



Materials Testing and Sustainability of Composites for Motorsport & Automotive Industries

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1.0 Introduction

This report investigates the mechanical performance and sustainability profiles of seven composite and metallic materials relevant to motorsport and automotive engineering. Through tensile testing conducted at the University of Wales Trinity Saint David, stress-strain behaviour, Young's Modulus and Ultimate Tensile Strength are experimentally characterised for an aluminium baseline, carbon woven and non-woven bio-resin composites, carbon woven epoxy, flax woven and non-woven bio-resin composites and Kevlar woven bio-resin. Experimental results are validated against manufacturer datasheets and published literature bands, with the Rule of Mixtures calculations applied where consolidated laminate data was unavailable. Alongside the mechanical analysis, a sustainability assessment evaluates each material system through Life Cycle Assessment, recyclability, legislative compliance and carbon footprint reduction potential, providing a dual-criteria framework for material selection that balances structural performance against environmental impact in the context of tightening automotive and motorsport regulation.

2.0 Literature Review

2.1 Composite Material Structure & Phases

Composite materials combine a reinforcing phase, which carries primary tensile and compressive loads, with a matrix phase that provides shear resistance and transfers load between fibres (Rajak, 2022). In most high-performance applications the matrix is an epoxy thermoset, a network polymer whose three active covalent bonds produce a rigid, crosslinked structure that cannot be remelted once cured. This molecular architecture delivers dimensional stability and chemical resistance, but as later discussed in section 3, it also creates significant end-of-life challenges that thermoplastic alternatives do not share.

$$E_c(u) = E_m V_m + E_p V_p$$

Equation 1 – Law of Mixtures Upper

$$E_c(l) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

Equation 2 – Law of Mixtures Lower

- E_c - Elastic Modulus Composite
- E_m - Elastic Modulus Matrix
- E_p - Elastic Modulus Particle
- V_m - Volume Fraction Matrix
- V_p - Volume Fraction Particle

The overall stiffness of the composite is governed by the Law of Mixtures (Equation 1 & 2), making fibre volume fraction a critical process control parameter, whilst fibre orientation (Figure 1) determines the directional distribution of that stiffness; woven architectures spreading load bidirectionally, unidirectional lay-ups concentrating the load along a single axis (Composites UK, 2025). Increasingly, petroleum-based epoxies are being substituted with bio-derived resin systems that reduce lifecycle carbon footprint without significantly compromising mechanical performance (Khan, 2021), offering a matrix-level response to the regulatory pressure explored in Section 3.

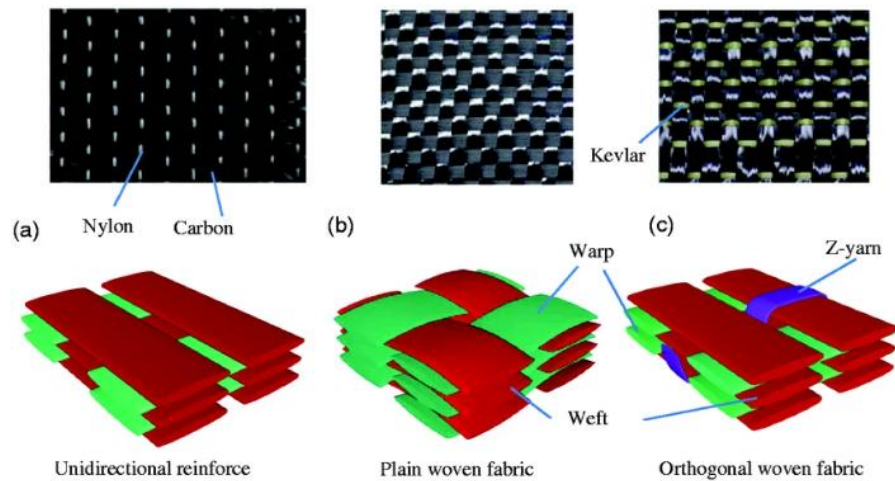


Figure 1 – Fibre Orientation Comparison (Composites UK, 2025)

2.2 Carbon Fibre Reinforced Polymers (CFRP)

CFRP remains the benchmark composite in motorsport and automotive engineering, offering an exceptional strength-to-weight ratio, high specific stiffness, fatigue resistance and chemical inertness, covered by Davidson, (2026). McLaren's introduction of the carbon fibre monocoque in Formula 1 in 1981 marked the point at which CFRP moved from aerospace curiosity to motorsport standard (figure 2), a trajectory that has since extended into high-performance road cars and electric vehicles. The automotive carbon fibre market reflects this: valued at USD 21.13 billion in 2022 and projected to reach USD 64.05 billion by 2032 (Semitekolos, 2024). As CFRP scales into volume production, however, the energy intensity of its manufacture has drawn increasing scrutiny, setting up the central tension explored in the sustainability analysis that follows.



Figure 2 – McLaren Carbon Fibre Monocoque (Motorsport, 2022)

2.3 Natural Fibre Composites

Natural fibre composites represent a growing area of research for sustainable application. Flax fibres possess a Young's Modulus of up to 140 GPa, comparable to aramid fibres and their mechanical merits alongside biodegradability, making them increasingly considered as reinforcements in sustainable composite design (Zhu, 2013). From a sustainability standpoint, flax fibre components can provide up to 85% CO_2 reduction in initial energy expenditure compared to equivalent carbon fibre parts (Bcomp, 2026). Bcomp's ampliTex™ woven flax reinforcement has demonstrated this in motorsport, with full natural fibre composites presenting challenges including moisture absorption, lower absolute strength and greater variability in fibre properties compared to synthetic alternatives requiring surface treatment and careful processing control to achieve consistent performance (Skosana, 2024).

2.4 Manufacturing Processes

Table 1 summarises the principal manufacturing routes used in automotive and motorsport composite production, ranging from low-cost open mould methods to highly controlled closed mould processes, each offering distinct trade-offs in fibre volume fraction, surface quality, and cost.

PROCESS	ADVANTAGES	DISADVANTAGES	TYPICAL APPLICATION
Hand lay-up	Low cost, simple tooling, suitable for large parts, no size restriction	Labour intensive, inconsistent quality, requires secondary finishing, low fibre volume fraction	Low-volume motorsport bodywork, marine hulls
Autoclave prepreg	Highest fibre volume fraction, minimal voids, excellent dimensional accuracy, consistent quality	Very high cost, slow cycle time, size limited by autoclave, high energy consumption	F1 chassis, aerospace structures
Resin transfer moulding (RTM)	Good surface finish both sides, consistent quality, low emissions, moderate fibre volume fraction	High tooling cost, limited to moderate complexity, injection pressure can cause fibre displacement	Automotive structural panels, GT racing components
Vacuum-assisted RTM (VARTM)	Lower tooling cost than RTM, large parts possible, good fibre volume fraction, low emissions	Slower than RTM, one finished surface only, process sensitive to leaks	Wind turbine blades, marine structures
Vacuum bag moulding	Better fibre volume fraction than hand lay-up, low tooling cost, removes excess resin	Requires oven cure, one finished surface, labour intensive, not suitable for complex geometries	Prototype components, low-volume production
Filament winding	Highly automated, excellent repeatability, high fibre volume fraction, low material waste	Limited to convex shapes, poor off-axis properties, expensive mandrel required	Pressure vessels, drive shafts, roll hoops
Compression moulding	Fast cycle times, good surface finish, suitable for high volume, low material waste	High tooling cost, limited to relatively simple shapes, high press investment	High-volume automotive panels

Table 1 – Manufacturing Routes Advantages & Disadvantages

Autoclave prepreg remains the dominant route for F1 and aerospace applications, delivering the highest fibre volume fraction and lowest void content, though high energy demand and slow cycle times limit its use at volume (Campbell, 2003). RTM and VARTM offer a practical middle ground at lower tooling cost, whilst compression moulding suits the highest production volumes despite geometric constraints. No single process is universally superior; the selection is always application driven.

