

# Materials Testing and Sustainability of Composites for Motorsport and Automotive Industries

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## INTRODUCTION

Composite materials are increasingly important in motorsport and automotive engineering because they offer significant weight reduction while maintaining high strength and stiffness. This makes them attractive where vehicle performance, structural efficiency and safety are critical. Composite selection, however, is also influenced by sustainability, manufacturing route, and end-of-life considerations.

This report examines three composite systems relevant to vehicle applications: carbon fibre reinforced polymer, aramid fibre reinforced polymer (Kevlar), and flax-based natural fibre composites. Through literature review, sustainability analysis and tensile testing, the materials are compared in terms of mechanical behaviour, manufacturing, application, and environmental impact, before recommendations are made for their use.

## LITERATURE REVIEW

Composite materials are widely used in motorsport and automotive engineering because they offer major weight reduction while maintaining high specific strength and stiffness. This makes them attractive where acceleration, handling, braking, and structural efficiency are critical. As noted by *Khan et al. (2025)*, the most relevant composite families for vehicle applications include carbon fibre reinforced polymer (CFRP), aramid fibre reinforced polymer (AFRP), and natural fibre reinforced composites. This review focuses on these three material systems and compares them in terms of properties, applications, and limitations.

*Table 1* compares the three composite systems considered in this review: CFRP, AFRP/Kevlar and natural-fibre composites based on flax. The table summarises their reinforcement form, typical properties, common vehicle applications, and the main advantages and limitations relevant to motorsport and automotive design.

**Table 1 – Material Properties (Granta, 2026)**

| Parameter                           | Carbon Fibre Composite (CFRP)                                     | Aramid Fibre Composite (AFRP/Kevlar)                           | Natural Fibre Composite                                     |
|-------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------|
| Fibre Type                          | Carbon                                                            | Aramid                                                         | Natural                                                     |
| Typical matrix material             | Epoxy Resin                                                       | Epoxy Resin                                                    | Furan Resin                                                 |
| Reinforcement form                  | Biaxial lay-up, Woven fabric prepreg                              | Quasi-isotropic lay-up                                         | Short fibre                                                 |
| Density                             | 1.54e3 - 1.61e3                                                   | 1.38e3                                                         | 1.2e3 – 1.35e3                                              |
| Tensile strength                    | 627 - 910 MPa                                                     | 355-392 MPa                                                    | 70 – 80 MPa                                                 |
| Young's modulus                     | 62.7 - 68.7 GPa                                                   | 23.5 – 30.9 GPa                                                | 8 – 12 GPa                                                  |
| Elongation at break                 | 0.98% - 1.41%                                                     | 0.374 – 0.42 %                                                 | 3 – 3.5%                                                    |
| Maximum service temperature         | 220° Celsius                                                      | 220° Celsius                                                   | 147° Celsius                                                |
| Typical manufacturing processes     | Manual prepreg lay-up with autoclave curing                       | Manual prepreg lay-up with vacuum bagging, or autoclave curing | Hand lay-up, spray-up, prepreg, vacuum infusion, pultrusion |
| Motorsport application              | Lightweight Structural members                                    | Lightweight, impact resistant structures, body panels          | Interior panels and secondary structural panels             |
| Main advantages                     | High strength to weight ratio, low density, high stiffness        | High toughness, good impact resistance, low density            | Low density, recyclable, good fire and chemical resistance  |
| Limitations                         | Not biodegradable, limited recyclability, mostly sent to landfill | Lower stiffness and poorer compressive strength than CFRP      | Lower stiffness and strength than CFRP and AFRP             |
| Embodied energy, primary production | 654 - 721 MJ/kg                                                   | 217 – 239 MJ/kg                                                | 39.2 - 43.2 MJ/kg                                           |

## CARBON FIBRE REINFORCED POLYMER (CFRP)

Carbon fibre composites are widely used in high-performance automotive and motorsport structures because they combine low mass with high specific strength and stiffness. *Adam (1998)* reported weight reductions of 50-70% relative to metallic alternatives, including a 63% reduction for a carbon fibre vehicle cabin compared with a steel equivalent. *Zhang et al. (2023)* similarly describe CFRPs as highly engineered materials suited to applications where low weight, stiffness and structural efficiency are critical. This explains their continued use in chassis structures, aerodynamic components, and other heavily loaded motorsport parts.

However, CFRP performance depends strongly on material quality and manufacturing control. *Kobets and Deev (1997)* showed that carbon fibre strength is influenced by fibre size and defect concentration, meaning that surface and internal flaws can reduce performance. Wider use is also limited by cost and production speed, particularly outside low-volume specialist sectors, while end-of-life remains a major weakness. *Zhang et al. (2020)* note that most end-of-life carbon composite waste in the UK has traditionally gone to landfill or incineration rather than true recycling, highlighting an important sustainability drawback of thermoset CFRP systems.

## ARAMID FIBRE REINFORCED POLYMER (AFRP/KEVLAR)

Kevlar is a high-performance aramid fibre valued for its strength to weight ratio, toughness, and thermal resistance. *Singh and Samanta (2015)* note that Kevlar performs well at elevated temperature for a polymeric fibre, which contributes to its suitability for demanding engineering use. Its main advantage over carbon fibre is not maximum stiffness or tensile strength, but impact tolerance. The same review reports that Kevlar composites absorb high impact energy, making them attractive in damage-tolerant or crash-related applications. This is reflected in automotive work by *Muthalagu et al (2020)*, who investigated Kevlar-based hybrid composites for bumper structures where brittle failure is undesirable.

