Research Article

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Computational Investigation of Eco-Friendly Fiber Reinforced Composite with the Application of Ansys ACP for Automobiles

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ABSTRACT

Nowadays, natural fiber reinforced composites and their application in various components in the automotive industry are one of the important issues. They are also considered an important also considered an important alternative to classical materials such as metals. This case study highlights the importance of the automotive industry turning to sustainable materials and practices to address environmental issues and achieve sustainability goals. These findings contribute to the knowledge regarding the process of carbon emission reduction strategies in the automotive industry. In this study, composites were evaluated under static loading, creating similar conditions and loads, but adjusting the lamination process and performing tensile tests of each section. Since Ansys workbench ACP-(pre) results in different distortions while analyzing data, an Ansys ACP-(post) was used to obtain more accurate results. The results show that composite 2 (bamboo–sisal-jute) of the temporary lamination has the least deformation in the Z-direction and the smallest total value 33 mm and 13987 mm. This study shows that replacing conventional materials likecomposites of steel, aluminium, carbon fiber and glass fiber with Natural Fiber Reinforced Composites (NFRCs) can yield significant reductions in carbon emissions, with potential emission reductions of up to 21.92 times depending on the material replaced. This transition to NFRCs presents a promising strategy for achieving substantial environmental benefits in the automotive industry.

Keywords: Natural fiber; Ansys-ACP (post); Eco-friendly material; Reinforced composite; Carbon emission.

1. INTRODUCTION

In recent years, there has been a focus on producing environmentally friendly solutions to cope with the impact of traditional products, especially in the automotive industry. The widespread use of materials such as metal, aluminium and plastic cause serious damage to the environment by affecting energy consumption and causing greenhouse gas emissions. As concerns about climate change and sustainability continue to grow, there is an urgent need for innovations that will reduce the environmental footprint of vehicle production and use. Using more environmentally friendly fibers in cars is a good way to do this. Composites obtained from fibers added to natural or bio-based resins offer a solution to reduce the environmental impact of traditional products. By integrating practices and valuable information from across the automotive industry, manufacturers can reduce energy consumption, emissions and waste generation while managing the operating and safety standards of their operations. Current work explores the potential of fiber-reinforced materials to revolutionize vehicle design manufacturing. With the advancement of technology and bio-based resins, automobile manufacturers can use the energy of natural fibers such as, flax, hemp and kenaf to create lightweight, durable and environmentally friendly components that contribute to a better transportation ecosystem. In addition, the use of recycled fibers and biodegradable resins further improves the environmental properties of fiber products, resulting in a closed loop of product lifecycle management and thus reducing dependence on limited resources.