2.5 Applications in Motorsport & Automotive Engineering

Around 80% of an F1 vehicle's volume is made from composite materials, with composites used in the chassis, engine covers, brake ducts, bodywork, wings, diffusers and suspension systems (PIRAN ADVANCED COMPOSITES, 2024). Beyond Formula 1, composites are now standard in MotoGP, GT racing and high-performance road cars. The selection between CFRP, bio-resin CFRP and natural fibre reinforced polymer (NFRP) ultimately involves balancing mechanical performance, manufacturing cost and lifecycle environmental impact, a trade-off that is central to both the experimental testing and sustainability analysis presented in this report.

2.6 Material Properties

2.6.1 Youngs Modulus (Elastic Modulus)

Young's Modulus, E , describes a material's stiffness within the linear elastic region, where deformation is fully recoverable upon load removal.

$$E = \frac{\sigma}{\epsilon}$$

Equation 3 – Youngs Modulus

CFRP typically achieves longitudinal moduli of 70-200 GPa depending on fibre type and layup, far exceeding aluminium on a weight-normalised basis (Davidson, 2026).

2.6.2 Ultimate Tensile Strength (UTS)

UTS represents the maximum stress a material sustains before fracture, calculated as:

$$\sigma_{UTS} = \frac{F_{max}}{A_0}$$

Equation 4 - UTS

Where F_{max} is the maximum applied force (N) and A_0 is the cross-sectional area (mm²). In fibre-reinforced composites, UTS is highly sensitive to fibre orientation, longitudinal loading produces significantly higher strength than transverse loading, where the matrix and fibre-matrix interface govern failure rather than the fibre itself (Rajak, 2022).

2.6.3 Failure Strain

Failure strain defines the total strain at fracture, providing a measure of material ductility or brittleness:

$$\varepsilon_f = \frac{\Delta L}{L_0}$$

Equation 5 – Failure Strain

Thermoset composites typically exhibit failure strains below 2%, reflecting brittle fracture behaviour, compared to ductile metals such as aluminium which may exceed 10% before failure. Natural fibre composites generally display slightly higher failure strains than CFRP due to the viscoelastic nature of plant-based fibres. (Callister, 2018)

2.6.4 Stress & Strain

Engineering stress and strain are the foundational quantities from which all mechanical properties are derived:

$$\sigma = \frac{F}{A_0} \quad \varepsilon = \frac{\delta}{L_0}$$

Equation 6 – Stress & Strain

Where F is the applied load (N), A_0 the original cross-sectional area (mm²), δ the measured extension (mm), and L_0 the original gauge length (mm). In this study, both values were calculated directly from load-displacement data recorded by the Denison machine, with cross-sectional dimensions measured prior to each test.

3.0 Sustainability Analysis

3.1 Life Cycle Assessment

LCA provides the methodological foundation for comparing the true environmental cost of composite materials, governed by ISO 14040 and ISO 14044, which define system boundaries and data quality requirements to ensure comparisons are transparent and consistent. In automotive applications, a full cradle-to-grave assessment spans raw material extraction, material production, component manufacturing, assembly, use phase and end-of-life, and for CFRP, the production stage dominates. PAN-based carbon fibre carries an embodied energy of 183-286 MJ/kg against approximately 22 MJ/kg for steel (Meng, 2017), and as shown in figure 3, fibre production accounts for 558 MJ of a CF/epoxy laminate's cumulative energy demand, dwarfing the epoxy resin and processing contributions (Rosa A. L., 2016). Weight savings during the use phase can offset this initial burden, but the calculation is sensitive to vehicle type, usage profile and regional energy mix. Bio-resin substitution reduces the matrix-phase fossil carbon intensity by up to 50% without requiring changes to the fibre production process (Rosa, 2018), a meaningful and immediately accessible improvement.

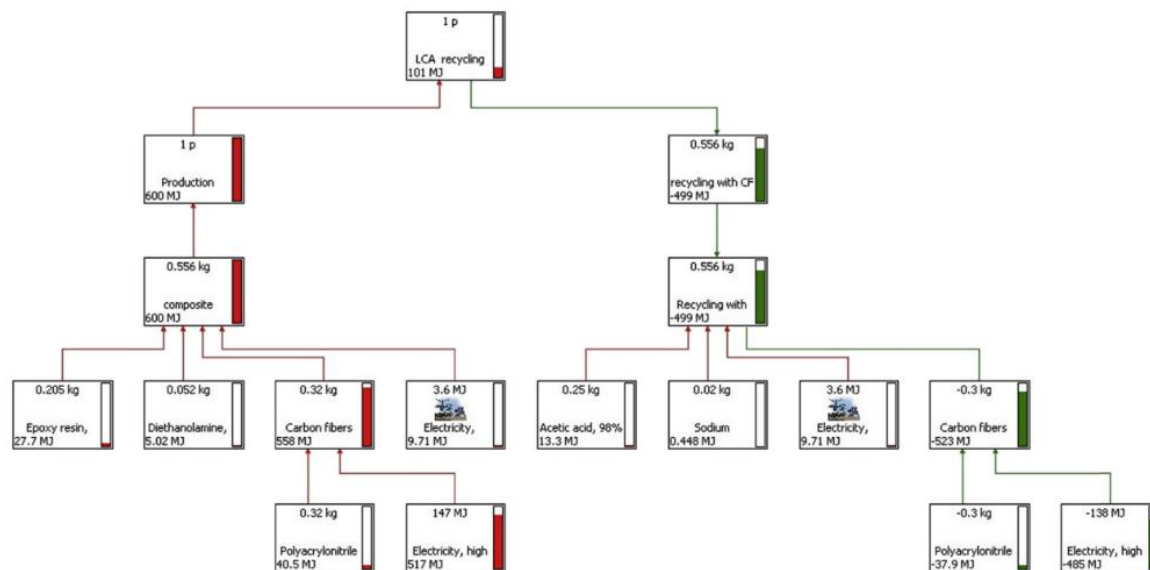


Figure 3 – Life Cycle Assessment energy demand tree for CF/epoxy composite production and solvolysis recycling pathway (Rosa, 2018)

3.2 Recyclability & End-of-Life

Unlike thermoplastics, the crosslinked thermoset matrix in epoxy composites cannot be remelted, ruling out conventional recycling routes. CFRP is primarily recovered through pyrolysis, which reclaims carbon fibres for reuse but reduces fibre length and adds energy cost, limiting the structural grade of the recovered material. As illustrated in figure 4 adapted from Naqvi, (2018), the pyrolysis route takes woven CFRC through thermal decomposition to produce short, fluffy, non-aligned recovered fibres, which following post-pyrolysis treatment can be reprocessed into new composite, closing the material loop. Studies report only around 5-10% loss in tensile strength using pyrolysis compared to approximately 50% loss via combustion (Naqvi, 2018), suggesting the process is viable if infrastructure and process parameters are optimised.

