

University of Wales Trinity Saint David

Wales Institute of Science & Art



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

Trinity Saint David

Materials Testing and Sustainability in Composites for Motorsport & Automotive Industries

Automotive Materials and Sustainability (ACHA6012)

Tim James

2112656

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1 Introduction

Composite materials are widely used in the automotive and motorsport industries due to their exceptional mechanical properties and strength-to-weight performance over metallic materials such as steel. With the increasing global pressure on sustainability, the environmental impact of these materials throughout their lifecycle from manufacturing to end-of-life has become a critical consideration in their use. This report investigates a range of composite materials through a literature review, tensile testing and a sustainability analysis. The aim is to assess the performance of synthetic and natural fibres and to provide recommendations for their application within the automotive and motorsport industries.

2 Literature Review

This literature review examines current uses of composite materials in automotive and motorsport engineering. A focus on structural properties, applications and sustainability are the main considerations. Particular attention is given to the issues of recyclability, energy consumption and compliance with environmental regulations. Drawing on peer-reviewed research, industry standards and recent innovations, this review provided a critical foundation for the subsequent experimental testing and sustainability analysis. Key gaps in existing research regarding the use of composites in high performance environments are identified to guide this investigation.

2.1 Introduction to Composite Materials

A composite is a material that has been created using two or more constituent materials with different structural and chemical properties. The two materials that make up a composite are called a reinforcement layer and a matrix, when they are combined, they create a completely different material with characteristics that are different from the individual materials (Ahmad *et al.*, 2019).

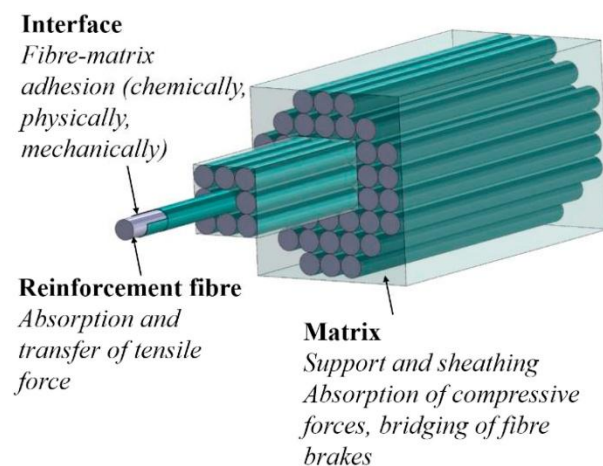


Figure 1 - Composite Structure (Nguyen et al., 2020)

Figure 1 illustrates the structural breakdown of a composite material, highlighting the constituent materials and their relationship. The reinforcement provides the strength and stiffness of the composite, while the surrounding matrix binds the reinforcements together, transferring loads and protecting them from environmental factors (El-Reedy, 2022).

2.2 Overview of Common Composite Materials

This section contains a comparison between common composite materials used in both automotive and motorsport application.

2.2.1 Carbon Fibre Reinforced Polymer

Carbon Fibre Reinforced Polymers (CFRP) are a widely used synthetic composite in the motorsport industry with the first composite monocoque being used in the 1981 Formula One season by McLaren. The exceptional strength-to-weight ratio and mechanical properties of CFRP have made it a prime material in manufacturing structural components due to its improvements in crashworthiness and weight-saving which results in a performance increase (Kamae and Drzal, 2022). CFRP use in the automotive industry has also been increasing due to the lightweight factor whilst retaining or improving strength in non-structural components to increase fuel efficiency. A study was performed looking at the Body-in-White (BIW) of automotive chassis and how implementing carbon composite materials could directly reduce the fuel consumption of a vehicle and reduce the overall emissions by reducing the vehicle mass (Zhang et al., 2024).



Figure 2 - Carbon Fibre Products (Ursache, Cerbu and Hadăr, 2023)

Figure 2 displays the various forms of carbon fibre, each tailored to meet specific structural or performance requirements when infused with a matrix. Each type and configuration affect the mechanical properties, manufacturing complexity and the overall cost. Different weaves or orientations in layouts can be used to optimise performance for specific conditions. A study examined how different fabric types influence the mechanical properties of a carbon fibre composite and evaluated the tensile strength, flexural strength and shear strength of the various composite, results showed that the weave composite demonstrated superior tensile properties (Ma, Zhang and Zhu, 2022). Fibre type and orientation in composites is a critical factor in determining the strength characteristics of the component, various orientations can be used to maximize the strength of the material depending on the stress and strains that the component is expected to withstand (Khayrnasov, 2023).

