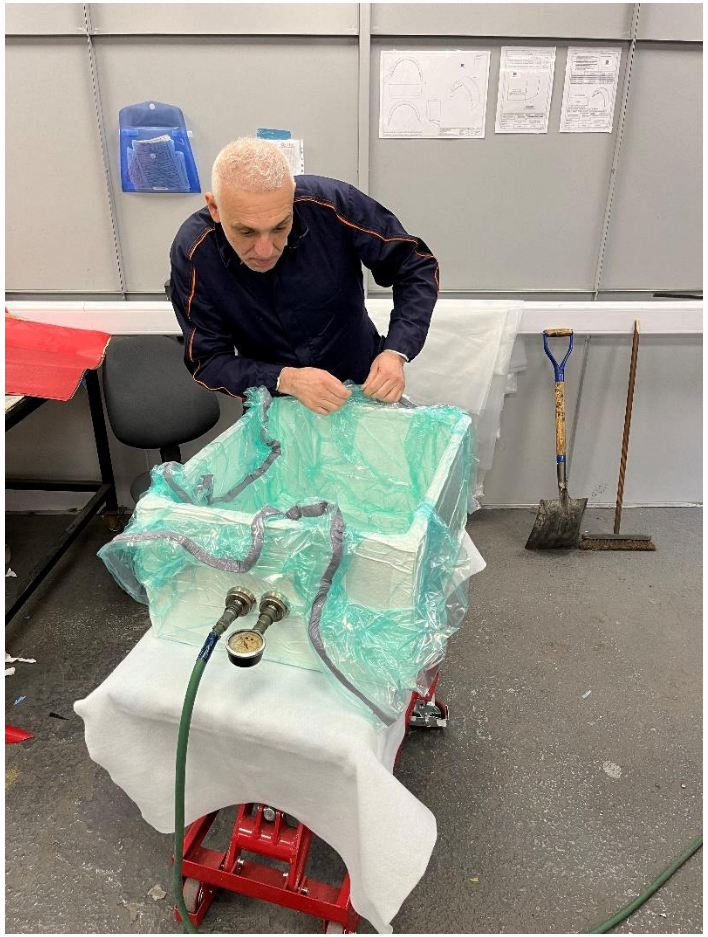
Methodology

1. Design and Machined Novel stainless steel mould for the box and steel plate for lid (Titanium bolts for High pressure Autoclave)
2. Develop built-in steel flange within box that bolted to lid.



Lamination Pattern of materials

- 4F-4H-4F for the box, CF oriented in the direction of carrying load.
- Debulking, peel ply, release film, breather, vacuum bagging (HT 250°C)
- 3F-4H-3F for the lid, same bagging procedure



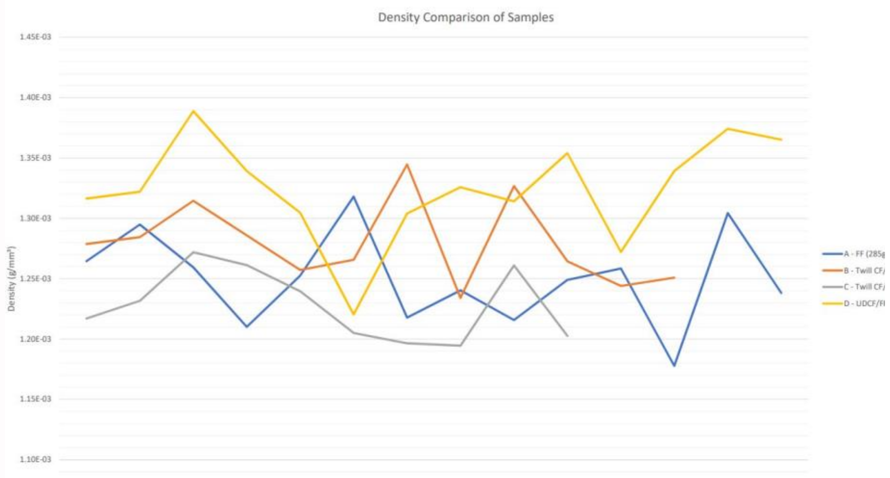
Curing cycle for the FFRS

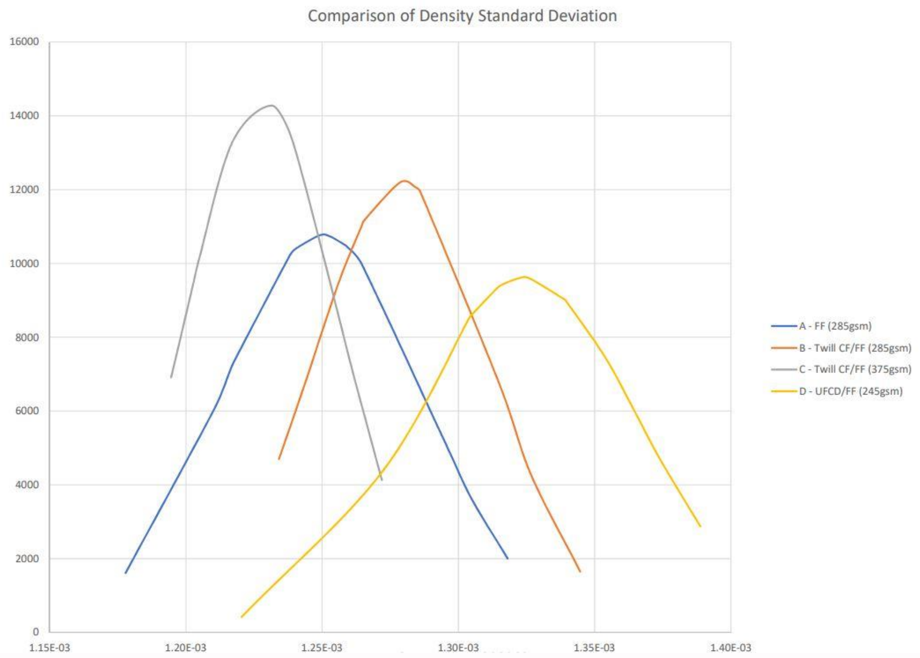
1. Vacuum at 10^{-6} mbar
2. Ramp to 120°C at 5 °C/min
3. Pressure to 8 bar at 0.2 bar/min
4. Ramp to 220°C at 5 C/min
5. Hold for 4 hours.
6. Cool to room temperature/pressure

Density is vital element in term of Fibre volume fractions

The density of Filava is 2.35 g/cm^3, CF is 1.7 g/ cm^3, cured SilRes-H62 1.1 g/ cm^3 so optimum density for Hybrid composite at 60vol% fibres :