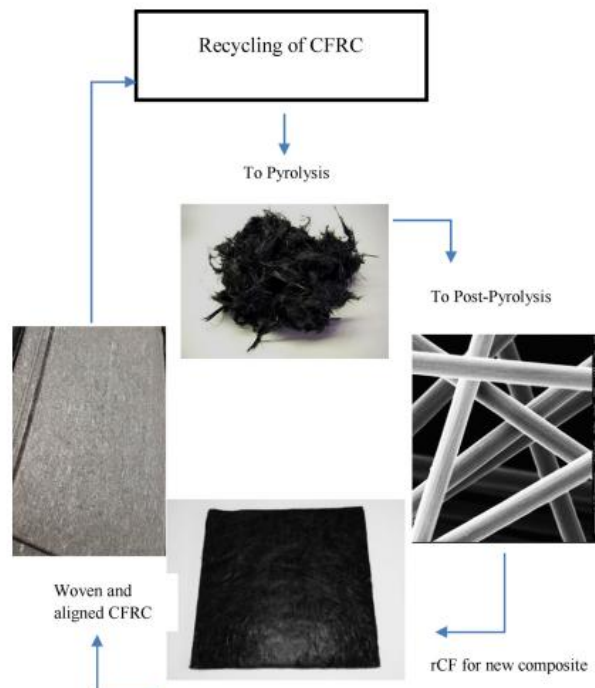


Figure 4 - Closed-loop pyrolysis recycling pathway for CFRC, from woven laminate through pyrolysis to reclaimed carbon fibre for new composite production (Naqvi, 2018)

3.3 Legislation & Governing Body Policy

The EU End-of-Life Vehicles Directive mandates 85% reusability or recyclability and 95% recoverability by vehicle mass, placing growing pressure on manufacturers as composite content increases (EUR-Lex, 2000). The UK Net Zero Strategy and EU Green Deal both impose legally binding carbon neutrality targets by 2050, driving demand for bio-based feedstocks and credible LCA documentation throughout the automotive supply chain (GOV-UK, 2022). Within motorsport, Formula 1's net zero carbon target by 2030 encompasses materials and supply chain, with the FIA's Technical Regulations progressively favouring sustainable material provenance (F1, 2019). Bcomp's flax-based composite panels have been homologated for use in Formula 2, Formula 3 and GT categories, confirming that natural fibre composites can satisfy both structural and regulatory requirements in competitive motorsport (Bcomp, 2026).

3.4 Carbon Footprint Reduction Potential

Conventional CFRP carries the greatest environmental burden, whilst bio-resin substitution reduces matrix-phase fossil carbon by up to 50% (La Rosa, 2018). Natural fibre composites offer the most significant reduction, lifecycle studies report 75-95% greenhouse gas savings over synthetic equivalents through lower production energy and biogenic carbon sequestration (SAGE Publications, 2021). Lower absolute mechanical performance currently limits NFRP to secondary and non-load-bearing applications, though as embodied carbon regulation tightens this boundary is likely to shift (Witik, 2011).

4.0 Experimental Testing

4.1 Methodology

Tensile testing was conducted using the Denson Tensile/Compression test equipment at the University of Wales Trinity Saint David. All testing was conducted in accordance with laboratory Health and Safety requirements with appropriate PPE worn throughout.

Seven materials were tested: an aluminium baseline, carbon twill with bio-resin, carbon twill with traditional epoxy, carbon non-woven with bio-resin, flax twill with bio-resin, flax non-woven with bio-resin and Kevlar twill with bio-resin. As shown in figure 5, the full range of specimens reflects the expected effects of testing, from the metallic baseline through synthetic and natural fibre composites to Kevlar samples. All composite materials were sourced from Easy Composites, with manufacturer datasheets available for validation. Twill materials were laid up as three layers of 200 g/m² fabric at 45° to each other, giving a total area weight of 600 g/m². Non-woven materials consisted of a single layer of 300 g/m² fabric. The 45° ply orientation establishes upper and lower performance boundaries, with the longitudinal direction representing the upper strength boundary and the transverse direction the lower. Carbon composites were assumed to have a 50:50 fibre-to-epoxy volume fraction.

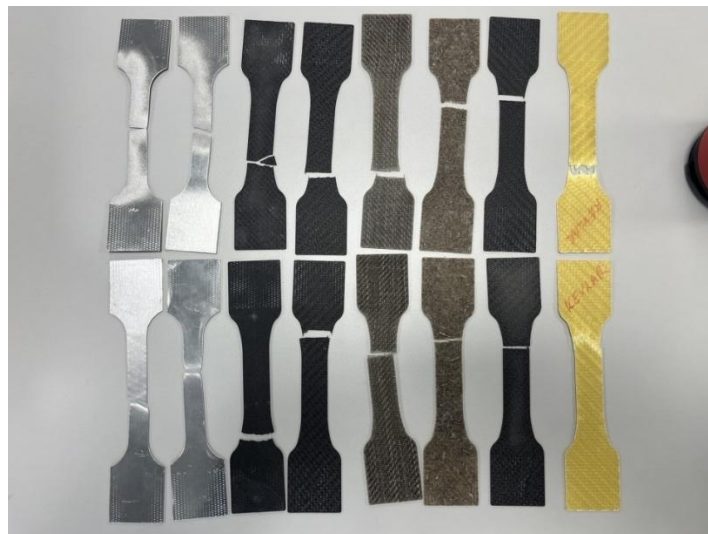


Figure 5 – Test Sample Fracture Comparison

Prior to testing, specimen dimensions were measured to calculate cross-sectional area. Each specimen was loaded into the Denison machine using the wedge-action grips shown in figure 6, with additional mesh material bonded to the grip regions to prevent jaw induced failure at the tab zones, a precaution necessary given the brittle failure modes typical of thermoset composites under tensile loading.



Figure 6 - Denison Machine wedge-action grips

4.2 Reference Validation Data

Manufacturer datasheets supplied by Easy Composites provided expected values of Young's Modulus and UTS for each material, against which experimental results were validated. For the carbon woven composites, datasheet properties were given separately for fibre and matrix, requiring a Rule of Mixtures calculation, covered in Section 2.1, to determine the expected laminate modulus range prior to comparison.

5.0 Results & Analysis

Table 2 presents the empirical mean Young's Modulus, UTS and failure strain percentage average across three tests per material, compared against literature bands and calculated values. For the carbon woven bio-resin and epoxy, no consolidated laminate modulus was available, so the Law of Mixtures was applied to fibre and matrix properties separately, producing the upper and lower bands shown as T-c Up and T-c Low.