Despite this toughness, Kevlar is less suitable than CFRP for stiffness critical components. *Singh and Samanta (2015)* report that Kevlar composites have much lower compressive strength than carbon and glass systems, often failing by fibre kinking. *Moorthy et al. (2013)* similarly found that although Kevlar/epoxy could reduce driveshaft mass compared with steel, it was less suitable than carbon/epoxy for a stiffness critical design. Another limitation is fibre-matrix bonding: Kevlar's smooth, inert surface can lead to poor adhesion, so surface treatment and hybridisation are often used to improve overall composite performance.

## NATURAL FIBRE COMPOSITES (FLAX)

Natural fibre composites have gained interest as lower-impact alternatives to conventional synthetic composites. *Yan et al. (2014)* identify several advantages of natural fibres, including low density, low cost, renewable origin, and lower manufacturing energy demand. Among these materials, flax is widely regarded as one of the most promising because it offers a favourable combination of low density, low cost, and useful specific properties. Yan et al. also note that flax has become one of the most relevant natural reinforcements in European automotive applications, especially for interior and semi-structural components.

Their main limitation is that performance is less consistent than that of carbon or aramid-based systems. *Lau et al. (2017)* note that wider structural use is restricted by moisture sensitivity, variable fibre quality, poorer fibre-matrix bonding and reduced long-term durability. *Pickering et al. (2016)* further show that natural-fibre composite performance depends strongly on fibre selection, dispersion, orientation, and interfacial strength. As a result, although flax composites can provide useful lightweighting and sustainability benefits, they are better suited to secondary or non-safety critical structures than to highly loaded primary components.

## SUSTAINABILITY ANALYSIS

The environmental impact of composite materials must be considered across their full lifecycle in both automotive and motorsport applications. This includes raw material sourcing, manufacturing route, service life, repairability and end-of-life treatment. This section compares three common composite systems relevant to motorsport and assesses their environmental impact, manufacturing requirements, and alignment with current sustainability policies.

**Table 2 – Material Analysis (Granta, 2026)**

| Factor                               | CFRP                                               | Aramid fibre composite                   | Natural Fibre composite                                                     |
|--------------------------------------|----------------------------------------------------|------------------------------------------|-----------------------------------------------------------------------------|
| Raw material source                  | Carbon Fibre (60-65 wt%) + epoxy resin (35-40 wt%) | Aramid fibre (45-50 wt%)                 | Natural fibre/cellulose reinforcement (25-35 wt%) + furan resin (65-75 wt%) |
| Matrix / resin type                  | Epoxy Resin                                        | Epoxy Resin                              | Furan resin                                                                 |
| Reinforcement form                   | Woven prepreg, biaxial lay-up                      | UD prepreg, quasi-isotropic lay-up       | Short fibre (<5mm)                                                          |
| Embodied energy                      | 654 – 721 MJ/kg                                    | 217-239 MJ/kg                            | 39.2 – 43.2 MJ/kg                                                           |
| Climate change (CO <sub>2</sub> -eq) | 45.6 – 50.3 kg CO <sub>2</sub> -eq/kg              | 11.9 – 13.1 kg CO <sub>2</sub> -eq/kg    | 2.94-3.24 kg CO <sub>2</sub> -eq/kg                                         |
| Water usage                          | 1250-1380 l/kg                                     | 438-484 l/kg                             | N/A                                                                         |
| Typical manufacturing route          | Prepreg lay-up with autoclave curing               | Prepreg lay-up with autoclave curing     | Hand lay-up, spray up, vacuum infusion, pultrusion                          |
| Manufacturing energy impact          | 20.9-23 MJ/kg (autoclave moulding)                 | 20.9-23 MJ/kg                            | N/A                                                                         |
| Recyclable?                          | No                                                 | No                                       | Yes                                                                         |
| Energy recovery possible?            | Yes – by combustion                                | Yes – by combustion                      | N/A                                                                         |
| Landfill likely?                     | Yes                                                | Yes                                      | N/A                                                                         |
| Biodegradable?                       | No                                                 | No                                       | N/A                                                                         |
| Most sustainable vehicle use         | High-load structural components                    | Lightweight, impact resistant structures | Interior panels and secondary structural panels                             |

Table 2 compares the three selected composite systems using Granta sustainability indicators. CFRP shows the highest embodied energy, climate change burden, and water usage, reflecting the energy intensive production associated with carbon fibre composites. Aramid composites remain synthetic and non-biodegradable, but their production impacts are lower than those of CFRP. The natural fibre composite shows the lowest embodied energy and climate impact of the three, suggesting the strongest environmental case where maximum structural performance is not required. End-of-life performance also differs significantly, with the natural fibre record indicating recyclability, whereas the selected CFRP and aramid records did not indicate conventional recycling routes and therefore remain more strongly associated with landfill or incineration.

## MANUFACTURING PROCESSES

Sustainability is influenced not only by material composition, but also by the manufacturing route used to produce the component. Composite processes differ significantly in cost, labour intensity, material utilisation, and energy demand. These differences help explain why some materials carry a higher overall environmental burden than others.

