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**Materials Testing and Sustainability of
Composites for Motorsport & Automotive
Industries**

Automotive Materials & Sustainability (ACHA6012)

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1 Introduction

Material selection in motorsport and automotive engineering is increasingly driven by both mechanical performance and environmental impact. Composite materials offer high strength and stiffness, but their use must be justified against manufacturing complexity, resin choice, recyclability and end-of-life limitations. This report compares aluminium with four resin-infused composite systems: woven carbon fibre with conventional epoxy, woven carbon fibre with bio-based epoxy, non-woven carbon with bio-based epoxy, and woven flax fibre with bio-based epoxy.

The aim is to identify which material systems provide the most suitable balance of tensile performance, manufacturability, lifecycle impact and practical application potential. Tensile testing is used to compare strength, stiffness, repeatability and failure behaviour, while datasheet values and published research are used to validate the results. The mechanical findings are then considered alongside sustainability factors including raw material origin, manufacturing route, repairability, recycling potential and alignment with current motorsport and automotive sustainability targets.

2 Literature review and material background

2.1 Composite structure and reinforcement architecture

Composite materials consist of a matrix surrounding fibre reinforcement. In fibre-reinforced polymers (FRPs), the matrix supports and protects the fibres, while the fibres carry most of the structural load. Fibre volume fraction, orientation and architecture therefore control laminate stiffness and strength (Chowdhury, 2024). Woven reinforcements use interlocked yarns in defined directions, giving better dimensional stability, delamination resistance and fatigue behaviour. Non-woven random mats are more quasi-isotropic but less efficient, because short, randomly orientated fibres transfer their properties less effectively (Chowdhury, 2024). Twill fabrics reduce crimp compared with plain weave, improving on-axis stiffness. Cantera (2024) confirms that architecture governs the available stiffness envelope, which is directly relevant to the carbon and flax twill samples tested.

2.2 Carbon fibre and recycled carbon fibre

Carbon fibre reinforced polymers (CFRPs) remain the benchmark for motorsport structures because of their high specific stiffness and strength. The 3K twill carbon cloth used here is a common aerospace and motorsport format, with CFRP use expanding into body-in-white structures, battery enclosures and aerodynamic parts as EV lightweighting becomes more important (Chen et al., 2025). Recycled carbon fibre (rCF) non-woven mat is usually produced by pyrolysis of end-of-life composites at 500–600°C. Recovered fibres retain around 80–95% of tensile modulus, although strength variability is higher due to discontinuous fibres, random architecture and mixed feedstocks (Ren et al., 2022; Frontiers in Materials, 2024). Pyrolysis also removes fibre sizing, so resizing is recommended to improve matrix adhesion (Meessen et al., 2024). Martulli et al. (2023) found a 20–30% tensile modulus reduction compared with virgin CFRP, but with lower cost and embodied energy. This makes rCF better suited to stiffness-led secondary structures than peak-strength critical parts.

2.3 Flax fibre composites

Flax is a natural fibre with a hierarchical cellulosic structure. Woven flax composites typically achieve tensile strengths of 58–80 MPa and moduli of 6–10 GPa, below carbon fibre but useful for secondary structures and interior components where low mass and reduced environmental impact matter (Haggui et al., 2024). Raja et al. (2024) showed that woven flax/epoxy composites can provide suitable tensile and flexural performance. Non-woven flax mats are approximately 30% weaker than

woven equivalents and suit cosmetic panels, liners and low-load applications. The main limitation is moisture sensitivity. Hydroxyl groups make flax fibres hydrophilic, so water ingress can cause swelling, matrix microcracking and property loss. Saidane et al. (2021) found that moisture uptake follows Fickian behaviour and can be reduced through fibre surface treatment.

2.4 Resin systems and manufacturing route

The resin system affects infusion behaviour, cure, mechanical performance and sustainability. This study compares petroleum-derived IN2 epoxy with IB2 bio-based epoxy, which contains around 31% plant-derived content. Tran et al. (2021) found that commercial bio-based systems can achieve tensile modulus, compressive strength and glass transition temperature values broadly comparable with conventional DGEBA epoxy at moderate bio-content levels. Riccetti et al. (2023) also found no statistically significant reduction in quasi-static tensile or flexural properties when conventional epoxy was replaced by a bio-based equivalent. Both systems were processed by vacuum infusion (VARTM), which can achieve fibre volume fractions of 50–60% and void contents below 2% without autoclave equipment (Li et al., 2020). Void content is therefore a key manufacturing quality factor when comparing the tested laminates.

2.5 Literature gap

The literature shows a performance/sustainability trade-off between carbon, recycled carbon and flax composite systems. However, directly comparable empirical data for woven carbon, recycled carbon non-woven mat and flax laminates, manufactured using the same vacuum infusion route with both conventional and bio-based epoxy, remains limited. This study addresses that gap by comparing these material combinations under consistent test conditions and relating the results to motorsport and automotive application suitability.

3 Experimental method and data processing

3.1 Materials and sample preparation

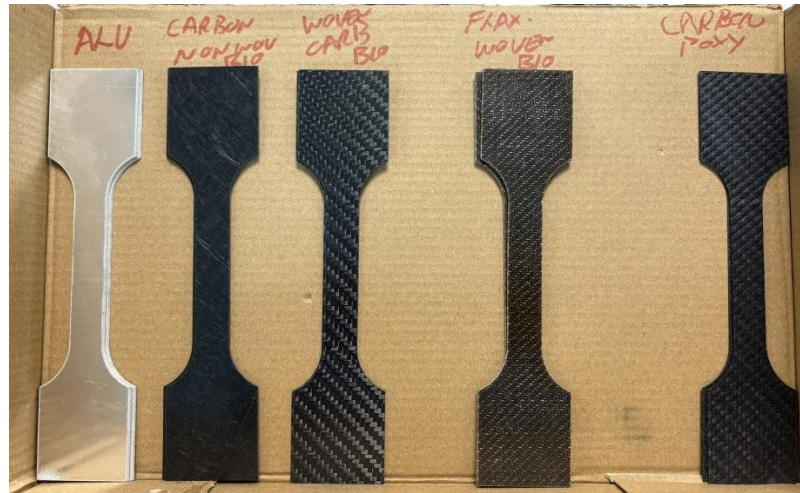


Figure 1 - Material samples tested.

Five material systems were tested in uniaxial tension to compare their mechanical behaviour under the same loading condition. Aluminium was used as the conventional baseline, while the composite samples allowed comparison between woven carbon, recycled carbon non-woven and woven flax reinforcement systems. The material systems, resin type, layup, and number of repeat samples are summarised in Table 1.

Table 1 - Material systems, reinforcement type, matrix system, layup configuration and repeat quantity used for tensile testing.

Material	Reinforcement / material	Resin	Structure / layup	Sustainability relevance	No. of repeats
Aluminium	Aluminium sheet	N/A	Isotropic metallic sheet	Conventional recyclable baseline material	4
Carbon non-woven + bio resin	100% recycled carbon fibre non-woven mat	IB2 bio epoxy	1 × 300 g/m ² non-woven layer	Recycled fibre with partially bio-derived resin	4
Carbon woven + bio resin	3k twill carbon fibre	IB2 bio epoxy	3 × 200 g/m ² woven plies, rotated 45° between layers	High-performance reinforcement with lower-impact resin system	4
Carbon woven + epoxy resin	3k twill carbon fibre	IN2 epoxy	3 × 200 g/m ² woven plies, rotated 45° between layers	Conventional high-performance composite reference	4
Flax woven + bio resin	Twill 2×2 European flax fibre	IB2 bio epoxy	3 × 200 g/m ² woven plies, rotated 45° between layers	Renewable natural fibre with partially bio-derived resin	4

All composite samples were manufactured using vacuum-assisted resin infusion. The woven carbon and flax laminates used three plies, with each ply rotated by 45° to improve in-plane load distribution. The recycled carbon non-woven samples used a single 300 g/m² layer. Datasheet information was used to define the reinforcement and resin systems, including the recycled carbon fibre mat, woven flax reinforcement, IN2 epoxy and IB2 bio-epoxy resin systems (Easy Composites, 2024; EcoTechnilin, 2023).

