

# Investigating The Feasibility of Basalt Fiber as A Carbon Fiber Substitute in Composites for Automotive Applications

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## Abstract

*The escalating carbon footprint, a consequence of dwindling natural resources and surging energy demand, necessitates immediate measures to mitigate environmental impact. This prompted the current study: to look at alternative manufacturing materials that could be utilized as a carbon-free substitute without compromising on mechanical properties. Basalt fiber was identified as a potential eco-friendly replacement to carbon fiber which has several advantages over carbon fiber and is entirely natural and biodegradable. The study encompasses the various benefits of basalt fiber and its direct comparison with Carbon Fibre through a complete Life Cycle Assessment (LCA) Analysis from procurement to production to fabrication and finally recycling. The potential health hazards of carbon fiber have been discussed and compared against our choice of material. To validate the study, a trade-off analysis has also been shown between the two with the help of computer numerical simulation on a model of a prototype vehicle, with the ANSYS ACP software to show the benefits of the basalt fiber. Through a comprehensive literature review, practical insights, and showcasing eco-friendly materials for the manufacturing process of our vehicle, this study intends to contribute to the worldwide move from carbon-intensive manufacturing processes to more innovative and ecological techniques.*

**Keywords:** Carbon fiber; basalt fibre; composites; life cycle assessment; simulation

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## INTRODUCTION

The escalating depletion of natural resources and ever-rising pollution levels necessitate a paradigm shift towards sustainable materials, particularly in industries with a significant environmental footprint. Research in sustainable technologies across various domains is playing a crucial role in this transition, driven by the urgent need to mitigate the environmental impact of manufacturing processes [1, 2, 3]. This research specifically delves into the realm of highly efficient monocoque vehicles, aiming to identify the most suitable fiber source that can contribute to their overall sustainability. Carbon fiber (CF), traditionally used in such applications, has come under scrutiny due to its high carbon content and its consequent contribution to the environmental burden. Basalt fiber (BF), derived from volcanic rock basalt, emerges as a potential alternative. While still under development for core manufacturing purposes, BF exhibits promising mechanical properties,

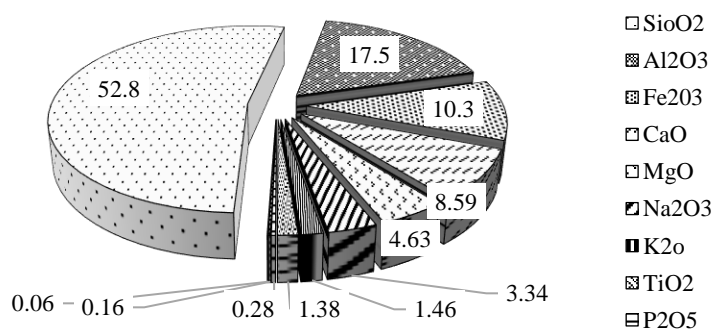
including good tensile strength, thermal resistance, and chemical resistance. Additionally, it boasts a significant cost advantage and a lower environmental impact compared to its synthetic counterpart. Given its comparable physical properties, BF presents itself as a viable candidate to replace CF in automotive component manufacturing, potentially mitigating the environmental costs associated with traditional carbon fiber production.

