

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

Trinity Saint David

Materials Testing and Sustainability of Composites for Motorsport & Automotive Industries

Automotive Materials & Sustainability ACHA6012

Rhys Thomas

2303931

April 2026

Contents

1	Introduction	2
2	Literature review.....	3
2.1	Composite Materials in Motorsport and Automotive Engineering.....	3
2.2	Material Structure and Properties.....	3
2.3	Manufacturing Processes	3
2.4	Applications in Industry	3
3	Sustainability Analysis.....	4
3.1	Introduction.....	4
3.2	Carbon Fibre Epoxy.....	4
3.3	Carbon Fibre with Bio-Epoxy	4
3.4	Recycled Carbon Fibre with Epoxy (Non – Woven)	4
3.5	Flax Fibre with Bio-Epoxy	5
3.6	Conclusion	5
4	Experimental Testing	6
4.1	Testing Methodology.....	6
4.2	Results	6
4.3	Validation Against Manufacturer Data.....	7
4.4	Analysis.....	7
5	Recommendations	10
6	Conclusion.....	11
7	References	12
8	Appendix	13

Table Of Figures

Figure 1 - Test Samples Before Fracture	6
Figure 2 - A Graph Showing Stress - Strain Curves of Woven Carbon Fibre Composites	7
Figure 3 - A Graph Showing Stress - Strain Curves of Recycled Carbon Fibre, Flax and Aluminium.....	8
Figure 4 - A Graph Showing UTS Values from Experimental Data and Manufacturer Data	9

Table Of Tables

Table 1 - A Table Showing All Test Sample Results.....	6
Table 2 - A Table Showing A Comparison Between Collected Data and Manufacturer Data.....	7

1 Introduction

Composite materials are widely used across the motorsport and automotive industries due to their high strength-to-weight ratio and ability to be tailored for specific performance requirements. However, as sustainability becomes an increasingly important factor in material selection, there is growing pressure on manufacturers and motorsport governing bodies to consider the environmental impact of the materials they use. The FIA has committed to achieving net zero carbon emissions across all World Championship events by 2030 (FIA ,2020), and the UK government has set a broader net zero target for 2050, meaning the industry needs to start making changes to how materials are selected and used.

This report looks at four composite materials and one reference material, testing them in a Science Lab to evaluate their mechanical performance through tensile testing. The four composites tested cover conventional carbon fibre with standard epoxy resin through to natural flax fibre with bio-epoxy, representing a spectrum from least to most sustainable. The aim is to assess how these materials perform mechanically, compare the results against manufacturer data, and evaluate their suitability for use in motorsport and automotive applications from both a performance and sustainability perspective, before making recommendations for future material selection.

2 Literature review

2.1 Composite Materials in Motorsport and Automotive Engineering

Composite materials consist of two or more constituent materials combined to produce properties superior to those of the individual components alone, typically comprising a reinforcing fibre and a polymer matrix resin (Mallick, 2007). Their exceptional strength-to-weight ratio has made them indispensable in motorsport and high-performance automotive engineering, where reducing mass whilst maintaining structural integrity is a primary design objective. Carbon fibre reinforced polymers (CFRP) have become the dominant structural material in Formula 1 and endurance racing, with the entire monocoque chassis, bodywork and aerodynamic components typically manufactured from woven carbon fibre laminates (Savage, 1991). The mechanical performance of CFRP is well documented, with tensile strengths typically ranging from 400-600 MPa for woven laminates depending on fibre architecture and volume fraction, combined with densities of approximately 1.5-1.6 g/cm³, giving a specific strength far exceeding that of aluminium or steel (Mallick, 2007).

2.2 Material Structure and Properties

The mechanical properties of fibre reinforced composites are governed by the properties of the constituent fibre and matrix materials, the fibre volume fraction, and the orientation of the reinforcement. The Rule of Mixtures provides a widely used framework for predicting composite stiffness, establishing upper and lower bounds based on fibre and matrix moduli and their respective volume fractions (Gay, 2014). Woven twill fabrics, such as the 3K carbon and flax twill materials used in this study, provide balanced properties in two directions and are commonly used in motorsport applications where loading is multidirectional. Natural fibre composites, particularly flax fibre reinforced polymers, have attracted growing research interest as sustainable alternatives to synthetic fibres. Wambua et al. (2003) demonstrated that natural fibre composites can offer competitive specific mechanical properties to glass fibre composites whilst providing significant environmental benefits, though their absolute strength remains considerably lower than carbon fibre.