Experimental & Manufacturer Data

	Literature				Empirical		
	Calculated GPa				Mean Across 3 Tests		
	T-c Up	T-c Low	UTS (Mpa)	YM (GPa)	YM (GPa)	UTS (MPa)	Failure Strain %
Aluminium	x	x	90 - 110	68 - 72	51.83	109.46	5.04
Carbon Non Woven BIO	x	x	50 - 200	25 - 35	36.94	188.36	2.31
Carbon Woven BIO	118.47	5.59	316 - 856	x	72.41	533.25	2.68
Carbon Woven Epoxy	118.55	6.12	316 - 1185	x	68.37	368.71	2.45
Flax non woven BIO	x	x	18 - 43	5.00	5.18	30.05	1.98
flax woven bio	x	x	60 - 115	6.50	12.03	100.58	3.65
kevlar woven bio	x	x	140 - 303	83 - 124	23.64	182.54	4.88

Table 2 – Empirical & Literature supported testing results, UTS & Young's Modulus

Both carbon woven variants performed within their literature UTS bands, with the bio-resin returning 533.25 MPa and the epoxy 368.71 MPa. The epoxy result sits at the lower end of its 316-1185 MPa band, likely reflecting potential for a human error during testing. Kevlar woven bio-resin recorded 182.54 MPa within its 140-303 MPa band, with a failure strain of 4.88% reflecting aramid's characteristic energy absorption. Both flax tests fell within their respective literature bands, with the woven variant at 100.58 MPa significantly outperforming the non-woven at 30.05 MPa, a difference driven entirely by fibre architecture rather than material composition. The aluminium UTS of 109.46 MPa aligned well with the 90-110 MPa literature band, though the modulus of 51.83 GPa fell below the expected range.

5.1 Stress-Strain Material Analysis

5.1.1 Aluminium Baseline: Three Test Comparison

All three tests follow a similar profile, elastic rise to yield around 100 MPa, short strain hardening to a mean UTS of 109.46 MPa, then an extended plastic plateau before fracture, characteristic ductile behaviour consistent with the literature band of 90-110 MPa (Callister, 2018). Variation between tests is limited to failure strain, with Test 1 fracturing earlier than Tests 2 and 3 due to natural variability in necking behaviour. Failure strain values in Table 2 reflect extensometer data only up to instrument removal, final fracture occurred at much higher crosshead displacements as visible in Figure 7 and is not reported as true material strain. The modulus of 51.83 GPa falling below the 68-72 GPa literature range is likely attributable to extensometer compliance at the low loads present during the initial elastic region.

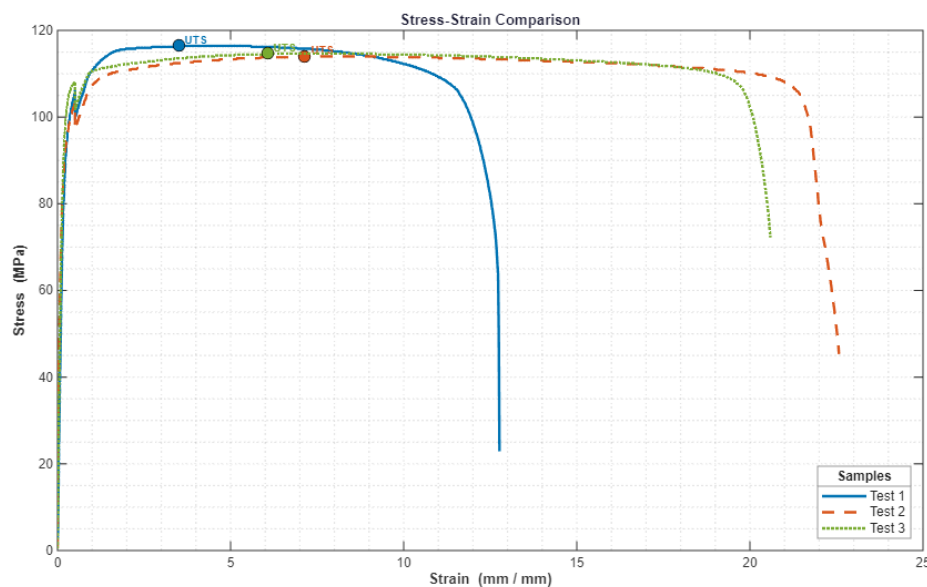


Figure 7 – Aluminium Stress-Strain 3 Test Sample Comparison

The stress-strain profile observed across all three tests shows strong agreement with the characteristic aluminium curve presented by (Yun, 2021), illustrated in figure 8. Both display the same key features, a linear elastic region, a gradual yield transition at the 0.2% proof stress, strain hardening to a UTS plateau and an extended ductile fracture.

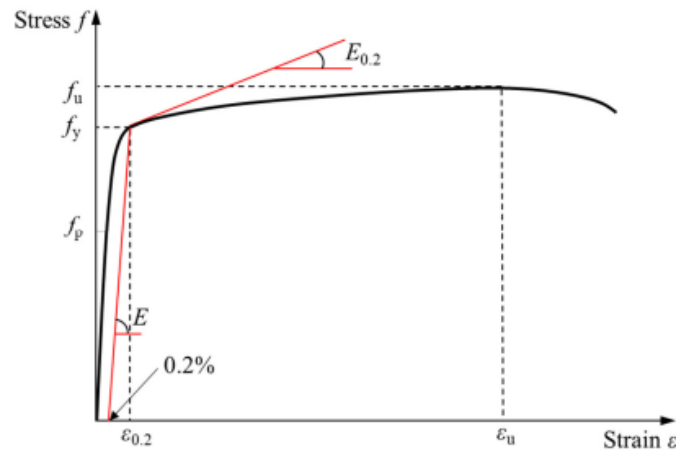


Figure 8 – Aluminium Stress-Strain image from literature for comparison (Yun, 2021)

5.1.2 Carbon Woven Epoxy: Three-Test Comparison

Test 1 achieves 1277.8 MPa with a continuous load increase to failure, consistent with fibre-dominated fracture. Tests 2 and 3 peak at 390.4 and 477.0 MPa, both showing a two-stage failure, an initial load drop around 0.5 mm/mm suggesting matrix cracking or delamination, followed by a secondary load-bearing phase before final fracture. Near-identical initial stiffness across all three tests suggests the material is consistent, the UTS divergence more likely reflecting variability in specimen alignment or tab bonding during lay-up. Test 1 sits within the upper portion of the literature band of 316-1185 MPa whilst Tests 2 and 3 fall at the lower end, pulling the mean to 368.71 MPa and highlighting the limitation of averaging when one specimen behaves fundamentally differently to the others. Shown in Figure 9.

