IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁙ Peer-reviewed / Refereed journal ⁙ Vol. 11, Issue 11, November 2024

DOI: 10.17148/IARJSET.2024.111105

Design-Analysis And Evaluation Of Gfrp-Epoxy Composite Reinforced With Aloe-Vera And Prosopis Juliflora Based Bio-Natural Composite For Automotive Interior Components

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Abstract: This study explores the potential application of glass fiber-reinforced polymer (GFRP) epoxy composite reinforced with natural fibers of Aloe Vera and Prosopis Juliflora for automotive interior components, specifically the instrument panel. Finite element analysis (FEA) was performed to evaluate the tensile and compressive strength of the proposed composite compared to conventional materials like polypropylene. The analysis demonstrates that the GFRP-epoxy composite exhibits improved tensile and compressive properties, offering a lightweight and environmentally sustainable alternative for automotive applications. This research highlights the integration of bio-natural reinforcements to enhance mechanical performance while supporting eco-friendly material development.

Keywords: GFRP-Epoxy, Aloe Vera, Prosopis Juliflora, Automotive Interior, Finite Element Analysis, Bio-Natural Composite.

1. INTRODUCTION

The automotive industry has long sought innovative materials to improve performance, sustainability, and cost-efficiency in manufacturing. Among these, composites have gained significant attention due to their lightweight and high-strength characteristics. Glass Fiber Reinforced Polymer (GFRP) composites are particularly valued for their superior mechanical properties and versatility. However, the reliance on synthetic reinforcements and non-biodegradable matrices raises environmental concerns, driving the need for sustainable alternatives [1].

This study focuses on the potential of integrating natural reinforcements, such as Aloe Vera and Prosopis Juliflora fibers, into GFRP-epoxy composites. Aloe Vera, known for its high tensile strength and biodegradability, and Prosopis Juliflora, with its abundant availability and robust mechanical properties, present a promising combination for enhancing composite performance while promoting eco-friendliness [2]. By reinforcing the GFRP-epoxy composite with these natural fibers, the research aims to address the dual objectives of material efficiency and environmental sustainability.

The application scope of such composites is vast, and in this research, the focus is narrowed to automotive interior components. Specifically, the instrument panel is chosen as the test case, given its critical role in structural integrity and aesthetic appeal. Through finite element analysis (FEA), the tensile and compressive properties of the proposed composite are evaluated and compared to conventional materials like polypropylene, commonly used in automotive interiors [3].

This paper contributes to the field by exploring the feasibility of bio-natural reinforcements in high-performance composite materials, paving the way for a greener and more sustainable automotive industry.

2. MATERIALS AND METHODS

This section describes the materials considered for analysis and the methodologies adopted for assessing the performance of Glass Fiber Reinforced Polymer (GFRP) composites. The study focuses on evaluating the mechanical properties and environmental implications of incorporating natural reinforcements in GFRP composites.

2.1 MATERIALS CONSIDERED

- **Glass Fiber:** Widely used as a reinforcement in composites due to its high tensile strength, durability, and compatibility with various polymer matrices [1].
- **Epoxy Resin:** Selected as the matrix material for its excellent bonding, load distribution properties, and resistance to mechanical stress [2].
- **Natural Fibers**
  - Aloe Vera Fiber: Known for its tensile strength and biodegradability, making it a sustainable alternative to synthetic fibers [3].
  - Prosopis Juliflora Fiber: A cost-effective and environmentally friendly fiber derived from an invasive plant species, offering significant potential in composite materials [4].

2.2 DESIGN AND SIMULATION

The design of the automotive instrument panel was created using CATIA software to meet the functional and aesthetic requirements of automotive industry standards. CATIA, a leading CAD software, allows for the creation of complex, three-dimensional models and simulations, ensuring that the design aligns with ergonomic and safety considerations for automotive interiors.