2.3 Manufacturing Processes

The samples tested in this study were manufactured using vacuum resin infusion, a closed mould process in which dry fibre reinforcement is placed in a mould, sealed under a vacuum bag, and liquid resin is drawn through the fibres under atmospheric pressure (Mallick, 2007). This process produces high quality laminates with good fibre volume fractions and low void content compared to hand layup, making it widely used in motorsport component manufacture. The use of both conventional epoxy and bio-based epoxy resin systems in this study reflects the growing industry interest in reducing the environmental impact of the matrix material without compromising processing characteristics (Holbery and Houston, 2006).

2.4 Applications in Industry

Carbon fibre composites are now widely used beyond motorsport, appearing in road car structures, aerospace components and sporting equipment (Witten, Kraus and Kühnel, 2016). Natural fibre composites have begun to appear in automotive interior components, with manufacturers including BMW and Porsche incorporating flax and hemp fibre panels into production vehicles as part of their sustainability programmes (Holbery and Houston, 2006). Recycled carbon fibre is an emerging material category with growing commercial availability, offering reduced environmental impact compared to virgin production whilst providing mechanical properties suitable for non-structural applications (Pimenta and Pinho, 2011).

3 Sustainability Analysis

3.1 Introduction

The sustainability of composite materials is becoming increasingly important in motorsport and automotive engineering, as governing bodies and manufacturers face growing pressure to reduce their environmental impact. The FIA has committed to achieving net zero carbon emissions across all World Championship events by 2030, whilst the UK government has set a broader net zero target for 2050 (FIA, 2020). The European Union has also introduced increasingly stringent End of Life Vehicle directives, placing pressure on manufacturers to consider recyclability and environmental impact at the design stage (European Parliament and Council, 2000). These legislative frameworks are fundamentally changing how materials are selected for both motorsport and road car applications, and the four composite materials tested in this study represent a clear spectrum from least to most sustainable, allowing for a meaningful comparison of their environmental credentials across their full lifecycle.

3.2 Carbon Fibre Epoxy

Conventional carbon fibre with IN2 epoxy resin is the least sustainable material tested in this study. Its production requires extremely high temperatures exceeding 1000°C to convert petroleum derived polyacrylonitrile (PAN) into usable carbon fibre, resulting in significant CO₂ emissions and an estimated energy consumption of around 183-286 MJ/kg (Khalil, 2017). This is considerably higher than many competing structural materials, making the manufacturing phase of conventional CFRP particularly carbon intensive.

As a result, most carbon fibre components currently end up in landfill or incineration, both of which are increasingly incompatible with current and future environmental legislation. Whilst the lightweight nature of CFRP does reduce fuel consumption and emissions during its service life, this benefit alone is insufficient to offset the significant environmental costs associated with its production and disposal, making it the least viable option from a sustainability perspective (Scelsi et al., 2011).

3.3 Carbon Fibre with Bio-Epoxy

Carbon fibre with IB2 bio-epoxy resin represents a meaningful and practical step forward in sustainability. Approximately 31% of the resin content is derived from renewable plant-based sources, specifically using plant derived glycerol in place of petroleum-based propylene during manufacture (Easy Composites Ltd, 2024). This reduces the carbon footprint of the matrix material without compromising mechanical performance, with experimental results from this study showing a mean UTS of 419.28 MPa, comparable to conventional carbon fibre at 400.05 MPa. The bio-epoxy resin also utilises co-products and waste materials from other industrial processes, meaning it does not compete with food sources or displace agricultural land (Easy Composites Ltd, 2024). Whilst the carbon fibre reinforcement itself still carries the same environmental production costs as conventional CFRP, the substitution of the resin system alone represents a significant improvement, making this material a more environmentally responsible choice for high performance motorsport applications where mechanical performance cannot be compromised.