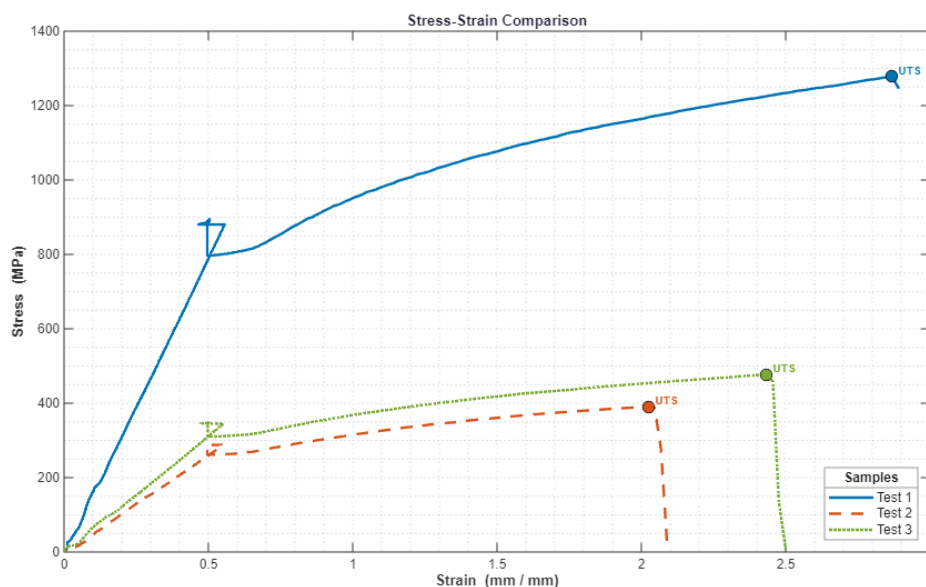


Figure 9 – Carbon Woven Epoxy Stress-Strain 3 Test Sample Comparison

5.1.3 Carbon Woven Bio-Resin: Three-Test Comparison

All three tests share the same initial stiffness and a characteristic load drop around 0.5mm/mm strain. All three continue to carry load to final fracture, confirming consistent fibre-dominated failure. The UTS values all fall within the literature band with variation between tests limited primarily failure strain rather than strength, Test 1 fracturing at 2.0 mm/mm against test 2's 2.75 mm/mm. The visible stress recovery loop in Test 1 is characteristic of partial delamination followed by load redistribution to intact fibre tows. Compared to the epoxy variant, the bio-resin produces lower absolute strength but considerably more repeatable results, suggesting more consistent fibre-matrix wet-out during infusion. Shown in Figure 10.

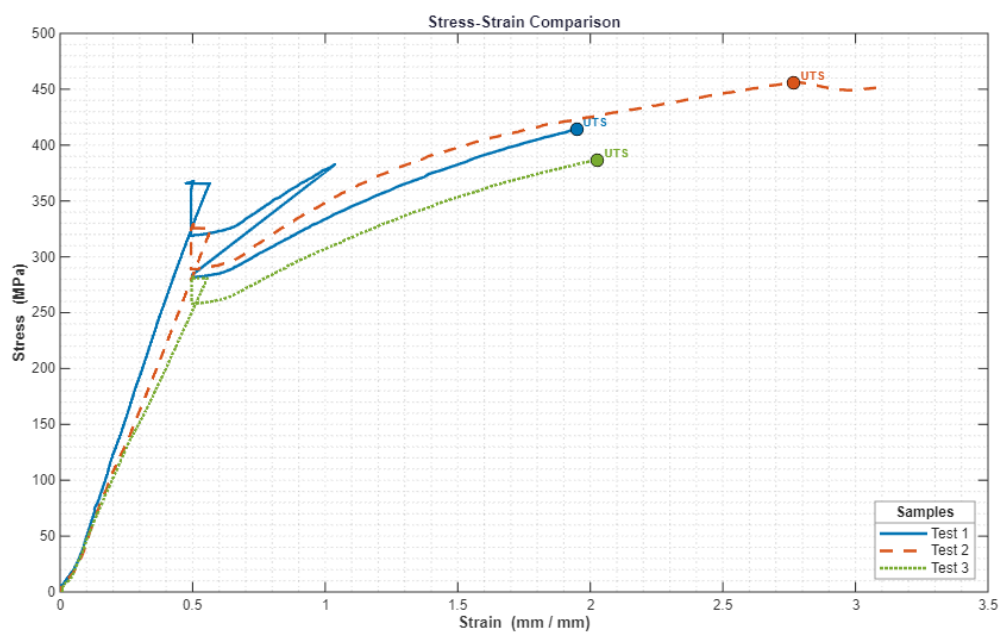


Figure 10 – Carbon Woven Bio-Resin Stress-Strain 3 Test Sample Comparison

5.1.4 Carbon Woven Bio vs Carbon Woven Epoxy

Figure 11 shows the same fibre and same weave, 1277.80 MPa versus 414.5 MPa. Both curves share a similar initial gradient before diverging as damage accumulates, with the epoxy recovering from the transition event at 0.5 mm/mm and continuing to climb, whilst the bio-resin plateaus after load redistribution. The performance gap is matrix-dominated rather than fibre-related, pointing to differences in interfacial adhesion or crosslink density between the two resin systems. Where loading stays within the elastic region, bio-resin CFRP performs comparably, but for applications demanding maximum ultimate strength, the conventional epoxy retains a clear advantage (Rosa, 2018).

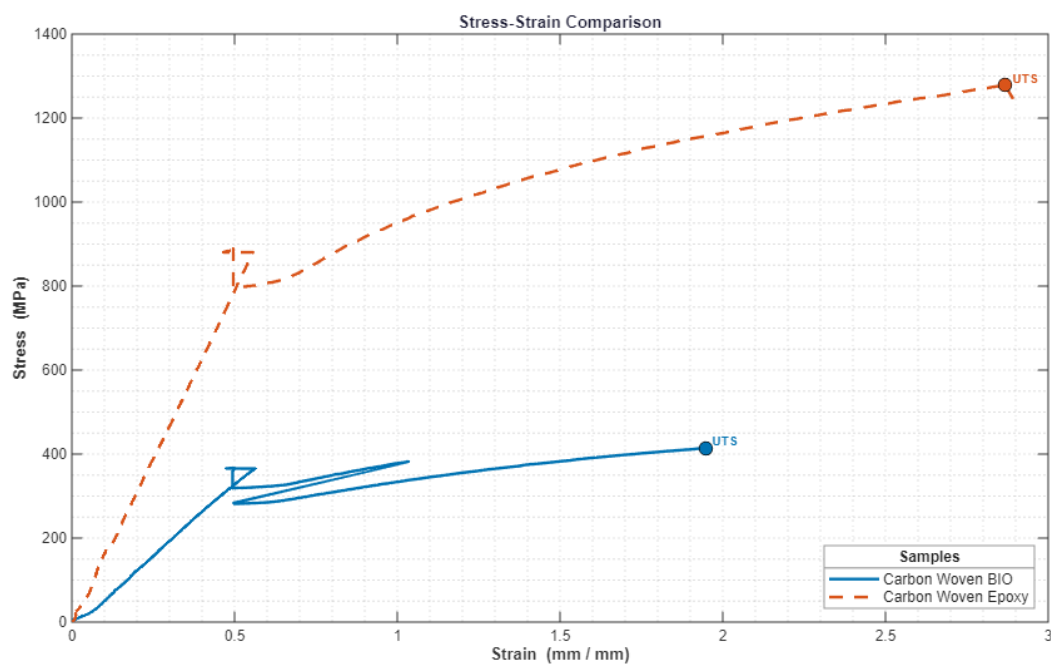


Figure 11 – Carbon Woven Bio vs Carbon Woven Epoxy Comparison

5.1.5 Flax Woven vs Flax non-Woven

Figure 12 shows the same fibre and resin similar to the previous section but looking at the weave behaviour comparing a 90.8 MPa and 29.6 MPa, a threefold difference driven entirely by architecture. The woven specimen redistributes load progressively through the weave to failure at 3.8mm/mm, whilst non-woven's random fibre orientation produces inconsistent load paths, an irregular stress-strain profile and brittle failure at 1.9 mm/mm. Both fall within their literature bands, but the gap between them makes a clear point that the layup selection is as consequential as material choice when specifying natural fibre composites (Skosana, 2024).

