



Wales Institute of Science and Art

Materials Testing and Sustainability of Composites for Motorsport & Automotive Industries

Automotive Materials & Sustainability (ACHA6012)

Benjamin Hilton

2220555

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1 Introduction

Composite materials are increasingly important in automotive and motorsport engineering because they offer high strength-to-weight ratios and can be designed for specific performance requirements. In these industries, reducing vehicle mass is a major priority because it can improve acceleration, braking, handling and energy efficiency. For road vehicles, lightweighting can also contribute to reduced energy consumption and lower emissions during use. (William D. Callister and David G. Rethwisch, 2015)

A composite material is made from two or more different constituents that work together to produce improved properties. In fibre-reinforced polymer composites, the fibres provide most of the strength and stiffness, while the matrix binds the fibres together, transfers load between them and protects them from damage. This combination allows composites to achieve mechanical properties that are difficult to obtain from the individual materials alone.

However, the use of composites also creates sustainability challenges. High-performance composites such as carbon fibre can require energy-intensive manufacturing processes, and many thermoset composite systems are difficult to recycle at end of life. As a result, there is increasing interest in bio-resins, recycled fibres and natural fibre reinforcements such as flax, which may reduce environmental impact while still providing useful mechanical performance.

The aim of this report is to investigate the mechanical performance and sustainability potential of selected metallic and composite materials for automotive and motorsport applications. This will be achieved by reviewing relevant composite materials, analysing sustainability considerations, carrying out tensile testing, comparing the experimental results with supplier data, and making recommendations for suitable material applications.

2 Literature Review

The main composites used in automotive and motorsport are carbon, glass, aramid and natural fibre composites. Carbon fibre is the main high-performance option because it has high strength, high stiffness and low density, making it suitable for monocoques, aerodynamic parts, bodywork and crash structures (Mallick, 2007). Glass fibre reinforced polymer is cheaper and offers good corrosion and impact resistance, so it is often used in road vehicle panels and semi-structural parts (Clyne and Hull, 2019). Aramid composites, such as Kevlar, are useful where toughness and impact resistance are important, including protective panels and hybrid laminates. Natural fibre composites, such as flax and hemp, are more suitable for lower-load parts such as interior panels, trim and covers because their properties are more variable due to moisture, fibre quality and growing conditions (Mohd Ghazali, Pickering and Le, 2015).

Composite performance depends strongly on fibre orientation and reinforcement structure. Woven fabrics have organised fibres in warp and weft directions, giving clearer load paths and better tensile performance when aligned with the load. Non-woven reinforcements contain shorter or more randomly orientated fibres, which improves formability but usually reduces strength and stiffness. Therefore, woven composites are more suitable for structural or semi-structural parts, while non-woven composites are better suited to lower-load panels, cosmetic parts, recycled fibre products and complex moulded shapes.

Manufacturing method also affects quality. Prepreg lay-up gives good control of resin content and fibre alignment, making it suitable for high-performance motorsport parts, but it is expensive and labour-intensive (Campbell, 2010). Resin Transfer Moulding is more repeatable for automotive production because resin is injected into a closed mould containing dry reinforcement (Advani and Hsiao, 2012). Vacuum infusion is a lower-cost method that uses vacuum pressure to draw resin through the fibres and reduce trapped air. Hand lay-up is simple and low cost, but less repeatable because resin content and consolidation depend heavily on operator skill.

Overall, composite selection depends on fibre type, reinforcement structure, manufacturing method, cost and application. CFRP gives the highest performance, GFRP offers a cheaper option, aramid composites provide toughness, and natural fibre composites are best suited to lower-load applications.

3 Lifecycle Assessment (LCA)

The sustainability of composites must be assessed across their full lifecycle, from raw material production to end-of-life disposal. In motorsport, being lightweight is valuable because lower mass improves acceleration, braking, cornering and lap-time potential. This explains the continued use of CFRP in monocoques, crash structures, aerodynamic parts and bodywork. However, CFRP has a high production burden; reports that carbon fibre production is about 14 times more energy-intensive than conventional steel production. Therefore, CFRP is most justified where the performance gain or use benefit outweighs its manufacturing impact (Das, 2011) .

Aluminium provides a useful lifecycle comparison with composites. Primary aluminium is energy intensive, but recycled aluminium requires only 8.3 GJ/t compared with 186 GJ/t for primary aluminium, giving a 95.5% energy saving (*international-aluminium*, 2024). Aluminium can also be recycled repeatedly while retaining its main mechanical properties, provided alloy composition and contamination are controlled. This gives aluminium a stronger end-of-life route than thermoset composites.

Conventional thermoset CFRP has greater end-of-life challenges. Its manufacture requires fibre production, resin manufacture, moulding, curing, vacuum consumables and trimming, which can create offcuts, rejected parts and single-use process waste. Once cured, the resin matrix cannot be remelted like a metal. Mechanical recycling can grind composite waste, but this shortens fibres and reduces material value. Pyrolysis and solvolysis can recover carbon fibres, but they require specialist equipment and may reduce fibre surface quality. Therefore, composites are harder to return to their original performance level and are often reused in lower stress applications (Oliveux *et al.*, 2015).