## LITERATURE REVIEW

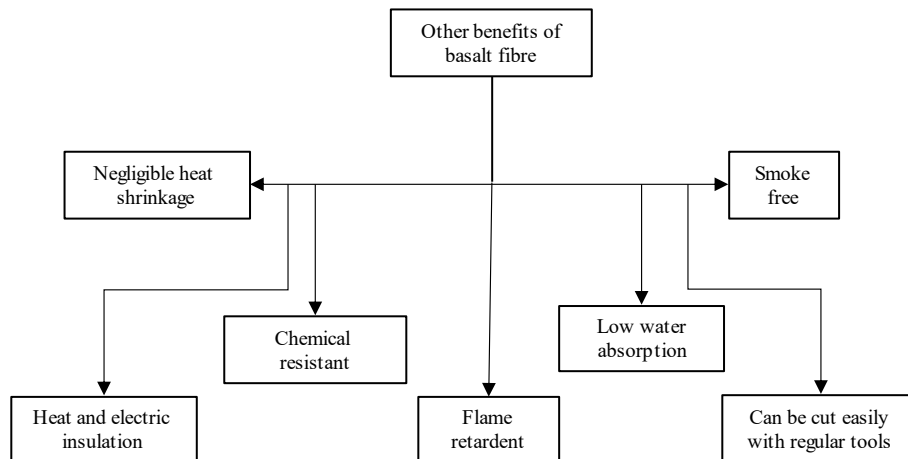
Multiple research efforts have convincingly demonstrated the viability of basalt fibers (BF) in composite technologies. Studies by Dobiszewska et al [6]. explored the modification of cement paste and mortar using basalt powder, highlighting its potential as a reinforcement material. Research by Fořt et al [7]. and Laiblová et al [8]. emphasized the environmental benefits of BF compared to conventional steel fibers and ordinary concrete solutions, respectively. These studies point to the lower density and improved life cycle assessment of BF composites. Furthermore, Mingfeng et al [9]. demonstrated the successful production of Engineered Cementitious Composites (ECC) using BF, showcasing its potential for high-performance applications. Yu et al [10]. added to this promise by revealing that both recycled and repaired BF composites exhibit mechanical properties comparable to virgin materials, promoting resource efficiency. Kamal et al [11]. provided a vital environmental comparison, highlighting the significantly lower impact of basalt fiber composites (CBF) compared to glass and carbon fibers. However, they cautioned against direct comparisons with carbon fiber due to potentially outdated data on its production methods [12]. This collective body of research offers compelling quantitative evidence for the advantages of BF in composites. The studies demonstrate environmental benefits, comparable or superior mechanical properties to traditional materials, and cost-effectiveness. These findings paint a promising picture for BF as a practical and versatile solution across the composite industry, justifying further exploration and implementation. Beyond civil engineering applications, research by Chandrashekharan et al [17]. explored the use of BF composites in car bumpers, demonstrating their superior strength and affordability compared to steel. Similarly, Alshahrani et al. [18]. investigated the use of hybrid jute-basalt fiber composites for lightweight automotive structures, showcasing the potential for further property enhancement through hybridization.

## ADVANTAGES OF BASALT FIBRE OVER CARBON FIBRE

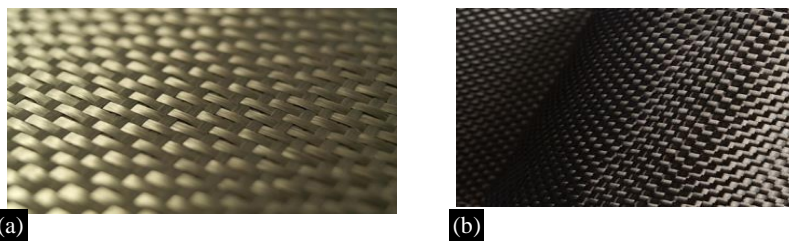
Basalt fiber has been found to have many benefits over carbon fibers. Because they cannot enter the respiratory system, particles larger than 3 microns in diameter, such as those in basalt powder (6 microns in diameter), are far safer than dust made of carbon fiber (2–3 microns in diameter). Whereas basalt fibers break more slowly and gradually, allowing the fracture to be predicted and lowering the chance of shard injuries, carbon fibers tend to "shatter" suddenly and catastrophically. Basalt fiber comes from rocks that are entirely devoid of carbon. One of the major advantages of moving to basalt fiber is this [4]. Because of its strong tensile strength, excellent thermal resistance, and resilience to chemicals, basalt fiber is made from basalt rock (Table.1) When compared to many synthetic fibers, it is more affordable and environmentally friendly. Because of its remarkably high tensile strength and stiffness, carbon fiber—which is made up of carbon atoms—is perfect for applications needing both strength and lightweight, such as sports equipment and aircraft. Compared to basalt fiber, it is more costly and produces waste that affects the environment less [Figure 1-4].



**Figure 1.** Composition of basalt fiber [5].



**Figure 2.** Advantages of basalt fiber.



**Figure 3.** (a) Basalt fiber (b) Carbon fiber

**Table 1.** A comparative table between Basalt Fiber and Carbon Fiber.

Feature	Basalt fibre	Carbon fiber
Composition	Made from fine fibers of basalt, a volcanic rock.	Made from crystal-aligned carbon atoms..
Mechanical Properties	Good tensile strength, slightly lower than carbon fiber.	Exceptional tensile strength and stiffness.
Thermal Properties	Excellent resistance to high temperatures and fire.	High thermal stability but less heat resistant than basalt.
Chemical Resistance	Resistant to alkalis and acids.	Resistant to chemicals but can be affected by some acids.
Electrical Properties	Non-conductive.	Conductive, depending on the precursor material.
Environmental Impact	More environmentally friendly, less energy-intensive production.	Higher environmental impact due to production processes.
Cost	Generally, less expensive than carbon fiber.	Expensive due to the complex production process.
Applications	More expensive due to the complex production process.	Aerospace, high-performance vehicles, sporting goods.
Advantages	Lower cost, good thermal and chemical resistance.	Superior strength-to-weight ratio, high stiffness, lightweight.
Disadvantages	Lower strength compared to carbon fiber.	Costly, less thermal resistant, environmental concerns.