$0.3\ (2.35)+0.3(1.7)+0.4(1.1)=1.655$ g/cm^3

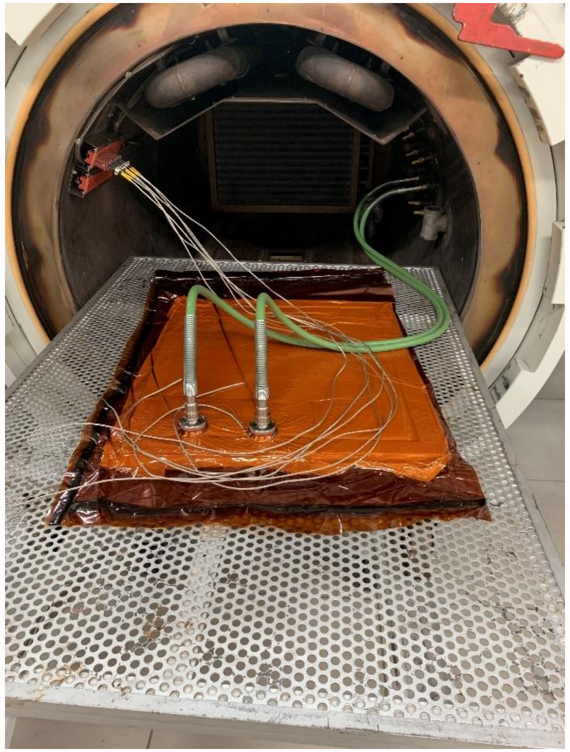




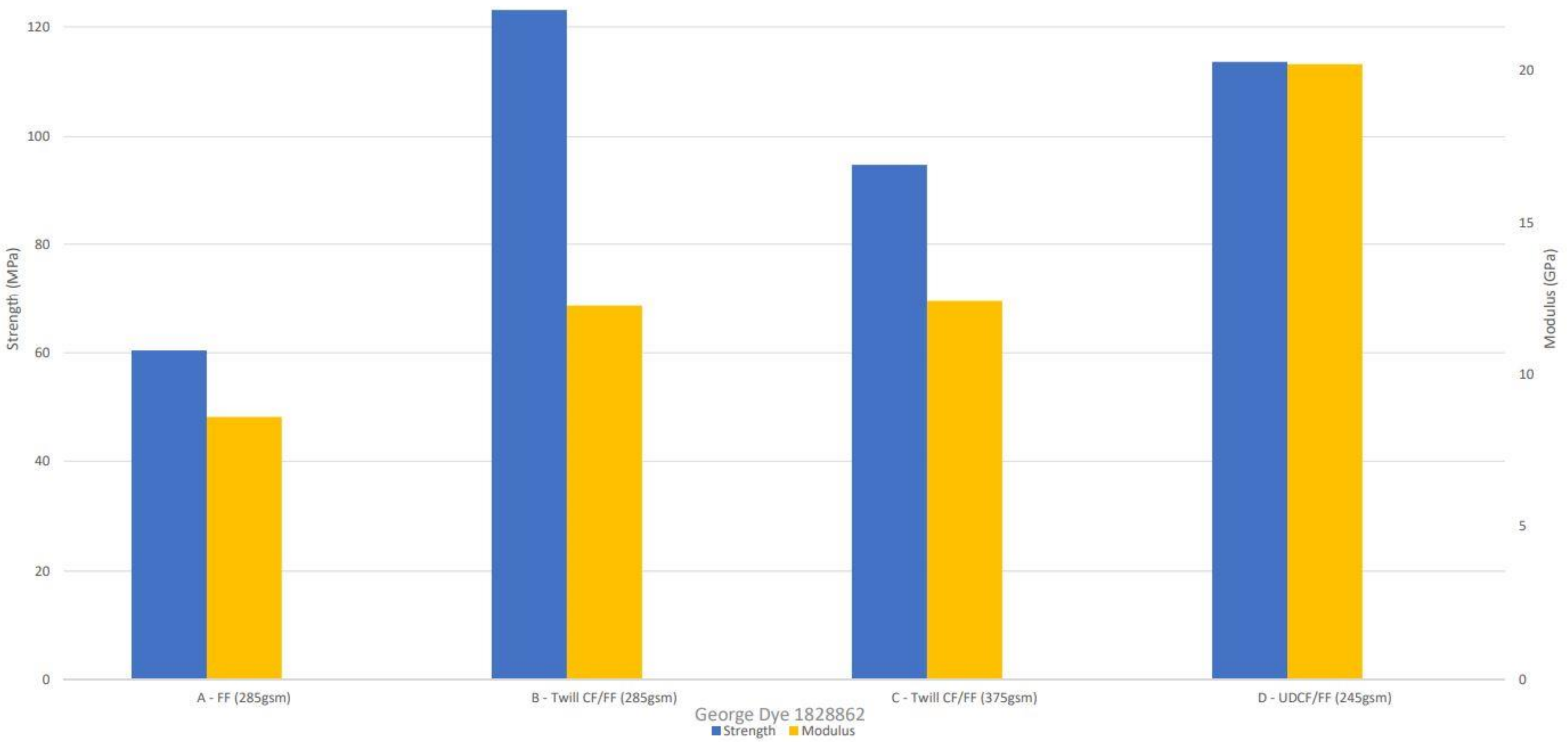
Lid manufacturing process

3 Filava- 4 Hybrid and 3 Filava plies

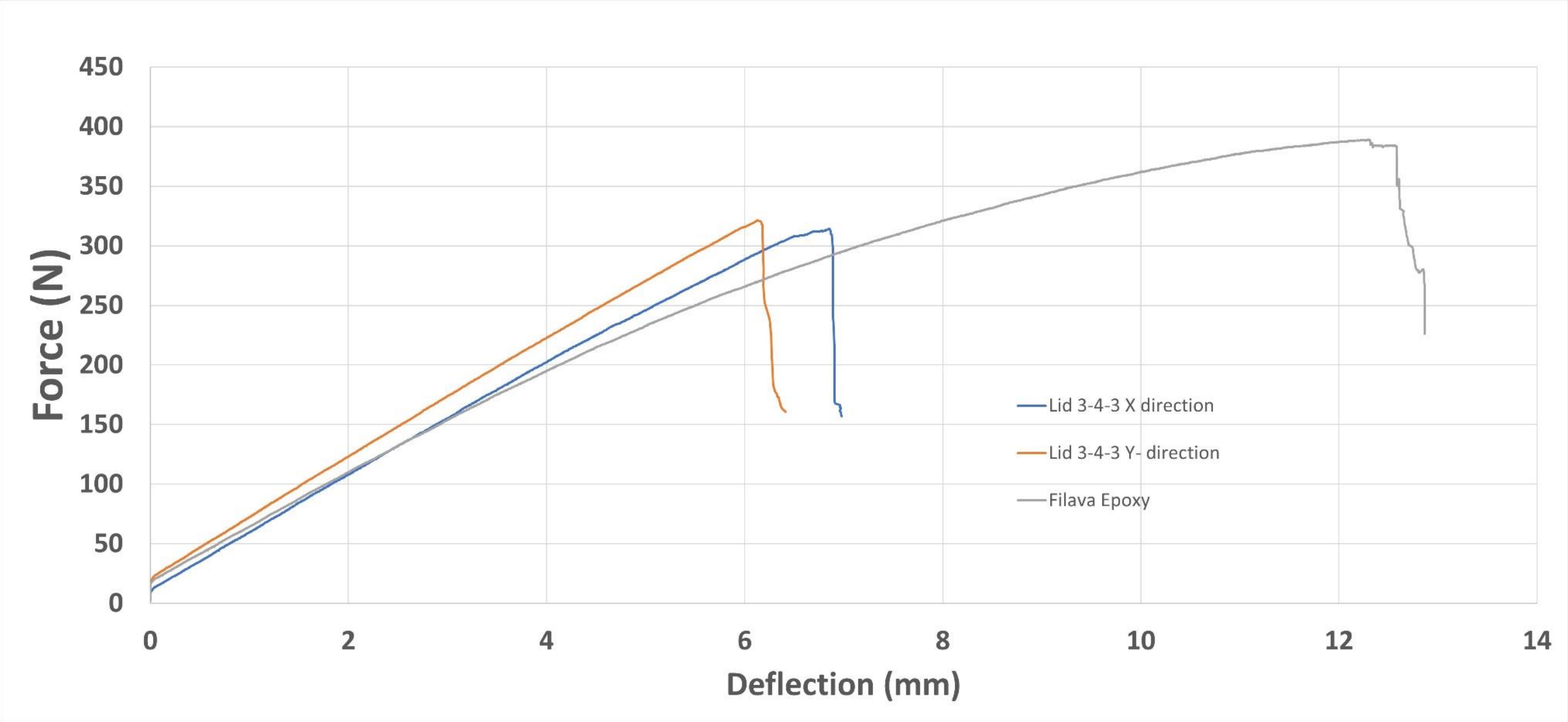
(620x520x3.5), density 1.668 g/cc, not density of CFRP is 1.4 g/cc