Bio-resins reduce one part of this impact by replacing some fossil-derived resin chemistry with bio-based alternatives. explains that bio-based epoxy systems can replace fossil-based epichlorohydrin with bio-based epichlorohydrin produced from renewable glycerol, while other bio-epoxy routes use renewable feedstocks such as vegetable oils, saccharides, lignin and cardanol. This reduces dependence on petroleum-based resin chemistry, but it does not fully solve end-of-life issues if the final resin is still a thermoset (Chen, 2025).

Recycled carbon fibre offers a stronger route for reducing the footprint of CFRP because it avoids some virgin fibre production. Meng *et al.* (2017) found that recycled carbon fibre components can achieve lower lifecycle impacts than aluminium, steel and virgin CFRP, but the benefit depends on component design, fibre alignment and fibre volume fraction. This makes recycled carbon fibre suitable for lower-load panels, covers, trims and non-critical

motorsport or automotive components, while safety-critical structures require stricter validation (Meng et al., 2017).

Natural fibre composites provide another sustainability route because fibres such as flax and hemp are renewable and reduce reliance on synthetic reinforcement. describe natural fibre composites as promising for sustainable industrial applications, although their properties vary due to fibre quality, moisture and growing conditions. This makes them more suitable for interior panels, fairings, covers and non-structural bodywork than for highly loaded motorsport safety cells or crash structures (Peças *et al.*, 2018).

Legislation and motorsport policy are increasing pressure to improve lifecycle performance. UK end-of-life vehicle regulations require 95% recovery and 85% recycling by average vehicle weight, which favours materials with established recycling routes and challenges mixed thermoset composites (Regulations: end-of-life vehicles, 2021). The UK ZEV mandate also requires 80% of new cars and 70% of new vans sold in Great Britain to be zero emission by 2030, rising to 100% by 2035 (Anthony Browne, 2024). In motorsport, Formula 1 is targeting Net Zero Carbon by 2030 and reported a 26% emissions reduction by the end of 2024 against its 2018 baseline (*Formula 1*, 2025).

Overall, composite sustainability depends on application-specific material selection. Conventional CFRP should be reserved for parts where lightweighting provides a clear performance or efficiency benefit. Bio-resins reduce fossil-derived content but do not fully solve recycling. Recycled carbon fibre reduces demand for virgin fibre and is suited to lower-load components. Natural fibre composites are best for renewable, non-structural applications. Aluminium remains important where ductility, repairability and established recycling are more valuable than maximum strength-to-weight ratio.

4 Methodology



Figure 1 - Testing Samples

Tensile testing was carried out on the supplied aluminium and composite materials to compare their behaviour under tensile loading. The tested samples are listed in Table 1.

Material	Number of Tested Samples
Aluminium	38
Carbon non-woven bio	20
Carbon Woven Bio	20
Carbon Woven Epoxy	19
Flax non-Woven Bio	21
Flax Woven Bio	19
Kevlar Woven Bio	20

Table 1 - Samples Tested - Sample Amount

The main outputs taken from the tensile test data were ultimate tensile strength, tensile modulus, 0.2% proof stress, maximum force and break stress. These values were used to compare the strength, stiffness and failure behaviour of each material.

All raw test results were first brought together and reviewed. As shown in Figure 1, some tests showed a large difference from the main group of results. These abnormal results were removed before calculating the final averages, as they were not representative of the typical material behaviour.