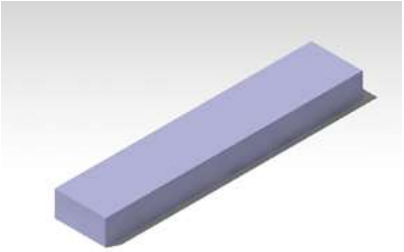

Fig 1. 3D Model

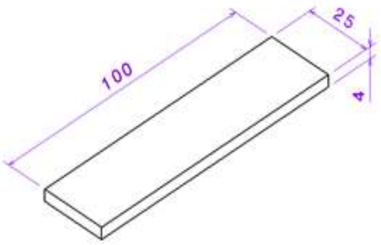

Fig 2. Dimension Image

To evaluate the mechanical behavior of the instrument panel under operational conditions, Finite Element Analysis (FEA) was performed using ANSYS software. ANSYS provides advanced simulation capabilities for mechanical, thermal, and fluid behaviors. The FEA simulations modeled the instrument panel made from both the conventional polypropylene material and the proposed Aloe Vera/Prosopis Juliflora composite. The analysis focused on stress distribution, strain, deformation, and displacement of the material when subjected to typical automotive loads, such as impacts and vibrations. The results from these simulations were compared to assess the feasibility and performance of the proposed composite material in comparison to the existing polypropylene material.

2.3 ANALYTICAL METHODOLOGY

- Finite Element Analysis (FEA)
  - A computational model of an automotive instrument panel is developed using CAD software to study the integration of natural fibers in GFRP composites.
  - The mechanical behavior of the composite, including tensile and compressive properties, is analyzed using FEA software. Load distribution, failure patterns, and material performance are compared with conventional materials like polypropylene [5].
- Mechanical Property Analysis
  - Simulations are conducted to determine critical mechanical properties such as tensile strength, compressive strength, and stiffness.
  - The analysis includes studying stress-strain relationships and evaluating the failure mechanisms of the composite under varying load conditions [6].
- Data Interpretation
  - Analytical results are interpreted to understand the potential of natural fibers in enhancing the mechanical and environmental performance of GFRP composites.
  - Comparisons are drawn to highlight the advantages and limitations of incorporating Aloe Vera and Prosopis Juliflora fibers.

DOI: 10.17148/IARJSET.2024.111105

3. RESULTS AND DISCUSSION

3.1 FINITE ELEMENT ANALYSIS (FEA) RESULTS

The Finite Element Analysis (FEA) simulations reveal significant differences in the mechanical behavior of the GFRP-epoxy composite reinforced with Aloe Vera and Prosopis Juliflora fibers when compared to conventional polypropylene. Key mechanical properties—such as total deformation, equivalent stress, and normal stress—were examined under both tensile and compression loading conditions to evaluate the materials' performance for automotive applications.

TENSILE TESTING

The tensile test results indicate that the GFRP-epoxy composite offers superior performance over polypropylene. The total deformation under tensile load for the composite was 0.50465 mm, which is lower than 0.55371 mm for polypropylene. This indicates that the composite material undergoes less elongation under tensile forces, suggesting better rigidity. Furthermore, the equivalent stress for the composite (8.6239 MPa) is lower than that of polypropylene (17.248 MPa), signifying that the composite can withstand higher forces before failure, a crucial factor for components exposed to dynamic loads in automotive applications.

In addition, the normal stress for the composite (9.9368 MPa) is also lower than that for polypropylene (19.874 MPa). This suggests that the composite material experiences less stress under tensile loading, enhancing its ability to resist deformation and failure under tensile forces.