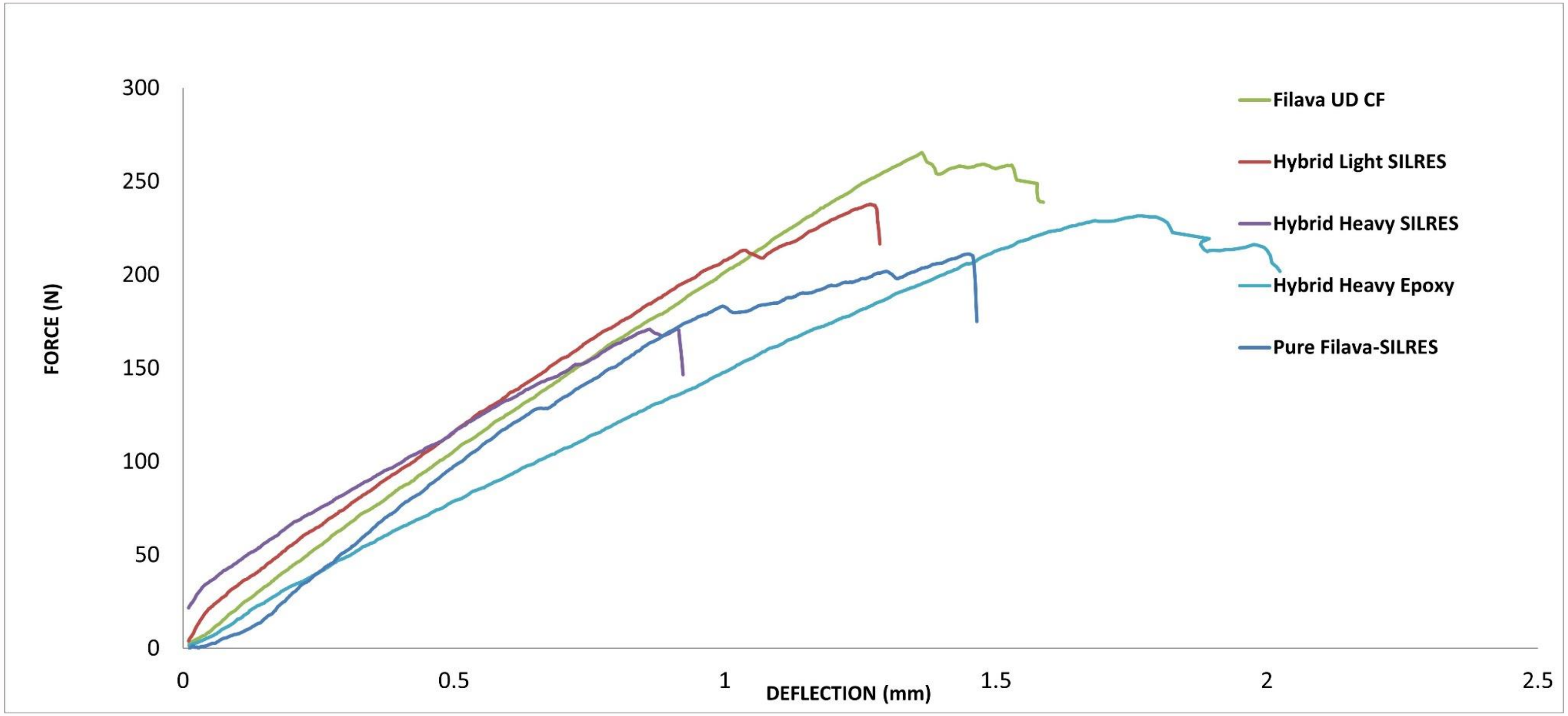
Flexural Strength(BS-ISO-14125) of all fabric in Silres-H62



Flexural strength comparison (Lid 3-4-3) to Epoxy resin matrix

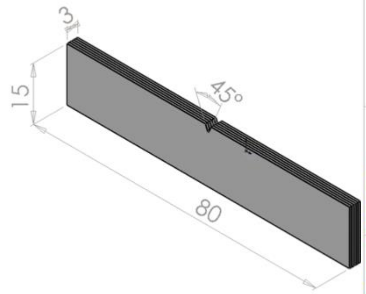


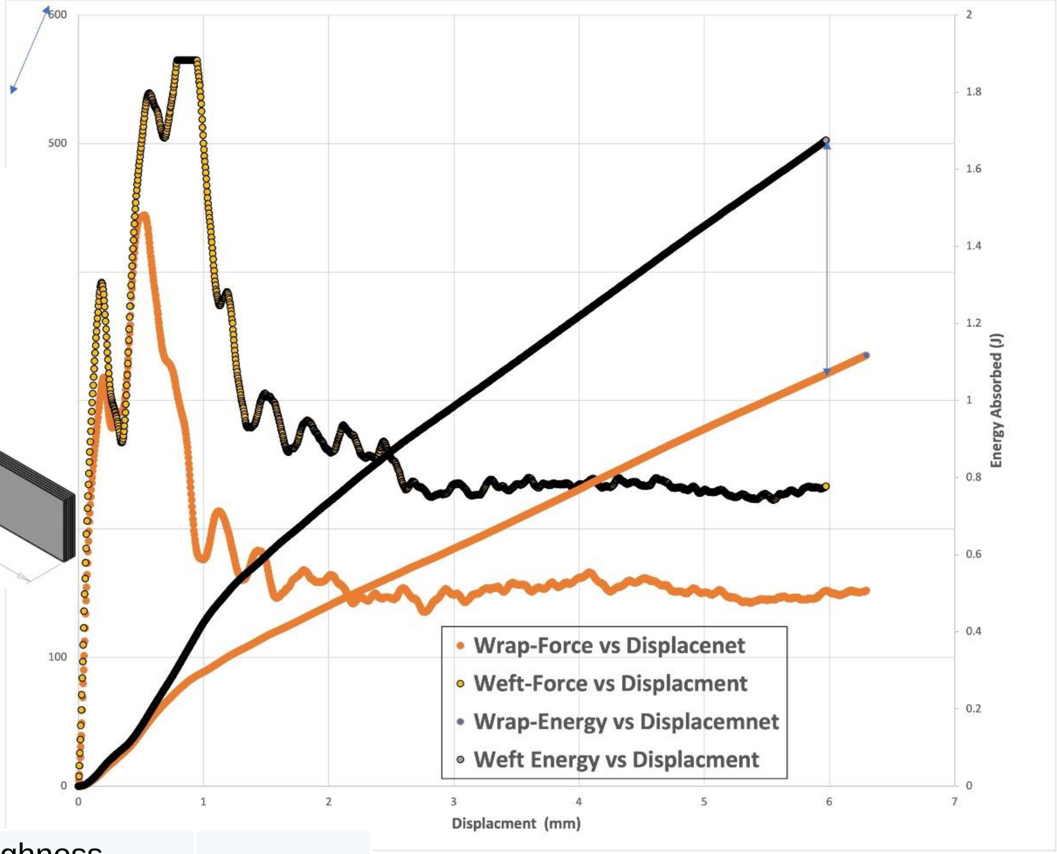
Impact resistance of all type of fabric in Silres-H62



Hence, it was our choice to use Filava UD CF

Impact strength (Lid)