3.4 Recycled Carbon Fibre with Epoxy (Non – Woven)

Recycled carbon fibre with epoxy resin offers significant sustainability advantages by giving existing carbon fibre a second life rather than requiring new raw material production. Studies suggest that recycling carbon fibre can achieve energy savings of up to 70% compared to virgin production, substantially reducing the carbon footprint of the manufacturing phase (Khalil, 2017). This makes recycled carbon fibre a much more environmentally attractive option than virgin CFRP. However, the

experimental results of this study highlight a notable reduction in mechanical performance, with a mean UTS of 162.17 MPa compared to over 400 MPa for virgin carbon fibre composites. The non-woven random fibre orientation of the recycled mat also limits the ability to optimise strength in a specific direction. This limits its suitability to non-structural motorsport and automotive components such as body panels, aerodynamic covers and interior trim, where the sustainability benefits clearly outweigh the reduction in mechanical performance (Pimenta and Pinho, 2011). As recycling infrastructure continues to develop, the quality and consistency of recycled carbon fibre is expected to improve, potentially expanding its range of applications in the future.

3.5 Flax Fibre with Bio-Epoxy

Flax fibre with IB2 bio-epoxy resin is the most sustainable material tested in this study by a considerable margin. Flax is a naturally renewable crop that absorbs CO₂ during growth, partially offsetting the emissions associated with its processing and manufacture (Wambua et al., 2003). Unlike carbon fibre, it does not require energy intensive high temperature production, significantly reducing its manufacturing carbon footprint. The combination with IB2 bio-epoxy resin, which contains approximately 31% plant derived content, further reduces the overall environmental impact of the composite. At end of life, the natural flax fibre is biodegradable, addressing one of the key disposal challenges associated with synthetic composites and making it far more compatible with circular economy principles (Holbery and Houston, 2006). Manufacturers such as Porsche have already begun incorporating natural fibre composites into road car components as part of broader sustainability strategies, demonstrating the real-world viability of this approach (Porsche AG, 2019). Whilst the experimental mean UTS of 84.5 MPa limits its use in primary structural applications, flax composite is well suited to interior panels, trim components and aerodynamic bodywork where sustainability is the primary consideration.

3.6 Conclusion

Overall, the sustainability analysis highlights a clear trade-off between mechanical performance and environmental impact. Conventional carbon fibre offers the highest performance but at the greatest environmental cost, whilst flax fibre with bio-epoxy offers the lowest environmental impact but with reduced mechanical properties. The most promising near-term direction for the motorsport and automotive industries appears to be the adoption of bio-epoxy resin systems and recycled carbon fibre as transitional solutions, offering improved sustainability without significantly compromising performance. As FIA regulations and government legislation continue to tighten towards 2030 and 2050 net zero targets, the industry will need to increasingly embrace greener material alternatives to remain compliant whilst maintaining the performance standards that define motorsport (FIA, 2020).

4 Experimental Testing

4.1 Testing Methodology

Tensile testing was carried out on five different materials in the Science Labs at UWTSD. The five materials tested were aluminium, carbon fibre twill with IN2 epoxy resin, carbon fibre twill with IB2 bio-epoxy resin, recycled carbon fibre non-woven mat with epoxy resin, and woven flax fibre with IB2 bio-epoxy resin. Two Samples of each material were tested. Before testing, the width and thickness of each sample were measured so that the cross-sectional area (CSA) could be calculated, which was then used to calculate the stress values throughout the test. Load, displacement, stress and strain were recorded continuously during each test until the sample failed. Young's Modulus and breaking stress were recorded for each Sample and a mean value calculated across the two Samples for each material.