As the automotive industry transitions to cleaner and greener technologies, the use of environmentally friendly energy products is an important step in achieving development goals to be stable and meet regulatory requirements. By implementing innovation and collaboration across all entities, stakeholders can bring meaningful change, paving the way for a future where cars are not just good and safe, but work in harmony with the natural environment. Through this research, we are exploring the transformative potential of fiber composites to create the next generation of environmentally friendly vehicles that have the potential to make a positive impact on the world. In recent years, there has been a growing interest in the development and use of sustainable products to solve environmental problems and reduce the ecological footprint in various industries (Balaji *et al.* 2021). It is widely accepted that the use of renewable materials as building materials is important for increasing the sustainability of the construction industry. Thus, the use of natural fiber-based composite materials are good alternatives to synthetic materials. Natural fibers obtained from plants such as kenaf, flax, hemp, bamboo and jute are attracting attention due to their environmental benefits. These fibers are a good choice for industry and researchers due to their properties such as, low energy consumption during production, biodegradability and recyclability. The incorporation of natural fibers into composite materials provides an exciting opportunity to strike a balance between efficiency, effectiveness and sustainability (Bavan *et al.* 2013). Some fiber studies by Ashik *et al.* (2017) evaluated the properties of glass fiber mats and bidirectional jute hybrid composites. In their study, tests were carried out using static test methods based on ASTM standards to determine tensile strength, bending strength and impact strength. ANSYS finite element analysis was used to analyze the experimental results. The performance of composite laminates was evaluated using FEA data and compared with experimental results. Suryawanshi *et al.* (2016) developed a hybrid polymer matrix composite with banana fiber added to the cashew nut shell liquid biodegradable polymer matrix containing different proportions of general purpose resin. It was found that the stress intensity decreases when the fiber discontinuity is above the pre-crack level. Dixit *et al.* (2019) studied the process of creating composite structures with five different types of fibers (synthetic fibers such as, carbon, glass and natural fibers such as, banana, jute and cactus). Several permutations and combinations of these fibers were used to select configurations. After the model was created, various verifications were made by applying the force point to the model on Mechanical APDL ANSYS. In this study, hybrid composites were evaluated and deflection effects were analyzed under simultaneous loading, thus taking a step towards sustainable hybrid composites. Wambua *et al.* 2003) studied compression moulding using film stacking technology to produce natural fiber reinforced polypropylene composite. The different properties of different natural fiber products were analyzed and compared. Many similarities exist between these products and polypropylene composites. Composite materials made from coconut fibers have the lowest properties, but they are more resistant to impacts than composite materials made from jute and kenaf. The properties of natural fiber are generally better compared to glass. Murali Mohan Rao *et al.* (2010) studied the tensile, dielectric and bending properties of composites made by incorporating a novel natural fiber, vakka into the polyester resin matrix. The fiber composites were tested for tensile, bending and dielectric properties and compared to existing environmentally produced products such as bamboo, sisal and banana. When fiber fractions are compared, vakka fiber has greater bending strength than banana fiber and has a similar volume as sisal fiber. The flexural modulus of vakka fiber composites is also higher than sisal and banana fiber.

The introduction of natural fibers reduces the cost of composites. Bavan *et al.* (2013) developed a composite cable composed of corn fibers in a non-polyester resin polymer matrix. Testing was performed using ANSYS software to determine deflection and stress using the finite element method. The results suggest that the stress at the matrix and fiber interface can be reduced by increasing the fiber content to the desired level. prepared and compared the properties of jute fiber reinforced composites and banana fiber reinforced composites. Hybrid resin matrices are made from general purpose material and cashew nut shell (CNSL) resin through a manual process to create a natural product. For banana fiber reinforced hybrid resin composites and jute fiber reinforced hybrid resin composites, properties such as CNSL%, fiber amount and length were determined during the optimization process using ANOVA to obtain the best load-bearing capacity. evaluated the mechanical properties of various composite materials, including, impact strength, flexural and tensile strength, and Young's modulus. Here, ANSYS was used for accuracy analysis. tested the tensile strength, bending strength and impact strength properties of epoxy resin and banana fiber selected as reinforcement and matrix in the preparation of composites. studied a series of composites reinforced with natural fibers, where their usability, methods of processing, effects of fiber modification, and matrices (degradable and non-degradable)were studied.

José da Silva *et al.* (2012) focused on the calculation and testing of unidirectional sisal and banana fiber reinforced epoxy resin composites. Tensile tests were performed to verify the numerical results and evaluate the interaction between the design stages. Singh *et al.* (2021) demonstrated its effect on elastic properties by comparing the recorded percentage of fiber deformation with experimental and finite element analyses. This increase in strength was mostly due to the increase in the percentage of fiber contained in the packaging material. developed a composite material using banana fiber as reinforcement and polyester as matrix. Ansys software was used to analyze material defects including tensile strength, impact strength, and flexural strength determined by appropriate testing methods conducted experiments on banana coconut fiber reinforced epoxy composites to evaluate the tensile, bending and impact properties of treated and untreated fibers. When all composite materials were analyzed, it was favourable for fiber materials to replace the elements made of other materials, except for repair materials. Products of natural fibers from plant and animal species are beneficial to the environment (Fig. 1). Examples of vegetable fibers are jute, sisal, banana, bamboo, straw, kenaf, cotton and hemp. Plant fibers contain plenty of cellulose, whereas animal fibers are rich in protein. The third type of fiber is mineral fiber such as, asbestos fiber.