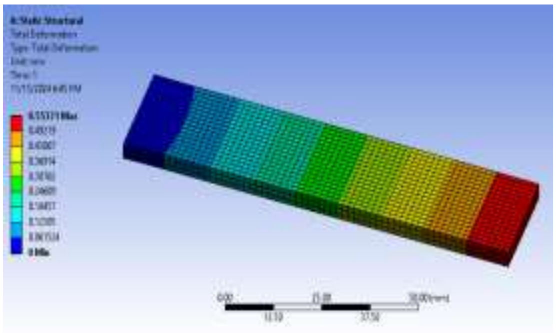

Fig 3. Total Deformation for Exiting System

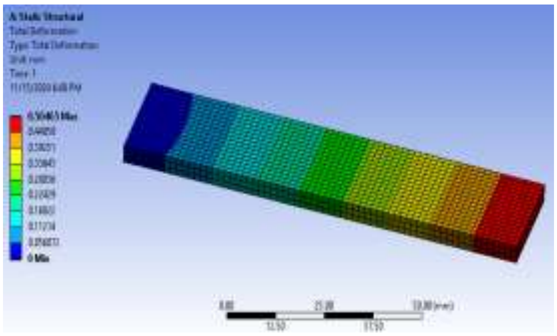

Fig 4. Total Deformation for Proposed System

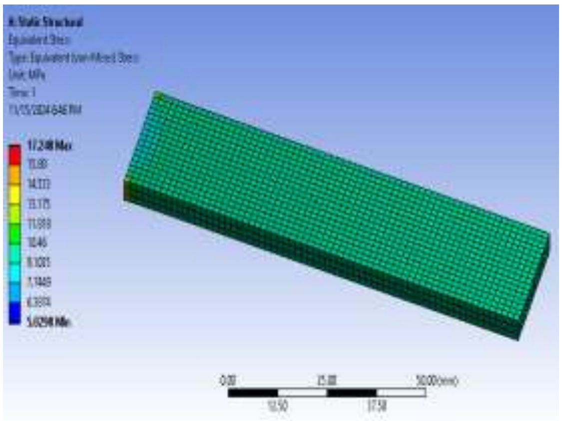

Fig 5. Equivalent Stress for Exiting System

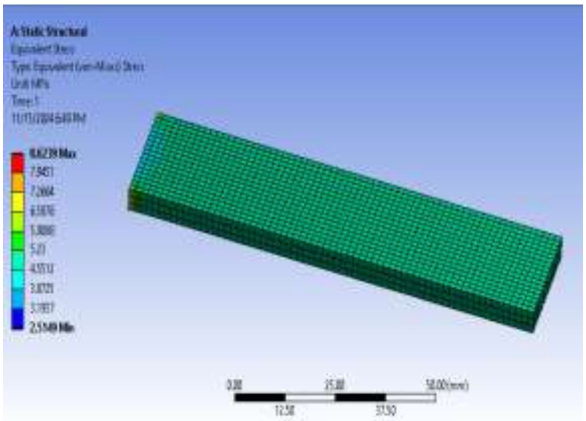

Fig 6. Equivalent Stress for Proposed System

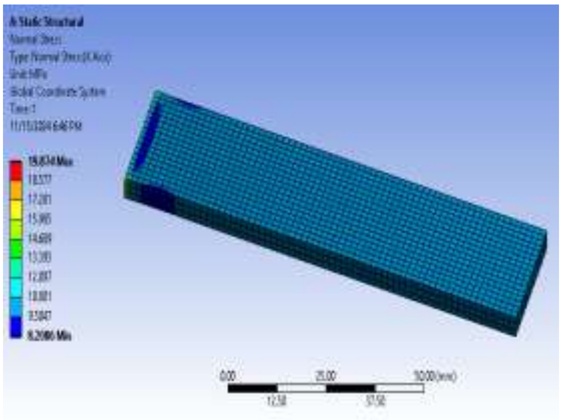

Fig 7. Normal Stress for Exiting System

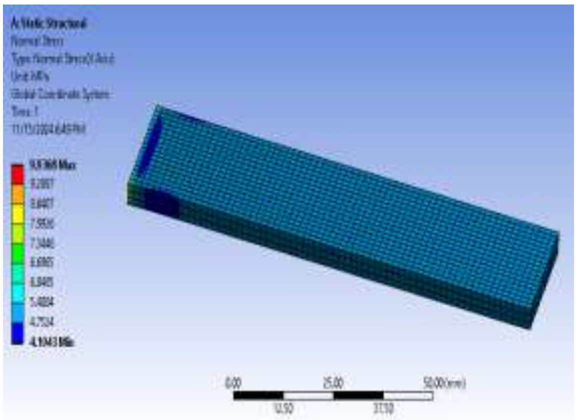

Fig 8. Normal Stress for Proposed System

COMPRESSION TESTING

Under compression, the GFRP-epoxy composite again outperforms polypropylene. The total deformation for the composite was 0.50465 mm, significantly lower than 1.093 mm for polypropylene. This suggests that the composite has superior resistance to compression, making it better suited for maintaining structural integrity in components such as instrument panels, which may be exposed to compressive forces from impacts or pressure.