4.2 Results



Figure 1 - Test Samples Before Fracture

Table 1 - A Table Showing All Test Sample Results

Material	Sample	Width (mm)	Thickness (mm)	CSA (mm ²)	Young's Modulus (GPa)	Peak Load (kN)	UTS (MPa)
Aluminium	1	15	1.5	22.5	46.44	1.14	116.44
	2	15	1.5	22.5	48.96	1.02	114
	Mean				47.7		115.22
CF Twill & Epoxy	1	14.5	0.75	10.88	58.5	4.07	374.08
	2	14.5	0.75	10.88	62.41	4.45	426.01
	Mean				60.46		400.05
CF Twill & Bio-Epoxy	1	14.6	0.7	10.22	70.55	3.91	382.58
	2	14.6	0.7	10.22	60.57	4.61	455.97
	Mean				65.56		419.28
Recycled CF Non-Woven	1	14.7	1.35	19.84	11.44	3.68	185.48
	2	14.7	1.35	19.84	42.34	0.84	138.86
	Mean				26.89		162.17
Flax Twill & Bio-Epoxy	1	15	1.7	25.5	1.61	1.88	90.78
	2	15	1.7	25.5	1.73	0.68	78.23
	Mean				1.67		84.51

4.3 Validation Against Manufacturer Data

To check whether the results were reliable, the mean UTS values were compared against manufacturer datasheets and published research values as shown in Table 2.

Table 2 - A Table Showing A Comparison Between Collected Data and Manufacturer Data

Material	Experimental Mean UTS (MPa)	Reference UTS (MPa)	Experimental Mean YM (GPa)	Reference YM (GPa)	Source
CF Twill & Epoxy	400.05	400–600	60.46	50–80	Mallick, 2007
CF Twill & Bio-Epoxy	419.28	400–600	65.56	50–80	Mallick, 2007
Recycled CF Non-Woven	162.17	290–330	26.89	25–35	Easy Composites, 2024
Flax Twill & Bio-Epoxy	84.51	58–61	1.67	5–7	EcoTechnilin, 2023

4.4 Analysis

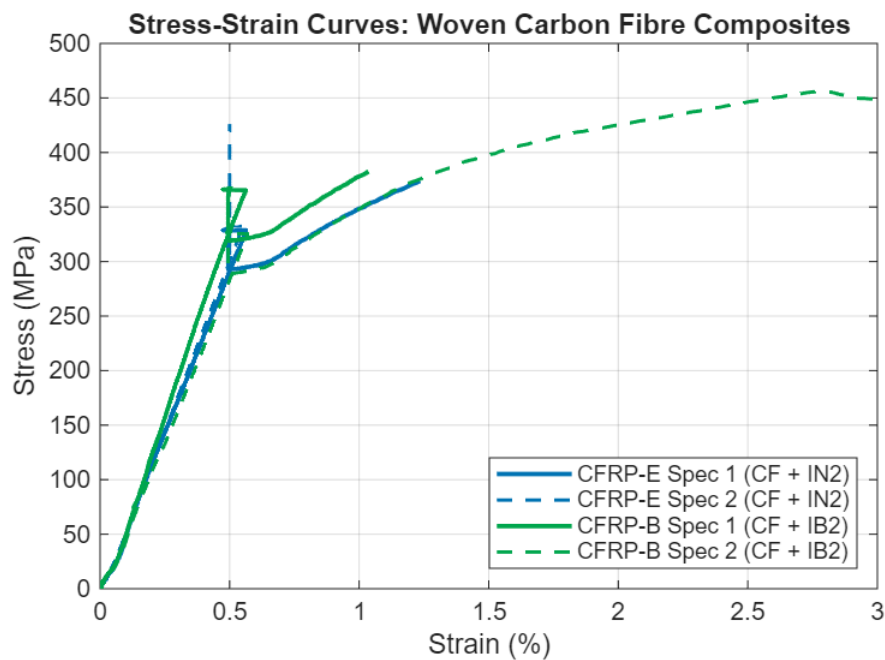


Figure 2 - A Graph Showing Stress - Strain Curves of Woven Carbon Fibre Composites

As shown in Figure 2, both woven carbon fibre laminates show a very similar stress-strain response — a steep, linear rise in stress with very little strain before sudden catastrophic failure. This is characteristic of brittle fibre-dominated fracture, where there is no plastic region or yielding before the material breaks (Mallick, 2007). The CFRP-E samples failed at 374.08 MPa and 426.01 MPa, whilst the CFRP-B samples failed at 382.58 MPa and 455.97 MPa. The near-identical shape of the curves for

both materials confirms that substituting the IB2 bio-epoxy for the conventional IN2 resin has no meaningful effect on the stiffness or failure behaviour of the laminate, which is an important result for considering bio-epoxy as a more sustainable alternative in motorsport applications. The variation between samples within each group around 50 MPa for CFRP-E and 73 MPa for CFRP-B is within the normal range for vacuum infused laminates and does not indicate a problem with the material itself.