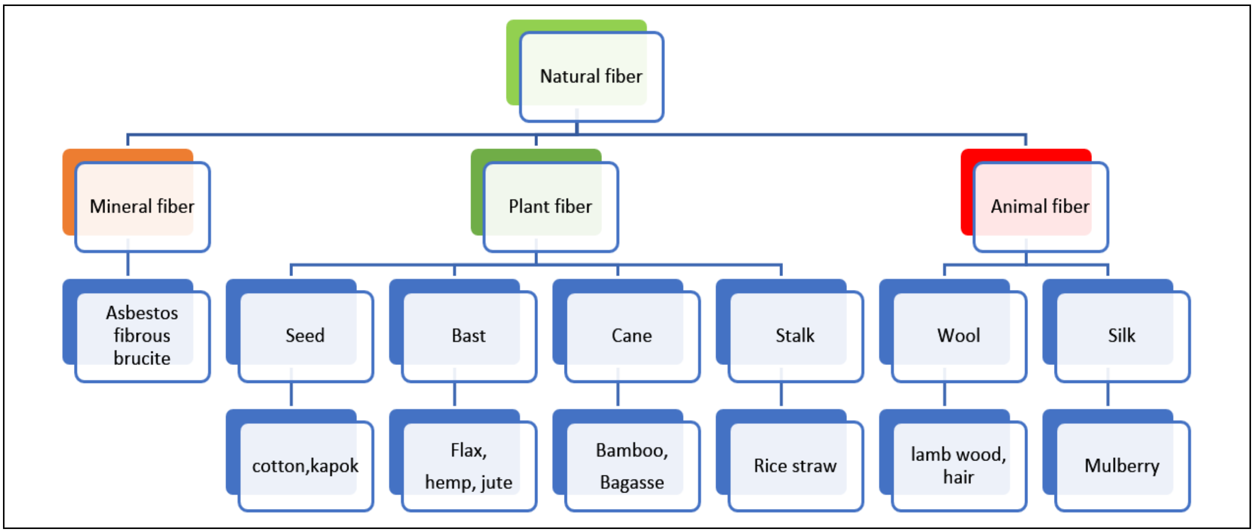

Fig. 1: Types of natural fibers

2. ENVIRONMENT IMPACT ASSESSMENT DUE TO VARIOUS MATERIALS

- Conventional steel: Steel production often involves high-temperature processes using coal as a reducing agent. Iron ore mining, coal mining, transportation and steelmaking processes produce a lot of carbon. The high speed of the metal increases fuel consumption and carbon emission during vehicle operation.
- Conventional aluminium: Aluminium production requires significant amounts of energy, especially in the electrolysis process to extract aluminium from bauxite ore. Although aluminium is lighter than steel and helps increase fuel efficiency, it emits high amount of greenhouse gases.
- Traditional plastics (e.g. ABS, PP): Plastics are derived from petrochemicals, primarily crude oil and natural gas. Extraction and processing of crude oil and natural gas releases greenhouse gases. Excessive use of electricity in the plastic production process causes carbon emissions.
- Traditional glass fiber composites: Glass fiber production involves melting silica sand at high temperatures, which requires significant durability. The resin processing process in composite production also emits carbon dioxide. Although fiberglass composites are lightweight and have a high strength-to-weight ratio, their manufacturing processes produces very little carbon.
- Composites reinforced with natural fibers (such as, flax, hemp): Natural fibers are obtained from renewable materials such as plants. These materials contain less carbon compared to traditional materials. They require less labour to synthesize than synthetic fibers. Growing and processing natural fibers involves agriculture, which absorbs carbon dioxide from the atmosphere.