### LIFE CYCLE ASSESSMENT OF BASALT FIBER AND CARBON FIBER

Life cycle assessments for materials like carbon fiber and basalt fiber aim to comprehensively evaluate their environmental impacts from production to disposal. This involves analyzing production processes, fabrication, emissions, and waste generation across their entire life cycle. By comparing these factors, these assessments help identify which stages contribute most to environmental impact and highlight areas for potential improvement in sustainability practices.

### DYNAMIC USAGE OF BASALT FIBER WITH FLAX

Composites built from natural fiber reinforcements and polymer matrices made from renewable resources have become more popular as an alternative to traditional fiber-reinforced composites throughout the years. This is owing to their low cost, low density, low energy consumption, renewable nature, carbon neutrality, and excellent strength-to-weight ratio. Flax fiber has exhibited noteworthy mechanical qualities among various natural fibers as reinforcements with epoxies with a density of 1.45 g/cm<sup>3</sup> and stiffness comparable to glass fiber [Figure 5]. When comparing continuous basalt fiber to a fiber composite of Flax and basalt, it was discovered that the fiber composite had 100% natural content with better flexural capabilities and decreased water absorption as compared to other alternatives [13].

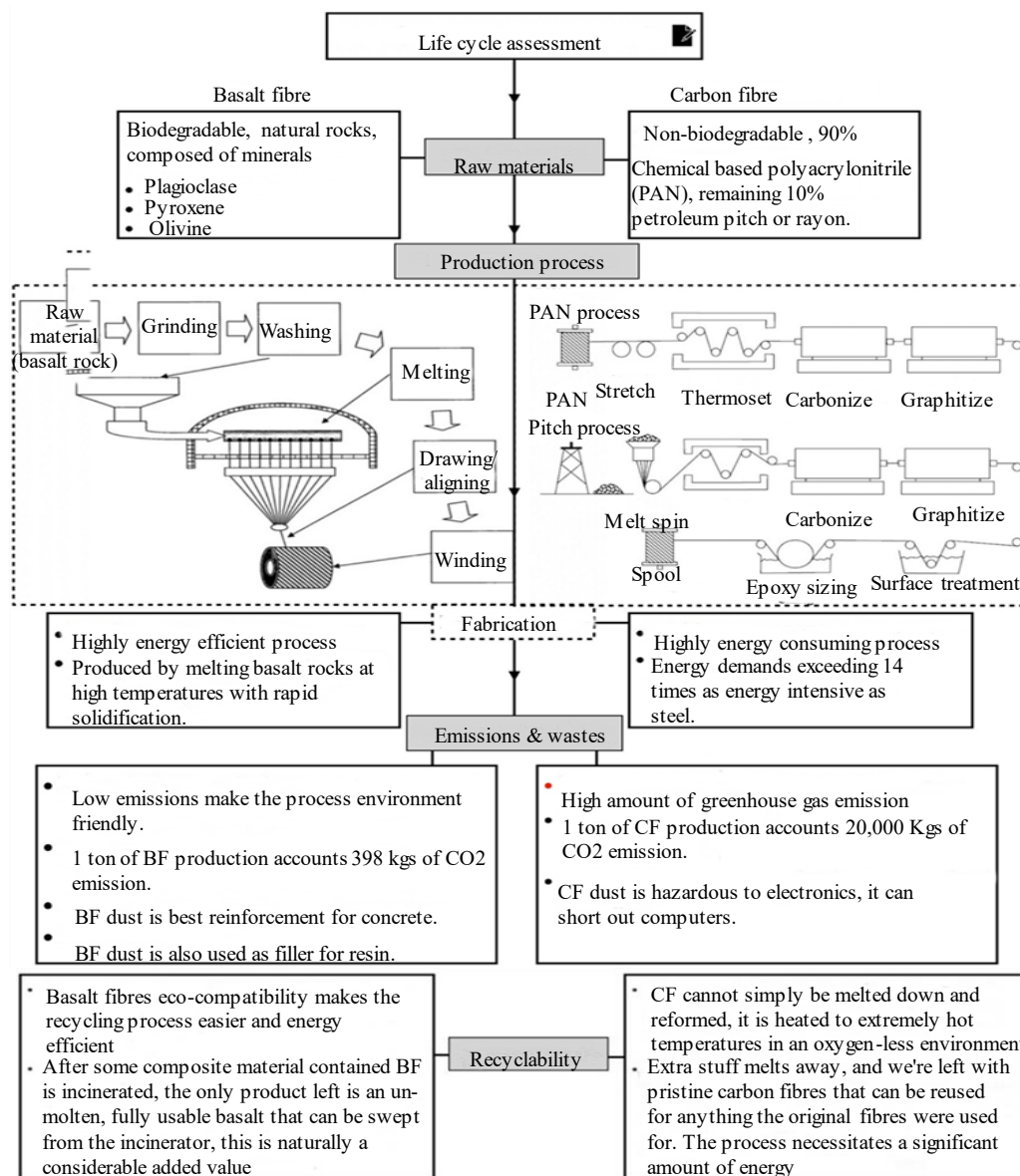
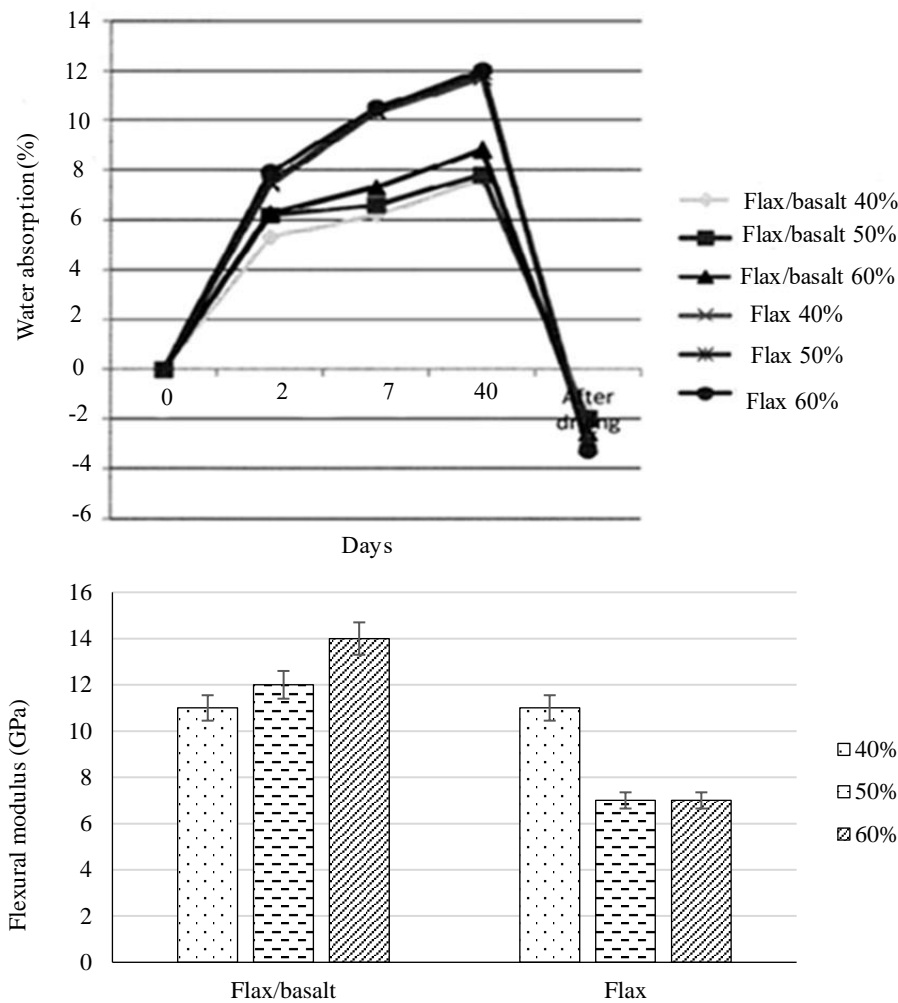


Figure 4. A Comparative life cycle assessment of basalt fiber and carbon fiber.