2.2.2 Glass Fibre Reinforced Polymer

Glass Fibre Reinforced Polymers (GFRP) are synthetic composite materials using a glass fibre reinforcement with a polymer matrix. GFRP are used in motorsport applications due to their significant cost-effectiveness whilst offering good mechanical performance, impact resistance and corrosion resistance, however, they are not as strong as carbon fibre composites (Sathishkumar, Satheeshkumar and Naveen, 2014). The combination of low cost, moderate strength and lightweight characteristics make them a suitable choice in lower-budget racing categories where body panels and non-structural components can be manufactured from GFRP. In the 1950s the first vehicle manufactured using GFRP body panels was the Glasspar G2 which resulted in fibreglass quickly becoming a choice material due to the ease of manufacturing whilst providing strong, lightweight bodies (Pian, Zhou and Xiao, 2023). The study by (Ude and Azhari, 2019) examined the crashworthiness of glass fibre and compared them with hybrid composites, the results demonstrated a relatively high peak load performance under compressive loading, highlighting that pure glass fibre composites showed lower crash energy efficiency when compared to the hybrid variant. The experiment concluded that GFRP remain effective for structural components, however their brittle nature and moderate energy absorption make them less ideal for application that require high crash energy dissipation.

2.2.3 Natural Fibre Composites

Natural fibre composites use a plant-based fibre such as flax and hemp, these materials offer advantages including low cost, lightweight and biodegradability, though they typically present lower mechanical performance compared to synthetic composites. The automotive industry is making steps in implementing natural fibre composites to produce components such as door panels and interior components as they offer significant reduction in vehicle weight which helps improve fuel efficiency and reduce CO₂ emissions. While natural fibre composites have a lower strength and impact to that of either Carbon or Glass fibre composites, their properties can be enhanced with appropriate treatment or hybridization with other materials (Olhan, Khatkar and Behera, 2021).

2.2.4 Summary

Table 1 - Material Properties of Composite Materials

Material	Form	Surface Weight	Tensile Strength		Young's Modulus		Elongation at Break		Density
		g/m ²	MPa		GPa		%		g/cm ³
			Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	
Kevlar 49 (2x2 Twill Weave)	Woven Fabric	300	3000		112.4		2.4		1.44
Flash (Non-Woven)	Non-Woven Mat	300	44	37	5	5	1.3	1.2	1.45
Hemp (Non-Woven)	Non-Woven Mat	100	46	108	6	11	1.5	2	1.45
Flax (Twill Weave)	Woven Fabric (2x2 Twill)	220	58	61	6	7	1.8	1.5	1.45
Carbon Fibre (Non-Woven)	Non-Woven Mat	100 / 300	330	290	35	25	N/A		1.51

The composite materials displayed in Table 1 display a range of mechanical and physical properties that would be suitable for different automotive and motorsport applications. The Kevlar exhibits the highest tensile strength (3000MPa) and Modulus (112.4GPa), which indicates exceptional resistance

to impact and deformation. The non-woven carbon fibre shows significantly lower tensile strength compared to the traditional woven carbon composite; however, it still offers increased performance over the natural fibres of Hemp and Flax that possess lower mechanical properties.