Table 1. Carbon emission from different materials used in automobiles (Rajulwar *et al.* 2023)

Material Type	Carbon Emissions (kg CO_2 per kg of material)
Conventional steel	1.87
Conventional aluminium	8.22
Conventional carbon fiber composite	10.96
Conventional glass fiber composite	3.48
Natural fiber reinforced composite (e.g., flax, hemp, jute, sisal)	0.5

Varying carbon emissions are associated with different materials depending on the production processes and lifecycle considerations. Conventional materials like steel, aluminium, plastics and glass fiber composites typically have higher carbon footprints compared to natural fiber reinforced composites. However, it is important to conduct comprehensive life cycle assessments to evaluate the overall environmental impact of materials used in the automobile sector, considering factors such as, extraction, processing, transportation, usage, and end-of-life disposal.

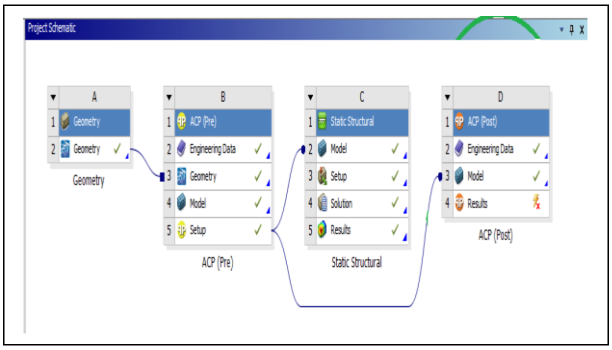

Fig. 2: Schematic diagram of the project

3. MATERIAL AND METHODS

Long-lasting natural fiber composites (LNFC) have been studied extensively and continue to be an important area of research. Recent developments in fiber extraction, resin processing and successful applications in the automotive industry create a strong future model for LNFC in the construction industry. There is a long history of development, high-end products, competitive data and inconsistencies in performance and climate; but many of the challenges have already been addressed by research community. Therefore, LNFC turn towards trade while resolving product incompatibility

3.1 Natural fibers in composite manufacturing:-

Commercial use of natural fibers is attracting attention in a wide range of production processes. The use of natural fibers in polymer composites is growing rapidly to serve a variety of end-use applications in transportation, low-rise construction and other industries. The quality of natural fibers is greatly affected by the growing environment, plant age, variety, temperature, moisture and soil quality. Many applications for natural fibers include: composite structures, vehicles, non-structural products, geotextiles, packaging, moulded products, adsorbents, filters and other materials. Natural fibers used in present work:

1. Jute: Jute fiber is produced from plants of the Jute genus belonging to the Malvaceae family. Jute is a lignocellulosic fiber composed partly of textile fiber and partly of wood. It belongs to the category of bast fibers (fibers collected from bast or plant bark). Chemical composition of jute fiber is: cellulose (64.4%), hemicellulose (12%), pectin (0.2%), lignin (11.8%), water soluble compounds (1.1%), wax (0.5%), water content (10%).
2. Sisal: Sisal fiber is obtained from the leaves of the sisal plant. There are four types of sisal plants in India: Sisalana, Vergross, Isle and Natale. Many plant species have high fiber yields. The leaves of the first two species produce more fiber than the leaves of the other species. Fiber content also varies depending on the age and location of the plant. The chemical composition of the leaf consists of water (87.25%), fiber (4%), cuticle (0.75%) and other dry substances (8%).
3. Bamboo: Bamboo is one of the largest plants in the world due to its unique rhizome-dependent system. Giant bamboo is the largest member of the grass family. As a fiber, bamboo is a biodegradable and environmentally friendly textile product regenerated with natural cellulose and is a cellulosic bast fiber. Its chemical composition and properties are similar to other bast fibers such as jute and flax. It contains cellulose (70-74), hemicelluloses (12-14), lignin (10-12), protein, pectin, wax and other extracts (2-3%).