**Figure 5.** Plots comparing flexural modulus and water absorption capacity of flax-basalt and flax composites [13].

### BASALT/CARBON FIBER WITH BIO-RESIN

Bio-based epoxy resins can be utilized to further reduce the usage of ecologically hazardous ingredients. Conventional synthetic epoxy resins are made by reacting epichlorohydrin (ECH) with bisphenol-A (BPA) with an inert solvent, methyl isobutyl ketone (MIBK). The chemicals listed above are extremely hazardous: BPA and ECH have deadly mutagenic and carcinogenic effects, while MIBK can cause nausea and diarrhoea. Bio-resin, on the other hand, is made up of ~35% plant material (Table.2) When combined with its hardener, the entire plant-based composition is ~27%. Unlike synthetic resins, bio-resins get their ingredients from plants. Epichlorohydrin, a fundamental component of epoxy, is made from sustainable plant-based Glycerol instead of petroleum-based propylene. Because the properties of bio-resins are the same as those of their synthetic equivalents, we may reap environmental advantages without compromising performance [13].

**Table 2.** Comparing mechanical properties of bio resin and synthetic resin [3].

Cured mechanical properties	Bio resin	Synthetic resin
Tensile Strength	79 MPa	67-75 MPa
Elongation at Break	5.80%	6-8%
Flexural Modulus	3.2 GPa	3.6-4 GPa
Flexural Strength	127 MPa	120-130 MPa

## MECHANICAL TESTING

According to the literature survey, Basalt fiber-reinforced polymer (BFRP) composites can substitute Carbon fiber reinforced polymer (CFRP) composites, validated by a flexural strength test study with a three-point bending tool [16].

### Laminate Preparation

For the test, fiber-reinforced polymer laminates were prepared using 14 layers of each: Basalt dry fabric with a weight of  $200 \text{ g/m}^2$  (in a plain weave pattern) and carbon dry fabric weighing  $180 \text{ g/m}^2$  (also in a plain weave pattern) and for the matrix, epoxy resin was used and the laminates were manufactured using the wet layup method and in both the laminates the fiber weight percentage was kept at 60. Basalt epoxy laminates will be referred to as BF60 and Carbon epoxy laminates as CF60 in the subsequent parts of the report (Figure 6)

### Testing

The data integrated into the analysis comes from the study by Yusuf Şahin and De Baets Patrick [14]. This research concentrated on creating composites made from basalt and carbon fabric embedded in epoxy, and it evaluated their mechanical characteristics including hardness, impact resistance, and flexural properties according to ASTM guidelines

### Results

The load versus extension plots for both the composite laminates as obtained by Yusuf Şahin and De Baets Patrick are shown below (Figure 7)



Figure 6. Three-point bending testing machine [14].

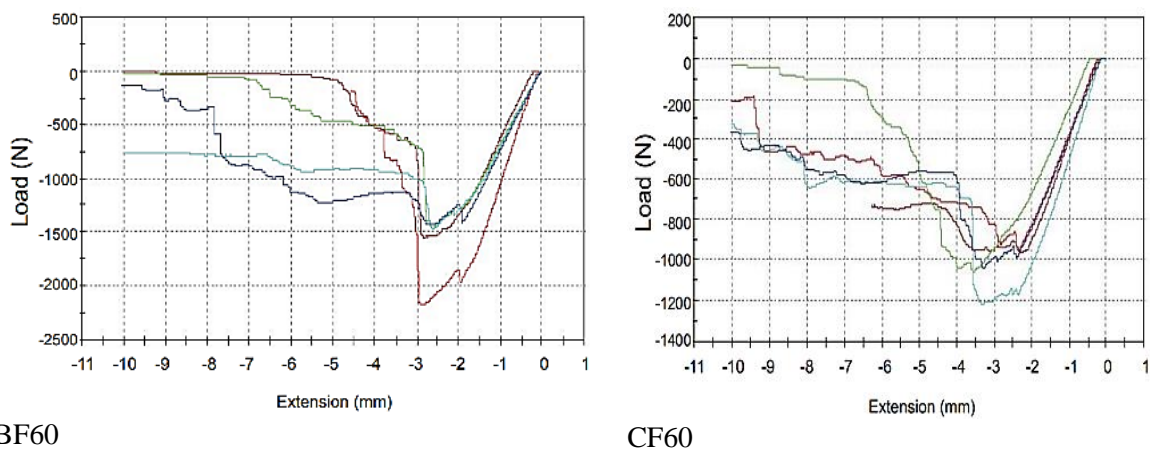


Figure 7. Load vs. extension plots for BF60 and CF60 laminates [14].

From these plots we can conclude that CF60 laminates fracture at a load of 1474 N and BF60 laminate fractures at 990 N. This shows that the load-bearing capacity of CF60 is more than that of BF60(Figure. 8)The results of the flexure test are summarized in the below Table-3.