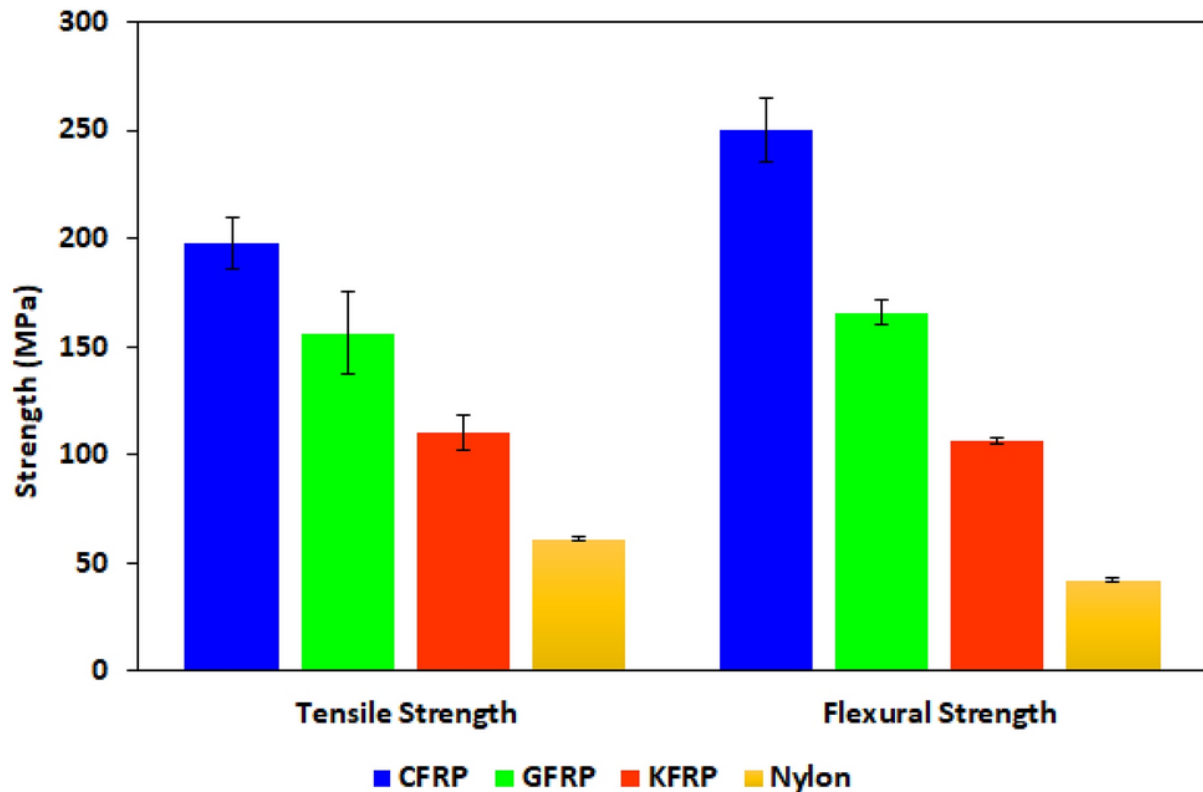


Figure 3 - Synthetic Fibre comparison (Sayam et al., 2022)

Figure 3 above gives a comparison between various fibres such as CFRP, GFRP, Kenaf Fibre Reinforced Polymer (KFRP) and Nylon. The results show that although CFRP had the highest overall strength properties, Kenaf, which is a natural fibre showed strong results.

CFRP offers the highest strength-to-weight ratio and stiffness among them, making it an ideal choice for high-performance applications where weight saving is crucial. However, due to the cost of manufacturing and difficulty in recycling due to using a polymer matrix, it has a high environmental impact from the energy intensive manufacturing processes. GFRP provides a more cost-effective alternative with good mechanical properties, though it is heavier than CFRP and faces recyclability issues due to being a synthetic fibre using a thermoset matrix. In contrast to natural fibres, although possessing lower mechanical strength and stiffness, it excels in that it is a renewable source with a recyclability or biodegradable property. The materials are increasingly used in automotive components where moderate performance is an acceptable parameter, when infused with a bio-resin it will further support their role in reducing the environmental footprint of composite materials.

To bridge the gap between synthetic and natural composite performance and sustainability, hybrid composites have become an increasing alternative where natural and synthetic fibres are combined within a single matrix. This approach allows engineers to tailor the characteristics of a composite and to offer a balance between performance and sustainability (Mohanavel et al., 2022).

2.3 Sustainability Considerations

Synthetic materials such as CFRP and GFRP contain constituent materials that are entirely man-made, produced through chemical processes, primarily from petrochemical sources. This distinguishes them from natural fibres, which are derived directly from a plant or animal source. A paper by (Begum K and Islam MA, 2013) provides an overview of the characteristics and implications of synthetic fibres and the need to develop sustainable synthetic fibres such as bio-based polymers to mitigate environmental impacts.