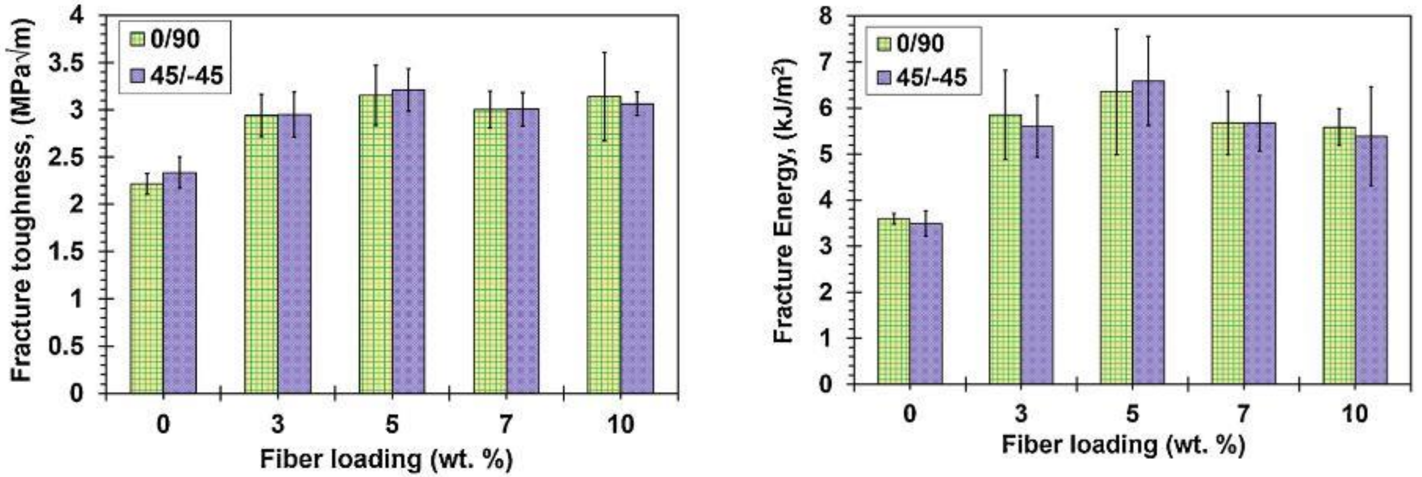




fracture energy			Fracture toughness		
GC weft	48374.9055	J/m2	Kc	24.09354408	MPa m^1/2
Gc wrap	33560.0907	J/m2		20.06791191	

Kc CFRP ~ 2.5 MPa m^1/2

Fracture Toughness of CFRP

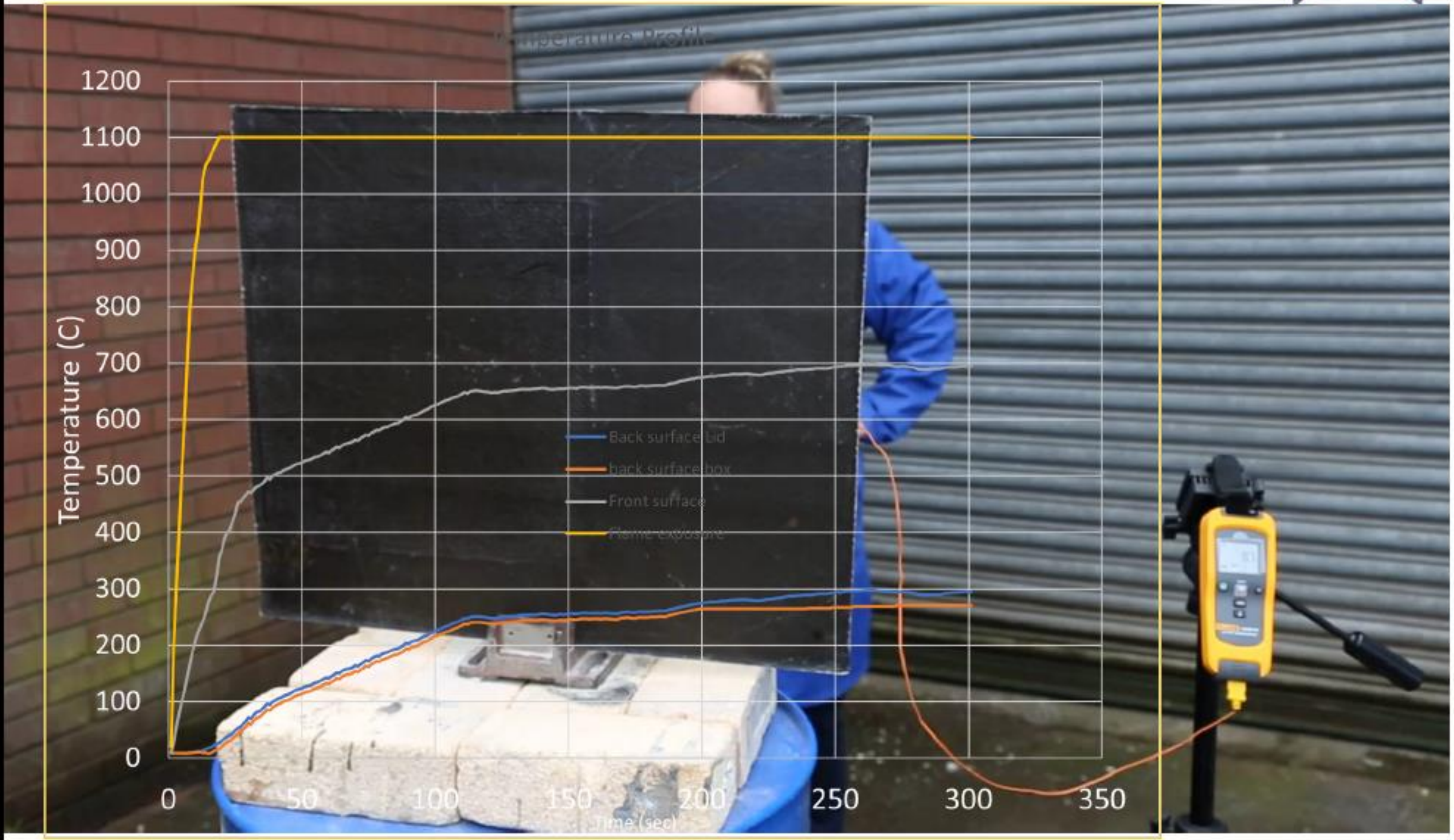


(a) Fracture toughness (b) Fracture energy

Fig. 8. Fracture toughness and fracture energy as a function of fiber loading for $45^0/-45^0$ and $0^0/90^0$ layer orientations.

Fracture toughness of carbon fiber reinforced composites
Et.al: E.Arafat Papon, Additive Manufacturing Volume 26, March 2019, Pages 41-52