**Table 3 – Manufacturing Process Overview (Granta, 2026)**

|                                      | <b>Autoclave Curing</b>       | <b>Vacuum bagging</b>                       | <b>Hand lay-up</b> | <b>Spray-up</b>                     | <b>Vacuum assisted RTM</b> | <b>Pultrusion</b>                                |
|--------------------------------------|-------------------------------|---------------------------------------------|--------------------|-------------------------------------|----------------------------|--------------------------------------------------|
| <b>Capital cost</b>                  | 5.92e4 – 7.39e5 GBP           | 5.92e4 – 7.39e5 GBP                         | 73.9 – 739 GBP     | 1.18e4 – 2.22e4 GBP                 | 739 – 7.39e3 GBP           | 7.39e4 – 2.96e5                                  |
| <b>Material utilisation fraction</b> | 0.8 – 0.95                    | 0.8 – 0.95                                  | 0.8 – 0.95         | 0.8-0.95                            | 0.85 – 0.9                 | 0.6 – 0.97                                       |
| <b>Application</b>                   | High quality structural parts | Improved consolidation of laid-up laminates | Simple large parts | Low-cost large non-structural parts | Closed mould manufacture   | Continuous production of specified cross section |
| <b>Labour intensity</b>              | High                          | medium                                      | high               | Not shown                           | medium                     | low                                              |

### PULTRUSION (ARAMID FIBRE, NATURAL FIBRE)

Pultrusion (*Figure 1*) is a continuous manufacturing process in which resin-impregnated fibres or fabrics are pulled through a forming die. The final die is heated to cure the resin and produce a rigid profile with a constant cross-section. The production rate depends on factors such as material thickness and cure time. This process is well suited to continuous components such as rods, beams, box sections, and ladder rails.

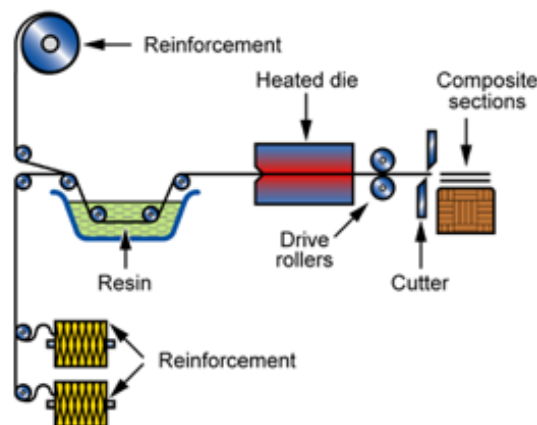


**Figure 1- Pultrusion Process (Granta, 2026)**

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## VACUUM ASSISTED RTM (ARAMID FIBRE, NATURAL FIBRE)

In vacuum assisted resin transfer moulding (VARTM), dry reinforcement is placed into the mould and covered with consumable layers such as peel ply before the mould is sealed under vacuum (see Figure 2). Resin is then drawn through the reinforcement by vacuum, impregnating the fabric before curing. Since the process does not require an autoclave, it offers a lower-cost alternative for producing composite parts with improved resin distribution and reduced void content compared with simple open-mould methods.

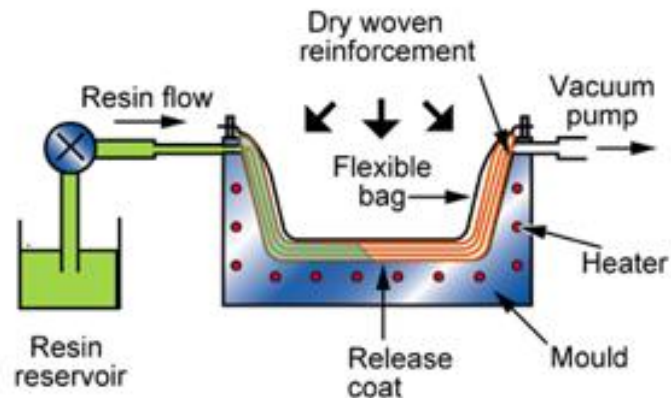


Figure 2- Vacuum Assisted RTM Process  
(Granta, 2026)

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## SPRAY UP (ARAMID FIBRE, NATURAL FIBRE)

Spray-up (Figure 3) is a straightforward process used to manufacture large composite parts with comparatively low-cost tooling. A gel coat is first applied to the mould surface. Chopped fibre and resin are then sprayed onto the mould, after which rollers are used to improve consolidation and ensure adhesion to the mould surface. The part is then left to cure without autoclave processing. Spray-up is generally suited to large components where high structural performance is not required, such as boat hull panels, building panels and shower trays.

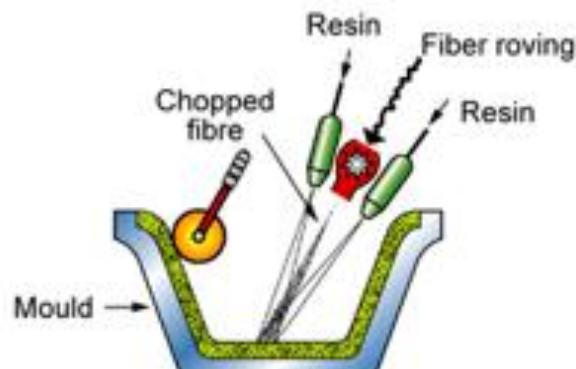


Figure 3- Spray Up Process (Granta, 2026)

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## HAND LAY-UP (ARAMID FIBRE, NATURAL FIBRE)

Hand lay-up is one of the most widely used composite manufacturing methods and is particularly suitable for large parts and relatively low-cost tooling. Layers of reinforcements are placed manually into the mould, and resin is applied by hand. Rollers are then used to improve wet-out, remove trapped air and ensure adequate adhesion. The laminate is then left to cure without autoclave processing. Typical applications include vehicle body panels, ducts, and boat hulls.