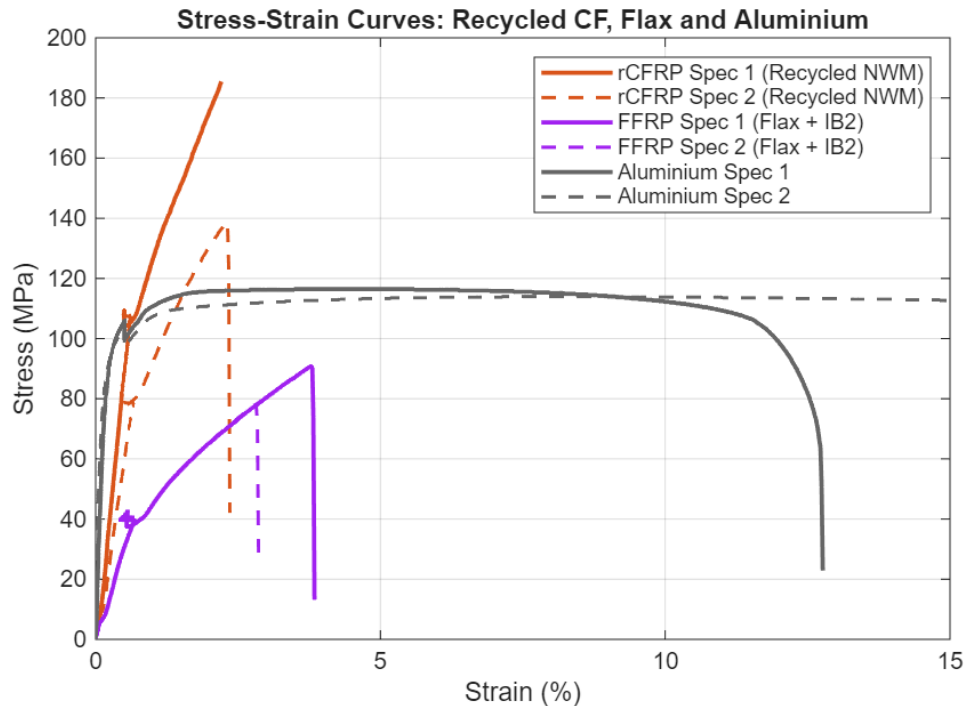


Figure 3 - A Graph Showing Stress - Strain Curves of Recycled Carbon Fibre, Flax and Aluminium

Figure 3 shows the three remaining materials on a common scale and reveals very different failure behaviours. The recycled carbon fibre non-woven samples show a broadly linear elastic response but with a significantly lower stiffness and UTS than the woven carbon fibre, with sample 1 reaching 185.48 MPa and sample 2 only reaching 138.86 MPa before brittle failure. The large difference between the two samples is visible in the graph and is a direct consequence of the random fibre orientation of the non-woven mat, where localised differences in fibre distribution can significantly affect strength from one sample to the next (Easy Composites, 2024). Like the woven carbon fibre, there is no plastic region, the material fails without warning once the fibres are overloaded. The flax composite samples show a much lower stiffness and a gradual curve, which reflects the lower Young's Modulus of 1.67 GPa compared to the carbon fibre materials. Failure occurred at 90.78 MPa and 78.23 MPa respectively, and the curve shape suggests a slightly more progressive failure than the carbon materials, consistent with the behaviour reported for natural fibre composites by Wambua et al. (2003). The aluminium samples behave very differently to all the composite materials; Figure 3 shows a clear linear elastic region followed by a distinct yield point where the curve flattens before the material continues to deform plastically before eventually failing. This ductile behaviour is fundamentally different to the brittle fracture seen in all four composite materials and explains why aluminium has largely been replaced by composites in performance automotive and motorsport applications where predictable high-strength failure resistance is required (Savage, 1991).