Fire testing



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Compression test

Ultimate strength

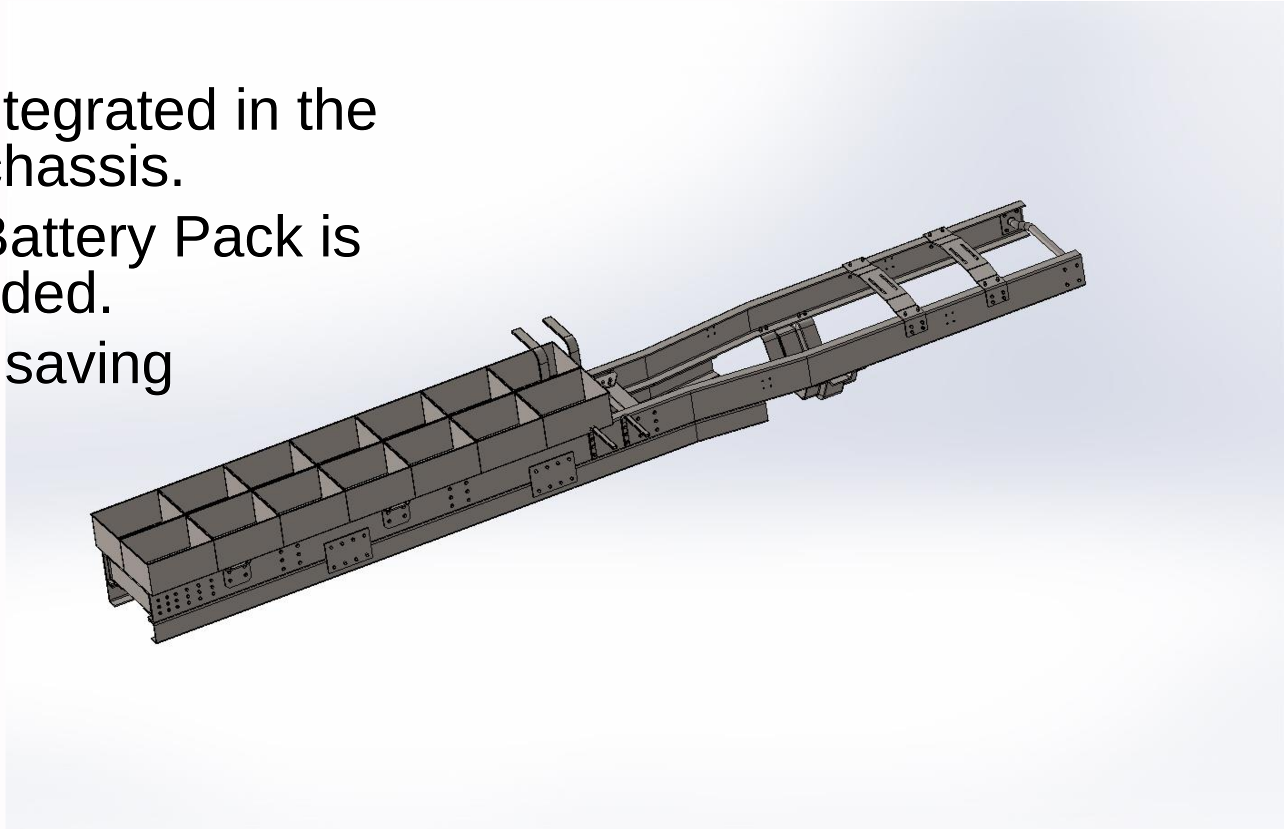
Fired Box: 4550/(260x150)= 0.1167 MPa
Unfired Box: 4050/(260x150)= 0.104 MPa

Final Module Assembly

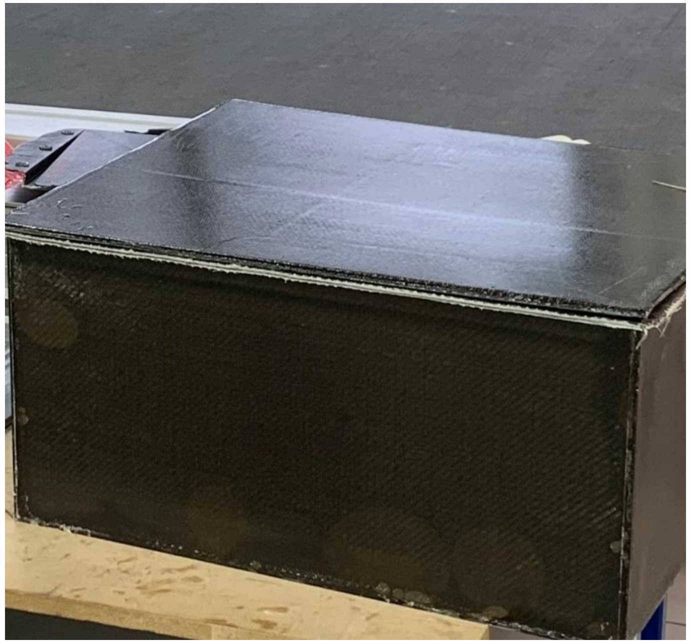
14 modules integrated in the truck chassis.

No external Battery Pack is needed.

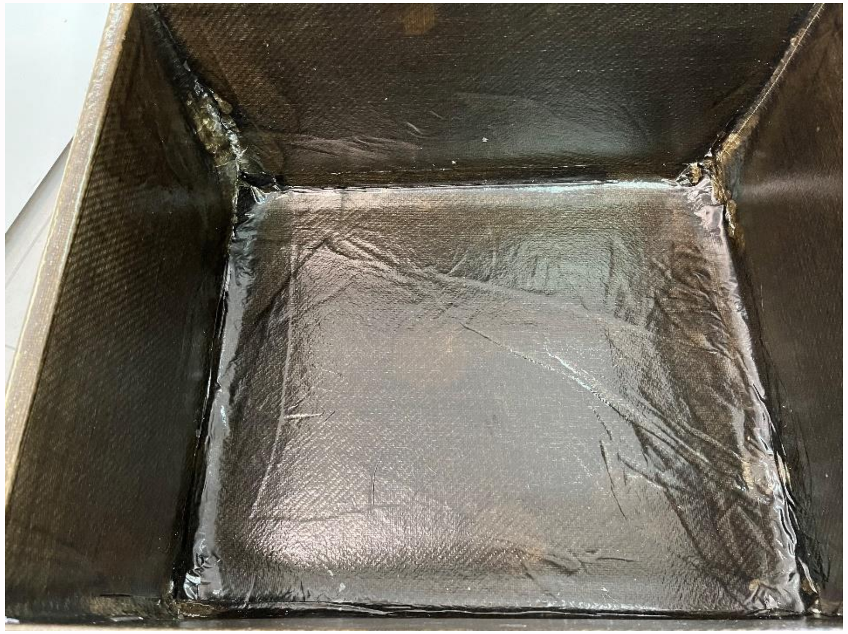
Great saving



Surface Finish



High pressure air intrusion



High resin content of Prepreg >50 wt%

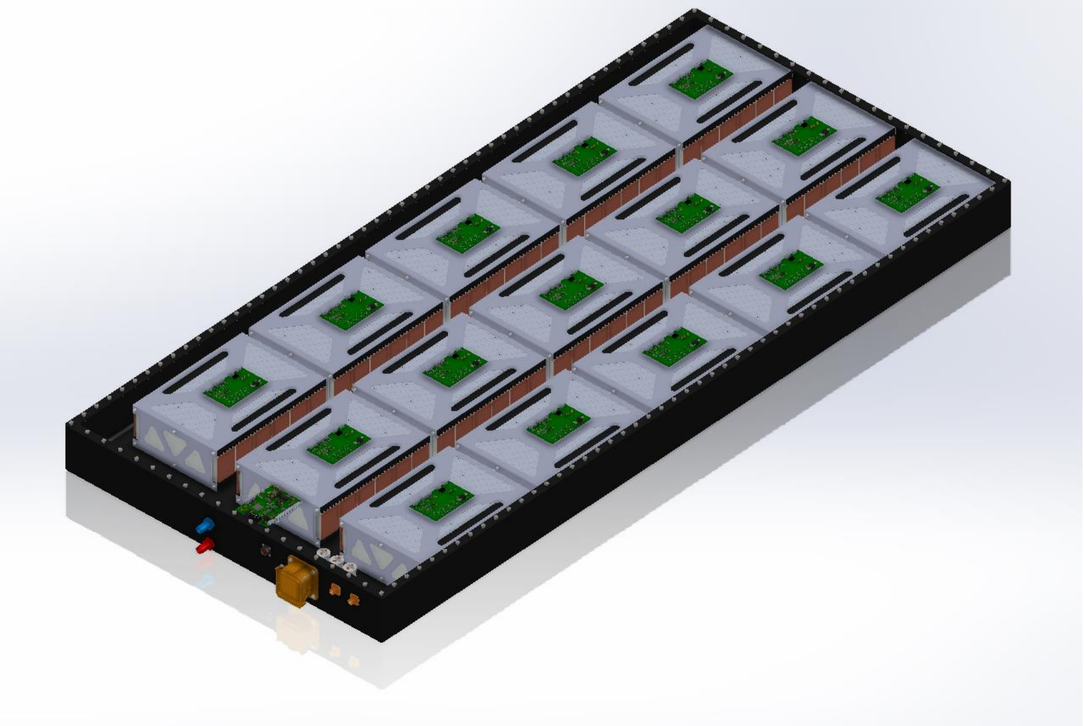
Result

- Proven fire proof and light weight composite
- Hybrid UD has compensate the weakness of Silres-h62 mechanical strength
- 5 time more impact resistance that like to like CFRP
- Stacked modules concept saving a lot in term of weight and cost in truck chassis design
- Great saving in fire testing (Local company cost £120 instead of £7000)
- Poor surface finish of the boxes evolve the need for change in the manufacturing process from autoclave to hot press.