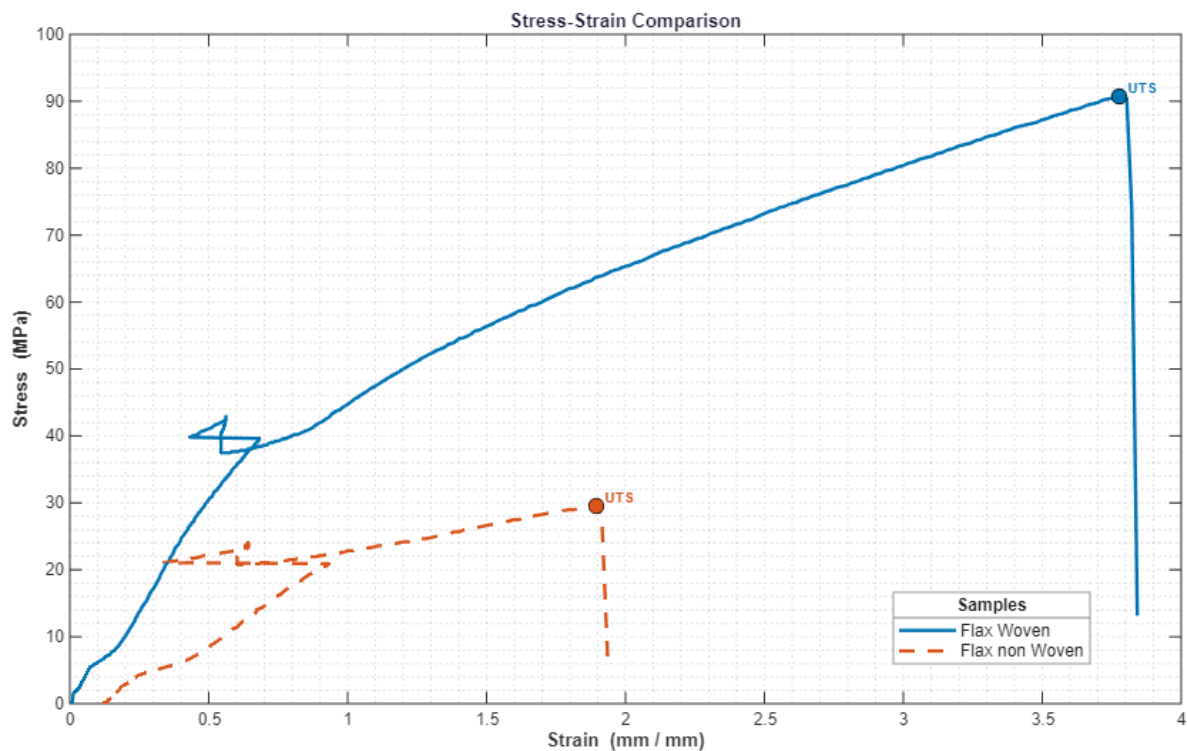


Figure 12 – Flax Woven vs Flax Non-Woven Comparison

More comparison graphs can be found in the Appendix.

5.2 Variation Study

Table 3 presents the coefficient of variation (CofV) for both UTS and Young's Modulus across all seven materials, providing a quantitative measure of test repeatability. CofV is calculated as the standard deviation expressed as a percentage of the mean, lower values indicating more consistent, repeatable results.

Variation Study						
	UTS (MPa)			Youngs Modulus (GPa)		
	AVG	STD Deviation	CofV	AVG	STD Deviation	CofV
Aluminium	109.46	8.18	7.47%	51.83	12.00	23.15%
Carbon Non Woven BIO	188.36	41.60	22.09%	36.94	4.11	11.12%
Carbon Woven BIO	533.25	190.93	35.80%	72.41	6.78	9.36%
Carbon Woven Epoxy	368.71	83.86	22.74%	68.37	3.30	4.82%
Flax non woven BIO	30.05	4.55	15.15%	5.18	1.74	33.57%
flax woven bio	100.58	71.46	71.05%	12.03	10.52	87.42%
kevlar woven bio	182.54	93.03	50.96%	23.64	1.63	6.91%

Table 3 – Coefficient Variation Data

The synthetic composites produced the most consistent UTS results, with carbon woven epoxy and carbon woven bio providing CofV values of 22.74% and 35.80% respectively. The carbon woven epoxy modulus CofV of just 4.82% confirms that despite the significant UTS variation between tests discussed in figure 9, the initial stiffness of the material was repeatable, supporting the argument that specimen preparation rather than material inconsistency drove the UTS scatter. Aluminium returned a UTS CofV of 7.47%, the lowest in the dataset, consistent with the tight clustering of the three stress-strain curves visible in figure 7.

Natural fibre composites showed the greatest variability, as expected. Flax woven bio returned the highest CofV values in the dataset, 71.05% for UTS and 87.42% for modulus, reflecting the inherent inconsistency of plant-based fibres discussed in Section 2.3. Flax non-woven bio was more consistent at 15.15% UTS CofV, likely because the random fibre architecture produces a more homogeneous stress distribution despite its lower strength. Kevlar returned low modulus variation at 6.91% but higher UTS scatter at 50.96%. It should also be acknowledged that user error in equipment setup, extensometer positioning, specimen alignment and grip torque, contributes to variability across all materials, and a single operator conducting all tests would likely reduce scatter, particularly for the more sensitive natural fibre specimens.