3.2 Analysis Method

After the installation of laminates, a statistical analysis was done. The ACP configuration was sent to the static model, boundary conditions were set and evaluated. Further, ACP (post) was used for better analysis. The Ansys workbench layout (front-back) of ACP is shown in Fig. 2. Various fault types using simple methods, including the use of regional connectivity patterns and symbol cracks based on virtual recording technology. ANSYS Composite Pre-Post supports all fault methods (from simple stress analysis to fault methods such as, Hasshin or Puck) for combinations of layers and cores. Detailed layer and floor results identify the fault pattern and its location in the structure. Ansys Space Claim design software was used to create the model (width 20 mm, length 200 mm). Layer analysis was performed by ACP tools, where the main steps of installing the laminate was done according to the ACP tree.

3.3 Computational analysis

3.3.1 Physical model

To test the mechanical properties of Ansys ACP-pre, samples were created from four different types of fiber materials. Good meshing provides good results (Fig. 3). After setting necessary conditions, a force of 100 N was applied to the composite laminate in the (-Y) direction. Fig. 4 shows the final composite stability and the direction of force. Sample sizes were measured as follows: thick sample was 20 mm and spam sample was 200 mm. A three layered laminate of 0.25 mm thickness was used (Fig. 5). The total thickness of the sample was 0.75 mm.

Once the meshing process was completed and the Finite Element Modelling (FEM) sent to ACP (pre) Ansys, the required steps including fiber design, material handling, garland design, orientation interference, integration, layer design, finished section cutting and product design are performed. Fabrics are often used with the support and distribution of their mechanical properties. The badge provides fiber optic routing and media. This step helps guide the laminate in the right direction. With the compliance of standards, the angles and thickness of the individual bends are achieved. Finally, the product structure interconnects the fibers distributed in the matrix to form the laminate. Finite element modelling was prepared for the solution using the Ansys static structural analysis tool. The static structural frame forms the basis of the external stabilization system of the entire support system (Rashid *et al.* 2019). The test sample is called a cantilever chain and a tensile load of 100 N is applied to each of the ends. Plot and display strain energy, directional deformation, total deformation in static structural systems are completed. In order to better understand the existence of these fibers, they are called by names such as, jute 1, sisal 2, and bamboo 3. The properties of these fibers is shown in Table 2.

Table 2. Properties of natural fibers

Properties	Jute	Sisal	Bamboo
Exx(GPa)	20	18	38
Vxy	0.38	0.325	0.36
Density (kg/m^3)	1300	1400	960