The equivalent stress for the composite in compression was 8.6239 MPa, compared to 17.248 MPa for polypropylene. This means the composite can endure greater compressive forces before failure, a desirable trait for materials subjected to dynamic compressive loading.

In terms of normal stress, the composite experienced 4.1043 MPa, which is much lower than 8.2086 MPa for polypropylene, indicating that the composite material distributes compressive forces more efficiently, reducing the likelihood of structural failure under compression.

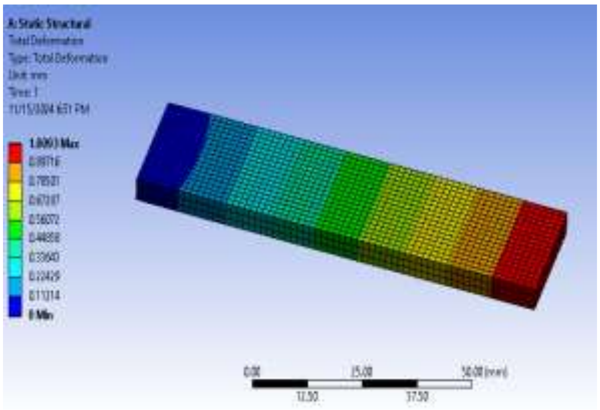

Fig 9. Total Deformation for Exiting System

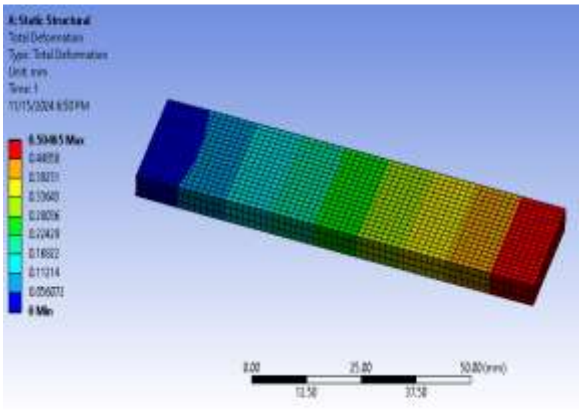

Fig 10. Total Deformation for Proposed System

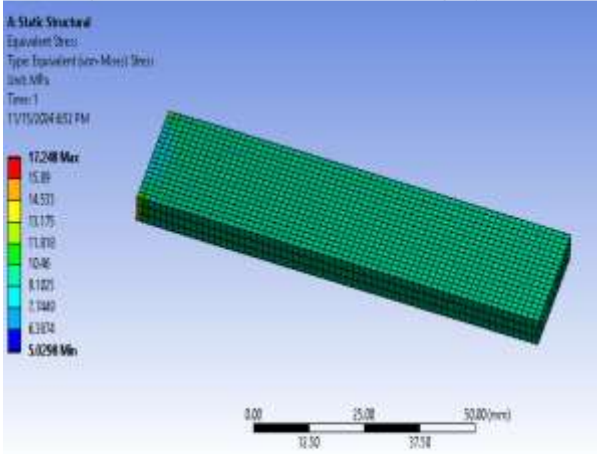

Fig 11. Equivalent Stress for Exiting System

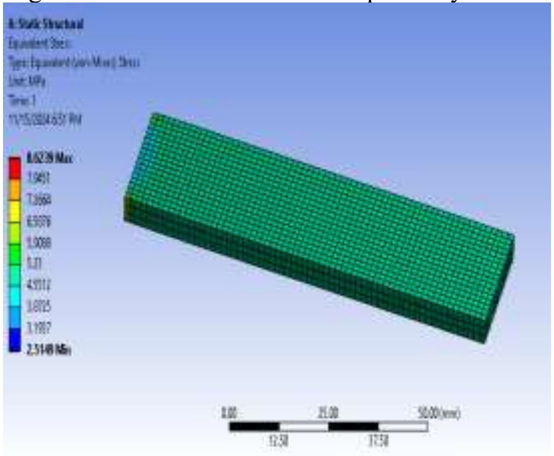

Fig 12. Equivalent Stress for Proposed System

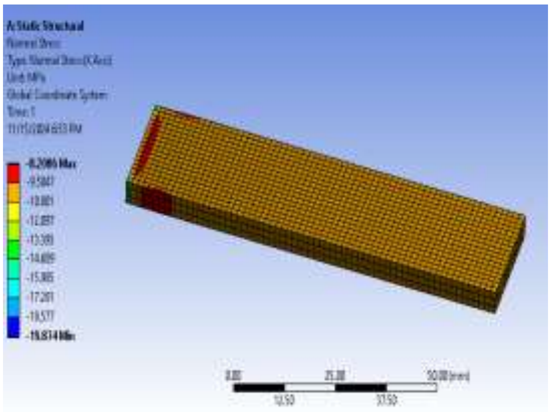

Fig 13. Normal Stress for Exiting System

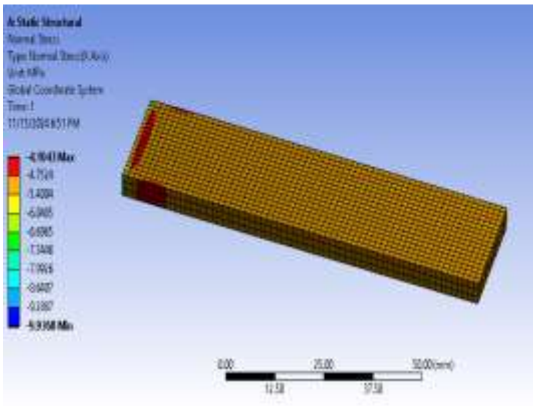

Fig 14. Normal Stress for Proposed System

Table 1: RESULTS COMPARISONS

Test	Materials	Total deformation	Equivalent Stress	Normal Stress
Compression	polypropylene	1.093	17.248	8.2086
	GFRP-aloe vera - Prosopis Juliflora composites	0.50465	8.6239	4.1043
Tensile	polypropylene	0.55371	17.248	19.874
	GFRP-aloe vera - Prosopis Juliflora composites	0.50465	8.6239	9.9368