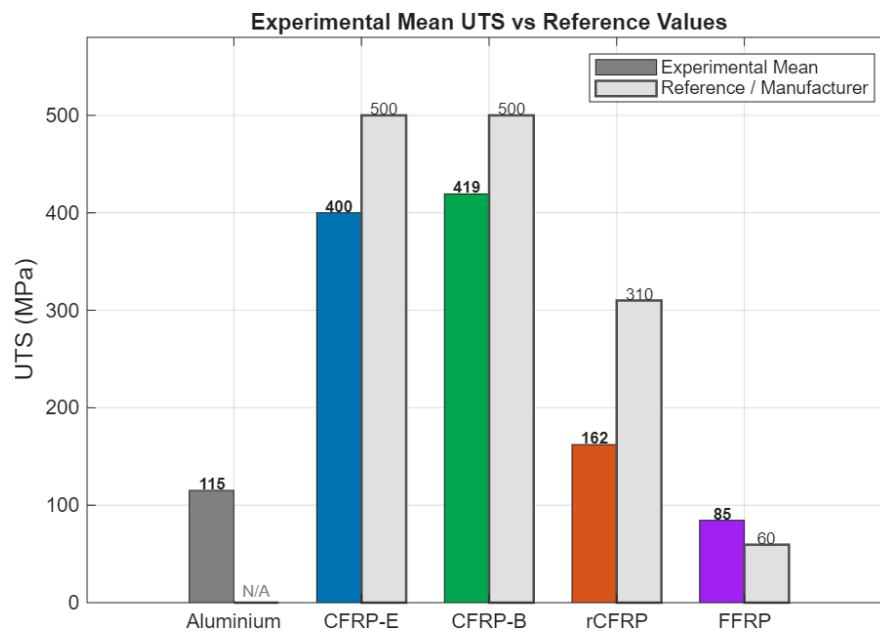


Figure 4 - A Graph Showing UTS Values from Experimental Data and Manufacturer Data

Figure 4 summarises the mean UTS results against the manufacturer and reference values for each material. The woven carbon fibre results both sit within the expected range, the recycled carbon fibre result is below the manufacturer indicative value, and the flax result sits above its reference value. Overall, the results confirm a clear performance hierarchy with woven carbon fibre at the top, followed by aluminium, recycled carbon fibre non-woven and then flax, though it is important to note that on a strength-to-weight basis all four composite materials outperform aluminium due to their significantly lower density.

5 Recommendations

Based on the experimental results and sustainability analysis carried out in this study, the following recommendations are made for the use of composite materials in motorsport and automotive applications.

The most immediately practical recommendation is the adoption of bio-epoxy resin systems as a direct replacement for conventional petroleum-based epoxy in carbon fibre components. The experimental results showed that carbon fibre with IB2 bio-epoxy achieved a mean UTS of 419.28 MPa compared to 400.05 MPa for conventional carbon fibre with IN2 epoxy, confirming that there is no meaningful reduction in mechanical performance when switching to a bio-based resin. Given that the IB2 resin contains approximately 31% plant derived content and requires no changes to the vacuum infusion manufacturing process, this represents the easiest and most cost-effective step the industry can take towards reducing the carbon footprint of structural composite components without compromising performance.

Recycled carbon fibre non-woven mat should be more widely adopted for non-structural applications such as body panels, aerodynamic covers and interior trim. Whilst the mean UTS of 162.17 MPa makes it unsuitable for primary structural use, it remains a viable material for components where strength is not the primary design requirement, and the significant energy savings associated with recycling carbon fibre compared to virgin production make it a far more sustainable choice in these applications.

Flax fibre composites with bio-epoxy resin are recommended for interior panels and trim components where sustainability is the primary consideration. The mean UTS of 84.51 MPa is sufficient for non-structural applications and the combination of a biodegradable natural fibre with a partially plant-based resin makes it the most environmentally friendly option tested.