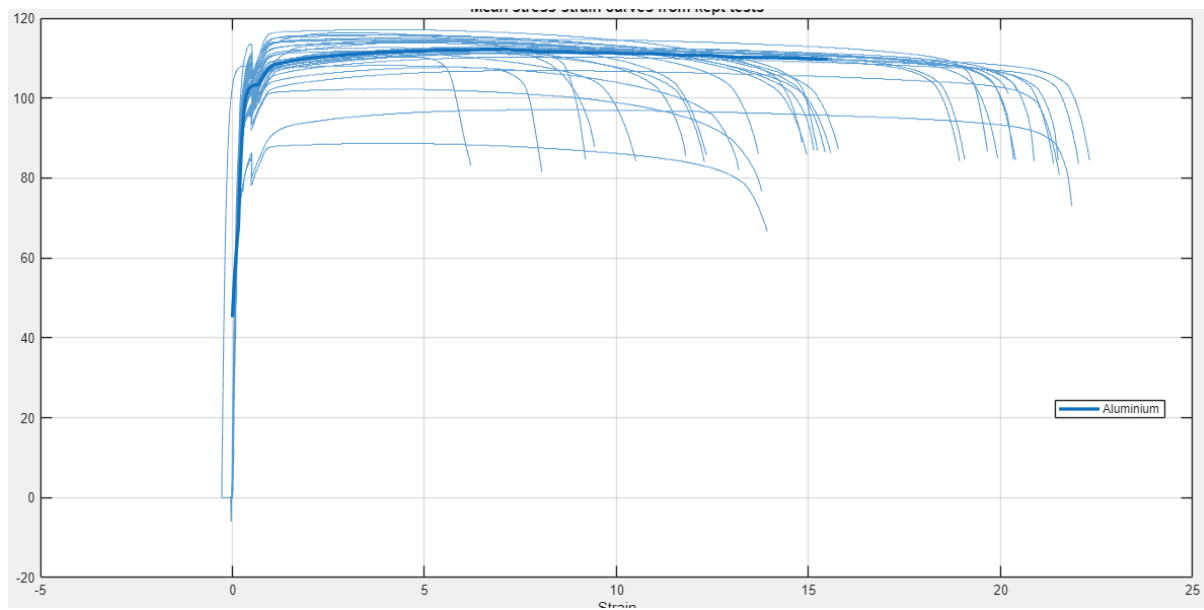


Figure 2 - Raw Aluminium Results in MATLAB script

The remaining valid tests were then averaged to produce representative values and stress-strain curves for each material. This allowed the analysis to focus on the repeatable behaviour of each material rather than being affected by failed or abnormal measurements.