3.2 Tensile test procedure

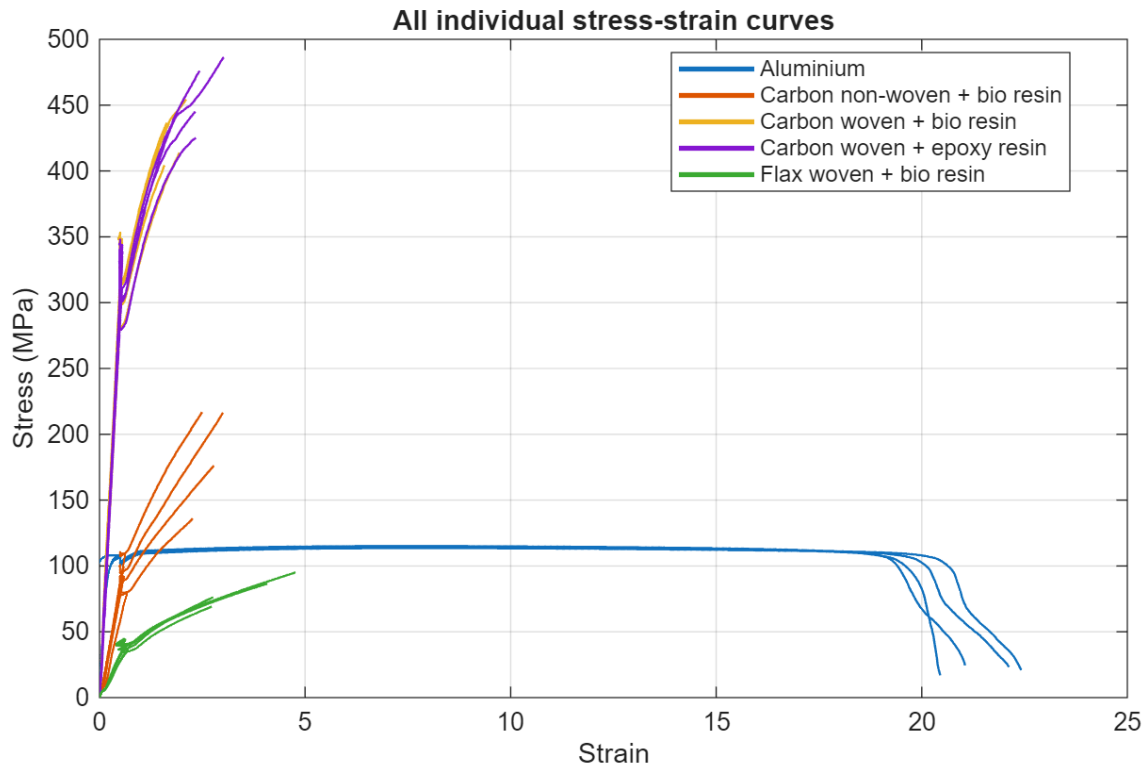


Figure 2 - The Denison tensile test machine with the extensometer fitted to a specimen.

Testing was carried out using a Denison-style tensile tester. Each specimen was clamped at both ends and loaded in tension until failure. An extensometer was fitted at the start of each test to measure the initial elastic deformation, then removed before large deformation or fracture to prevent instrument damage. Safety glasses were worn throughout, and operators stood to the side of the machine because of the risk of brittle composite failure.

3.3 Data processing and repeatability

Load, displacement and extension data were exported from the test machine and processed in MATLAB. The initial slack/load take-up region was removed before plotting. Engineering stress was calculated using the measured cross-sectional area of each specimen, while strain was derived from the recorded displacement data. Young's modulus was calculated from the linear elastic region of each stress-strain curve, and ultimate tensile strength was taken as the maximum stress before failure. Mean values and standard deviations were then calculated from the four repeat samples.



Graph 1 - All individual stress-strain curves showing repeatability of the testing method.

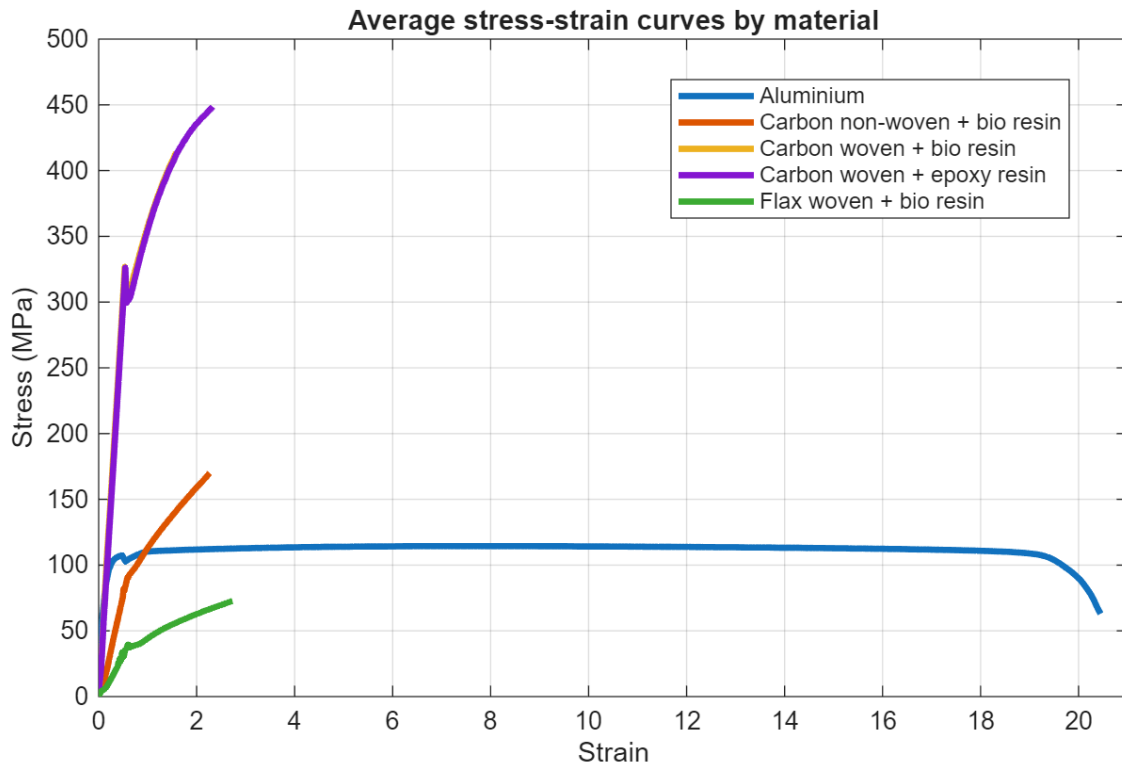
The overlaid stress–strain curves were used as a repeatability check before the main results were compared in Section 4. Scatter between repeats was retained rather than hidden, as it shows the effect of manufacturing variation, grip behaviour and material inconsistency.

3.4 Experimental limitations

Manual infusion can introduce fibre misalignment, voids, resin-rich regions and inconsistent thickness. One side of each laminate was cured against an aluminium sheet, while the other was formed against the vacuum bag, giving different surface finishes. This may have introduced local stress concentrations. Crosshead-derived strain may also include machine and grip compliance, so strain values are treated as comparative rather than absolute. Manufacturer datasheet values are therefore used for validation only, not as fixed design values.

4 Results, validation and discussion

4.1 Stress–strain behaviour



Graph 2 - Average stress-strain curves for all materials.

Graph 2 shows a clear separation between the woven carbon laminates and the remaining materials. The carbon woven + epoxy resin and carbon woven + bio resin samples show the steepest initial gradients and the highest stress response, confirming that the woven carbon reinforcement is the dominant factor controlling tensile performance. The close agreement between these two curves shows that changing from conventional epoxy to bio resin did not cause a major loss in tensile stiffness or strength. This is important because it suggests that resin substitution can improve the sustainability case without severely compromising mechanical performance.

Aluminium behaves differently from all composite samples. It reaches a much lower stress level but continues to deform to a significantly higher strain before failure. This confirms ductile metallic behaviour and makes aluminium useful as a baseline material for comparison rather than a direct competitor to woven carbon in tensile strength. The carbon non-woven + bio resin curve sits between aluminium and the woven carbon laminates, showing useful tensile strength but a much lower gradient. This highlights the effect of fibre architecture: the random, discontinuous fibre format does not transfer tensile load as efficiently as the woven carbon reinforcement. Flax woven +

bio resin gives the lowest stress response, confirming that it is not suitable for high-load structural applications without substantial section or laminate redesign.