Pack Preliminary Design

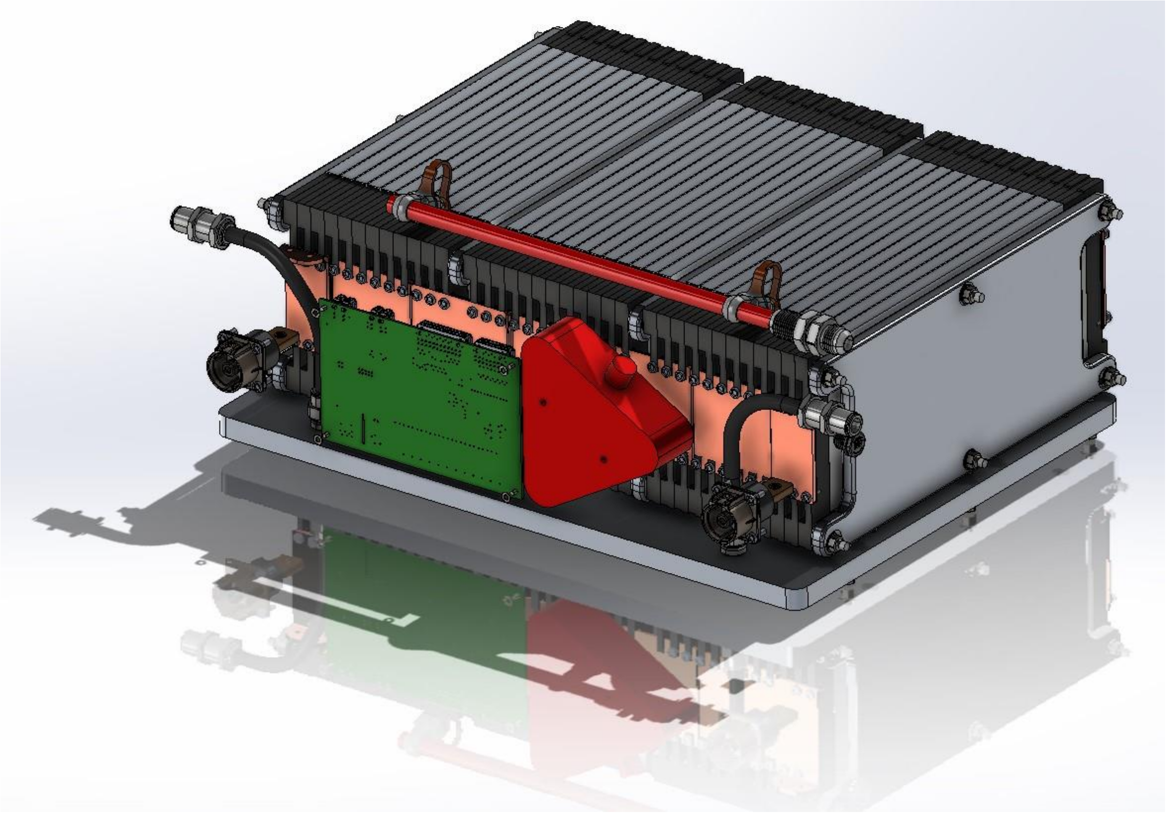
- Pack (based on a 3-pack battery system concept)
  - 100kWh per pack using 50Ah cells
  - 15 Modules/pack
  - Dimensions: 1200 x 2800 x 200mm
  - Weight approx. 650kg
  - Power = 500kW pk /pack
  - Nominal = 200kW /pack

  - Capacity confirmed with UK commercial bus manufacturer



Module Preliminary Design

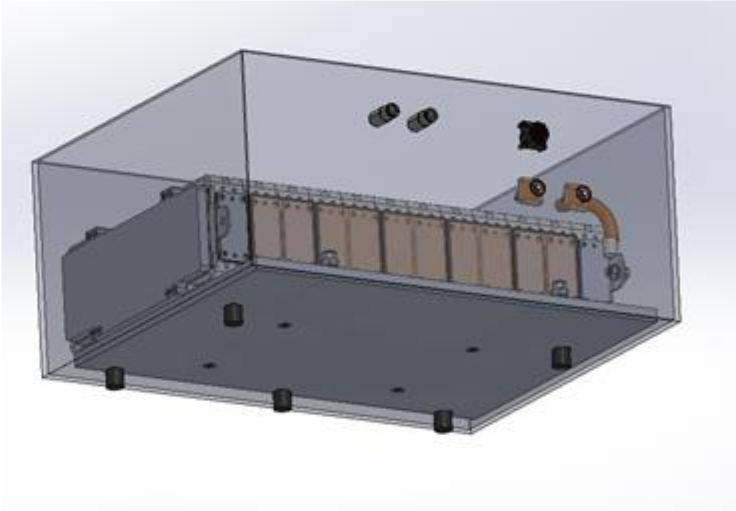
- Module
  - 36 cells
  - 6.6kWh
  - Dimensions 550 x 350 x 120mm
  - 50/50 Glycol Liquid Cooling via cold plate interface.
  - Monitored using MEP BMS
  - Module weight = 52kg in box (this includes the cooling plate and ancillaries)
  - Estimated real module weight (in full system) = 46kg (141Wh/kg at pack level)

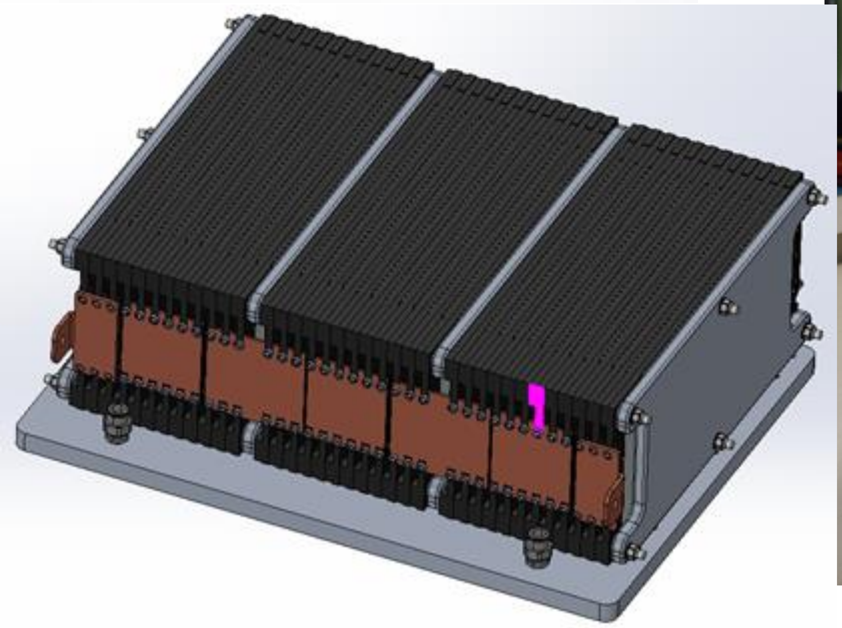


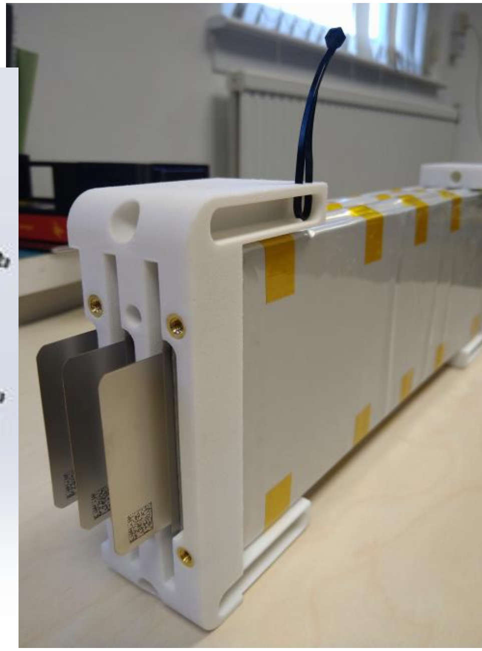
Project End Summary

T5.4 – Module build (see images)