5 Results and Analysis

5.1 Aluminium compared with composite materials

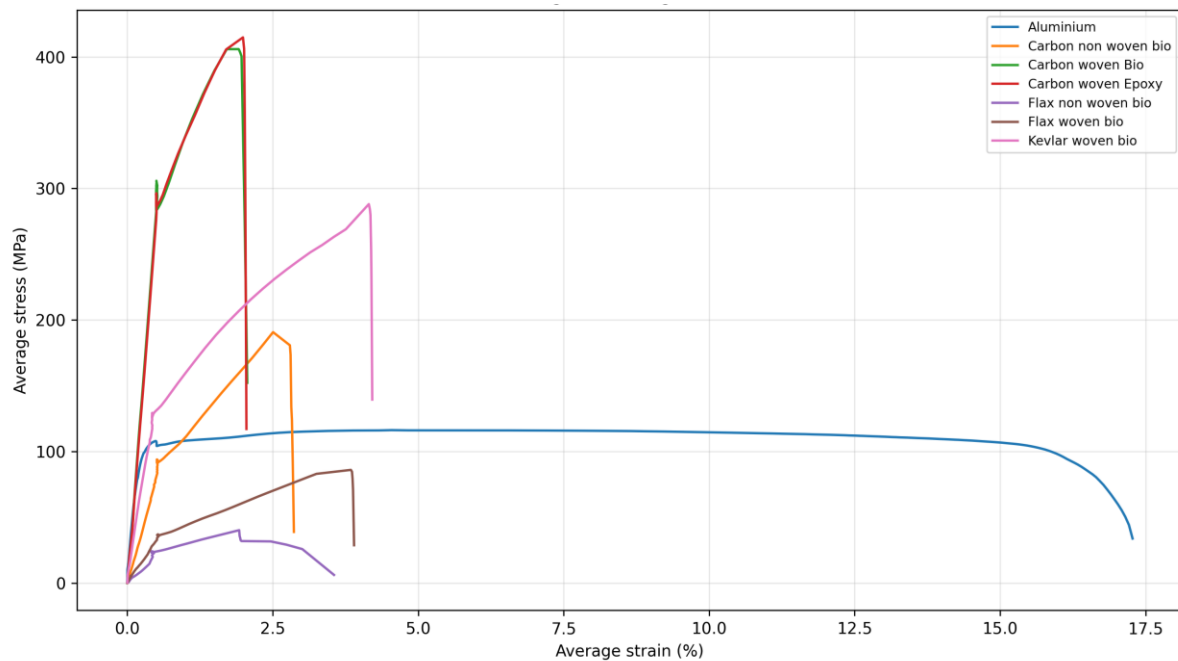


Figure 3 - Stress Strain Comparison

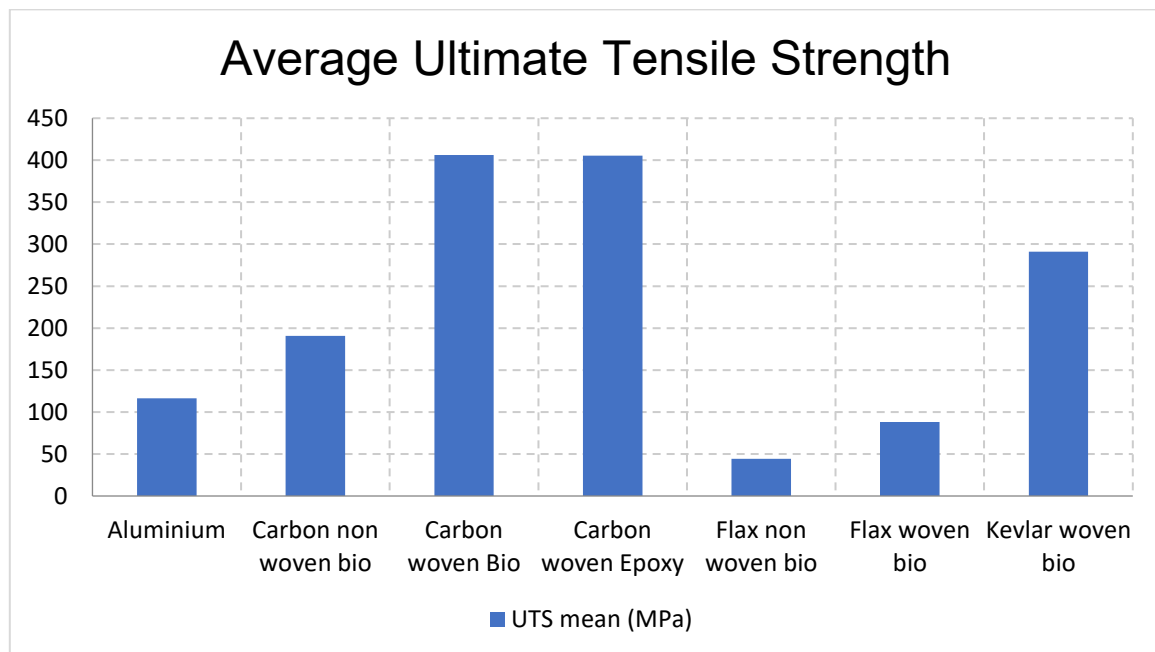


Figure 4 - UTS Comparison

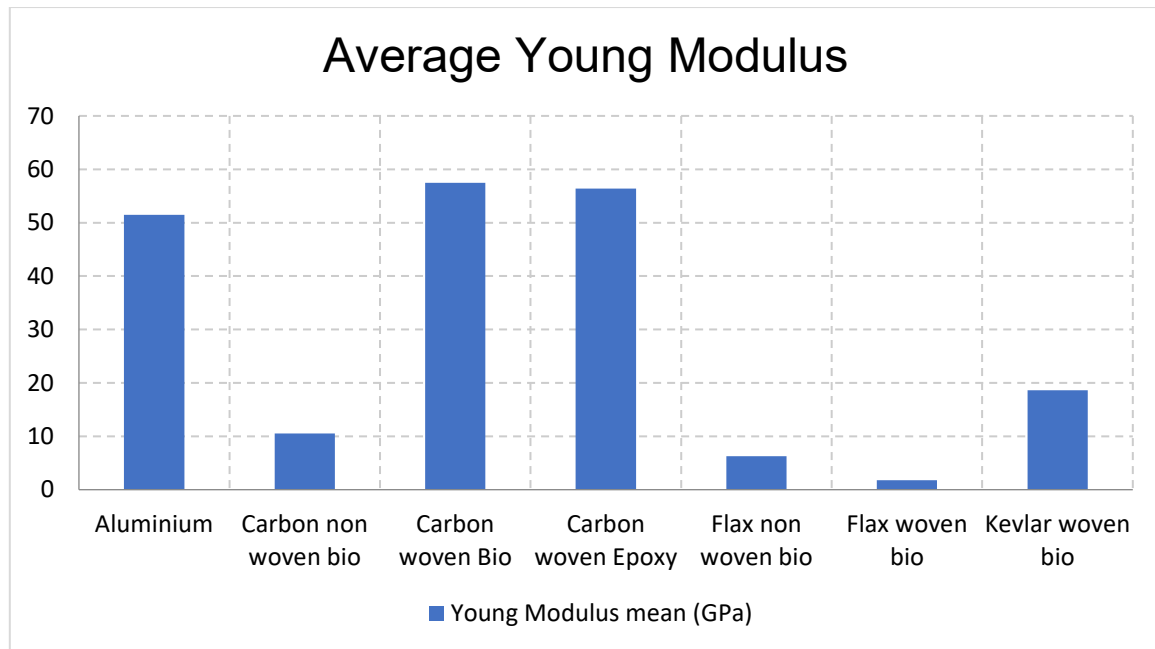


Figure 5 - Young Modulus Comparison

The stress-strain curve shows that aluminium did not achieve the highest tensile strength, as the woven carbon and Kevlar composites carried higher stresses. However, aluminium showed a much higher strain to failure, indicating greater ductility than the composite specimens.

A key difference is that aluminium remained close to its ultimate tensile strength over a much longer strain range before final failure. This gives a more gradual failure response, which is useful where controlled deformation and warning before failure are important.

Aluminium can deform in this way because dislocations in its crystal lattice can move under load, allowing plastic deformation before fracture. The composites fail more suddenly because their load carrying is controlled by stiff fibres and a resin matrix, which have limited plastic deformation. Once matrix cracking, fibre fracture or delamination begins, the load path through the laminate is disrupted and strength drops rapidly.

Therefore, aluminium is not the strongest material in the test set, but it offers better ductility and a more progressive failure response.



