BioComposites in Challenging Automotive Applications

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SUMMARY

This paper presents the results of a recently completed European Commission part-funded consortium project with the aim of developing biocomposites for challenging applications. This aim incorporates developing the material and processing approaches and evaluating demonstrator products. This paper gives the results of several automotive parts evaluated including automotive panels and structural beams.

Keywords: natural fibres, natural resins, structural tests, automotive panels and beams, environmental exposure

INTRODUCTION

The use of fibre-reinforced plastic composites in the automotive industry has grown significantly in recent years because of their low weight, design flexibility, corrosion resistance and cost-effectiveness. The use of continuous fibre composites and long fibre thermoplastics (LFTs) have been favoured for low volume, niche vehicles whereas chopped fibres in sheet or bulk moulding compounds (SMC and BMC) have strongly entered the high volume production markets [1]. Glass fibre is commonly used as the reinforcement, often in the form of random, chopped strand mats (CSM), and unsaturated polyester resin is a popular matrix. Currently, there is a significant drive to switch to more sustainable and renewable materials, whilst still reducing weight and cost and maintaining reliability. In addition, with some renewable materials, end-of-life vehicle issues are more easily addressed because the materials are biodegradable or easily recycled.

For composite materials made from renewable materials, the greatest advantage, environmentally, is to be gained by having natural fibres and natural resins. Natural fibres, such as hemp, flax and wood have already found applications in the automotive industry, primarily in non-structural parts such as interior panels, parcel shelves, etc. [2]. This is often because variability in the fibre properties can lead to variability of mechanical properties. In general, natural fibres are chopped and randomly distributed but they need to be used in mats or continuous fibre form to achieve significant advantages from reinforcement of the resin system. At present, the natural fibres are generally used with conventional resins such as unsaturated polyester and polypropylene, so the advantage to their use is limited [3-5].

Several natural resin systems (both thermoset and thermoplastic) have been considered as candidates for the automotive industry. Thermoplastic bio-resins such as polylactic acid (PLA), polyhydroxybutyrate (PHB) and starch-based polymers, originally targeted for food packaging have potential applications because of their biodegradable nature.

Thermoset resins derived from plant oils such as soybean and linseed are also under development for commercial application. The furan-based resins are being developed by TransFurans Chemicals under the trade-names BioRez™ and Furolite™ now are used in some interior panels [2]. The resins are synthesized from pre-polymers of furfuryl alcohol, which is derived from biomass sources including sugar cane bagasse. Furan resins offer a number of interesting properties such as high stiffness, fire resistance and chemical resistance to organic and inorganic acids. While this material is a natural, renewable material, it does not easily biodegrade.

Therefore, the gap in the technology that researchers are addressing is for the development of semi-structural, natural composites comprising both natural fibres and resins utilising manufacturing techniques that can be considered for high volume production. This topic was one of the themes addressed in a recently completed Integrated Project for SMEs entitled "BioComp", supported by the European Commission through the Sixth Framework Programme (FP6) and coordinated by Fraunhofer ICT. This project aimed to develop both thermoset and thermoplastic natural fibre/resin composites with "challenging" properties. The term "challenging" included good chemical resistance, surface finish, complex manufacturing high mechanical properties (stiffness, impact, strength, etc.) and addressed a number of industries including medical devices, industrial, automotive, marine and construction. To verify these composites, several model products and demonstrators were produced and evaluated using modelling and structural tests.

This paper presents some of the evaluation results of the model products within the BioComp project that had an automotive focus. This is achieved by presenting a summary of three case-studies on the evaluation of the model products. These three case-studies are an LFT moulded foot-well panel, an injection moulded structural beam and a hand-laid up Panel. This paper discusses the evaluation programme conducted by MERL within the project, with the aim to assess if these products could meet the improvements desired. Where available, the testing of these different products was compared to materials they may replace such as GRP. Finite element analysis (FEA) was also carried out to assess if modelling could be usefully used for biocomposite structural evaluations. The development and screening of the materials and the design and manufacturing of the components will be presented in more detail in a forthcoming publication encompassing the entire project [6].