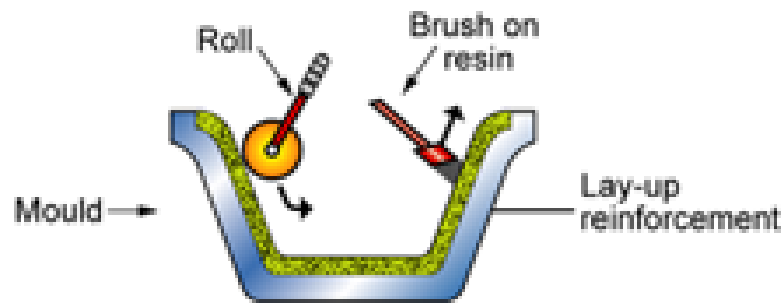


Figure 4- Hand Lay-Up Process (Granta, 2026)

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## VACUUM BAGGING (ARAMID FIBRE, NATURAL FIBRE)

In Vacuum bagging, the reinforcement and resin are first applied to the mould using hand lay-up or similar methods. The uncured laminate is then enclosed within a vacuum bag and subjected to vacuum pressure, which improves consolidation, removes trapped air and helps produce a more uniform laminate. Additional heat may be applied depending on the resin system to accelerate curing. This process generally improves part quality compared with simple open-mould lay-up.

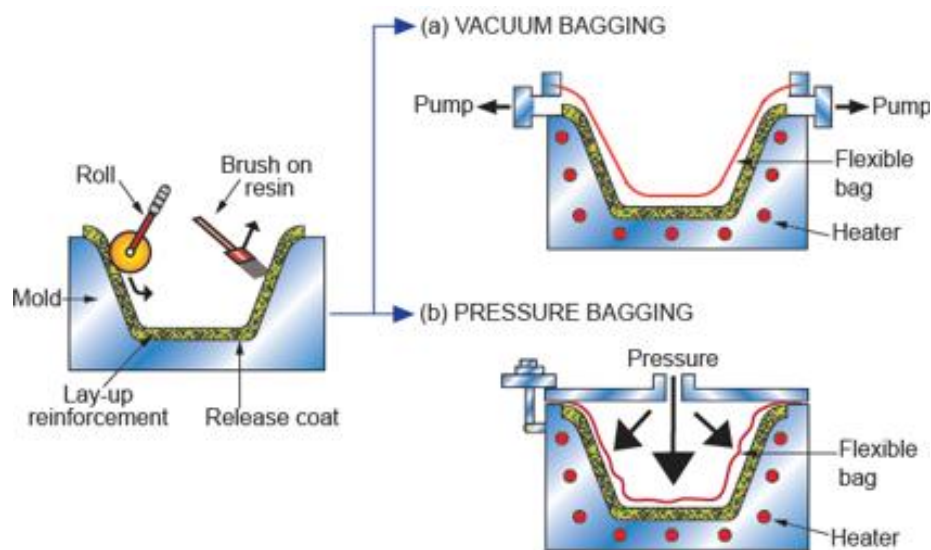


Figure 5- Vacuum Bagging Process (Granta, 2026)

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## AUTOCLAVE MOULDING (ARAMID FIBRE, CARBON FIBRE)

Autoclave moulding is a high-quality composite manufacturing process commonly used for aerospace and high-performance motorsport components. The laminate is laid up, covered with release film and absorbent materials, sealed in a vacuum bag, and then placed in an autoclave. Heat and external pressure are applied during curing, improving consolidation and reducing void content. This process produces high-quality structural parts, but the equipment and operating costs are significantly higher than for a simpler manufacturing method.

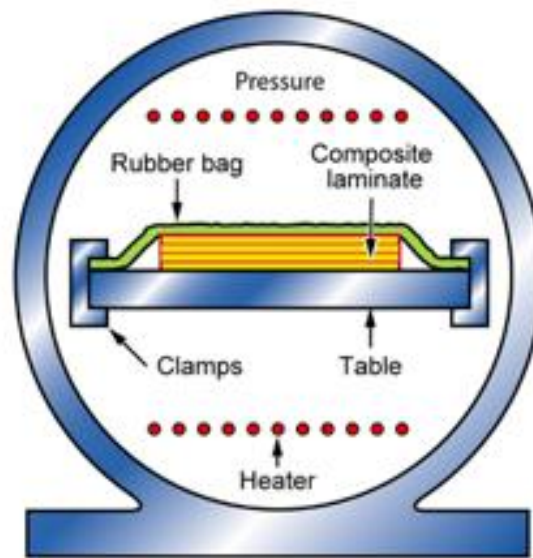


Figure 6- Autoclave Moulding Process (Granta, 2026)

Overall, the manufacturing comparison suggests that CFRP and aramid composites are more strongly associated with prepreg lay-up, vacuum bagging, and autoclave curing, which can produce high-quality structural parts but involve increased complexity and energy demand. Natural fibre composites are more commonly associated with simpler routes such as hand lay-up, spray up and vacuum assisted processes, which may reduce manufacturing energy. The most sustainable future for composite-intensive vehicles is therefore likely to depend on combining lower-impact materials, improved manufacturing routes, and better end-of-life strategies, rather than relying on a single material system.