6.0 Conclusion

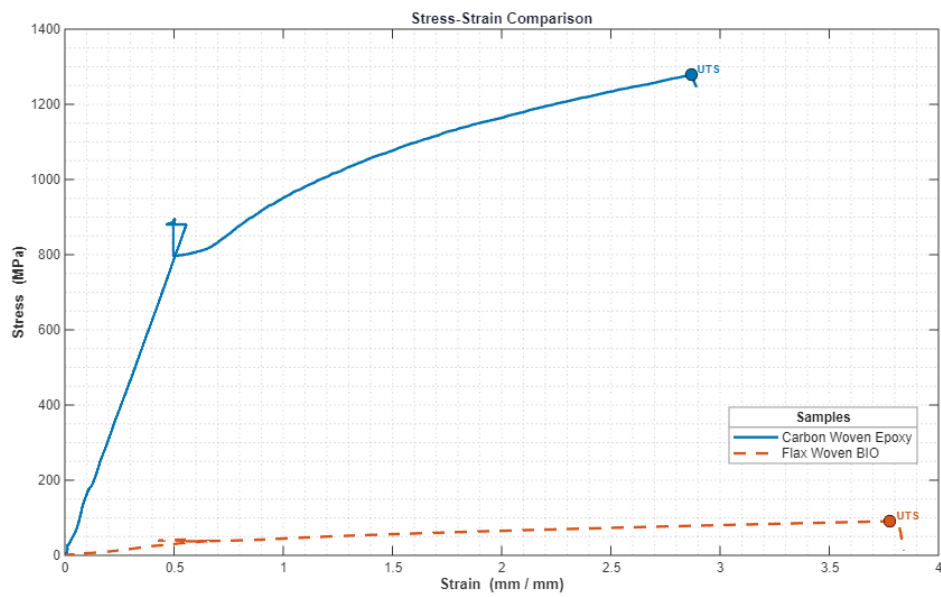
Experimental testing and sustainability analysis across seven materials confirms that conventional carbon woven epoxy remains the mechanical benchmark, whilst bio-resin substitution offers a viable compromise, lower peak strength but improved repeatability and a 50% reduction in matrix-phase fossil carbon. Flax woven bio-resin approached aluminium's UTS more closely than expected, demonstrating real potential for secondary structural applications. Natural fibre composites present the strongest environmental case but the greatest testing variability, highlighting that processing consistency remains the primary barrier to wider adoption. As embodied carbon legislation tightens, the performance-sustainability trade-off quantified here will become increasingly central to material selection decisions in both motorsport and mainstream automotive engineering.

7.0 References

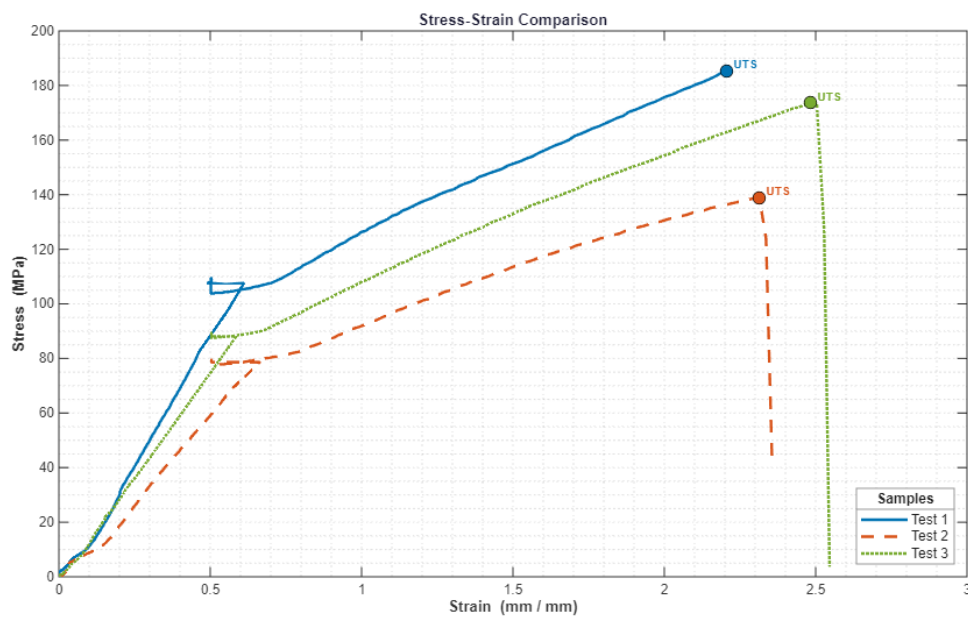
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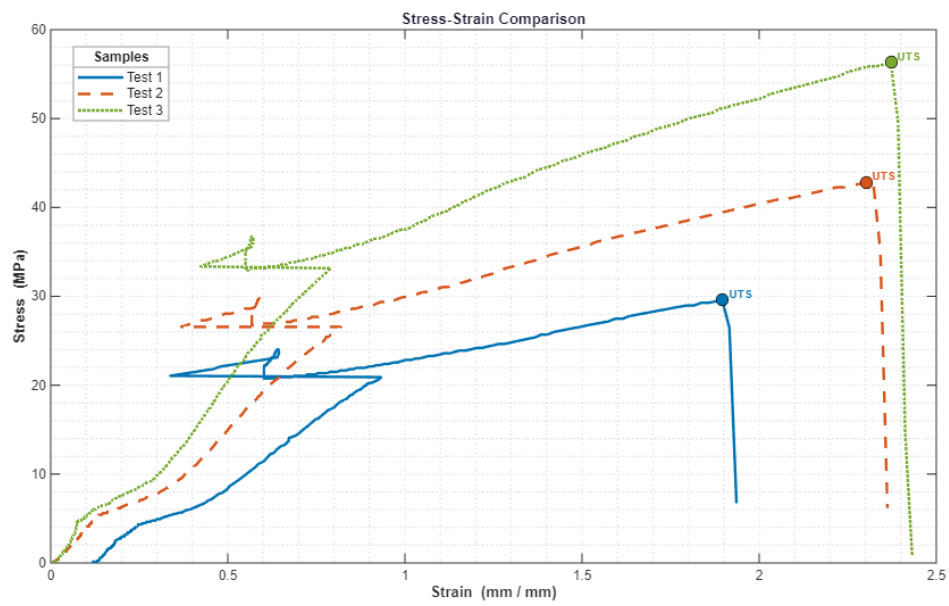
8.0 Appendix



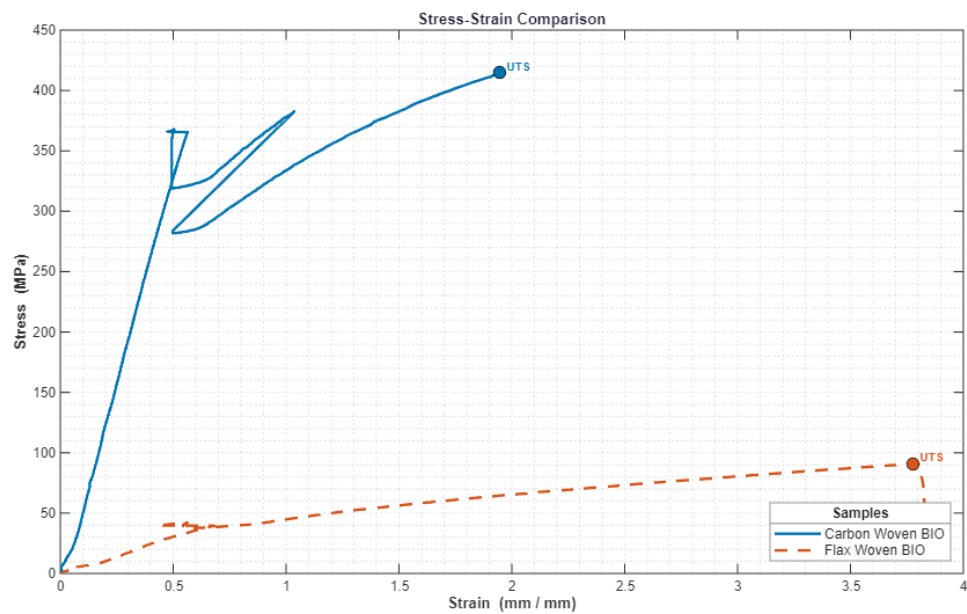
Appendix 1 - Carbon Woven Epoxy vs Flax Woven Bio