The manufacturing process of synthetic composites like CFRP are energy intensive and generate long-term waste which poses serious sustainability concerns. During manufacturing of CFRP temperatures of up to 3000 Celsius may be required in high performance applications (Sayam *et al.*, 2022). Growing environmental and economic concerns regarding the use of petroleum-based materials such as epoxy resins which are extensively used as a matrix in composite materials means that manufacturers are looking to natural replacements to reduce the environmental impact of composite materials (Bassett *et al.*, 2016).

Thermoset and Thermoplastic resins are the two primary matrix types used in fibre-reinforced composites with differing sustainability profiles. Thermoset resins such as epoxy have excellent mechanical strength, chemical resistance however they undergo irreversible recyclability once cured. In contrast, thermoplastic resins offer a better method of recyclability as they can be melted and reformed, allowing for potential reduced waste when producing composite components however do not have properties that are equal to thermoset variants (Vieille *et al.*, 2024).

2.4 Gaps in Current Research

With a growing interest in sustainable composite applications, several research gaps remain such as limited research on their long-term performance and industrial scalability. Standardised life cycle assessments (LCA) frameworks within composites are not currently set, making it difficult to compare the environmental impacts across the materials. Research into sustainable manufacturing processes and low energy production also remains underdeveloped. A study performing an LCA on the impact of composites from renewable sources was performed with an LCA specifically looking at hemp and flax fibres (Seile, Spurina and Sinka, 2022).

Limited performance data of bio-based resins and natural fibres remain a key gap in current research which could potentially reduce the reliance on petroleum-based components, allowing an exponential growth in sustainable composite implementation.

3 Experimental Testing

Using a Denison test bench, mechanical properties of various composite materials were assessed, specifically their tensile strength. A baseline aluminium sample was used tested to ensure setup accuracy. The material was sourced by Easy Composites and the test pieces were made using a resin infusion process. The Carbon and Kevlar materials are assumed to be a 50:50 Epoxy/Material volume relationship. Additional mesh material had been added to the process to enable the test pieces to be gripped by the device.

Seven groups were assigned two of each material to be tested, using the same parameters. Each material was measured to calculate the cross-sectional area prior to testing.

Table 2 - Material Properties List

Material	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Compressive Strength (MPa)	Elongation at Break (%)	Density (g/cm ³)
IB2 Epoxy Bio Resin	68	3.04	109	3.07	91	5.3	1.12
IN2 Epoxy Resin (AT30 SLOW)	76	3.5	120	3.5	100	8	1.12
Non-woven Flax Mat	44	5				1.3	1.45
Non-woven Hemp Mat	108	11				2	1.45
Twill Flax Cloth	61	7				1.5	1.45
Carbon Fibre Non-Woven Mat	330	35	500		330		1.51
300g Kevlar Cloth	3000	112.4				2.4	1.44

Table 2 contains the list of the reinforcement and matrix components that were used for the experiments.

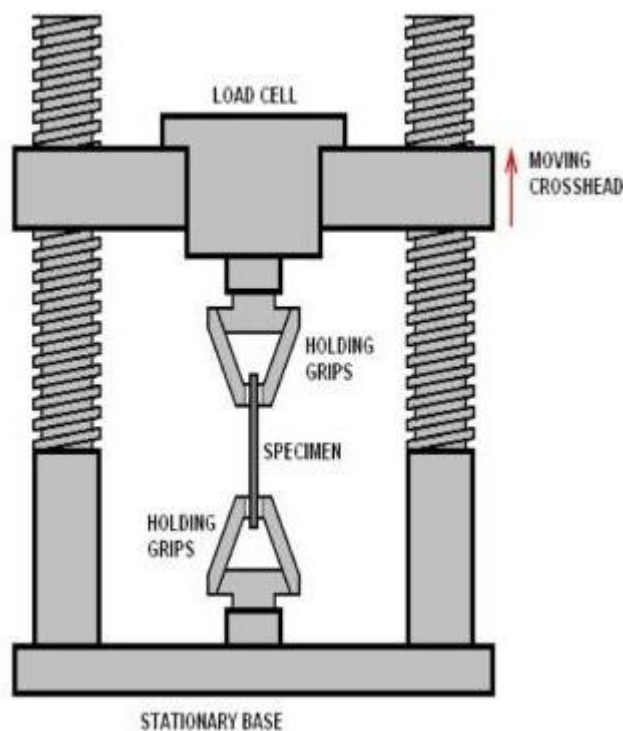


Figure 4 - Experimental Test Fixture (Subbareddy et al., 2019)

Figure 4 displays the experimental setup of the test material (specimen) within the testing rig.