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## SUSTAINABILITY REGULATIONS AND POLICY CONTEXT

Current regulation and policy indicate that composite material selection must be considered across the full vehicle lifecycle, not just in terms of performance. *The End-of-Life Vehicles Regulations 2003* place greater emphasis on reuse, recovery, recyclability, and producer responsibility, meaning that materials must be assessed not only for in-service behaviour, but also for how easily they can be identified, dismantled, and treated at end of life.

A similar direction is visible in motorsport governance. *Motorsport UK's Sustainability Strategy 2021-2030* shows that carbon reduction, resource efficiency and environmental accountability are now formal objectives within the sport, with sustainability expected to influence regulations, procurement and supply-chain decisions. Together, these developments suggest that future composite selection will increasingly be shaped by carbon impact and end-of-life treatment as well as by mechanical performance.

For the materials compared in this report, the natural fibre composite provides the lowest embodied energy and climate-change burden, while CFRP shows the highest. The selected natural-fibre record also offered the most favourable recycling outcome in Granta, whereas the CFRP and aramid records did not indicate conventional recycling routes. This gives natural fibre composites the strongest environmental case where high structural performance is not essential, particularly in interior and secondary applications.

However, CFRP and aramid composites remain justified where lightweight structural efficiency, impact resistance and safety are critical. Their longer service life in some applications may partially offset the environmental burden, but once damaged or obsolete they still offer limited recovery options compared with metallic materials.

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## RESOURCE EXTRACTION

Resource extraction also affects the sustainability of each composite system. CFRP and aramid composites rely on synthetic fibre and resin produced through energy intensive processing, whereas natural fibre composites use cellulose-based reinforcement from renewable plant sources combined with furan resin. As a result, the environmental burden begins before manufacture, with synthetic composites carrying a greater extraction impact than the natural alternative. This is reflected in the embodied energy and climate change data presented in *Table 1*.

Overall, improving sustainability in motorsport, motorcycle and automotive applications is unlikely to be achieved through a single material substitution. A more realistic approach is selective material use: natural fibre composites for lower-load or secondary components, aramid composites where toughness and impact resistance are required, and CFRP only when high structural performance is essential. Combined with lower-impact resins, design for disassembly and improved recycling technologies, this offers the strongest route to reducing the carbon footprint of composite materials.

## EXPERIMENTAL TESTING

Tensile testing was conducted on aluminium and a range of composite laminates to compare their mechanical response under axial loading. Representative stress-strain curves were selected from repeated tests using runs closest to the calculated average response, and the results were compared in terms of baseline behaviour, reinforcement architecture and mean tensile strength. Where appropriate, the experimental trends were considered alongside manufacturer data and published composite behaviour.

### STRESS – STRAIN CURVE (ALL MATERIALS)

Figure 7 compares the representative tensile response of all materials assessed. Aluminium provided the baseline response and showed the greatest strain to failure, indicating much higher ductility than the composite laminates. Among the composites, the woven carbon systems reached the highest stress levels, with carbon woven epoxy giving the highest peak stress overall and carbon woven bio following closely behind. Kevlar woven bio also showed robust performance but remained below the woven carbon laminates. Both flax composites showed substantially lower tensile performance, with the non-woven flax laminate giving the lowest stress response of all tested materials.