- Cell carrier designs complete
- On design review, there are several snag items to revise before completing to support B model maturity
- Build was conducted using solid aluminium heatsink instead of cold plate. The cold plate was late due initially to backlog on orders, and laterally due to Covid lockdown of supplies from China. Parts due to arrive in late April/early May







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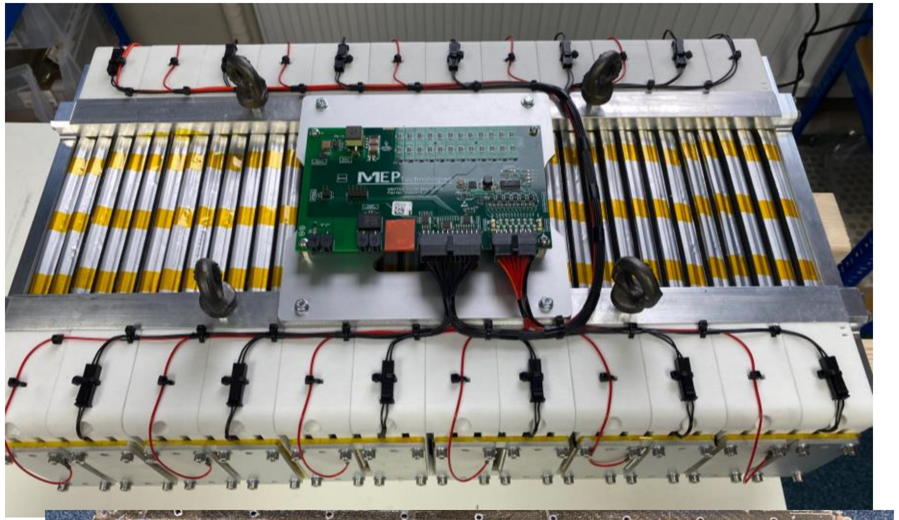
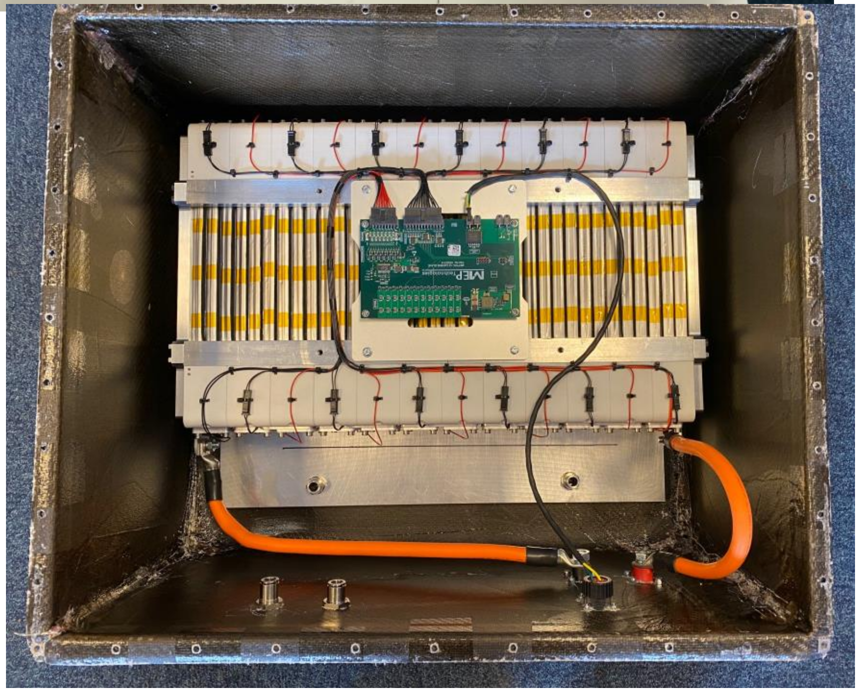
Project End Summary

T5.5 – Module Testing

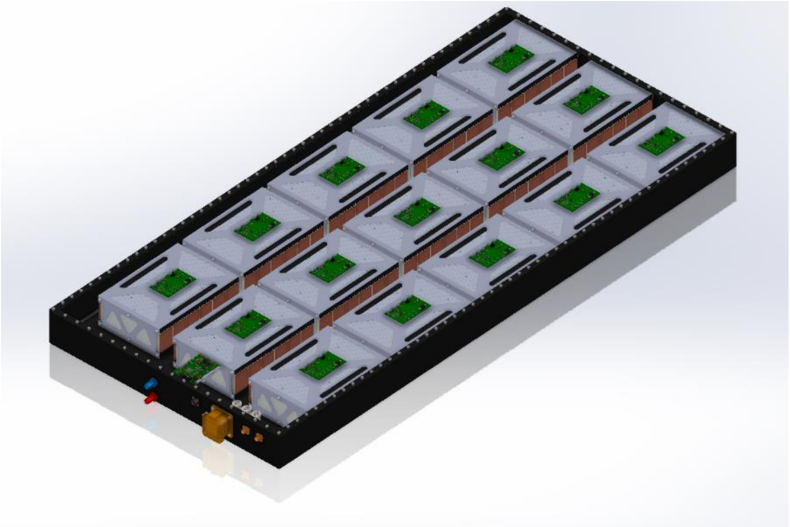
- Module was commissioned with solid aluminium cold plate.
- External BMS box supported module operation stand-alone
- Limited time for operational testing, but we conducted 2 complete charge and discharge cycles
- Discharge = 0.5C
- Charge = 0.4C
- See graphs opposite
- Setup with cell cooling heatsink worked well. Further study planned including the use of 2 different cooling compounds when fitted to the cold plate