### FINITE ELEMENT ANALYSIS OF A PROTOTYPE MONOCOQUE

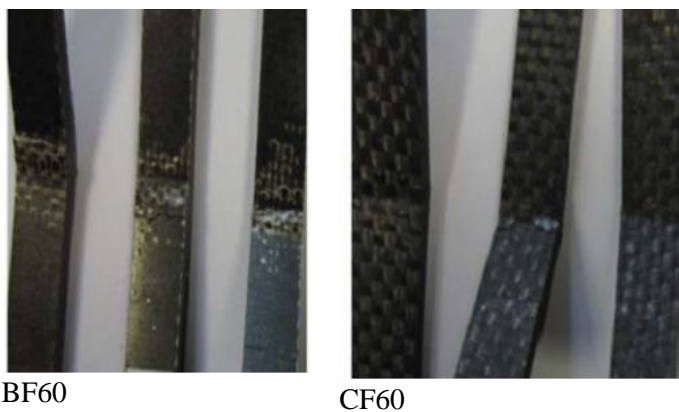
To further investigate the behavior of basalt fiber composites, structural analysis was carried out for a prototype monocoque chassis ANSYS 2020 R2. Different loads to account for powertrain assemblies, steering assembly, and driver weight were applied. The first step in the analysis was to specify the material for the simulation and since the properties of basalt fabric-reinforced epoxy composites are not included in Ansys, the material using the Ansys Material Designer. To validate the properties of the material, the results from the flexural bend test of Yusuf Şahin and De Baets Patrick [14]. were used. The properties of the material closely matched that of the bend test. The properties of both composite materials when manufactured using the wet layup method are shown below (Figure9)

After preparing the material model, the next step is to import the geometry in Ansys and generate an optimum mesh.

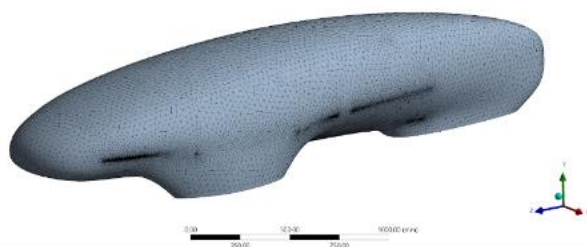
The next step was to specify the stacking sequence of the constituent materials and this was done using Ansys Composite Pre-Post. For comparison of both materials, two cases are considered: BFRP monocoque with PVC Foam Core and CFRP monocoque with PVC Foam Core. The ACP Pre results for both the cases are shown below (Figure10-11& Table4-5)

**Table 3.** Results of the flexural test [14].

Tested Material	Maximum force (Newton)	Standard deviation for Force (%)	Flexural strength (MPa)	Flexural modulus (GPa)
60% Weight Basalt Fiber (BF60)	990	87.58	359	18.36
60% Weight Carbon Fiber (CF60))	1474	92.08	700	41.68