4.2 Ultimate tensile strength comparison

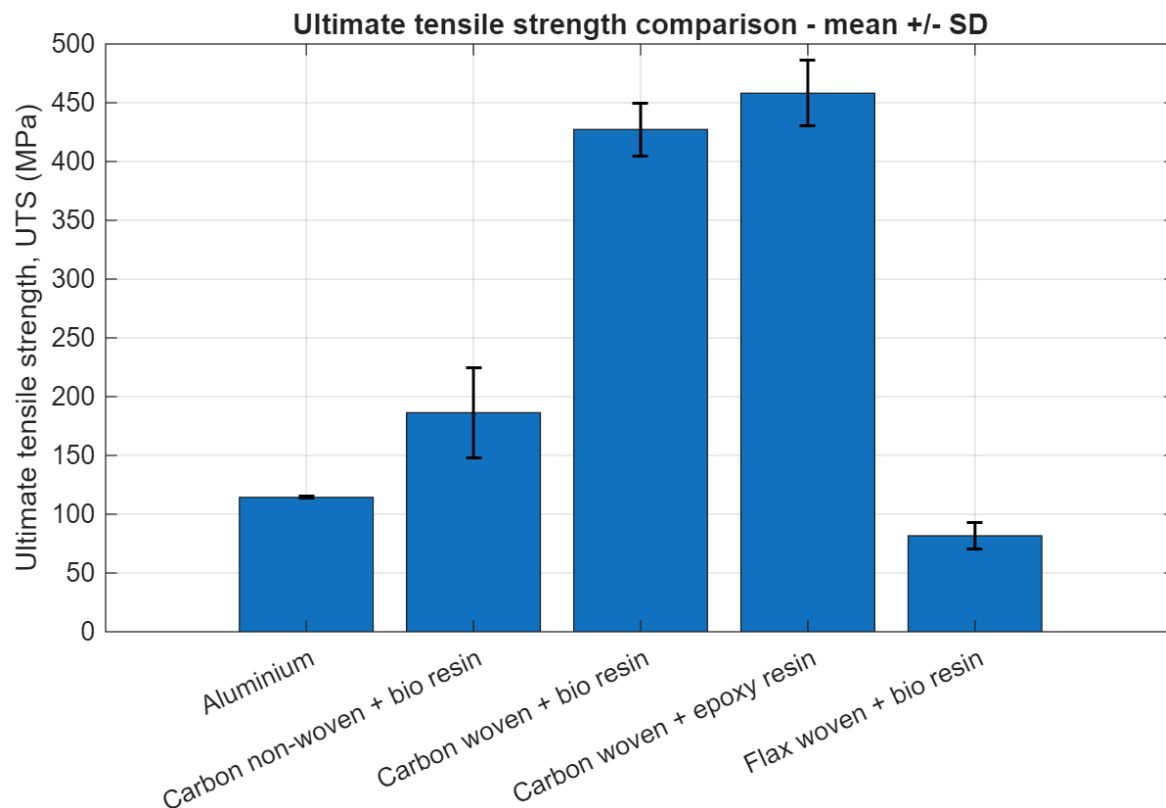


Figure 3 - Ultimate tensile strength comparison, mean $\pm$ standard deviation.

Figure 3 and Table 2 show that carbon woven + epoxy resin achieved the highest mean ultimate tensile strength at **458.14 MPa**, followed by carbon woven + bio resin at **427.30 MPa**. The bio resin laminate is therefore only **6.7% lower** in strength than the conventional epoxy laminate. This is one of the most important results in the section, as it shows that the bio resin system retains most of the tensile strength when paired with woven carbon fibre.

Table 2 - Summary of measured tensile properties for each material group. Standard deviation is included to indicate repeatability and confidence in the mean values.

Material	Mean UTS (MPa)	UTS SD (MPa)	Mean Young's modulus (GPa)	Modulus SD (GPa)	Mean failure strain (%)	Main interpretation
Aluminium	114.15	0.56	55.04	2.86	21.87	Ductile and highly repeatable, but low tensile strength compared with woven carbon
Carbon non-woven + bio resin	186.36	38.6	12.95	15.01	2.64	Useful recycled-content strength, but poor repeatability and unreliable stiffness
Carbon woven + bio resin	427.3	22.55	60.33	3.65	1.82	Best sustainable performance option; high strength and stiffness retained
Flax woven + bio resin	81.68	11.44	1.69	0.19	3.59	Low strength and stiffness, but compliant and suitable for low-load sustainable parts
Carbon woven + epoxy resin	458.14	28.1	61.23	2.22	2.53	Highest mechanical performance, but weaker sustainability case

The carbon non-woven + bio resin laminate reached **186.36 MPa**, which is higher than aluminium at **114.39 MPa**, but still less than half the strength of the woven carbon bio resin. This shows that carbon fibre content alone is not enough to guarantee high tensile performance. Fibre alignment, continuity and weave architecture are critical because the woven fibres carry the load more directly along the tensile direction. The flax woven + bio resin laminate had the lowest mean UTS at **81.68 MPa**, which limits its use to low-load components, interior panels, covers or fairings where sustainability and low mass are more important than peak tensile performance.

Standard deviation is used in Figure 3 to assess repeatability. A low standard deviation means the samples are close to the mean and the result is more reliable. A high standard deviation shows scatter, which reduces design confidence and would require higher safety factors or tighter process control. Aluminium showed very low scatter, confirming repeatable behaviour. In contrast, carbon non-woven + bio resin had a UTS standard deviation of **38.60 MPa**, showing poor consistency and limiting its suitability for primary structural use.

4.3 Tensile modulus and especific performance

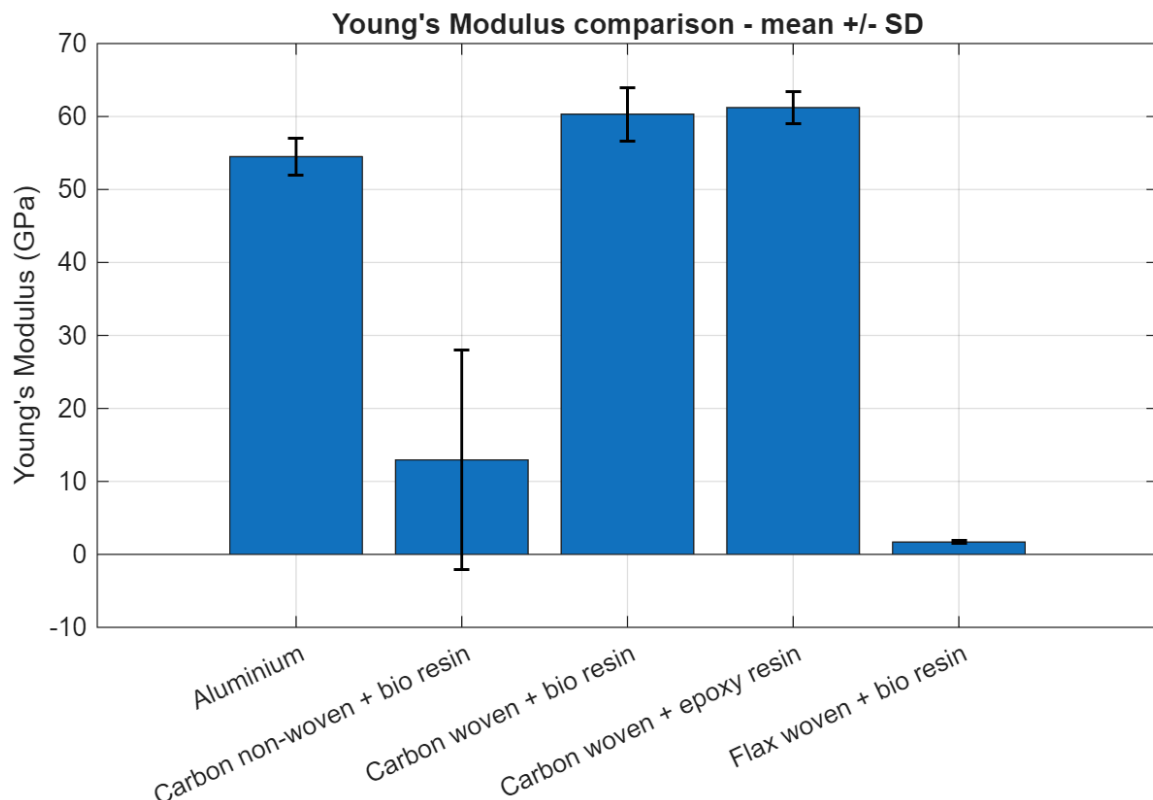


Figure 4 - Young's modulus comparison, mean $\pm$ standard deviation.