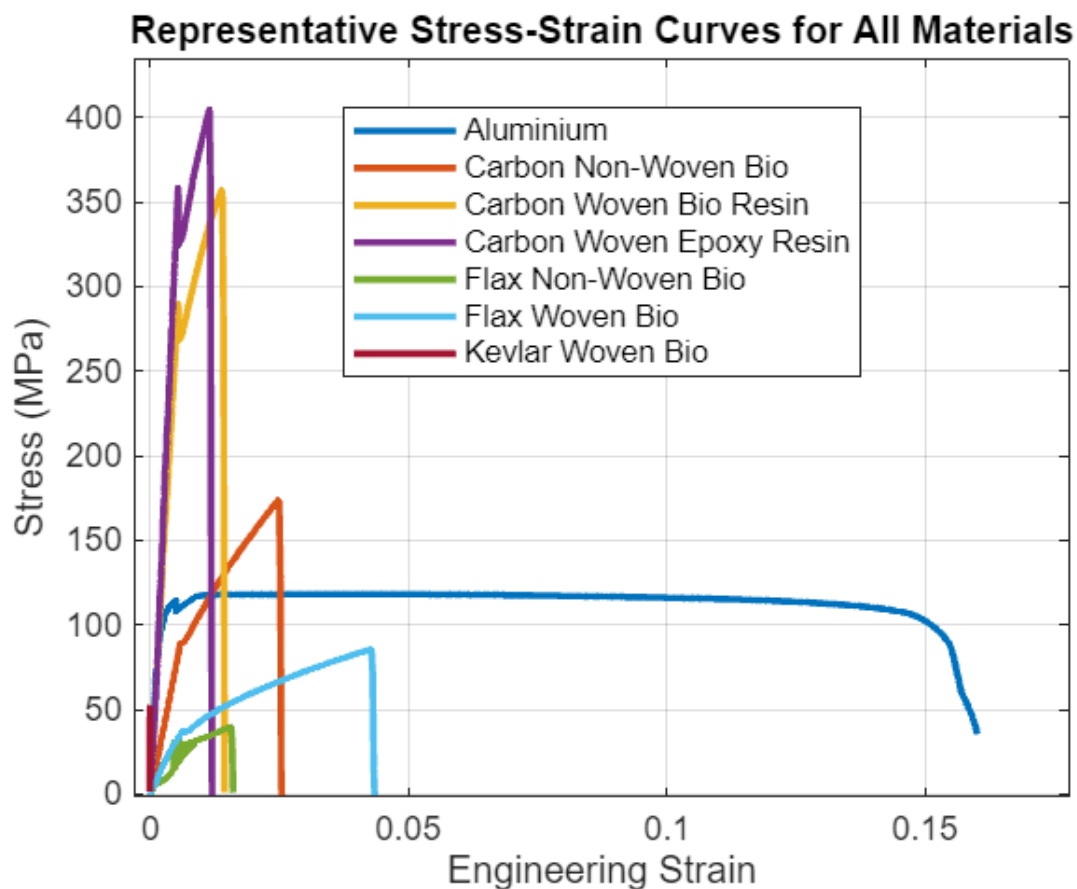


Figure 7- Stress and Strain Curve (All Materials)

## STRESS – STRAIN CURVE (FLAX WOVEN VS FLAX NON-WOVEN)

Figure 8 highlights the effect of reinforcement architecture in the flax composites. The woven flax laminate reached a much higher stress and sustained loading over a greater strain range than the non-woven flax laminate. This indicates that the woven architecture provided a more effective load transfer through the reinforcement, resulting in improved tensile performance. The more irregular behaviour seen in the non-woven flax laminate is also consistent with the greater variability typically associated with natural-fibre composites.

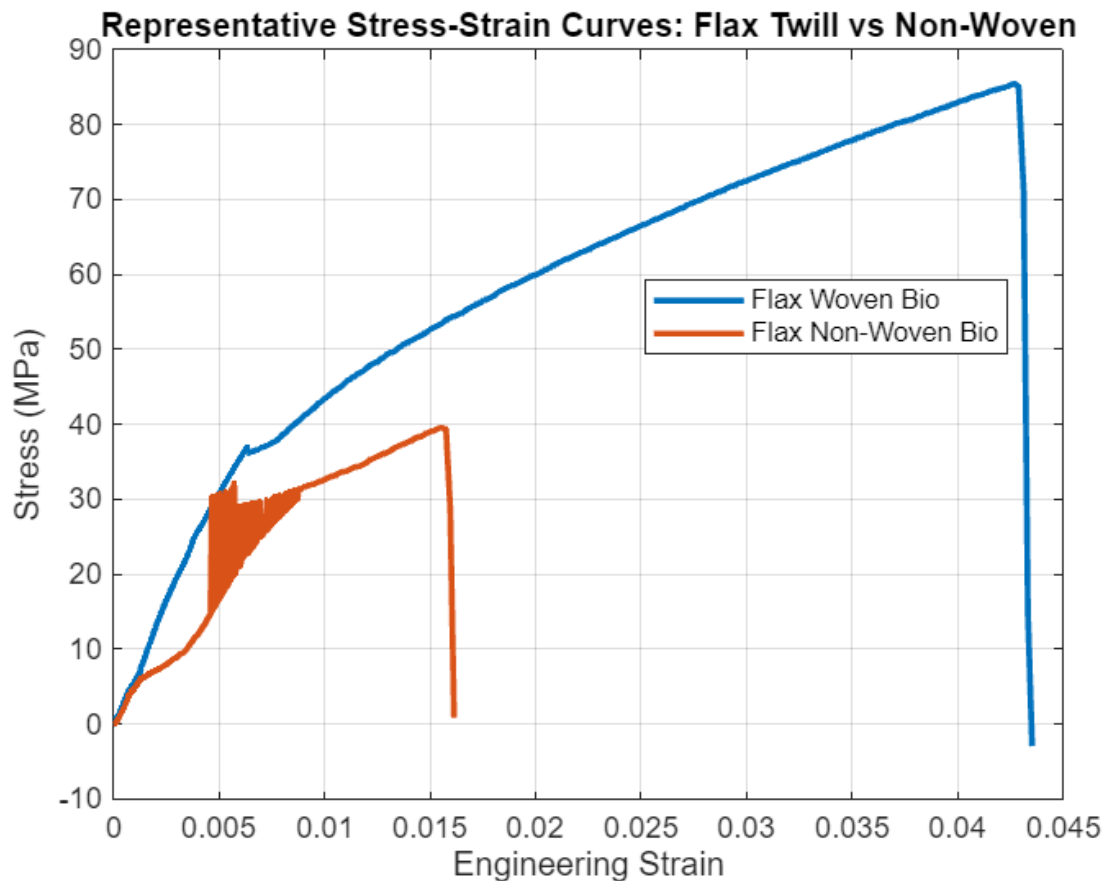


Figure 8- Stress and Strain Curve (Flax woven vs non-woven)

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## STRESS – STRAIN CURVE (CARBON WOVEN VS CARBON NON-WOVEN)

Figure 9 shows the same architecture trend in the carbon composites. The woven carbon bio-resin laminate achieved a much higher peak stress than the non-woven carbon laminate, although it failed at a lower strain. The carbon non-woven material displayed a more gradual rise in stress but a much lower overall tensile capacity. This suggests that the non-woven carbon laminate is less suitable for highly loaded structural applications, while the woven laminate provides a more efficient load path and a significantly greater strength.