**Figure 8.** The samples after the flexural test [14].



**Figure 9.** Prototype monocoque chassis geometry after the meshing process.

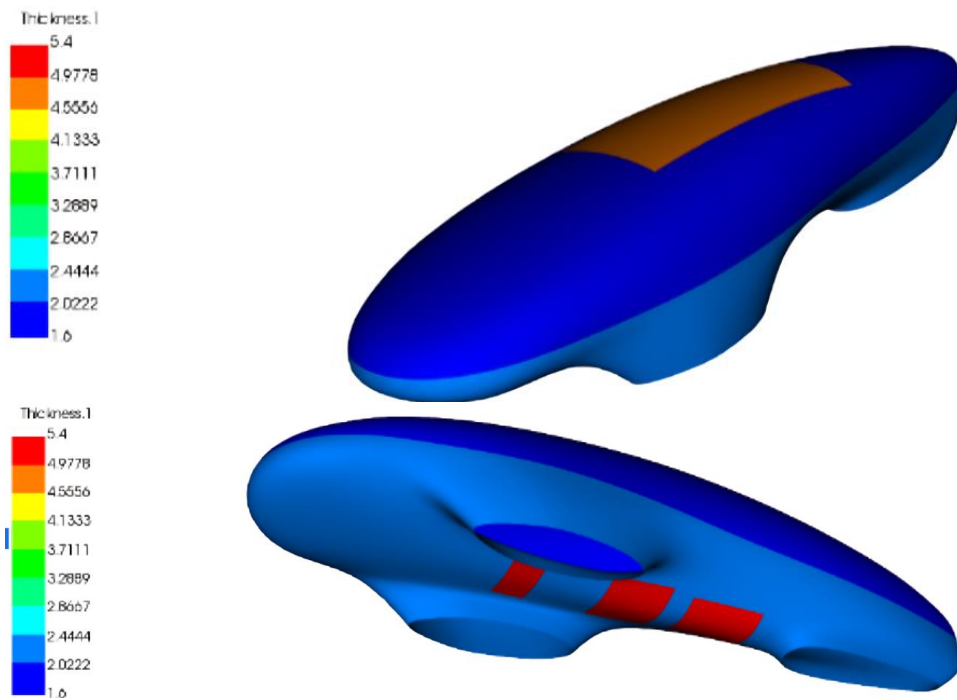
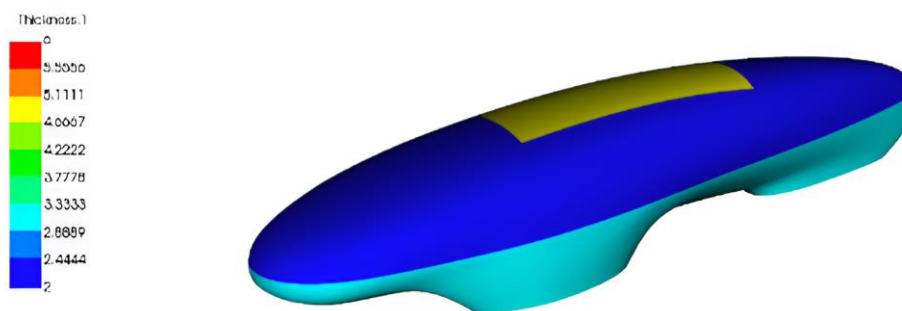
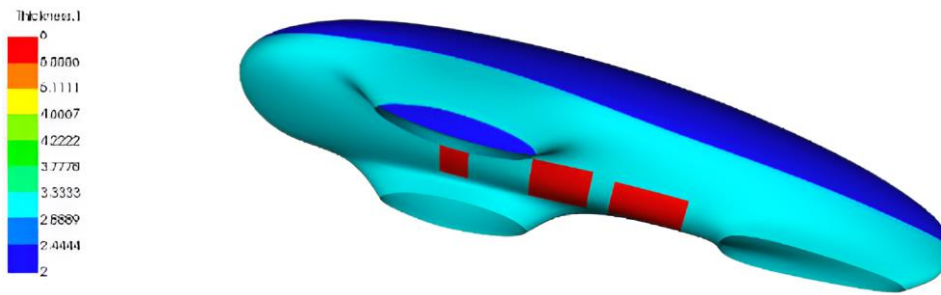


Figure 10. ACP Pre results for BFRP (Case 1)

Table 4. Mechanical properties of the composite materials when manufactured using wet layup method.

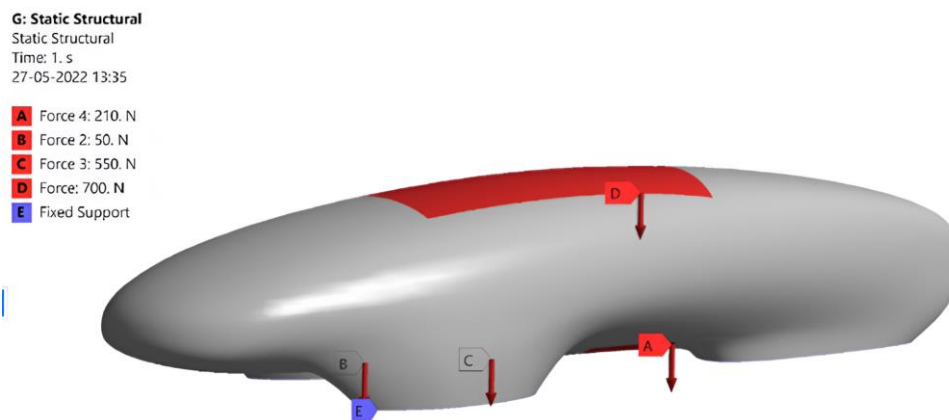
Name		Composites reinforced with plain weave basalt fabric	Composites reinforced with plain weave carbon fabric
<i>Engineering constants</i>	<i>Unit</i>	<i>Value</i>	<i>Value</i>
E1	Pa	3.2044E +10	1.5145E +10
E2	Pa	3.2044E +10	1.5145E +10
E3	Pa	1.2406E +10	9.8401E +09
G12	Pa	1.5078E +10	1.9849 +10
G23	Pa	3.1784E +9	2.8163E +09
G31	Pa	3.1784E +9	2.8163E +10
nu12		0.3153	0.75441
nu13		0.28065	0.12833
nu23		0.28065	0.12833
DENSITY			
Rho	kgm <sup>-3</sup>	1954.5	1479.5
Layer Thickness	mm	0.2	0.3