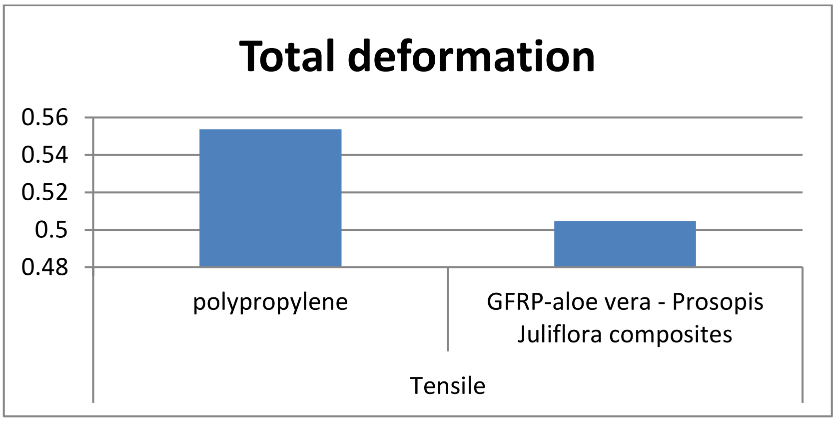

Fig 15. Comparison chart of Total Deformation for Tensile

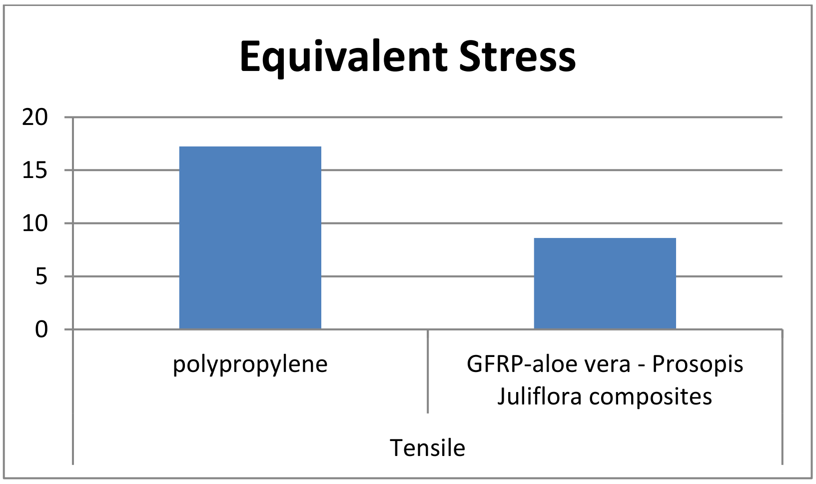

Fig 16. Comparison chart of Equivalent stress for Tensile

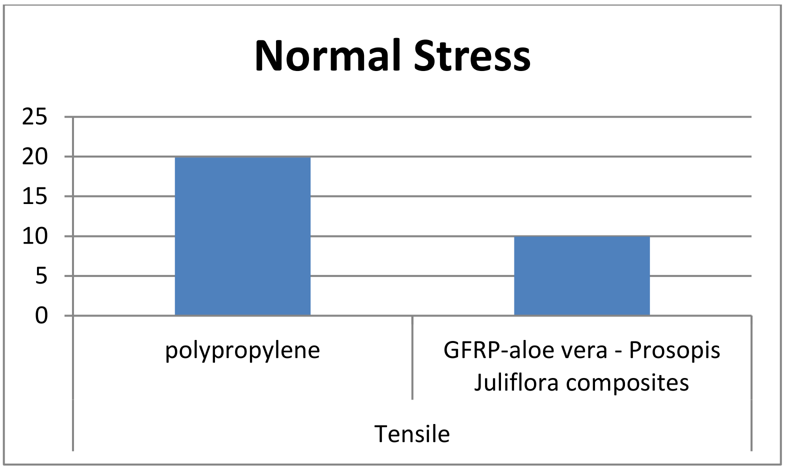

Fig 17. Comparison chart of Normal stress for Tensile

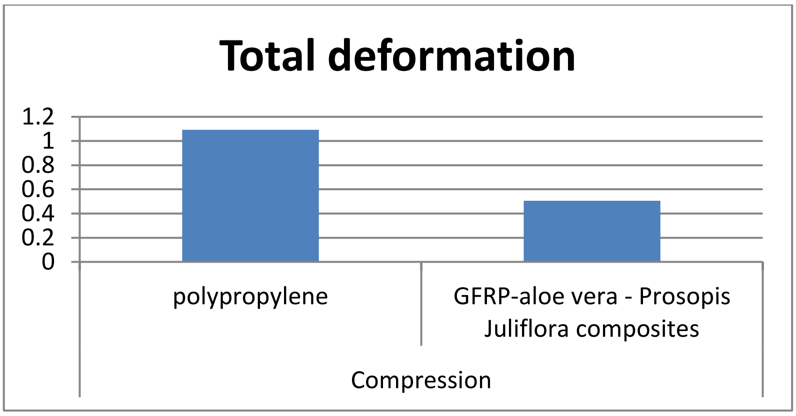

Fig 18. Comparison chart of Total Deformation for Compression

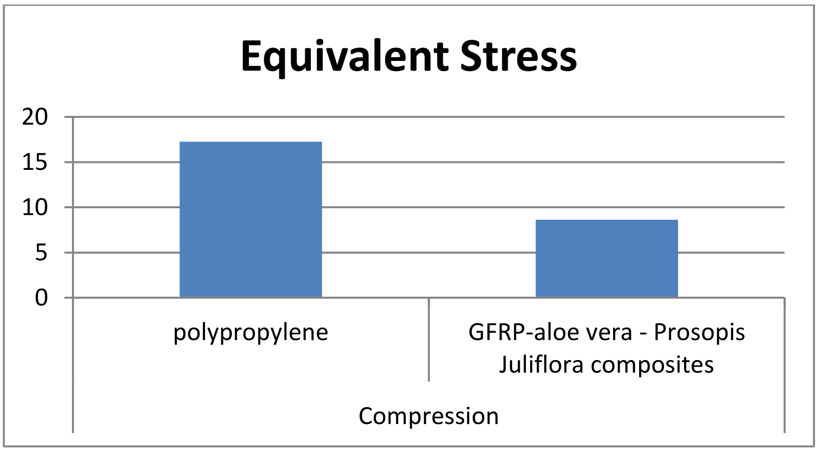

Fig 19. Comparison chart of Equivalent stress for Compression

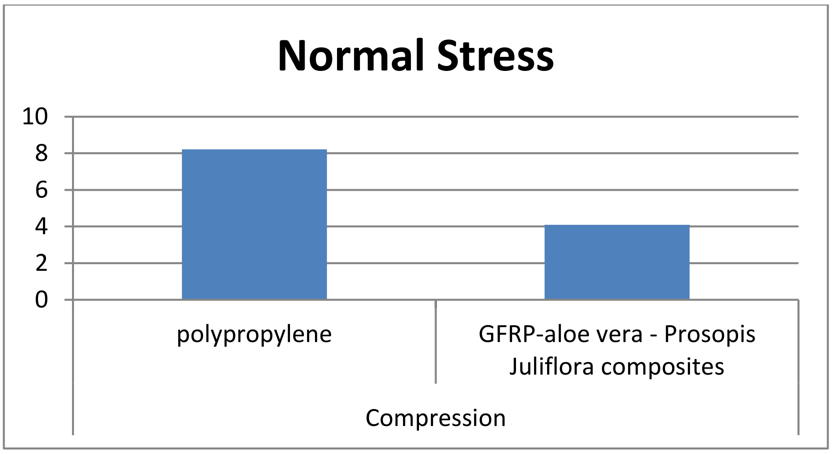

Fig 20. Comparison chart of Normal stress for Compression

- The FEA results demonstrate that the GFRP-epoxy composite reinforced with Aloe Vera and Prosopis Juliflora fibers offers superior mechanical performance compared to polypropylene. The composite shows:
- Lower total deformation in both tensile and compression tests, suggesting improved rigidity and resistance to elongation or compression.
- Lower equivalent and normal stresses, indicating a higher capacity to withstand forces without failure.

4. CONCLUSION