Figure 6 - Aluminium Sample Necking

5.2 Woven compared with non-woven composites

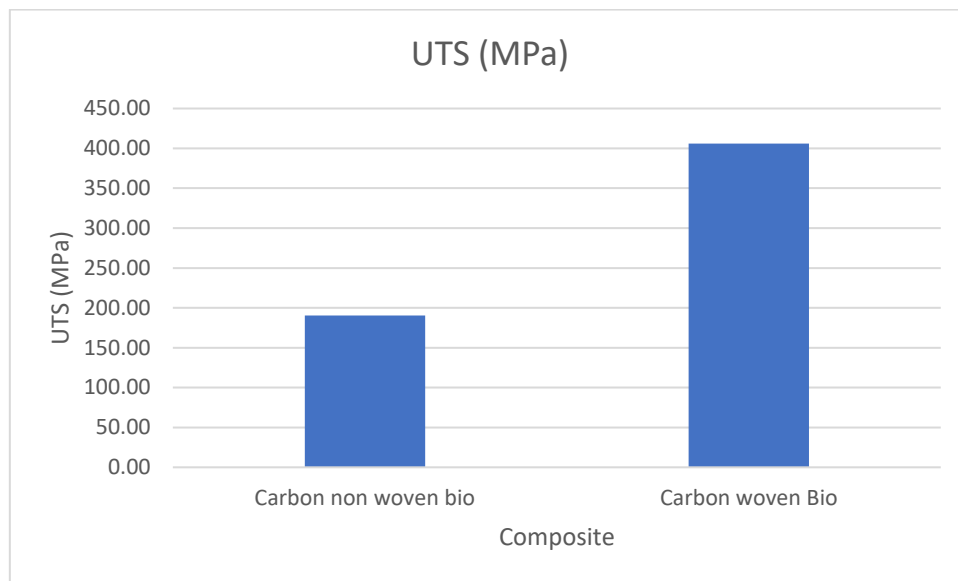


Figure 7 - UTS Woven vs Non-Woven Comparison

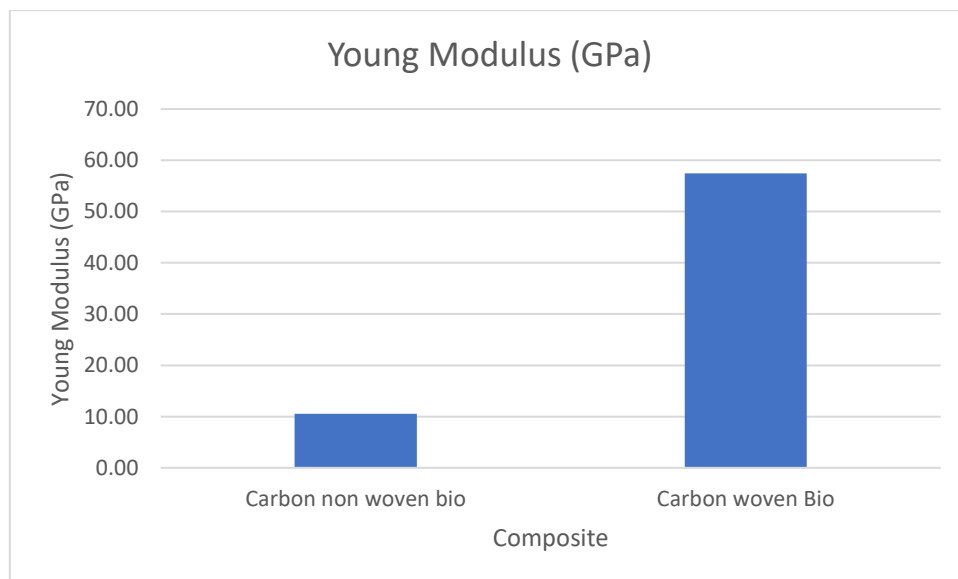


Figure 8 - Young Woven vs Non-Woven Comparison

The comparison shows that reinforcement architecture strongly affected tensile performance. The woven composites gave better load-carrying behaviour because their fibre paths were more continuous and aligned with the tensile direction. This supports the structure-property relationship discussed in the literature, where aligned reinforcement is more effective than randomly orientated fibres.

The non-woven composites were less suitable for load-bearing applications but remain useful for lower-load components such as trim, covers, cosmetic panels and complex

moulded shapes, were formability, cost or recycled fibre content may be more important than maximum strength.