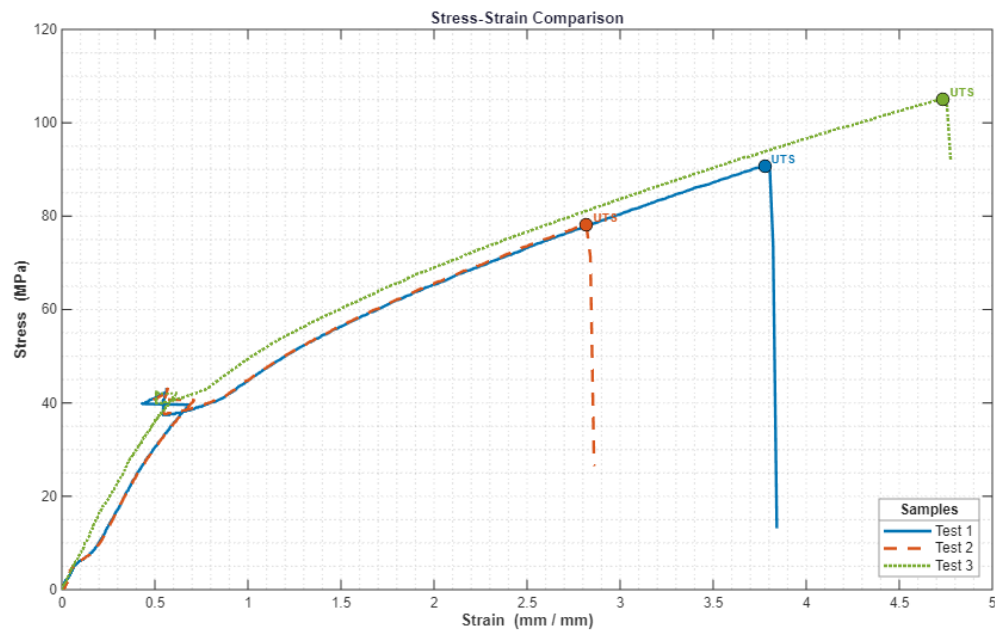
Appendix 2 - Carbon Non-Woven Bio 3 Sample Comparison



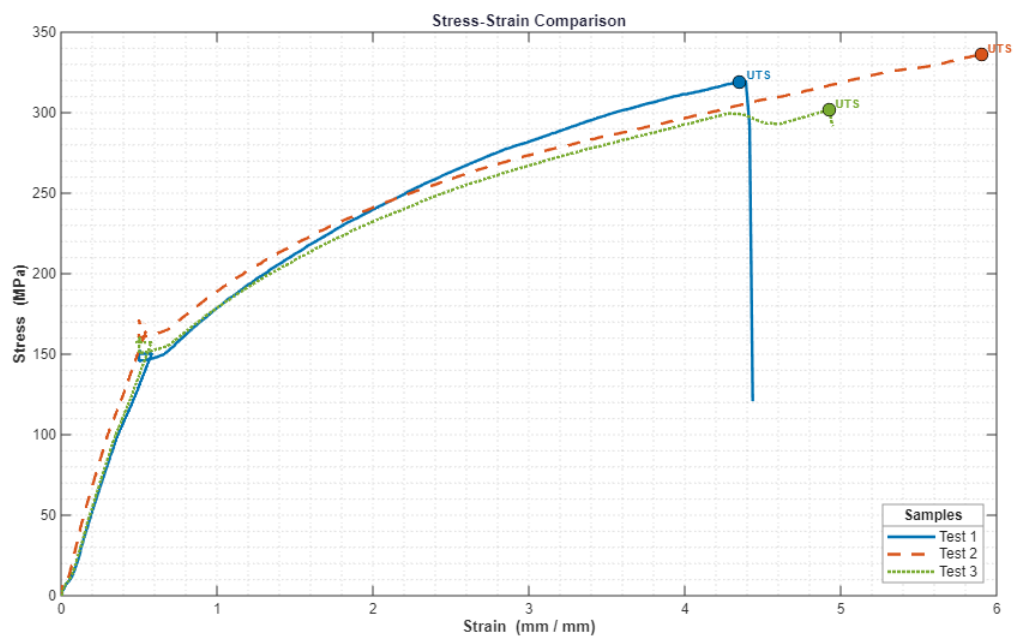
Appendix 3 - Flax Non-Woven Bio 3 Sample Comparison



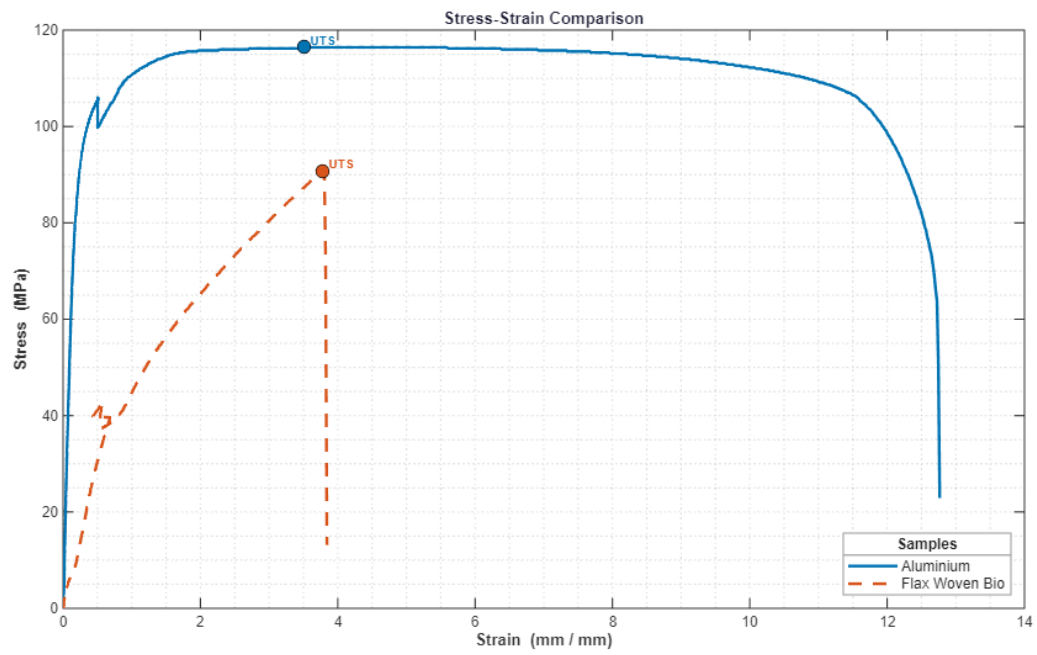
Appendix 4 - Flax Woven Bio vs Carbon Woven Bio



Appendix 5 - Flax Woven Bio 3 Sample Comparison



Appendix 6 - Kevlar Woven Bio 3 Sample Comparison



Appendix 7 - Aluminium vs Flax Woven Bio