The results of the Finite Element Analysis (FEA) conducted on the GFRP-epoxy composite reinforced with Aloe Vera and Prosopis Juliflora fibers demonstrate that this composite material offers significant advantages over conventional polypropylene in terms of mechanical performance. The composite showed superior resistance to both tensile and compressive forces, with lower total deformations, equivalent stresses, and normal stresses in comparison to polypropylene. These results suggest that the GFRP-epoxy composite is more rigid and capable of withstanding higher loads without undergoing significant deformation, which is crucial for automotive applications where components are subject to dynamic, high-stress environments.

The lower deformation and stress values indicate that the composite material can enhance the durability and performance of automotive components, particularly in areas exposed to dynamic loads, such as instrument panels. With these promising properties, the GFRP-Aloe Vera-Prosopis Juliflora composite represents a viable and environmentally friendly alternative to traditional materials, combining strength, durability, and sustainability for the future of automotive design. The GFRP-epoxy composite reinforced with natural fibers like Aloe Vera and Prosopis Juliflora presents a strong case for adoption in the automotive industry, offering improved performance characteristics while also contributing to sustainability goals. Further research and testing are recommended to validate these findings in real-world conditions and to explore the potential for scaling up production.

5. FUTURE WORK

- Perform impact and fatigue tests to see how the composite withstands dynamic and repetitive loads, which are common in automotive applications.
- Improve and scale up the production process to make it more cost-effective and suitable for large-scale automotive manufacturing.
- Combine Aloe Vera and Prosopis Juliflora fibers with other natural or synthetic fibers to improve specific properties like toughness or heat resistance.
- Investigate recycling methods and the environmental impact of the composite to ensure it aligns with sustainability goals in the automotive industry.
- Compare the composite's performance with other natural fiber composites (e.g., hemp, flax) to determine the best option for automotive use.
- Conduct a cost-benefit analysis to assess the economic feasibility of using the composite in automotive manufacturing, considering material costs and potential benefits like lighter vehicles and better fuel efficiency.

DOI: 10.17148/IARJSET.2024.111105

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