Figure 4 compares Young's modulus, which is particularly important for motorsport structures because many composite parts are stiffness-driven rather than strength-driven. Carbon woven + epoxy resin and carbon woven + bio resin produced very similar modulus values of **61.23 GPa** and **60.33 GPa** respectively. The difference is approximately **1.5%**, so the change in resin system had very little effect on stiffness. This supports the conclusion that the elastic response is controlled mainly by the woven carbon reinforcement and fibre orientation, rather than the resin.

The aluminium modulus was measured below the typical value expected for aluminium alloys, so it should be treated as an experimental limitation rather than a true material property. The carbon non-woven + bio resin modulus result is more concerning, with a mean of **12.95 GPa** and a standard deviation of **15.01 GPa**. Since the standard deviation is larger than the mean, the stiffness result is not reliable enough for design use. The flax woven + bio resin modulus of **1.69 GPa** confirms that it is highly compliant and unsuitable for stiffness-critical components.

Table 3 - Specific strength and stiffness comparison. Values should be treated as indicative where datasheet density is used instead of measured laminate density.

Material	Density used (g/cm ³)	Density source	Specific strength, UTS/density (MPa per g/cm ³)	Specific stiffness, E/density (GPa)	Interpretation
Aluminium	2.7	Standard aluminium reference value	42.37	20.19	Good ductility, but lower specific tensile performance than woven carbon
Carbon non-woven + bio resin	1.51	Manufacturer laminate datasheet	123.42	8.58	Good specific strength, but stiffness value is unreliable due to high scatter
Carbon woven + bio resin	1.46	Estimated from carbon fibre density 1.79 g/cm ³ and IB2 resin density 1.12 g/cm ³ , assuming 50:50 fibre/resin volume fraction	293.68	41.46	Expected to be strongest sustainable option on a strength-to-weight basis
Flax woven + bio resin	1.22	Estimated from flax fibre density 1.45 g/cm ³ , IB2 resin density 1.12 g/cm ³ and datasheet fibre volume fraction of 29%	67.17	1.39	Low stiffness limits structural use, even if density is favourable
Carbon woven + epoxy resin	1.45	Estimated from carbon fibre density 1.79 g/cm ³ and IN2 cured resin density approx. 1.10 g/cm ³ , assuming 50:50 fibre/resin volume fraction	317.05	42.37	Expected to have the highest specific mechanical performance

$$\text{Specific strength} = \frac{\text{UTS}}{\rho}$$

$$\text{Specific stiffness} = \frac{E}{\rho}$$

Table 3 strengthens the motorsport relevance by comparing specific strength and stiffness. Carbon woven + epoxy resin gives the highest specific strength at **317.05 MPa per g/cm³**, while carbon woven + bio resin remains close at **293.68 MPa per g/cm³**. This confirms that the bio resin laminate remains competitive when mass is considered. Aluminium performs well for ductility and damage tolerance, but its higher density reduces its strength-to-weight performance. Flax has a favourable low density, but its low measured modulus gives poor specific stiffness.

4.4 Validation against datasheets

Table 4 - Validation of measured tensile properties against manufacturer datasheet values. Datasheet values are used as indicative reference values, not guaranteed specification limits.

Material	Property	Measured value	Datasheet / reference value	Difference / comment	Validation judgement
Carbon non-woven + bio resin	UTS	186.36 MPa	290–330 MPa	Lower than datasheet range	Partly valid, but lower performance likely due to recycled fibre variability, fibre orientation, laminate quality or test direction
Carbon non-woven + bio resin	Young's modulus	12.95 GPa	25–35 GPa	Much lower than datasheet range	Poor stiffness validation; measured result is unreliable because SD = 15.01 GPa
Flax woven + bio resin	UTS	81.68 MPa	58–61 MPa	Higher than datasheet range	Strength result is encouraging and within a realistic order of magnitude
Flax woven + bio resin	Young's modulus	1.69 GPa	6–7 GPa	Much lower than datasheet range	Poor stiffness validation; possible strain measurement, ply orientation, fibre volume or fitting-range issue
Flax woven + bio resin	Failure strain	3.59%	1.5–1.8%	Higher than datasheet range	Suggests more compliant behaviour, but should be confirmed with further samples
Carbon woven + bio resin vs carbon woven + epoxy resin	UTS	427.30 vs 458.14 MPa	No direct datasheet comparison	Bio resin is 7.2% lower	Strong result for resin substitution because most strength is retained
Carbon woven + bio resin vs carbon woven + epoxy resin	Young's modulus	60.33 vs 61.23 GPa	No direct datasheet comparison	Bio resin is ~1.5% lower	Very strong stiffness retention; reinforcement architecture dominates

Table 4 compares the measured results with manufacturer datasheet values. These values should be treated as indicative rather than guaranteed design limits. The carbon non-woven material datasheet states that it is made from **100% recycled carbon fibre** and that mechanical properties are approximate because the recycled feedstock origin can vary. This agrees with the high scatter seen in the experimental results and supports the conclusion that this material requires more process control before structural use.

For flax woven + bio resin, the datasheet gives tensile strength values of approximately **58–61 MPa** and modulus values of **6–7 GPa** for a flax/bio-epoxy composite. The measured strength of **81.68 MPa** is higher than the datasheet range, which is encouraging. However, the measured modulus of **1.69 GPa** is much lower, suggesting that the stiffness result may have been affected by fibre volume fraction, 45-degree ply orientation, gripping effects or modulus fitting range.

4.5 Failure behaviour and interpretation

The failure strain results show a strong contrast between aluminium and the composites. Aluminium failed at **21.51% strain**, confirming ductile behaviour and high deformation capacity. The composites failed at much lower strains, generally between **1.8% and 3.6%**, which is consistent with brittle or

semi-brittle fibre composite failure. The woven carbon curves also showed a repeated disturbance around **0.5% strain**, likely linked to tow straightening, fabric crimp removal, early matrix cracking or grip settling.

Overall, the results show that woven carbon reinforcement gives the highest strength, stiffness and specific performance. Carbon woven + epoxy resin is the strongest material, but carbon woven + bio resin provides the best balance between mechanical performance and sustainability. Carbon non-woven + bio resin offers useful recycled-content potential, but its scatter limits design confidence. Flax woven + bio resin has the strongest natural-fibre sustainability argument, but its low stiffness restricts it to low-load applications.

Table 5 - Engineering interpretation of each material.

Material	Main mechanical result	Reliability / scatter	Engineering interpretation
Aluminium	Low UTS but highest failure strain	Very good repeatability	Useful ductile baseline; suitable where deformation tolerance and predictable yielding matter
Carbon non-woven + bio resin	Higher UTS than aluminium but far below woven carbon	Poor repeatability, especially modulus	Promising recycled-content material, but not suitable for primary structures without process improvement
Carbon woven + bio resin	High UTS and stiffness close to epoxy laminate	Acceptable repeatability	Best balance of mechanical performance and sustainability
Flax woven + bio resin	Lowest UTS and modulus, but higher strain than carbon woven bio resin	Moderate scatter expected for natural fibre	Suitable for low-load panels, covers, trim and sustainability-led components
Carbon woven + epoxy resin	Highest UTS and stiffness	Good performance consistency	Best pure mechanical performer, but less sustainable than bio resin option

5 Sustainability and lifecycle analysis

A simplified cradle-to-grave lifecycle comparison was used because the data does not support a fully quantified ISO 14040 LCA. The boundary covers raw material extraction, material production, component manufacture, use phase, repair/reuse and end-of-life. The aim is not to claim a precise carbon footprint, but to compare material origin, manufacturing route, use-phase value and circularity before linking sustainability to the tensile results. The comparison is qualitative because material-specific energy use, transport distance, fibre volume fraction and end-of-life processing data were not available for each laminate.