4 Results

4.1 Aluminium Results

Table 3 Aluminium Test Results

Aluminium														
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Test	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Type	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Size (width * thickness) (mm)	20*1.5	20*1.5	19.7*1.45	19.7*1.45	20.05*1.5	20.05*1.5	20.5*1.5	20.5*1.5	20*1.5	20*1.5	20*1.5	20*1.5	20*1.5	20*1.5
Cross-sectional Area(mm²)	30.00	30.00	28.56	28.56	30.08	30.08	30.75	30.75	30.00	30.00	30.00	30.00	30.00	30.00
Max Load(kN)	3.490	3.495	3.505	3.475	3.470	3.470	3.480	3.470	3.445	3.480	3.470	3.450	3.495	3.495
Ultimate Tensile Strength (MPa)	116	116	123	122	115	115	113	113	115	116	116	115	116	116
Break(kN)	3.42	3.43	0.71	0.70	0.70	0.70	0.72	0.70	0.82	0.73	0.70	0.70	0.81	1.04
Break(MPa)	114.00	114.33	24.86	24.51	23.27	23.27	23.41	22.76	27.33	24.33	23.33	23.33	27.00	34.67

Table 3 contains the results of each of the tests conducted by the groups with similarities between groups 2-7, however, group 1 displayed a higher breaking force than all the groups.

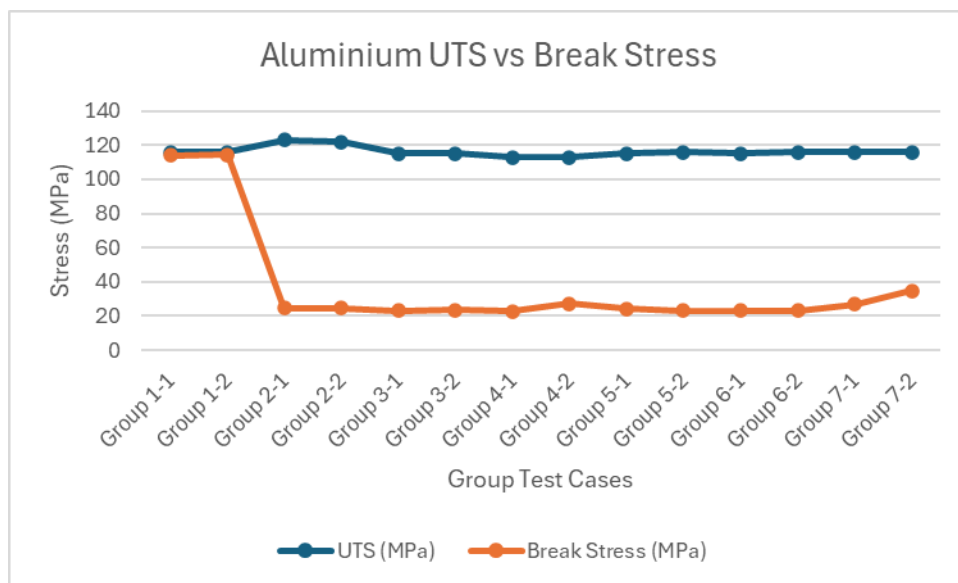


Figure 5 - Aluminium Stress results

Figure 6 displays the results for each test performed with the UTS and amount of stress on the component when it broke. The results for group 1 remained close to the UTS of the material with a failure load of 3.4kN, this displays that the material likely experienced ductile failure. Groups 2-7 failed at a much lower force; however, they remained consistent across each test which appears that the component likely experienced brittle or early failure due to the material where a consistent 0.7kN force was observed.



Figure 6 - Aluminium Fracture

The fracture of the aluminium in figure 7 shows an angular and rough break without obvious necking of the material. The material failed suddenly with little deformation, indicating a loss of ductility. Failure by localized shear plastic deformation without necking was observed.