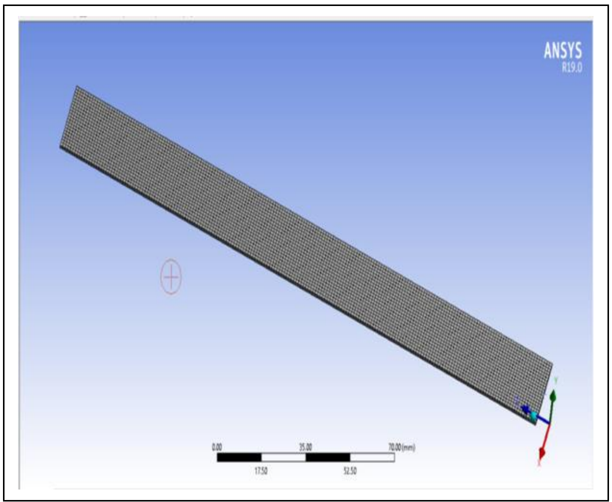

Fig. 3: Meshing of the composite sample

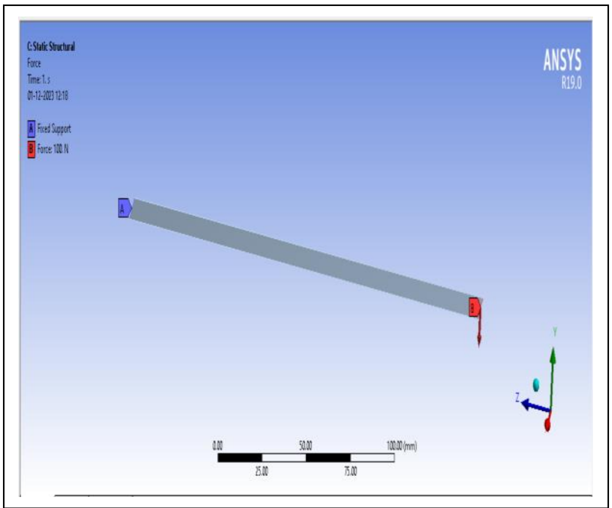

Fig.4: Fixed support and force on the sample

3.4 Finite element modelling

Finite element analysis technology plays an important role in research due to its advantages such as cost effectiveness, consistent performance and versatility. Due to its simplicity, the application of computer simulation technology is very fast today (Murali Mohan Rao *et al.* 2010; Suryawanshi *et al.* 2016; Rajkumar *et al.* 2021). ANSYS ACP (pre-post) Workbench 19.0 is a complex and specialized tool for working with mixed data, including numerical simulations. ANSYS ACP 19.0 provides tools and instructions (Rajulwar *et al.* 2023) to effectively increase efficiency facilitating economic development and optimization. This software provides orthotropic elements to support fibers. Also, the laminate design is more user-friendly with the added benefit of the matrix. The above sites ensure the reliability of the combined tests, which can also prevent the tests from being performed. In the current study, the initial design of the test specimens was done using ANSYS Space Claim19.0 and the detection process of the tensile test specimens was done using the Ansys Mesh tool. Composite numerical analysis does not require lamination analysis but requires internal analysis of the matrix and fibers done with the help of Ansys ACP 19.0.

4. RESULTS AND DISCUSSION

Among all the composites, composite 4 has the largest total deformation and directional deformation in the Z-direction (Table 4, Fig. 6). Test samples with side deformation such as Z (Jute-Sisal-Bamboo) are shown in Fig. 7 and Fig. 8. Fig. 8 shows the tensile strength in test specimens subjected to tensile loading. Table 3 shows that composite 1 has the smallest X-direction deformation, composite 2 has the smallest Y-direction and Z-direction deformation. The total cost of composite 1 is higher.

Table 3. Composite layup orders

Composite no.	Layup order
Composite 1	1-2-3
Composite 2	3-2-1
Composite 3	1-3-2
Composite 4	2-3-1
Composite 5	2-1-3
Composite 6	3-1-2

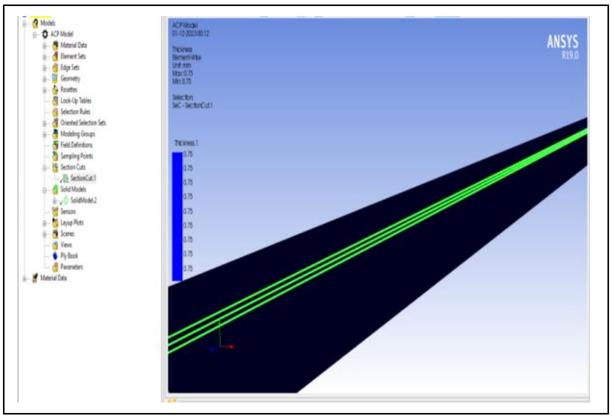

Fig. 5: Section cut view of laminate

The use of natural fiber reinforced composite materials (NFRCs) in automobile production can reduce environmental damage by reducing carbon emissions, promoting biodegradability, saving resources, increasing energy efficiency and ensuring health management. As the automotive industry increasingly focuses on the environmental sustainability and regulatory compliance, use of natural fibers has become a solution to reduce and eliminate environmental damage and to promote green transportation for the future. Carbon emissions can be highly reduced by using NFRCs compared to use of conventional materials (Table 5).