CASE STUDY 1 – LFT Panel

ICT Fraunhofer have developed a manufacturing technique for rapid manufacture of LFT mouldings [7]. The technique is a direct process of in-line compounding using two twin extruders where the resin is mixed in with additives and the fibres are fed in. The extrudite is cut to length and the pellets compression moulded to shape. Within the BioComp project, they used this technique to produce natural fibre and resin panels using a mould previously used to produce an in-board foot-well panel suitable for a car such as the SMART car, Figure 1. Several panels were manufactured using glass/PLA, flax/PLA, hemp/PLA and cellulose fibres/PLA.

Panels such as this one have several key performance requirements that are specified to ensure the panels are fit for purpose. One of the key specifications for this panel was that the maximum deflection must be less that 11.5mm with a 1.2kN load placed on the concave side. To determine if the BioComp panels met this requirement the different panels were modelled and structural tests were performed.

Experimental Work

The first step was to identify how the panel was supported in the vehicle so that a test fixture could be designed and boundary conditions added in finite element modelling. The panel was supported along three lengths, bolted in two positions and pinned. A frame to simulate this loading was fabricated and the panel mounted and loaded in flexure using a metal plate to simulate a foot on the panel, Figure 2. Three displacement transducers were used around the panel to measure local displacements along with the displacement of the loading cross-head that could be compared with the finite element analysis.

Figure 1 Flax/PLA interior floor-well panel.

Figure 2 Frame for holding the foot-well panel

Table 1 Material properties for modelling foot-well panels

Material	E (GPa)	Tensile Strength (MPa)
Flax/PLA	4.4	46.0
Regenerated cellulose/PLA	3.7	63.0
Hemp/PLA	2.7	36.3

Finite Element Analysis

A shell finite element model of the panel was developed using Abaqus/CAE software using the CAD file supplied by ICT. The thickness of the actual panels tended to vary locally, an average thickness of 3mm was used for the model. The loading plate and supports shown in Figure 2 were modelled as illustrated in Figure 3. The materials were modelled as isotropic because the fibres were chopped and randomly distributed. The properties obtained within the BioComp project and given in Table 1.

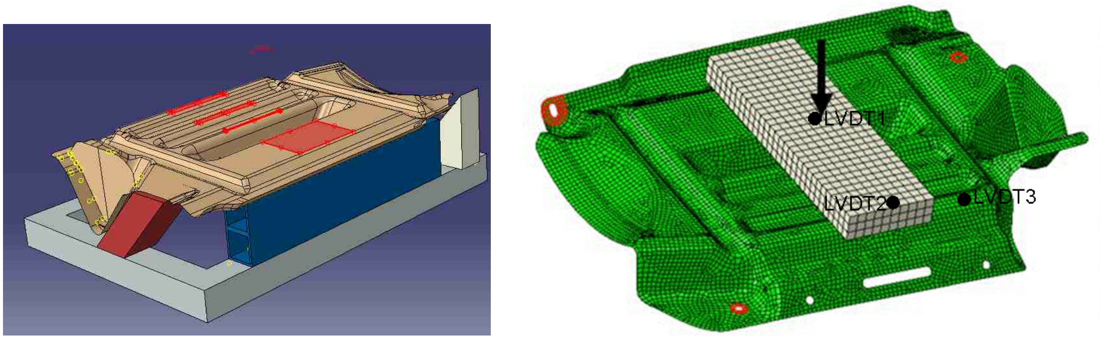


Figure 3 Finite element model and boundary conditions for foot-well panel

Results

The experimental and FEA load-displacement results for the flax/PLA panels are shown in Figure 4. The largest displacement was observed at LVDT3 at just over 9mm, well within the maximum design limit of 11.5mm at 1.2kN. Also shown in Figure 4 are the FEA predictions for LVDT2 and 3. These plots somewhat underestimate the final displacement values but catch the trend of the displacement very well. The underestimate may well have arisen from the average thickness assumption.