5.3 Conventional composites compared with bio-composites

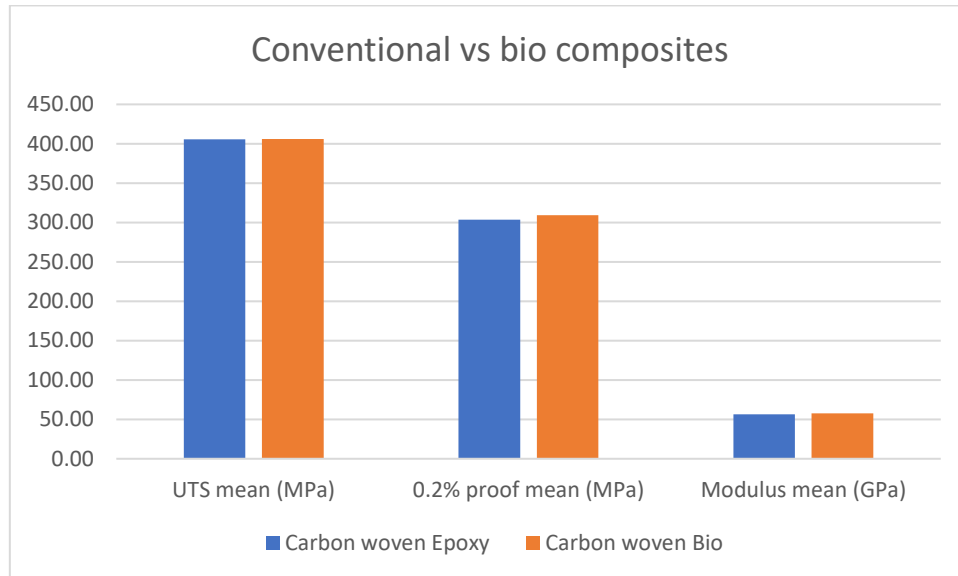


Figure 9 - Conventional vs Bio Composites

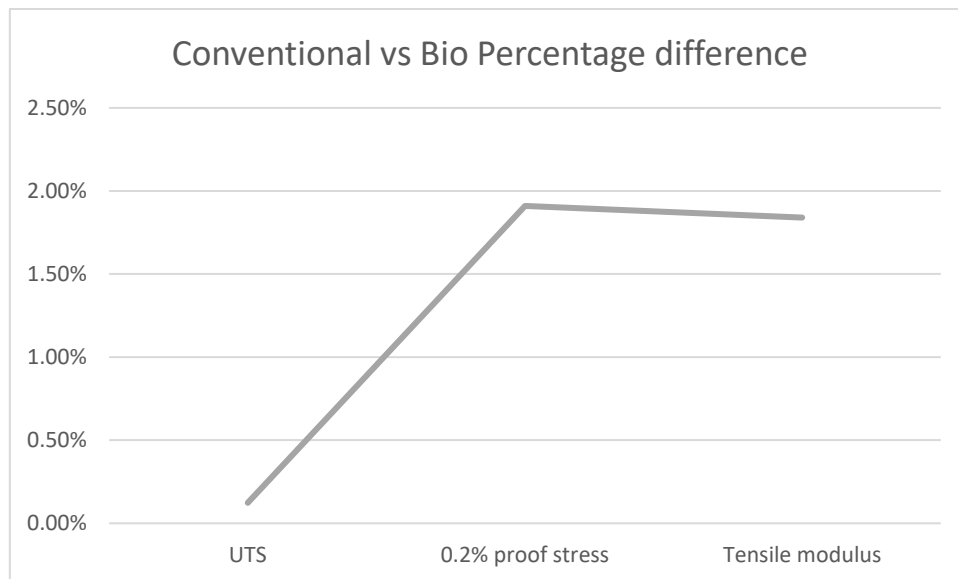


Figure 10 - Conventional vs Bio Composites Percentage Difference

The carbon woven epoxy and carbon woven bio-resin comparison shows that changing the resin system did not cause a clear tensile performance loss. This is important because both materials used woven carbon reinforcement, meaning the main variable was the resin system.

This suggests that bio-resin carbon composites could replace conventional epoxy carbon composites in structural parts, as it's able to match and outperformed the conventional resin composite.

The wider bio-composite results also show that bio-composites should not be treated as one group. Carbon woven bio-resin is suitable for higher-performance applications, while flax bio-composites are more appropriate for low-load components where sustainability is the main priority.