Table 4. Z-direction, total deformation and strain for the composites

Serial no.	Z- direction (mm)	Total Deformation (mm)	Strain
Composite 1	45	13987	0.50
Composite 2	33	13987	0.50
Composite 3	52	18989	0.58
Composite 4	54	18989	0.58
Composite 5	48	14751	0.52
Composite 6	34	14751	0.52

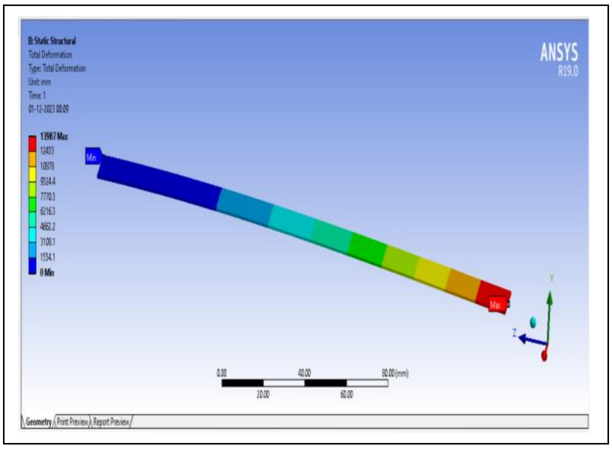

Fig. 6: Total deformation

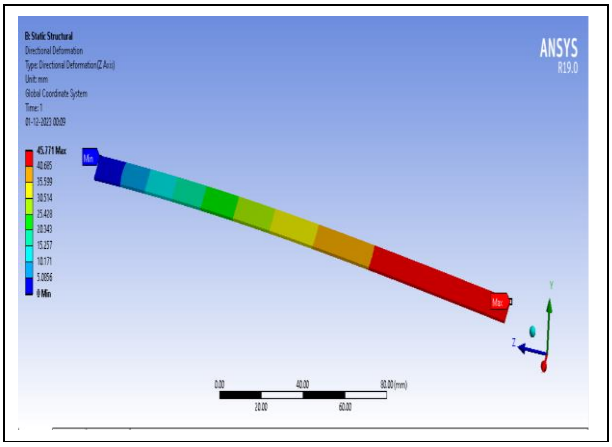

Fig. 7: Directional deformation in Z-direction

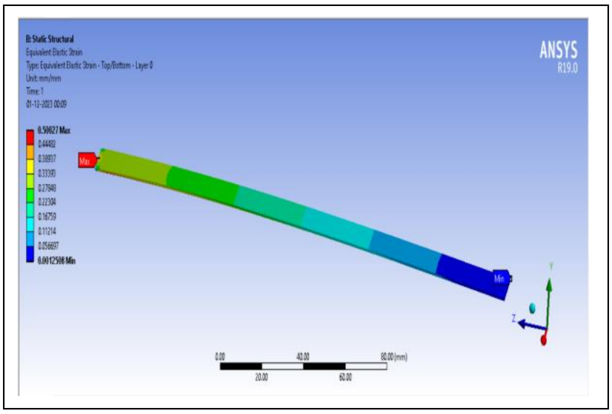

Fig. 8: Total elastic strain

Table 5. Reduction of carbon emission using NFRCs

Conventional material	Reduction in carbon emission by using NFRCs
Conventional Steel	3.74 times
Conventional Aluminium	16.44 times
Conventional carbon fiber composite	21.92 times
Conventional Glass fiber Composite	6.96 times

5. CONCLUSION

This article describes experimental examples using FEA analysis software, Ansys, ACP (pre). Four different types of natural fibers and composites were analyzed. Simulation results show that jute-sisal-bamboo composite1 has the best stress analysis properties with least impact on the environment. There is small amount of directional deformation in the Z-direction. The effectiveness of natural fiber-reinforced composite materials in mitigating environmental impact in the automotive industry is well demonstrated. With reductions in carbon emissions up to 21.92 times compared to conventional materials like steel, aluminium, carbon fiber composites, and glass fiber composites, NFRCs offer a sustainable solution for enhancing energy efficiency and promoting biodegradability. These findings underscore the potential of NFRCs to align with the automotive industry's goals of environmental sustainability and regulatory compliance, paving the way for greener transportation systems in the future.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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