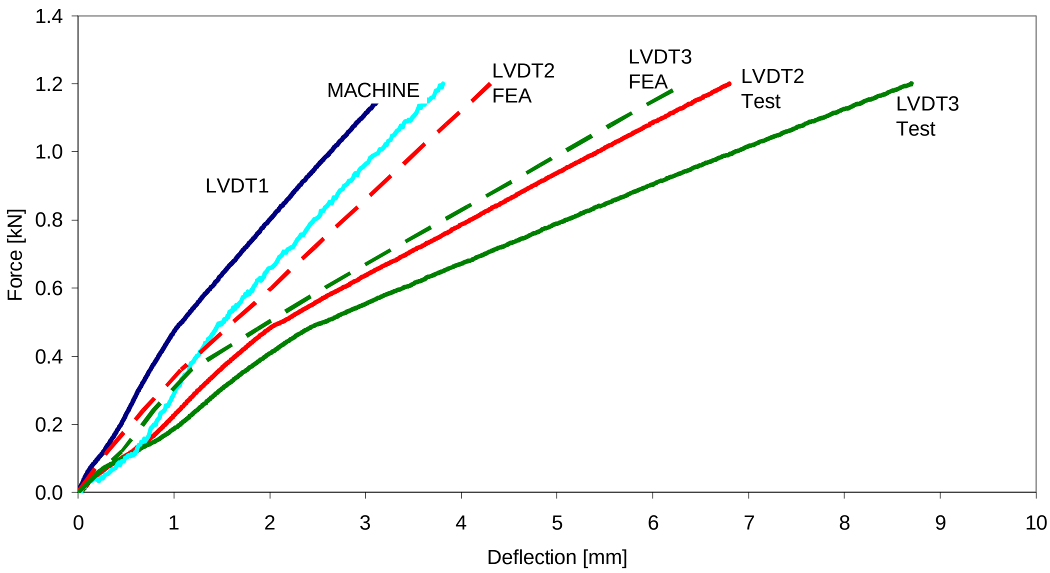


Figure 4 Finite element model and boundary conditions for foot-well panel

A comparison of LVDT3 displacement for all the materials tested is given in Figure 5. Several features of the test can be seen here. In the early stages of loading there is a larger stiffness, this is a result of some of the panels being warped following manufacture and needing additional force to bed to the fixture. In addition, as the test progressed, a stick-slip behaviour begun shown by the saw-tooth type loading curve. This was a result of the panels binding on the fixture during deflection. The final results show that the stiffest panel was the hemp and the least stiff the Cellulose/PLA. The glass/PLA panel may well be considered a benchmark material and had the same performance as the flax/PLA panel.

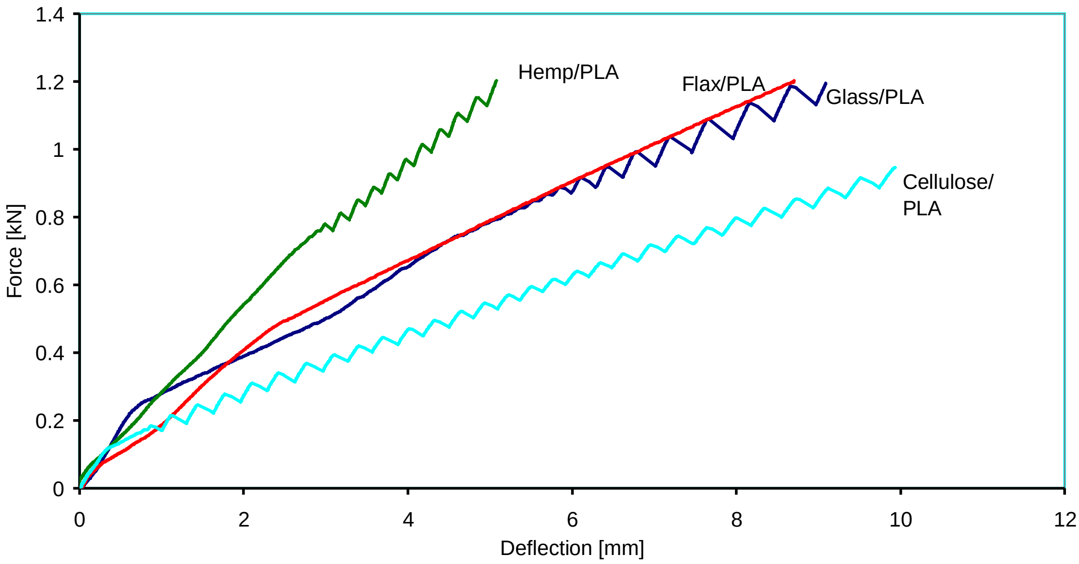


Figure 5 Comparison of different BioComp materials

Overall it can be summarised that the manufacture, test and analysis of these panels have made the first steps towards demonstrating BioComp materials are suitable for structural applications.