For future research, it would be beneficial to test these materials under a wider range of loading conditions including compression, impact and fatigue testing, as tensile testing alone does not fully represent the loading experienced by motorsport components in service. Further research into improving the consistency of recycled carbon fibre non-woven materials would also be valuable, as the large variation between specimens observed in this study highlights a key limitation of the material in its current form.

6 Conclusion

This study has tested five materials in tensile loading and evaluated four composite materials from both a mechanical performance and sustainability perspective. The results show a clear trade-off between the two. Conventional and bio-epoxy carbon fibres offer the highest mechanical performance with mean UTS values of 400.05 MPa and 419.28 MPa respectively but come with the greatest environmental cost. Recycled carbon fibre and flax fibre composites offer more sustainable alternatives, though with reduced mechanical performance that limits them to non-structural applications.

The key finding of this study is that switching from conventional epoxy to bio-epoxy resin in carbon fibre composites has no meaningful impact on mechanical performance, making it the most practical near-term step the industry can take towards reducing its environmental impact. As legislation from both the FIA and UK government continues to tighten towards 2030 and 2050 net zero targets, the adoption of greener material systems will become increasingly necessary across both motorsport and automotive manufacturing.

7 References

Climate Change Act 2008 (2050 Target Amendment) Order 2019, SI 2019/1056. London: HMSO.

Easy Composites Ltd (2024) Carbon Fibre Non-Woven Mat CF-NWM Technical Datasheet. Version 1.0. Stoke-on-Trent: Easy Composites Ltd.

Easy Composites Ltd (2024) IB2 Epoxy Infusion Bio Resin Technical Datasheet. Stoke-on-Trent: Easy Composites Ltd.

Easy Composites Ltd (2024) IN2 Infusion Resin Technical Datasheet. Stoke-on-Trent: Easy Composites Ltd.

EcoTechnilin (2023) FibriMat F300 Technical Data Sheet. Valliquerville: EcoTechnilin.

EcoTechnilin (2023) FlaxDry BL200 Technical Data Sheet. Valliquerville: EcoTechnilin.

European Parliament and Council (2000) Directive 2000/53/EC on End-of-Life Vehicles. Official Journal of the European Communities, L269, pp. 34–43.

FIA (2020) FIA Environmental Strategy 2020–2030. Paris: Fédération Internationale de l'Automobile. Available at: <https://www.fia.com/news/fia-introduces-sustainable-fuel-formula-1-and-commits-becoming-carbon-neutral-2021-and-net-zero> (Accessed: 23 April 2026).

Gay, D. (2014) Composite Materials: Design and Applications. 3rd edn. Boca Raton: CRC Press.

Holbery, J. and Houston, D. (2006) 'Natural fibre-reinforced polymer composites in automotive applications', *Journal of Minerals, Metals and Materials*, 58(11), pp. 80–86.

Khalil, Y.F. (2017) 'Environmental and cost analysis of carbon fibre composites recycling', *Composites Part B: Engineering*, 109, pp. 171–182.

Mallick, P.K. (2007) Fibre Reinforced Composites: Materials, Manufacturing and Design. 3rd edn. Boca Raton: CRC Press.

Pimenta, S. and Pinho, S.T. (2011) 'Recycling carbon fibre reinforced polymers for structural applications', *Waste Management*, 31(2), pp. 378–392.

Porsche AG (2019) New Porsche 718 Cayman GT4 Clubsport featuring natural-fibre body parts. Available at: <https://www.porsche.com/usa/aboutporsche/pressreleases/pag/?id=525217> (Accessed: 23 April 2026).

Savage, G. (1991) Carbon-Carbon Composites. London: Chapman and Hall.

Scelsi, L. et al. (2011) 'Potential emissions savings of lightweight composite aircraft components evaluated through life cycle assessment', *Express Polymer Letters*, 5(3), pp. 209–217.

Wambua, P., Ivens, J. and Verpoest, I. (2003) 'Natural fibres: can they replace glass in fibre reinforced plastics?', *Composites Science and Technology*, 63(9), pp. 1259–1264.

Witten, E., Kraus, T. and Kühnel, M. (2016) Composites Market Report 2016. Frankfurt: AVK.

8 Appendix