### Representative Stress-Strain Curves: Carbon Twill vs Non-Woven (Zoomed)

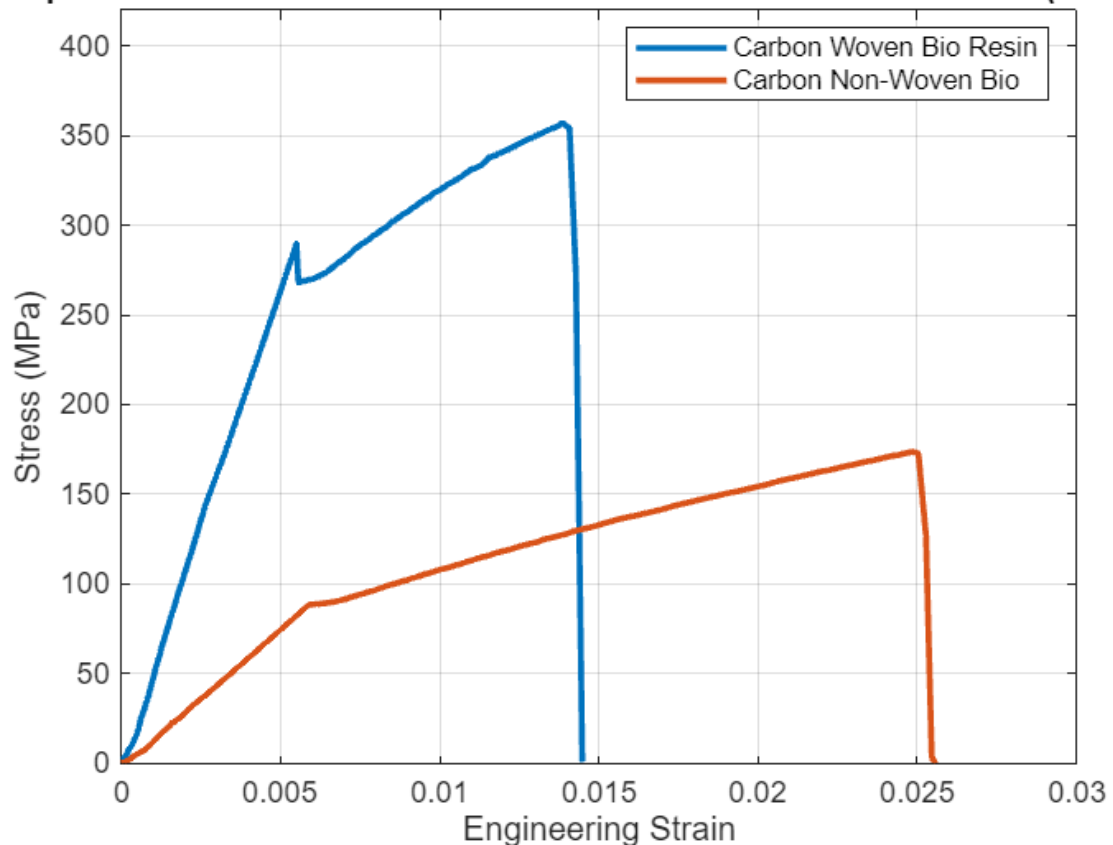


Figure 9- Stress and Strain Curve (Carbon woven vs non-woven)

## MEAN TENSILE STRENGTH (ALL MATERIALS)

Figure 10 summarises the average tensile strength values for all tested materials. Carbon woven epoxy achieved the highest mean tensile strength, followed by carbon woven bio, showing that the bio-resin system remained within a similar performance range to the conventional epoxy. Kevlar woven bio ranked next, indicating an intermediate performance between the woven carbon laminates and the natural-fibre composites. Aluminium showed a lower mean tensile strength than the strongest composite systems, but this should be considered alongside its much greater ductility. The two flax laminates produced the lowest average tensile strengths, with woven flax clearly outperforming non-woven flax.