4.2 Non-Woven Bio Resin Results

Table 4 - non-woven bio resin results table

Hemp Non-Woven (Bio Resin)														
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Test	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Type	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Size (width)	1.2*20	0.9*19.5	0.7*18.9	0.6*19	19.5*1	19.5*1	19.4*0.75	19.4*0.75	19.93 x 0.6	19.93 x 0.6	19.3*0.75	19.3*0.5	20*0.6	20*0.6
Cross-section	24.00	17.55	13.23	11.40	19.50	19.50	14.55	14.55	30.00	30.00	14.48	9.65	12.00	12.00
Max Load	0.420	0.380	0.415	0.375	0.290	0.340	0.255	0.455	0.320	0.305	0.380	0.335	0.350	0.470
Ultimate	18	22	31	33	15	17	18	31	11	10	26	35	29	39
Break(kN)	0.10	/	0.11	/	/	/	/	0.10	/	/	/	/	/	0.10
Break(MPa)	4.17	/	8.31	/	/	/	/	6.87	/	/	/	/	/	8.33
Carbon Non-Woven (Bio Resin)														
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Test	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Type	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Size (width)	1.5*19.6	1.5*19.6	1.4*19.7	1.4*19.1	19.5*1.5	19.5*1.5	19.5*1.25	19.5*1.25	19.97*1.4	19.97*1.4	19.96*1.5	19.97*1.4	20*1.4	20*1.4
Cross-section	29.40	29.40	27.58	26.74	29.25	29.25	24.38	24.38	27.96	27.96	29.94	27.96	28.00	28.00
Max Load	6.440	6.545	4.720	4.950	5.645	5.560	3.745	6.560	4.440	6.370	5.015	2.965	3.565	3.640
Ultimate	219	223	171	185	193	190	154	269	159	228	168	106	127	130
Break(kN)	6.44	6.54	4.72	4.95	5.64	5.56	3.74	6.56	1.80	3.14	1.18	1.49	1.24	1.14
Break(MPa)	219.05	222.45	171.14	185.12	192.82	190.09	153.40	269.07	64.38	112.30	39.41	63.29	44.29	40.71
Flax Non-Woven (Bio Resin)														
	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
Test	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1		Test 1	Test 2	Test 1	Test 2
Type	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat		Flat	Flat	Flat	Flat
Size (width)	1.2*19.7	1.1*19.8	1.2*19.2	1*19.5	19.6*1.1	19.6*1.1	19.8*1.2	19.8*1.2	19.99*1.5		19.97*1.1	19.98*1.2	20*1.3	20*1.3
Cross-section	23.64	21.78	23.04	19.50	21.56	21.56	23.76	23.76	29.98		21.97	23.98	26.00	26.00
Max Load	0.875	1.080	1.015	1.050	1.080	1.350	1.080	1.060	1.030		0.675	1.075	1.080	1.055
Ultimate	37	50	44	54	50	63	45	45	34		31	45	42	41
Break(kN)	0.60	1.08	1.02	0.68	1.08	1.35	1.08	0.74	0.76		0.50	0.30	0.85	0.68
Break(MPa)	25.38	49.59	44.27	34.87	50.09	62.62	45.45	31.14	25.35		22.76	12.51	32.69	26.15

Table 5 contains each of the results for the non-woven composite materials using a bio-resin, results for the breaking force of the Hemp material is unavailable for several test cases which may indicate the results being too sensitive to record during the test as the failure criteria may have been too low. The results for group 5 completing the Flax test were also unavailable.