6 Validation and Limitations

6.1 Validation

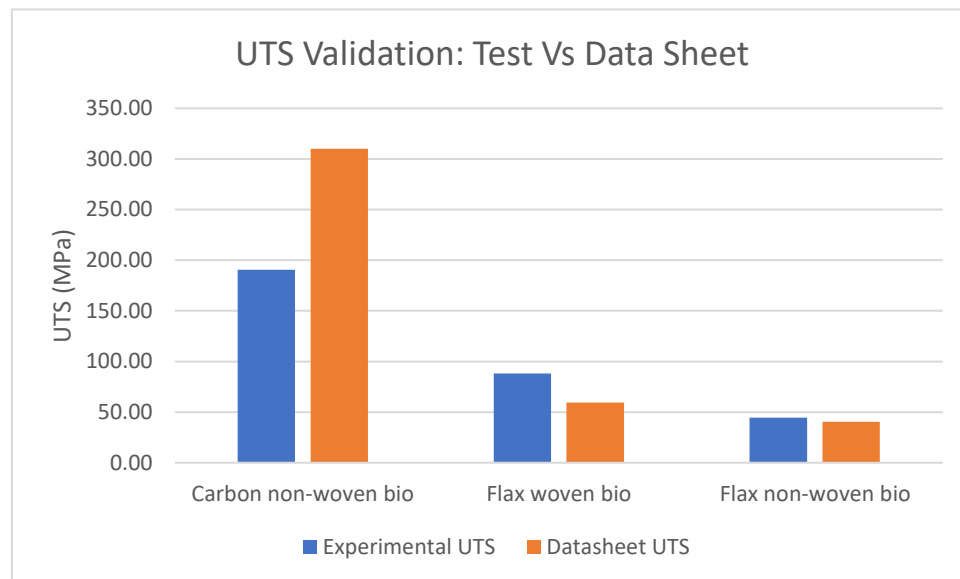


Figure 11 - Test Vs Data Sheet UTS Comparison

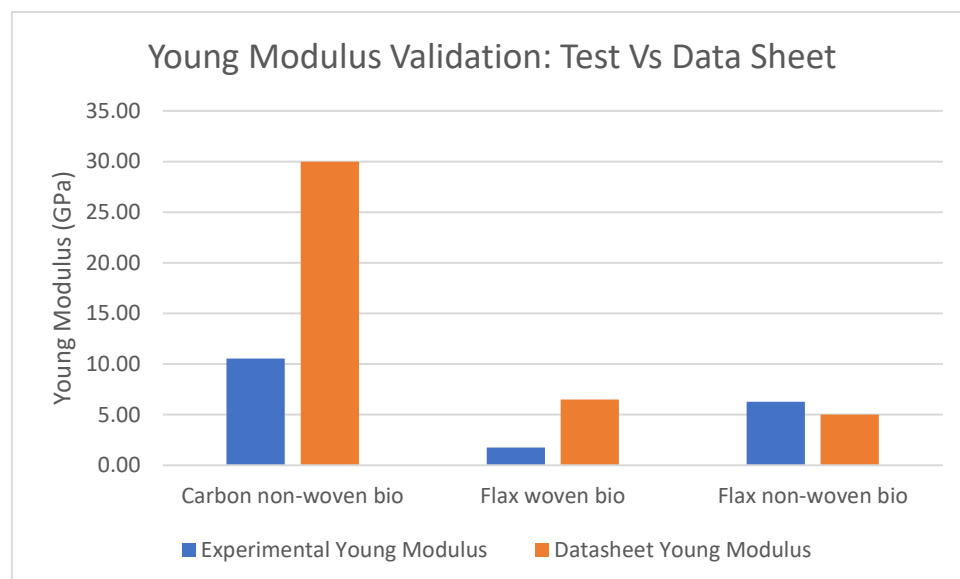


Figure 12 - Test Vs Data Sheet Young Modulus Comparison

The experimental results were compared with the supplied datasheets where a direct comparison was possible. This applied to carbon non-woven bio, flax woven bio and flax non-woven bio.

The carbon non-woven bio showed the weakest correlation with the datasheet data, with a 62.66% difference in UTS and a 184.36% difference in Young's modulus. However, the

datasheet states that the material uses recycled carbon fibre and does induce a range of error in the result, so the values are approximate rather than fixed specifications.

The flax woven bio showed mixed correlation. The UTS difference was -32.53%, meaning the experimental result was higher than the datasheet value. However, the Young's modulus difference was 269.32%, showing poor correlation.

The flax non-woven bio showed the strongest correlation. The UTS difference was only 8.87% different, and the Young's modulus difference was -20.38%, making it the closest match to the datasheet values.

The woven carbon bio, woven carbon epoxy and Kevlar woven bio results could not be directly validated because the supplied datasheets did not match the exact finished laminate systems. Fibre-only or resin-only datasheets cannot be directly compared with full laminate tensile results.

Overall, the validation supports the flax non-woven result most strongly, shows mixed correlation for flax woven, and shows weaker agreement for carbon non-woven because of the larger differences and the approximate nature of the recycled carbon fibre datasheet.

6.2 Limitations

The main limitation of the testing was the variation between repeated composite samples. Composite materials are more sensitive than aluminium with their fibre direction, resin distribution, void content, laminate quality and potential damage. This means small differences in manufacturing or sample preparation can have a large effect on the result.

Another limitation was the removal of abnormal test results before calculating the averages. This improved the reliability of the final comparison because failed or unrealistic tests did not distort the average values. However, it also introduced judgement into the analysis because decisions had to be made about which results were representative.