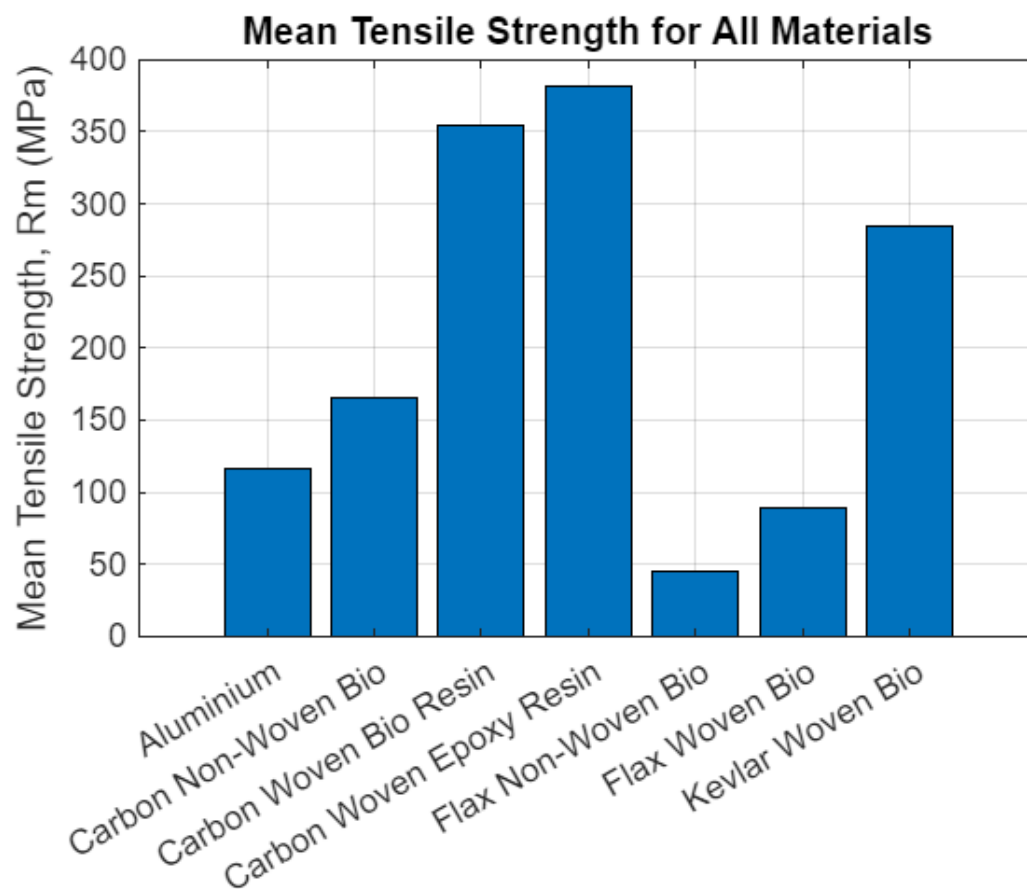


Figure 10- Mean Tensile Strength Comparison (All Materials)

**Table 4 – Tensile Strength Comparison (Test vs Datasheet)**

| <b>Material</b>      | <b>Rm (MPa)</b> | <b>Datasheet Tensile Strength</b> |
|----------------------|-----------------|-----------------------------------|
| Carbon non-woven bio | 165             | 330 MPa                           |
| Flax non-woven bio   | 45.4            | 44 ± 4 MPa                        |
| Flax woven bio       | 88.8            | 61± 6 MPa (warp)                  |

*Table 4* compares the experimental tensile strength values with available supplier data for the materials where a reasonably similar datasheet was available. The flax non-woven bio laminate showed the closest agreement with the supplied values, suggesting that the test procedure produced realistic results for this material. The flax woven bio laminate gave a higher tensile strength than the datasheet range, which may reflect differences in fibre construction, laminate quality, specimen preparation or test direction. In contrast, the carbon non-woven bio laminate performed below the supplied values. This is plausible given that the datasheet states that the recycled carbon laminate properties are approximate and depend on origin of material and construction. Overall, the comparison shows a broad agreement in material ranking and behaviour, even where exact numerical agreement was not achieved.

## RECOMMENDATIONS

Based on the experimental and sustainability findings, composite selection should be application-specific rather than based on one material alone. Carbon fibre composites are recommended for high-load structural applications in motorsport and high-performance vehicles, such as chassis, survival structures, suspension components, and aerodynamic parts, where their high tensile performance and low weight offer the greatest benefit. Carbon woven epoxy produced the highest average tensile strength, while carbon woven bio resin performed at a similar level, suggesting that bio-resin systems may offer a lower-impact alternative where a small reduction in performance is acceptable.

Kevlar composites are recommended where toughness and impact resistance are more important than maximum stiffness. This makes them more suitable for secondary structural parts, inner bodywork, and protective panels than for primary stiffness-critical structures. Their intermediate performance suggests that they can provide a useful balance between carbon fibre and natural fibre composites.

Natural fibre composites are not recommended for highly loaded motorsport structures based on the results of this study. However, they may still be suitable for low-load automotive components such as interior panels, trim and non-safety-critical body parts, where sustainability is a greater priority than maximum tensile strength. The woven flax laminate performed significantly better than the non-woven flax laminate, showing that reinforcement architecture is especially important when natural fibres are used.

Future work should focus on improving the structural performance of natural fibre composites through better fibre quality, improved fibre-matrix bonding, and tighter manufacturing control. A second priority is end-of-life management since carbon fibre and Kevlar composites remain limited by poor recyclability. Greater use of lower-impact resin systems, better design for disassembly, and improved recycling and recovery routes would help reduce the environmental burden of composite-intensive vehicles.

## CONCLUSION

This report has shown that composite material performance is strongly influenced by reinforcement architecture, material properties, and resin selection. The experimental testing demonstrated that the woven carbon laminates gave the highest tensile performance, with carbon woven epoxy producing the greatest average tensile strength and carbon woven bio performing at a similar level. Kevlar showed intermediate performance, while the flax composites gave the lowest tensile strength, with woven flax performing significantly better than non-woven flax. The sustainability analysis showed that natural-fibre composites offer the lowest environmental burden, but their mechanical performance currently limits them to lower-load, interior or secondary structural applications. Overall, carbon fibre remains the most suitable option for highly loaded motorsport structures, while improved natural-fibre properties, lower-impact resin systems and better end-of-life solutions represent the main priorities for future development.

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