5.1 Raw material and manufacturing impact

Woven carbon fibre with IN2 epoxy has the highest raw material impact. Carbon fibre is linked to energy-intensive PAN precursor production and carbonisation, with embodied carbon values typically around 20-30 kg CO₂e/kg. Its sustainability case is weak unless high specific strength and stiffness are required. Changing from IN2 to IB2 bio resin improves the matrix because IB2 contains about 31% plant-based content, using plant-derived glycerol instead of petroleum-based propylene in the epichlorohydrin route (Easy Composites, 2024b). The carbon fibre impact remains unchanged, so this is a partial improvement rather than a complete low-impact material.

Recycled carbon non-woven with IB2 gives the strongest circularity argument among the carbon options because it avoids virgin continuous fibre. Literature indicates that recovered carbon fibre can retain 80-95% of tensile modulus and 70-90% of tensile strength after pyrolysis, although feedstock variation reduces consistency (Ren et al., 2022). This makes it suitable for secondary structures, fairings, covers and backing layers, but not primary load paths without further validation. Woven flax with IB2 has the lowest raw material impact, with flax reported around 1-3 kg CO₂e/kg. It is renewable and matched to bio resin but requires moisture control and will not match carbon fibre in tensile performance. Aluminium sits between these groups: primary aluminium is energy intensive, but recycled aluminium, repairability and established supply chains make it a strong baseline.

All composite samples used resin infusion, avoiding the higher energy demand of autoclave processing. IB2 and IN2 are still thermoset epoxy systems, so manufacturing gains do not remove the end-of-life issue and must be judged against the measured tensile performance.

5.2 Use-phase benefit

In motorsport, material selection cannot be based only on raw material impact. Lower mass improves acceleration, braking, handling and energy demand per lap. Woven carbon with IN2 is justified for stiffness-critical or highly loaded parts where its measured mechanical advantage is used. It is not justified for lightly loaded bodywork if flax or recycled carbon already satisfies the load case. In these applications, unused strength becomes an environmental penalty. Woven carbon with IB2 becomes the strongest high-performance compromise where it retains 93.3% of the IN2 tensile strength with lower fossil-derived resin content.

5.3 End-of-life and circularity

End-of-life is the weakest point for all thermoset composites. Unlike aluminium, cured resin cannot be remelted and reformed, so recycling depends on degrading or separating the matrix. Pyrolysis can recover carbon fibre, but the matrix is lost and the recovered fibre is normally shorter or lower value than virgin woven reinforcement. Aluminium therefore has the best-established recycling route, while recycled carbon non-woven has the best circular-material input. Flax/bio resin reduces raw material impact, but the epoxy matrix still limits biological recovery and circularity.

5.4 Motorsport and automotive policy alignment

This approach aligns with current motorsport sustainability direction. Motorsport UK, the FIA, Mercedes, Williams and McLaren all emphasise carbon reduction, sustainable material sourcing, waste reduction and measurable reporting. McLaren is most directly relevant because it has trialled recycled carbon fibre on F1 parts and reports a potential 90% carbon reduction compared with virgin carbon fibre parts, as well as a 37% material circularity metric for 2024 constructor activities (McLaren Racing, 2024). This shows that circularity is now an engineering metric in motorsport manufacture, not just a general sustainability aim.

5.5 Summary

No single material is best across the full lifecycle. Woven carbon with IN2 gives the best tensile performance but has the least favourable sustainability case unless used selectively. Woven carbon with IB2 is the best high-performance compromise where the measured performance loss is small. Recycled carbon non-woven with IB2 is the strongest circularity option for secondary components. Woven flax with IB2 is the lowest-impact option for low-load panels. Aluminium remains important where ductility, inspection, repairability and established recycling routes are priorities.

Table 6 - Simplified cradle-to-grave lifecycle comparison of the five material systems.

Criterion	Aluminium	Woven Carbon + Epoxy (IN2)	Woven Carbon + Bio Resin (IB2)	Recycled Carbon Non-woven + Bio Resin	Woven Flax + Bio Resin (IB2)
Raw material impact	High if primary; lower with recycled stock	Highest: virgin CF and conventional epoxy	High fibre impact; lower fossil resin content	Lower than virgin CFRP due to recycled fibre input	Lowest: renewable flax; low embodied carbon
Manufacturing impact	Established forming and machining	Infusion avoids autoclave; thermoset chemistry remains	Same infusion route; improved resin source	Infusion compatible; non-woven conforms well	Infusion compatible; moisture control required
Use-phase benefit	Good, but density limits mass saving	Excellent specific stiffness and strength	Comparable if mechanical loss is small	Good for secondary lightweight panels	Good for low-load lightweight panels
End-of-life	Strongest recycling route; remeltable	Difficult; pyrolysis can recover fibre	Same thermoset issue as IN2 carbon	Circular input, but final part still thermoset	Low raw impact, but epoxy limits recovery
Recycled / renewable content	Excellent if recycled aluminium is used	Poor unless recycled fibre is introduced	Improved resin sustainability only	Strong: 100% recycled fibre input	Strong: renewable natural fibre reinforcement
Policy alignment	Repairability and recycling	Performance case but weak circularity	Transitional high-performance option	Strong circular economy alignment	Strong low-impact material alignment
Overall judgement	Best conventional baseline	Best performance; weakest sustainability	Best high-performance compromise if validated	Best circularity option for secondary parts	Best low-impact option for non-critical parts

6 Recommendations and future development

Material selection should be application-led rather than choosing one material as best overall. The results show that woven carbon remains the strongest structural option, but its use should be limited to applications where the stiffness or strength benefit is fully used. For lower-loaded parts, recycled carbon, flax and aluminium can provide a better balance between performance, sustainability, cost and repairability. Table 7 summarises the recommended use for each material system.

Table 7 - Recommended material applications.

Material	Recommended application
Woven carbon + IN2 epoxy	Highest-performance option, with 458 MPa strength and 61.23 GPa modulus. Recommended only for stiffness- or strength-critical components where the environmental cost is justified.
Woven carbon + IB2 bio resin	Strongest practical recommendation. Retained 93.3% of IN2 strength and lost less than 1.5% modulus, while reducing fossil-derived resin content. Suitable for bodywork, aero panels, diffusers and secondary structures.
Recycled carbon non-woven + IB2 bio resin	Suitable for semi-structural panels, backing laminates, covers, interior parts and bulking layers. Its 186 MPa strength is useful, but 38.60 MPa standard deviation limits confidence for primary load paths.
Woven flax + IB2 bio resin	Best low-impact natural fibre option for fairings, liners, covers and lightly loaded panels where damping, low mass and sustainability matter more than peak stiffness.
Aluminium	Still suitable where ductility, isotropic behaviour, inspection, repairability and established recycling routes are priorities.

The strongest recommendation from this study is woven carbon with IB2 bio resin. It gives near-equivalent tensile performance to the conventional epoxy system while improving the resin sustainability case, so it offers the most realistic short-term route for reducing impact without a major design compromise. Recycled carbon and flax should not be treated as direct replacements for woven carbon in primary structures, but they are valuable for secondary and low-load parts where circularity or low embodied impact is more important.

Table 8 - Recommended future development.

Future work	Reason
More repeat tests	Improves statistical confidence.
Flexural and impact testing	Better represents panels and motorsport bodywork.
Moisture ageing for flax	Assesses durability risk.
Void content and microscopy	Links manufacturing quality to scatter and failure.
Density measurement	Enables specific strength and stiffness comparison.
Quantified embodied-carbon LCA	Strengthens the sustainability argument.
Hybrid flax/carbon laminates	Balances performance with lower-impact fibre content.

Future work should focus on turning these comparative results into design-ready data. The priority should be flexural, impact and moisture-ageing tests, supported by microscopy and void-content measurement. This would show whether the observed scatter comes from fibre architecture, infusion quality or specimen preparation. A quantified LCA is also needed before firm embodied-carbon claims can be made.

7 Conclusion

This project has shown that no single material offers the best solution across all performance and sustainability requirements. Woven carbon fibre remained the strongest and stiffest option, making it the most suitable material for high-performance motorsport components where mass reduction and tensile performance are critical. However, its high embodied energy and difficult end-of-life route limit its sustainability benefit unless the reduced component weight gives a clear benefit during vehicle use.