CASE-STUDY 2- AUTOMOTIVE STRUCTURAL BEAM

To evaluate new materials and manufacturing methods, the automotive industry often tests generic structural configurations. One such configuration, called simply "structural beam", Figure 6a, was selected to evaluate BioComp materials against benchmark synthetic oil based materials. Two materials were evaluated experimentally, a glass/filled polypropylene and flax/PLA. The beams were injection moulded and manufactured at ICT Fraunhofer and supplied to MERL for testing.

Experimental Work

No clear specification exists for these beams, so they were tested in three point bending for comparison to each other. The test fixture is shown in Figure 6b.

Figure 6 (a) Structural Beam (b) Beam in three-point bend fixture

The span of the test in Figure 6b was 300mm and a constant displacement was applied at a rate of 2mm/min until failure. Five samples of each configuration were tested.

Representative load displacement traces are show in Figure 7. The flax/PLA beams had an average failure load of 2.11 kN compared with 1.33kN for the glass/PP beams. The latter showed significantly more ductility than the BioComp materials. In addition, the failure modes for the two materials were quite different as illustrated in Figure 8 where the flax/PLA material experienced a brittle failure and the glass/polypropylene a ductile failure not actually resulting in rupture of the beam.

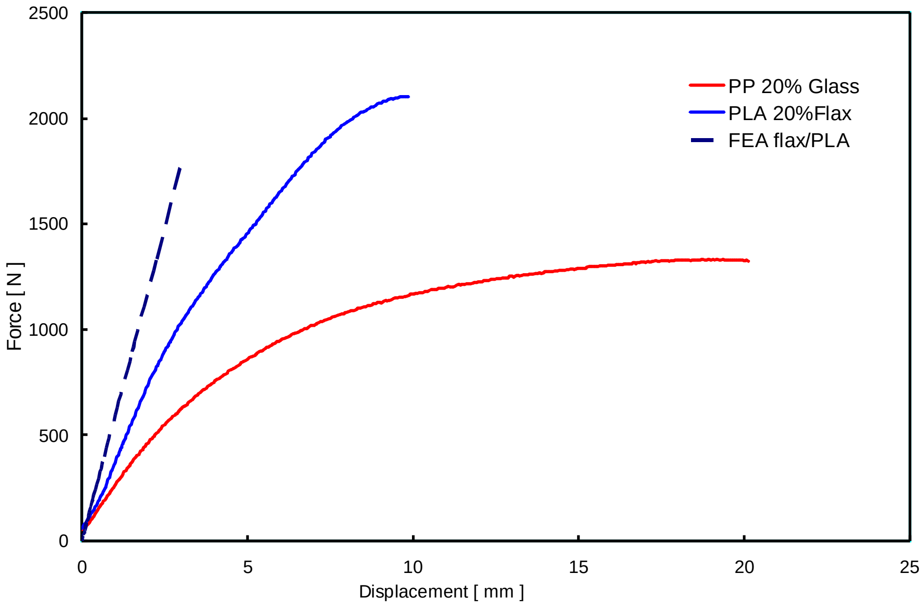


Figure 7 Load-displacement curves of the structural beam

While the two failure modes are different, the additional stiffness and failure load of the BioComp materials, demonstrate that these materials are viable candidates in structural applications and less materials would be needed with the BioComp material to achieve the same stiffness and maximum load.

Figure 8 Failure modes of the flax/PLA and glass filled/polypropylene beams

Finite Element Analysis

Finite element analysis was used to compare deflections of the beams with the experimental work. A 3-D Model was developed and solved using the Abaqus code. The materials were considered to be isotropic with the flax/PLA properties given in Table 1 and the loading was three-point bending to simulate the test conditions. The deformed mesh is shown in Figure 9. The FEA load-displacement curve is shown in Figure 7 showing that the beam was less stiff experimentally. The experimental displacement measurements would also include local crushing under the loading rollers, Figure 8 which the FEA did not. The maximum stress per unit load away from the loading rollers was 0.016 mm^{-2}. Assuming a failure strength of 46MPa, Table 1 this gives a predicted failure load of 2.9kN. A non-linear analysis would give a lower predicted failure load.