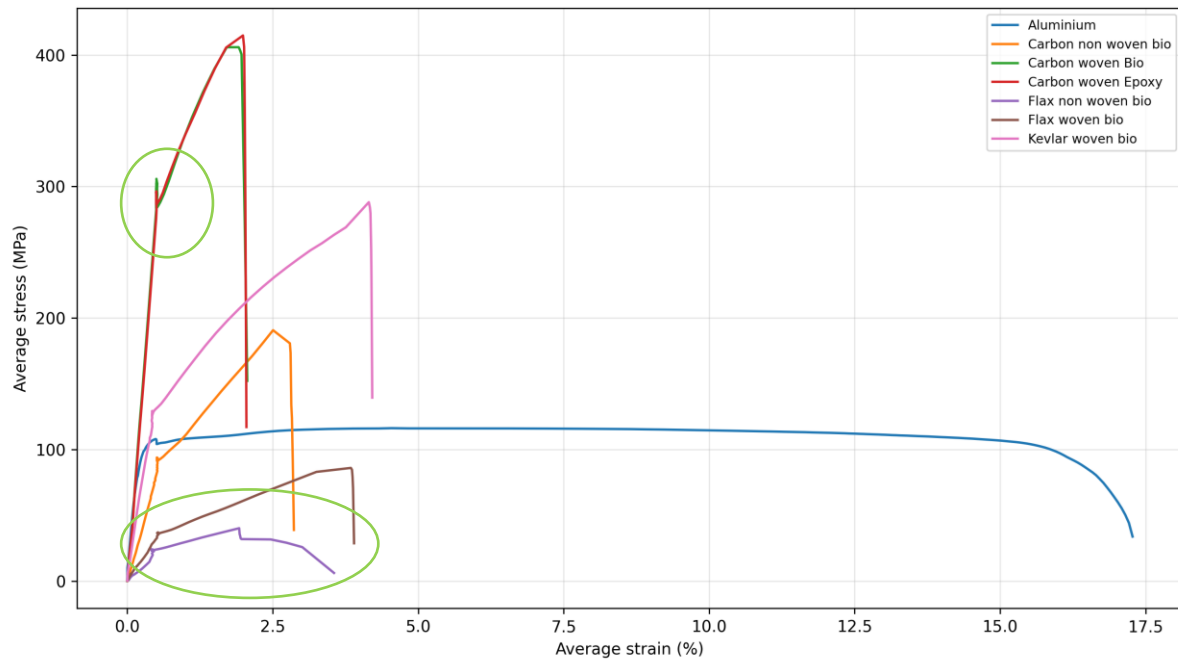


Figure 13 - Stress Strain Plot Limitation

A further limitation was the quality of the averaged stress-strain curves. Sharp spikes appeared around the yield/proof stress region and in the flax woven bio-resin curve. These peaks may not fully represent the true material behaviour. Further work should refine the averaging method by improving the results, removing abnormal points more consistently, smoothing the data where appropriate, and checking the average curves against the individual test results.

The tensile tester setup may also have introduced uncertainty. Grip slip, uneven clamping, misalignment or failure close to the grips could reduce the measured strength of a sample. Composite materials are especially sensitive to local damage because crushing or stress concentration near the grips can cause premature failure.

Validation was also limited by the datasheets available. Some materials could be compared directly with supplier data, but others could only be validated indirectly because the datasheets did not describe the exact composite tested. A more accurate validation would require datasheets for the same fibre, resin system, lay-up, fibre volume fraction and manufacturing method.

Finally, tensile testing alone does not prove that a material is suitable for automotive or motorsport use. Real components experience more complex loading, including bending, impact, vibration, fatigue, moisture exposure and temperature changes. Further testing should include flexural testing, impact testing, fatigue testing, interlaminar shear testing, environmental ageing and thermal cycling. A full life cycle assessment would also be needed

to compare sustainability properly, including raw material extraction, manufacturing energy, recyclability and end-of-life disposal.

7 Recommendation

The results suggest that the use of bio-resin composites should be pushed further in motorsport and automotive applications. The carbon woven bio-resin composite performed very closely to the conventional carbon woven epoxy composite, showing that bio-resins can do a similar job in suitable components without a clear loss in tensile performance. This means bio-resin carbon composites should be considered for parts such as body panels, splitters, diffusers, fairings, covers and semi-structural components where carbon fibre performance is still required.

The main issue with increasing the use of bio-resins is cost. Bio-resin systems may be more expensive than traditional epoxy systems, especially if they are produced in lower volumes or require changes to manufacturing processes. This means they may not be the cheapest option in the short term. However, their use should still be encouraged because they reduce reliance on fossil-derived resin systems while keeping similar mechanical performance to conventional composites.

Non-woven recycled carbon fibre composites should also be used more widely in lower-load components. Although they did not match the tensile performance of woven carbon composites, they are suitable for parts where maximum strength is not required. Possible applications include interior panels, access covers, mirror covers, dashboard parts, trim panels, mudguards and cosmetic bodywork. This would allow recycled carbon fibre to be reused in practical applications rather than relying only on virgin carbon fibre.

Flax bio-composites should also be used for low-load and non-structural parts where renewable fibre content is more important than high tensile strength. Suitable applications include door cards, interior trim, acoustic panels, fairing inserts and covers. Flax composites should not replace carbon composites in highly loaded or safety-critical parts, but they are a useful option for reducing the environmental impact of less demanding components.

Overall, the recommendation is to increase the use of bio-resin composites where they can match conventional composite performance, while using recycled non-woven carbon fibre and flax composites in lower-load applications. This allows more sustainable materials to be introduced without compromising the performance of critical components.

Further testing should be carried out before these materials are used more widely. Tensile testing alone does not show how the materials will behave in real automotive or motorsport conditions. Future work should include fatigue testing, impact testing, thermal cycling,

moisture exposure, vibration testing and long-term durability testing. This would give a stronger understanding of how bio-resin, recycled fibre and flax composites perform over time and would help confirm where they can safely replace traditional materials.

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