Recycled carbon non-woven provided a useful compromise, offering lower environmental impact and acceptable stiffness for secondary or non-critical components, although its random fibre architecture reduced strength and repeatability. Flax fibre composites gave the lowest mechanical performance, but their renewable origin, lower environmental impact and compatibility with bio-based resin make them suitable for lightly loaded panels, covers and interior parts. Aluminium remains relevant where recyclability, consistency and manufacturing simplicity are priorities. Overall, material selection should be application-specific, balancing mechanical demand, manufacturing quality, lifecycle impact and end-of-life potential.

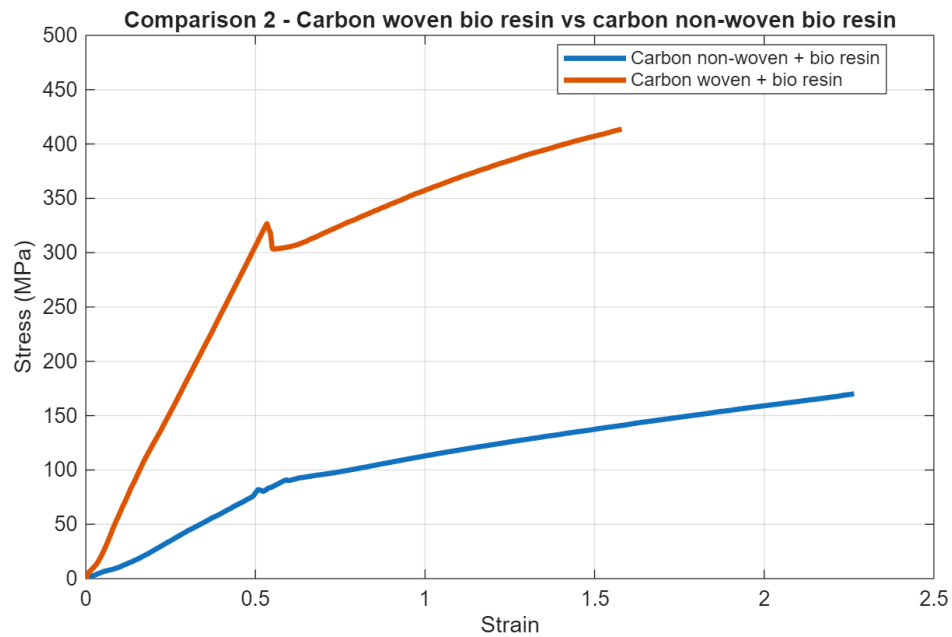
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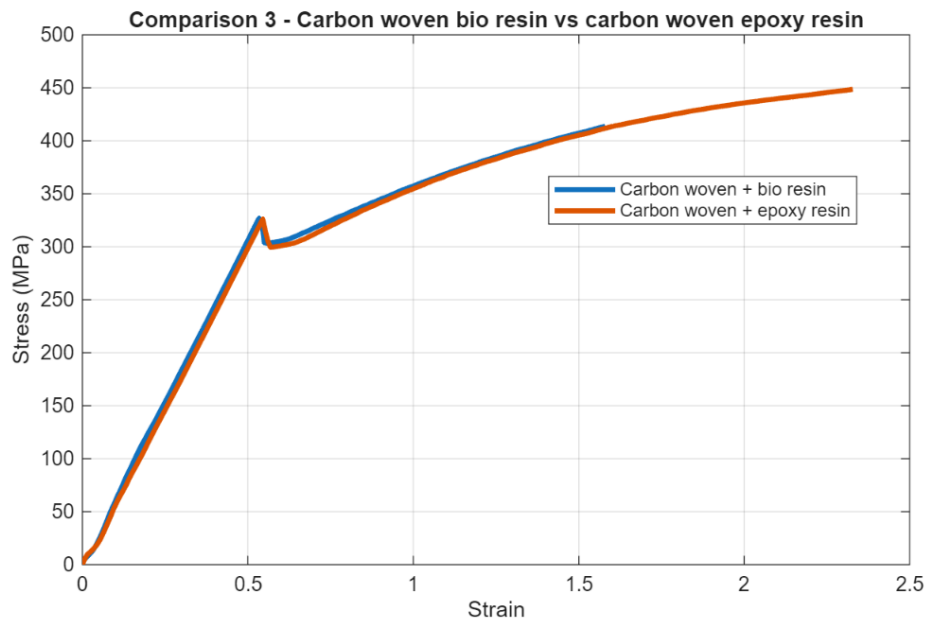
9 Appendix

9.1 Average stress comparison plots



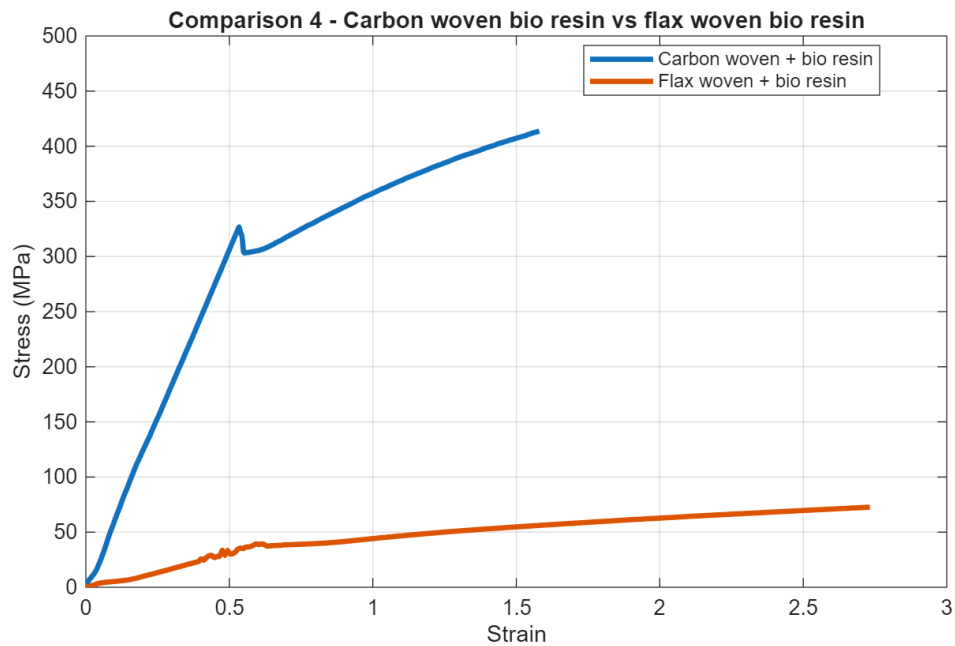
Graph 3 - Average stress-strain response: woven carbon/bio resin vs non-woven carbon/bio resin.

Shows the effect of reinforcement structure, with woven carbon producing a much higher stress response.



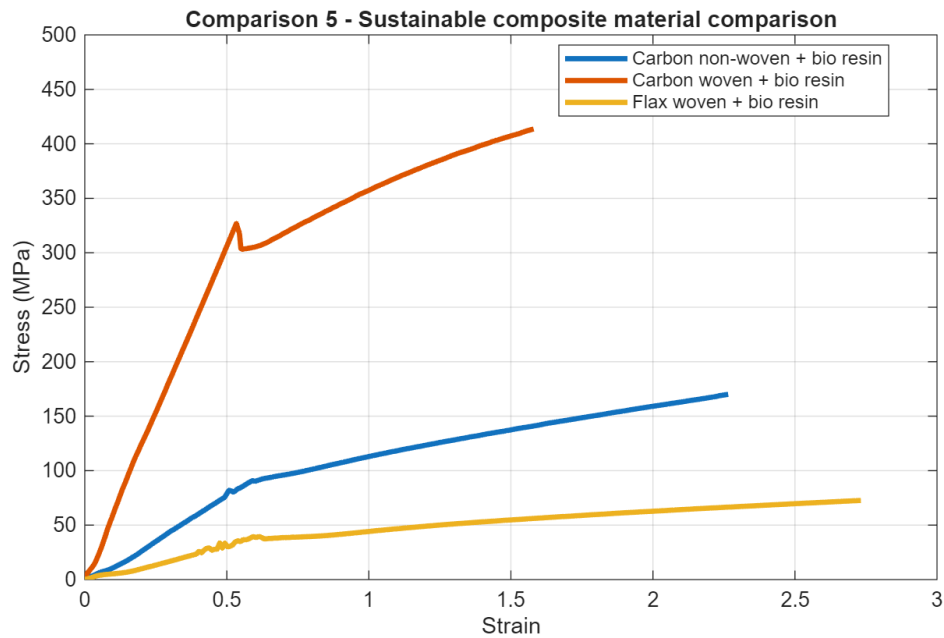
Graph 4 - Average stress-strain response: woven carbon/bio resin vs woven carbon/epoxy resin.