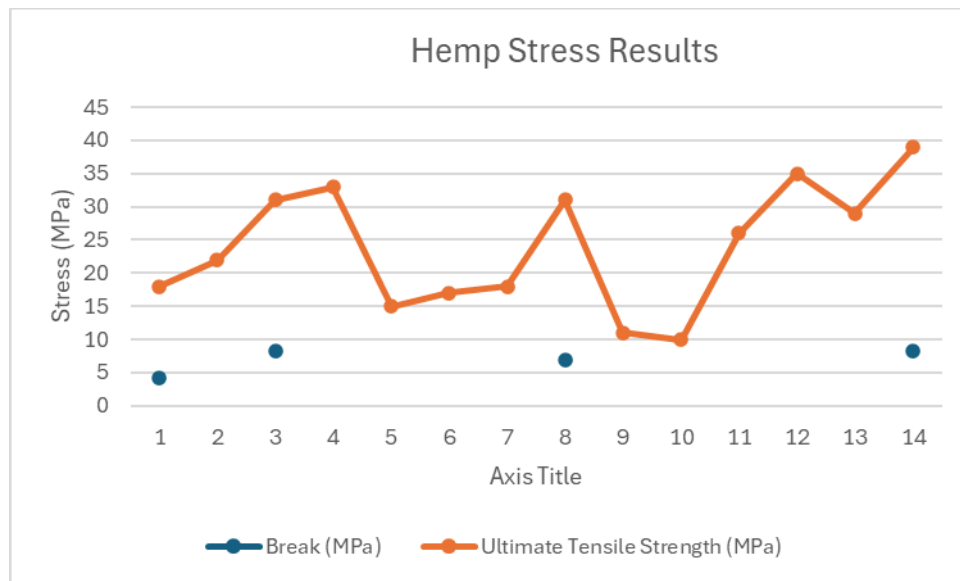


Figure 7 - Hemp UTS vs Break Stress

Figure 7 contains the results of the test with the non-woven hemp composite, it displays the various values for the UTS of the material due to the nature of a non-woven material with random orientations of fibres which results in a less accurate method of analysing their performance against one another.



Figure 8 - Hemp failure

Figure 8 displays visible bridging between the composite with fibres remaining intact across the fracture gap, suggesting a failure due to fibre pull-out rather than a clean fibre fracture. This is typical in non-woven or loosely bound composites and indicates the matrix-fibre bond is not strong. The bio-resin matrix appears brittle due to little evidence of plastic deformation.

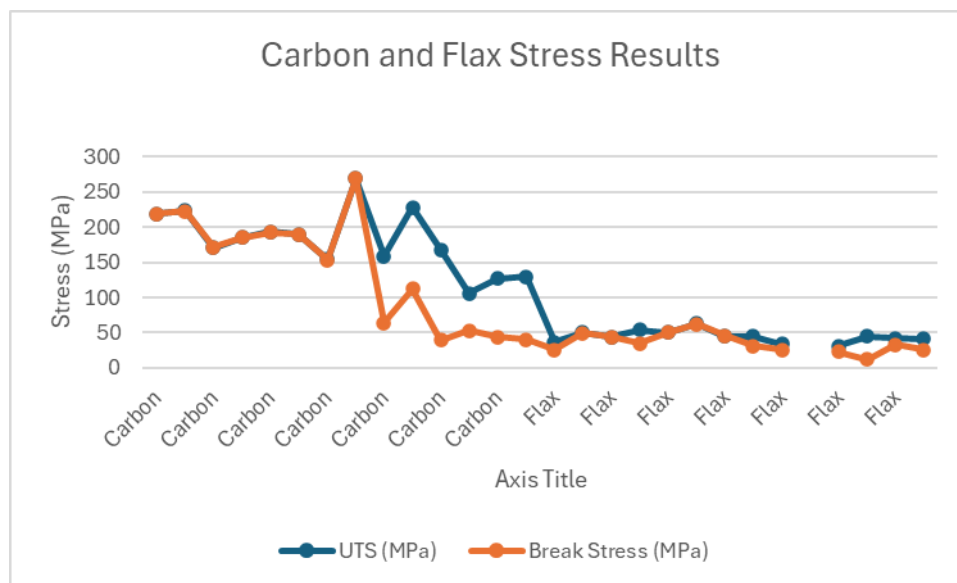


Figure 9 - Carbon vs Flax Stress results

Figure 9 above displays the UTS vs Break stress of both the Carbon non-woven and the Flax non-woven with bio resin. They indicate that the UTS and Break stress are closely aligned, especially in Tests 1-6 for the carbon. This indicates very little plastic deformation which suggests a brittle behaviour, which is typical for carbon composites. The material likely fails immediately after reaching the ultimate strength, both the flax and carbon may be combined with a matrix that cracks easily which could cause the matrix to quickly fail resulting in a loss of load-bearing capacity instantly. The results would appear that the material failure is due to matrix failure of the composites. Since the test machine captures only the peak force before failure without visible necking or extension, the system won't record a difference between the UTS and break value which is consistent with the findings. Material properties from table 2 gives a tensile strength value for Carbon of 330MPa, the results showed failures before that point which would indicate further that the failure was within the matrix.