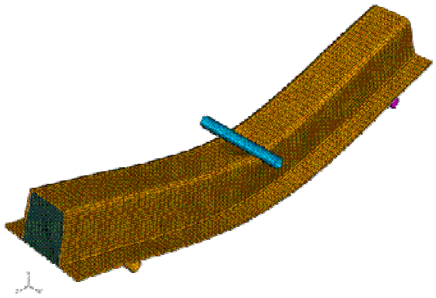


Figure 9 3-D Finite element representation of the structural beam test

CASE STUDY 3 – Body Panels

An external panel from a low-volume utility vehicle was used to demonstrate and evaluate the development of high-performance furan-based biocomposites using a single cavity epoxy board mould as the tooling [*] using vacuum bagging. The resins were supplied by TransFurans Chemicals, Belgium and the test samples and prototype panels were manufactured by NetComposites Ltd. UK. Two grades of panels incorporating furan resin were investigated: A two-part, low viscosity resin suitable for use with glass fibres (chopped strand mat) and a single part prepreg system for use with natural fibres. In addition standard glass fibre reinforced polyester panels were made up to provide benchmark testing. These materials are summarised as below and the panel is shown in Figure 10.

BIOCOMP A	Four layers of 450gsm glass CSM and the 2-part furan resin
BIOCOMP B	Four layers of furan-flax prepreg in a balanced cross-ply lay up $[0/90]_S$.
GRP	Four layers of glass CSM and polyester resin

Figure 10 Utility vehicle Panel and BioComp Prototype

Experimental Work

The performance specification for such a panel covers several aspects including mechanical integrity, impact resistance, environmental resistance, surface finish, acceptable cost at low production volumes (e.g. 200/year). A test and finite element analysis programme was carried on these panels to compare the full BioComp panel and the glass furan panel with the GRP benchmark. These results were partly reported in Reference [8]. The mechanical integrity tests were conducted before and after exposure to water and included:

- Impact to represent stone and debris impact
- Bolt bearing test to represent attachment of the hinges (not reported here [8])
- Fastener pull through tests to represent the locking catches

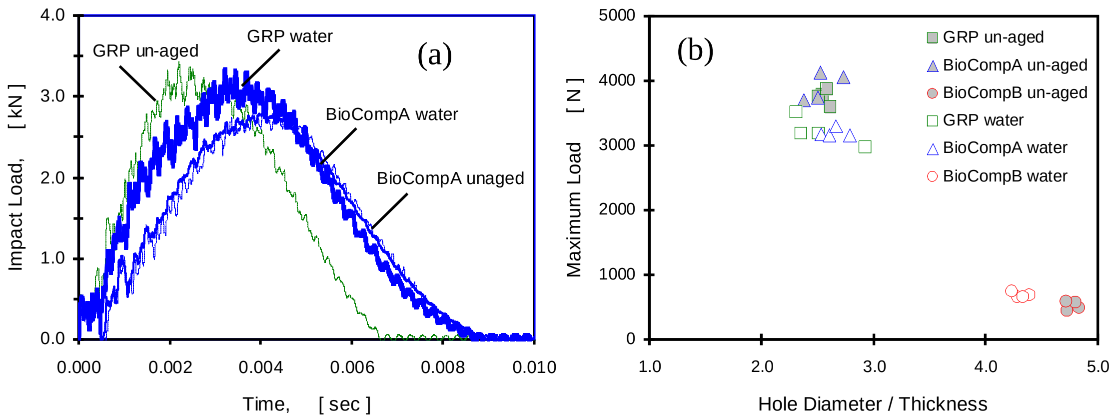
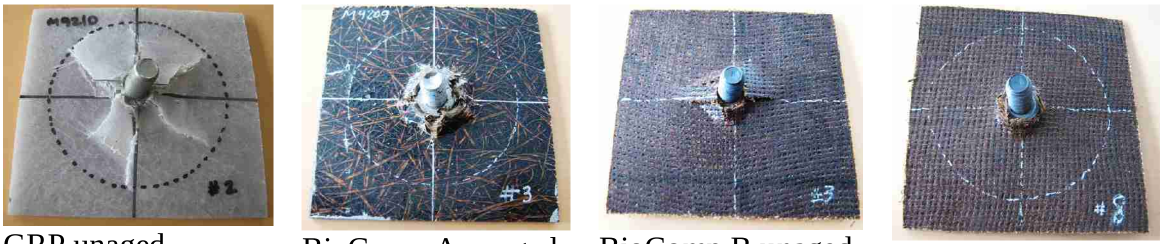


Figure 11 (a) Impact Force versus time (b) Fastener pull-through load versus hole size

The maximum impact force was used to assess the impact response of the different materials, Figure 11a. For similar impact energies (per unit thickness) the GRP samples showed marginally higher impact forces than the BioComp A samples, but the maximum impact force was not affected by water immersion. However, the saturated GRP samples have higher impact duration than the dry ones indicating higher levels of impact damage for these samples. This trend was not observed for the case of the BioComp A samples where the maximum impact force was lower than the GRP panels but remained unchanged with saturation. The BioComp B materials showed very little resistance to impact and could not be compared.