Direct resin comparison showing similar response, with epoxy resin reaching the highest final stress.



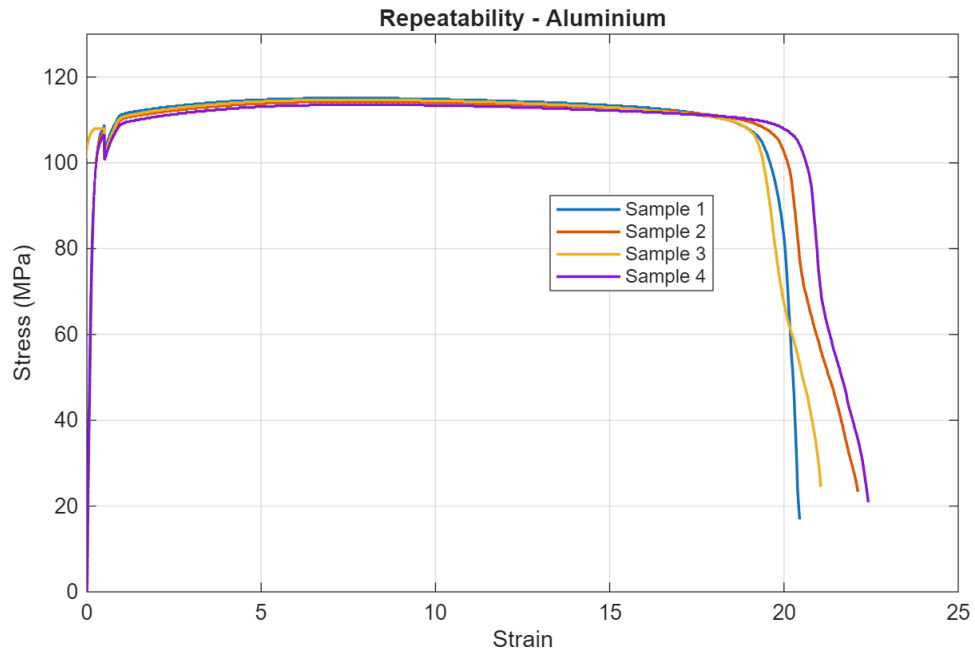
Graph 5 - Average stress–strain response: woven carbon/bio resin vs woven flax/bio resin.

Highlights the large strength difference between carbon and flax reinforcement under tensile loading.



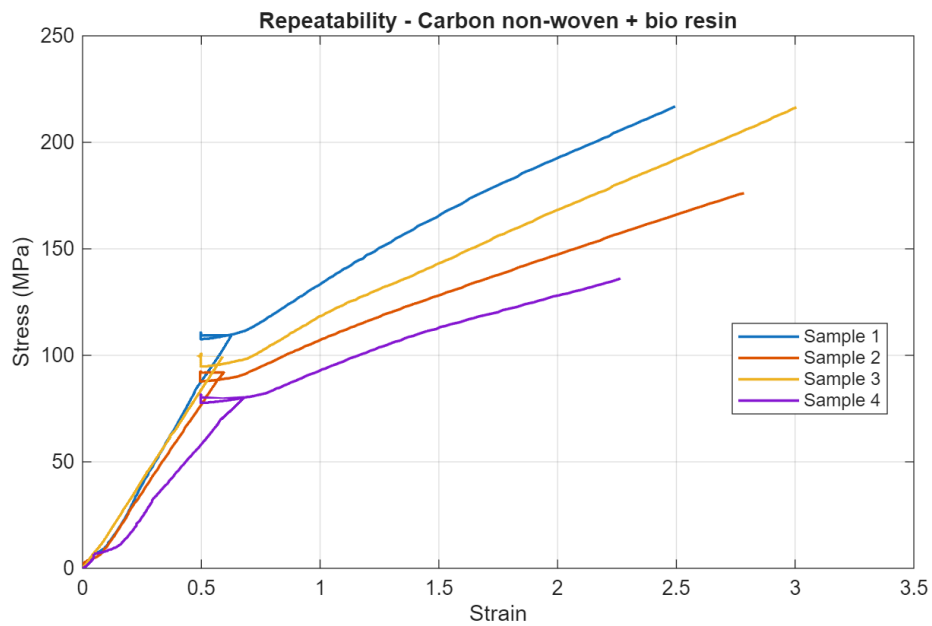
Graph 6 - Average stress–strain response: sustainable composite material comparison.

Compares the lower-impact composite options against the stronger carbon woven/bio resin laminate.



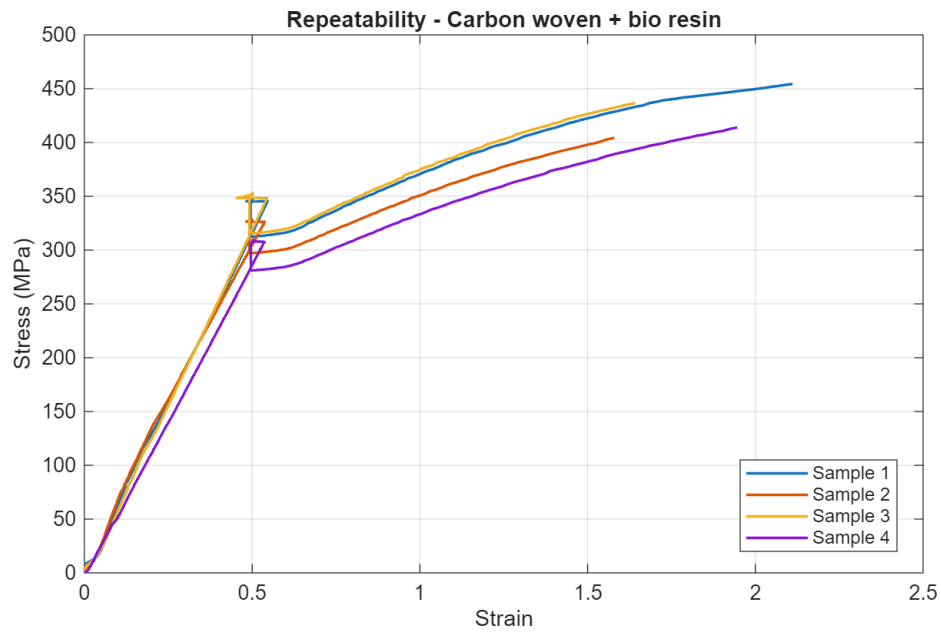
Graph 7 - Repeatability of aluminium tensile samples.

Shows consistent ductile behaviour and similar stress plateau before necking and failure.



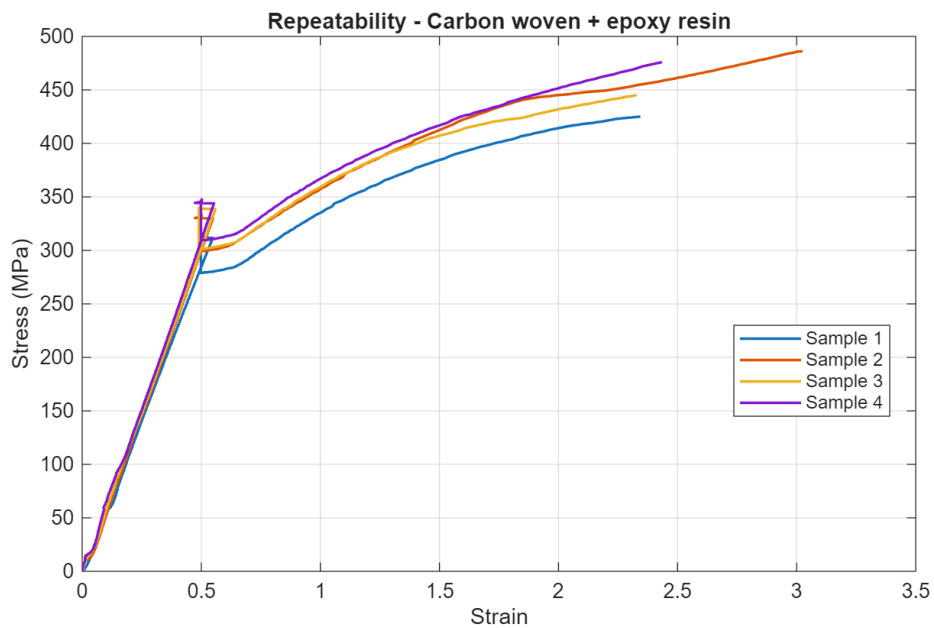
Graph 8 - Repeatability of carbon non-woven/bio resin samples.