5 Sustainability Analysis

To analyse the environmental impact of composite materials from extraction to end of life in motorsport and automotive industries, key areas were identified.

5.1 Resource Extraction

CFRP require high energy consumption and produce environmental pollution during manufacturing due to the method in extracting the materials from petroleum products which contributes significantly to greenhouse gas emissions (GHG). Studies looking into using electromagnetic field-driven technologies presents opportunities for the manufacturing of CFRP to offer rapid and environmentally friendly solutions to the process of manufacturing and recycling this synthetic composite(Zhu *et al.*, 2025).

An increased awareness in reducing the carbon footprint of synthetic materials has resulted in an increase in using natural materials that are biodegradable and recyclable in composites as well as their implementation into the automotive industry. Further analysis into the manufacturing processes and further research into the use of natural fibre composites is an ongoing process(Ho *et al.*, 2012).

The reusability of materials is an important aspect in protecting the environment from waste pollution. A book on composites identified three important factors when determining material properties in the recycling process. The reusability of the material, the less material lost in each recycle and the role of the waste products in self-renewal in ecosystems(Günay, 2018).

The choice between synthetic fibres in composite use involves a trade off between performance requirements and the environmental considerations. Synthetic fibres offer superior mechanical properties, however, at the cost of polluting the environment more than natural fibres.

5.2 Recyclability and End of Life

The recycling of CFRP has become an increasingly important topic in the automotive and motorsport industries. Several recycling methods of recovering carbon fibres exist to this date, however, they are still energy intensive processes and release harmful gases as the matrix component is released from the reinforcement. A study developed a method in recycling carbon fibre components whilst retaining up to 90% of their original strength in a less intense process called oxidative depolymerization where carbon fibre could be recycled at temperatures as low as 100 Celsius (Kim, Yu and Goh, 2021).

A study investigating a hybrid recycling process for CFRPs combined mechanical milling and a two-step thermal chemical treatment aimed at improving the recyclability and mechanical performance of composites that typically use thermosetting resins (De Fazio *et al.*, 2025). The research concluded that combining low temperature thermal solvent methods in combination with mechanical machining offers a viable recycling strategy that improves the quality and performance of recycled CFRP.

Projects such as the FiberEUse are developing solutions to enhance the profitability of composite recycling and reusability. Specifically looking at models towards sustainable circular solutions in

composite end-of-life stages. Three strategies were presented that included recycling of short and long fibres as well as car part designs that could be sustainably disassembled and remanufactured (Colledani and Turri, 2022).

6 Conclusion

This report has identified the structural performance and sustainability of various composite materials commonly used in motorsport and automotive industries. Through a detailed literature review and experimental testing, the benefits of synthetic fibres such as carbon and glass have been clearly demonstrated in terms of their mechanical properties in comparison to natural fibres. However, these advantages come at a significant cost to the environment due to the energy-intensive manufacturing processes in using synthetic fibres as well as their recyclability. Natural fibre composites such as flax and hemp when paired with bio-resins offer a promising sustainability benefit at the cost of lower mechanical performance. Experimental results reinforced these findings, highlighting the brittle nature of certain composites and the variability in performance. The sustainability analysis highlights opportunities for improving the life cycle and recycling methods of synthetic composites.

7 Recommendations

Based on the experimental findings and sustainability analysis, further research and development into the suitability of natural fibres needs to be addressed before large-scale adoption of these composites can be implemented into the motorsport and automotive sectors. The recyclability of synthetic reinforcements and petroleum-based resins containing them remains a challenge for the industries in developing a method of recycling that can restore the structural properties of the fibre, whilst minimizing the environmental impact during these processes.

The use of bio resins remains an important aspect in the manufacturing and recycling of composite materials due to their biodegradable nature without depending on petroleum products. The trade off between performance, cost and sustainability will be an important factor when manufacturers and legislation decide the future of composite use in both motorsport and automotive application.

Hybridization of materials that contain both synthetic and naturally occurring fibres may aid in the sustainability of composites where CFRP and GFRP may be used in conjunction with natural fibres such as flax or hemp in a bio resin matrix to reduce costs and retain some of the mechanical properties, however, further advances will need to be made in separating these materials for recycling and reuse.

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