For the fastener pull-through tests, there was no significant difference between the GRP and BioComp A materials in maximum pull through load, Figure 11b. However, the mode of failure for the two materials was different, Figure 12. The GRP samples showed a bending type failure, with cracks initiating around the fastener and propagating towards the support of the sample, while BioComp A samples presented a pure pull through failure. After water immersion there was a slight drop in the maximum pull load but no apparent change in the mode of failure. The BioComp B was found to have fairly poor pull through strength. The un-aged samples behaved in a brittle manner and a bending type failure occurred. These resins are particularly hydrophilic resulting in swelling and a more ductile behaviour.



GRP unaged | BioComp A unaged | BioComp B unaged | BioComp B saturated

Figure 12 Fastener pull through failure modes

Finite Element Analysis

A detailed finite element analysis was conducted on these panels to simulate a specific loading case: The accidental opening of the panel with one of the securing bolts still in place. Other load cases, not reported here included both bolts in-place and thermal loading. The GRP and BioComp A panels were modelled with as isotropic materials with a Young's Modulus of 9.GPa and 7.2 GPa, respectively. A Poisson's ratio of 0.35 was used for both materials. The von-Mises stresses are shown in Figure 13. For the GRP panel the maximum stress was 413 MPa compared to 375 MPa for the BioComp A panel. Based on the failure strength of these materials, this would require a 58 N load for the GRP panel and a 38N load for the BioComp A panel. Consequently, the BioComp A panel would need to be manufactured thicker to have the same performance.

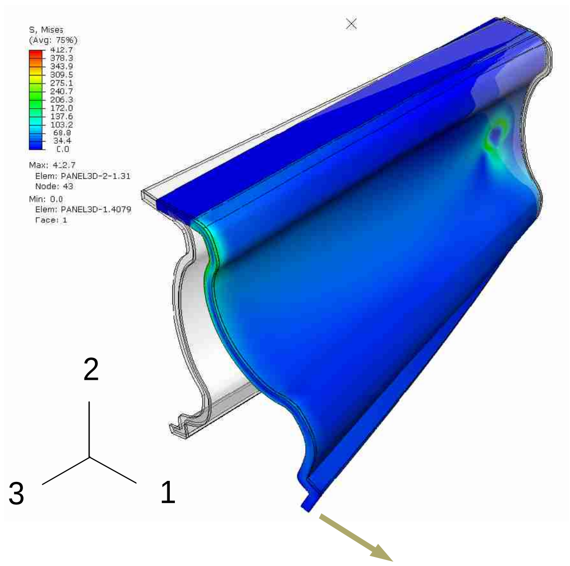


Figure 13 Von-Mises Stresses

The results in this case study gave mixed results – with the glass reinforced Bio-resin composite behaving at least as well as the GRP materials. However the all biocomposite material did not perform well. Part of the reasons for the latter was in the difficulties in manufacturing the material and achieving a good wet-out of the fibres. As a result further materials development has continued focussing on a mat prepreg material [9].

CONCLUDING REMARKS

The BIOCOMP project has investigated many different applications requiring different performance of the bio-composite (both fibre and resin) and three case-studies have been presented here focussed on automotive applications. Overall, the project has demonstrated a variety of manufacturing methods can be used to make a variety of geometries. In this paper, these methods included LFT moulding, injection moulding and vacuum bagging.

In general it can be summarised:

- The BioComp materials tested in this work all performed adequately structurally and compared well to the benchmark materials where available.
- The consistency and repeatability of BioComp materials was very good. In the past these materials have experienced wide scatter in the mechanical properties because of variation of fibre properties. This work has demonstrated that variability is less of an issue for the materials studied here.
- While bio-composites tend to be more brittle and hydrophilic than hydrocarbon based resins – these are properties that can be managed during the design phase. While this may result in increased material and weight, this needs to be balanced with the advantages of using sustainable materials.

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