Shows greater scatter, suggesting higher sensitivity to fibre distribution and laminate consistency.



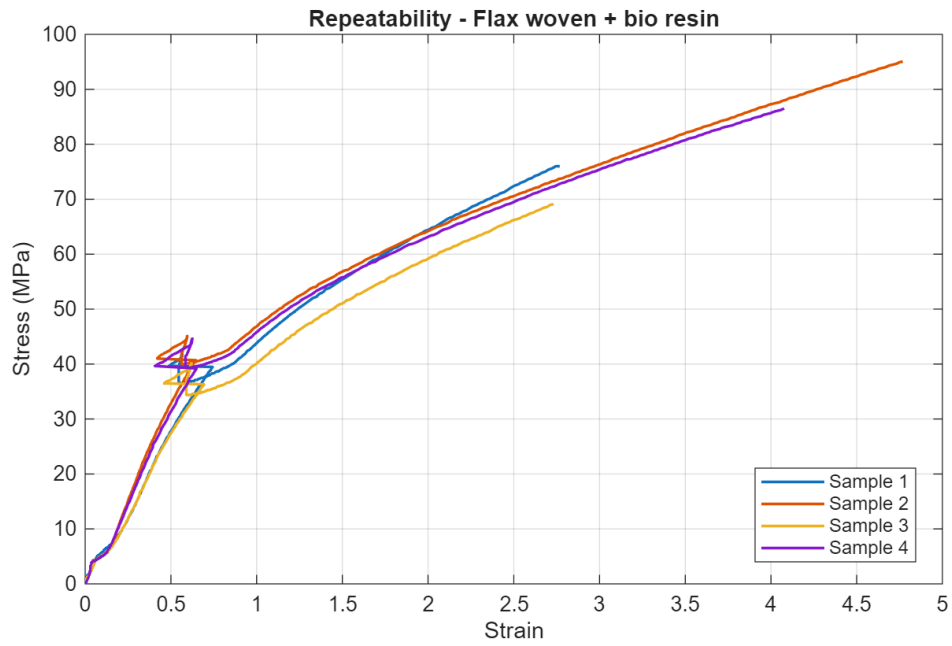
Graph 9 - Repeatability of carbon woven/bio resin samples.

Shows strong repeatability in the elastic region with some variation in final strain and strength.



Graph 10 - Repeatability of carbon woven/epoxy resin samples.

Shows the highest stress response with relatively consistent curve shape between samples.



Graph 11 - Repeatability of flax woven/bio resin samples.

Shows lower stress values but comparatively consistent progressive loading behaviour.

9.2 Failure strain summary

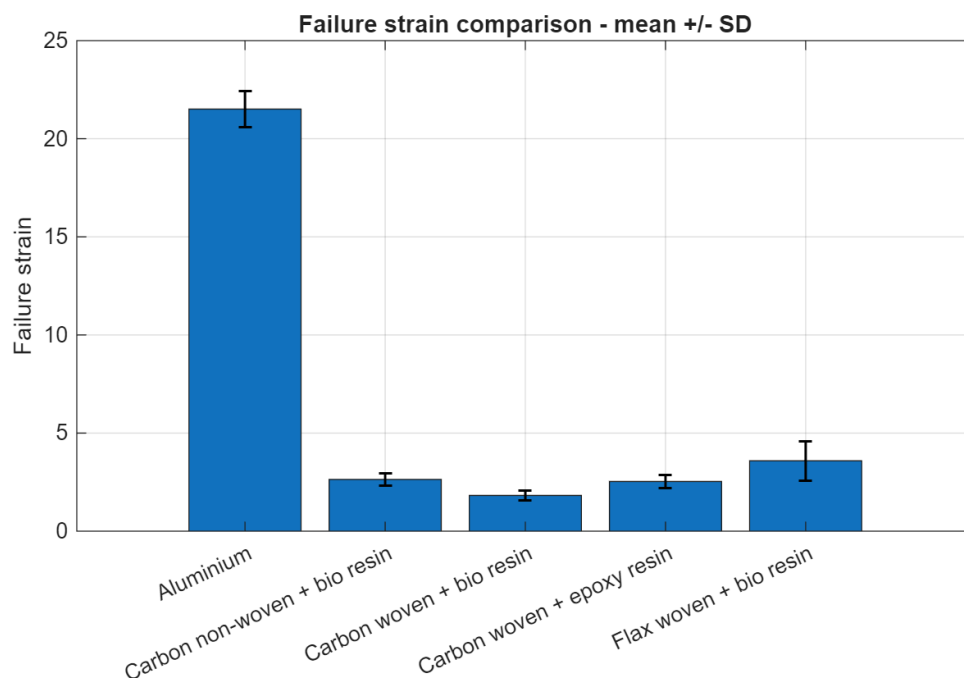


Figure 5 - Mean failure strain comparison with standard deviation.

Aluminium shows the highest ductility, while the composite samples fail at much lower strain values.

9.3 Specimen failure images



Figure 6 - Composite tensile specimen after failure in test grips.

Shows brittle composite fracture with limited visible plastic deformation.

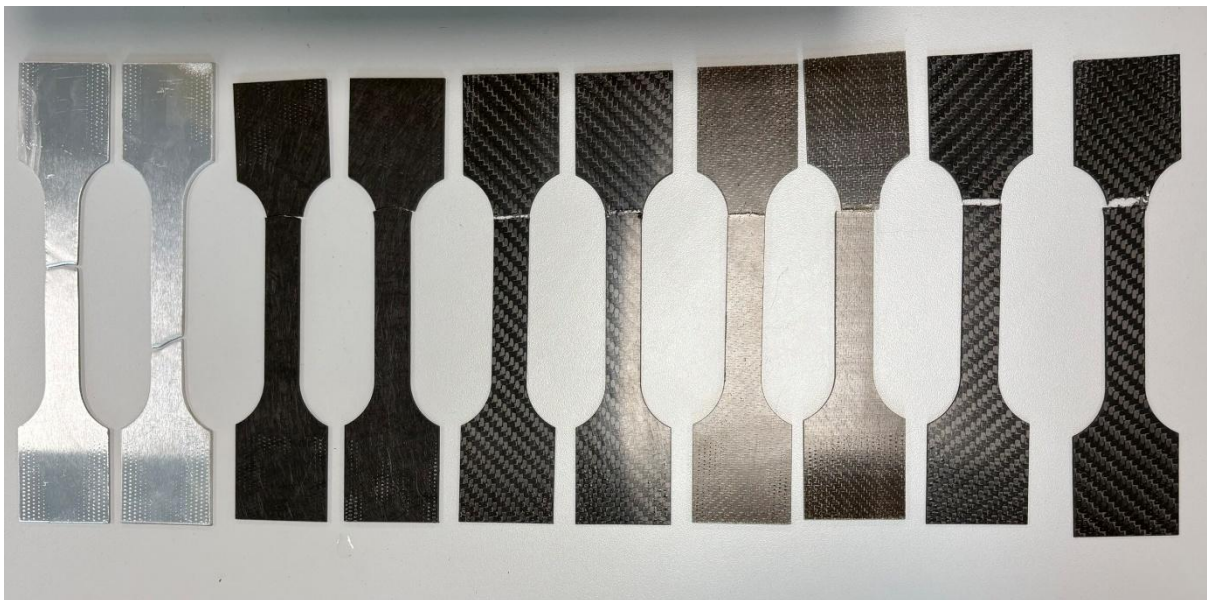


Figure 7 - Post-test tensile specimens showing aluminium necking and composite fracture locations.

Aluminium shows ductile necking, while the composite specimens fail more locally and consistently.