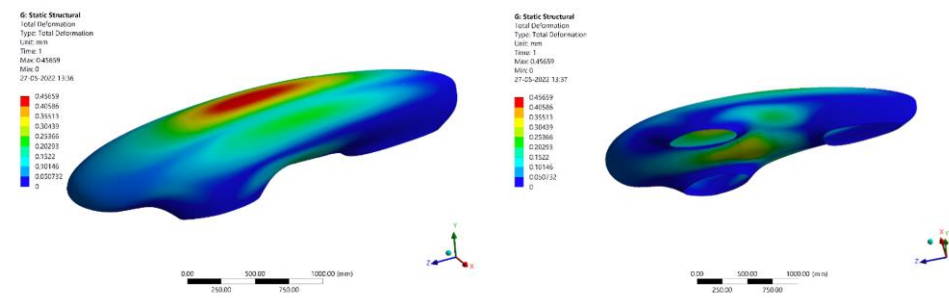


**Figure 11.** ACP Pre Results for CFRP (Case 2).

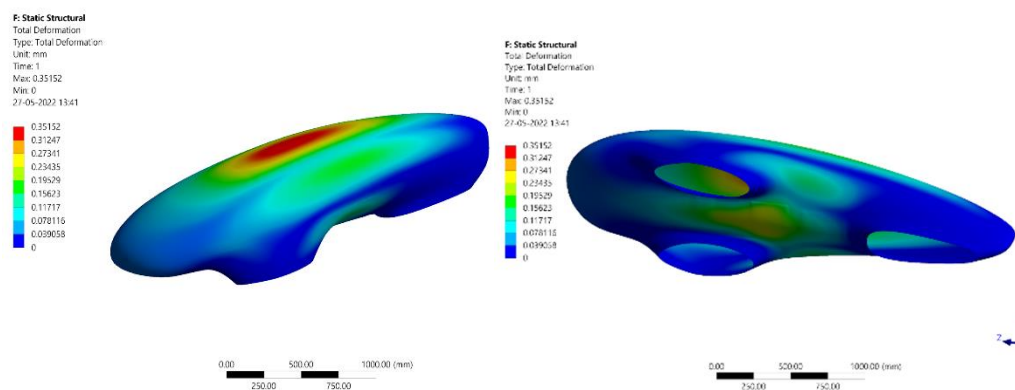
In the next step, the setup of the structural simulation was done, and the loads and boundary conditions are shown below (Figure 12-14).



**Figure 12.** Loads and boundary conditions for the structural analysis.



**Figure 13.** Total deformation for BFRP monocoque.



**Figure 14.** Total deformation for CFRP monocoque.

**Table 5.** Total weight of the monocoque when built with the BFRP and CFRP.

	Weight
BFRP MONOCOQUE	22.7 Kg
CFRP MONOCOQUE	21.5 Kg

### TRADE-OFF ANALYSIS

The monocoque will be heavier by 1.2 Kg if basalt fiber is used. This is a negligible disadvantage considering the huge environmental benefits. Although the simulations reveal that CFRP has a strong load-bearing capacity as compared to BFRP, deformations caused by the typical loading conditions on the vehicle would be under the safe limit if basalt fiber is used [15].

### CONCLUSION

The research into basalt fibre gave convincing. Strategies to reduce carbon have been discussed by analyzing the prospect of using basalt fiber as a substitute for carbon fiber. It has been found that by replacing carbon fiber (CFRP) with basalt fiber (BFRP), the vehicle's net carbon footprint can be significantly reduced without compromising overall performance. Every prospect, from procurement of raw materials to manufacturing to recycling was looked at and compared with the help of the LCA. Mechanical tests and trade-off analyses with the help of numerical simulations were also conducted. A maximum deformation of 0.56 mm was observed in the BFRP monocoque, compared to the 0.35 mm deformation in the CFRP monocoque. Although the simulations reveal that CFRP has a strong load-bearing capacity as compared to BFRP, deformations caused by the typical loading conditions on the vehicle would be under the safe limit if basalt fiber is used. The monocoque will be heavier by 1.2 Kg if basalt fiber is used. This is a negligible disadvantage considering the huge environmental benefits. To further bring about a reduction in the net carbon footprint of composite manufacturing, the usage of bio-resins and flax-basalt fibers was analyzed by the team and they were found to be a better fit over the conventional resins.

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