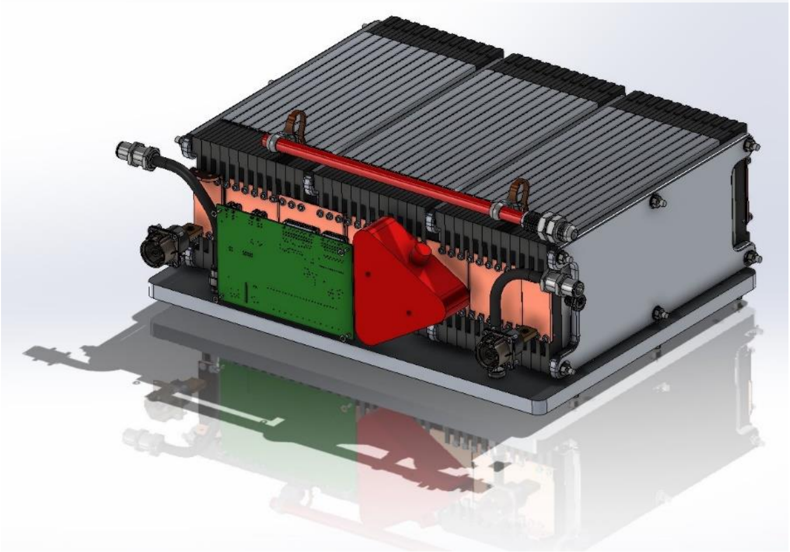




D1 - Commercial and technical targets

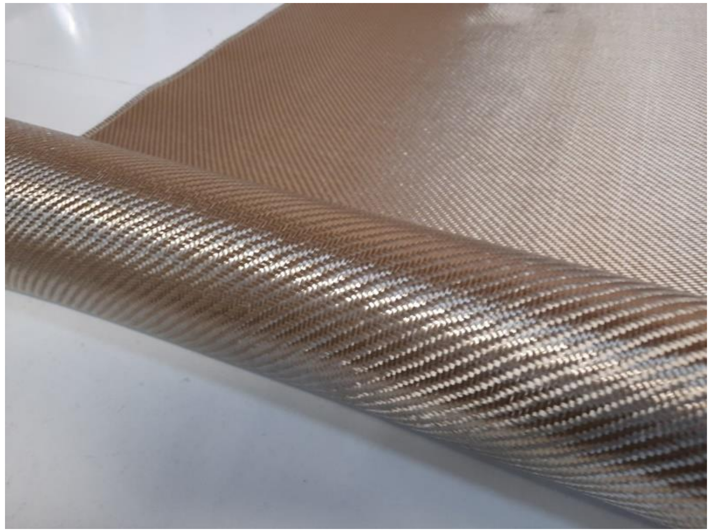
- Pack (based on a 3-pack battery system concept)
  - 100kWh per pack using 50Ah cells
  - 15 modules /pack
  - Dimensions 1200 x 2800 x 200mm
  - Weight approx. 650kg
  - Power 500kW /pack, Nominal = 200kW /pack
- Module
  - 36 cells /module
  - 6.5kWh
  - Dimensions 550 x 350 x 120mm
  - Weight approx. 52kg
  - 50/50 Glycol Liquid Cooling via cold plate interface
  - Monitored using MEP BMS
- Requirements confirmed with UK bus manufacturer





D2 - Temperature resistant fabrics

- 8 fabric types developed and tested
  - Filava
    - Temperature/fire resistant, impact performance, electrical insulating
  - Filava/carbon hybrids
    - Enhanced mechanical properties, tailored directional properties
  - Standard basalt and basalt/carbon hybrids
    - Lower cost options
  - Double fabrics (2.5D)
    - Reduced layup time, improved toughness/damage tolerance
  - Pitch carbon
    - High modulus, high thermal conductivity
- >600m manufactured for prepreg and composite trials



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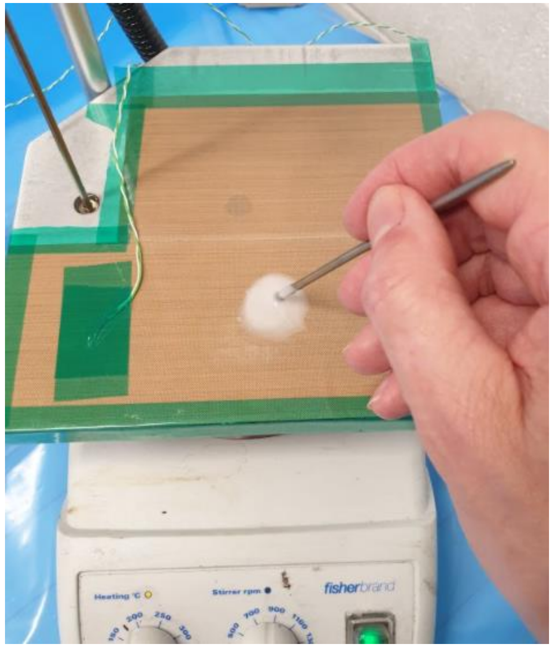
D3.1 - High temperature resin formulation

- 5+ polysiloxane resins sourced and tested
    - Also various additives, curatives etc.
- Silres H62 C selected as main project resin
    - 100kg sourced by UoW (despite supply shortages)
- Damisol 3551 identified as near equivalent
    - 20kg sourced by Carr as a backup
- Both resins have very good thermal properties
- Modifications to increase viscosity

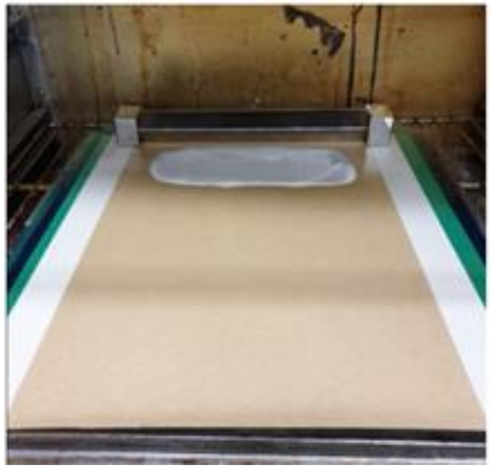
- Further work required to optimise resin characteristics for hot melt prepregging and vacuum assisted curing



D3.2 - High temperature prepregs

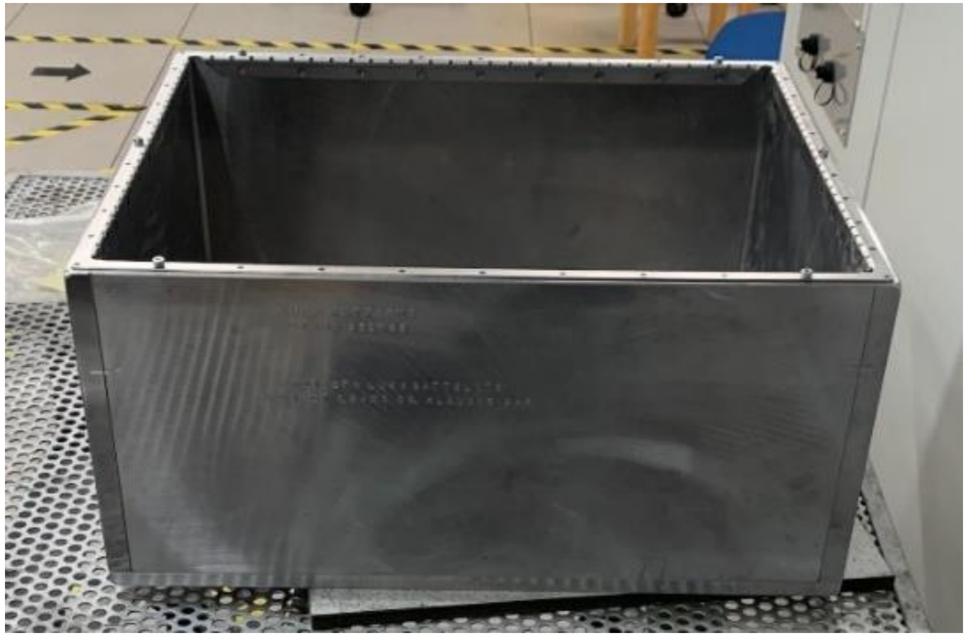
- Various prepregs developed and tested using the project fabrics and resins
- Lab scale to pilot scale
- Approx 120m^2 manufactured and supplied to UoW for composite testing and demonstrator enclosures
    - Silres H62 C + Filava
    - Silres H62 C + Filava/carbon hybrid
    - Silres H62 C + Filava/carbon UD hybrid

- Further work required to improve prepreg quality, tack and handling (pending the optimised resin)



D4.1 - Tooling for prototype enclosure

- Tooling designed and manufactured
- Stainless steel mould
  - High quality surface, durable, high temperature
- Titanium bolts for use in high pressure autoclave
- Novel moulded-in steel flanges for bolting box to lid



D4.2 - Prototype battery enclosures

- Composite laminate trials, mechanical tests and structural modelling to determine the best material and layup options
- 7 prototype enclosures and lids made with different material combinations and process adjustments
- Fire tests done on enclosure and lid
- Crush tests done on enclosures, before and after exposure to fire