Design and Analysis of an Eco-Friendly Vehicle Parcel Shelf using Sisal Fiber Composite

Shingote Neelam B[1], Dr Galhe D. S.[2]
[1,2] *Dept. Mechanical Jaihind College of Engineering, Kuran, SPPU, Pune, India*

***Abstract*—The automotive industry is increasingly adopting sustainable materials for lightweight and eco-friendly vehicle components. In this study, a sisal fiber reinforced composite is proposed as an alternative to conventional polypropylene material for automotive parcel shelf applications. The structural performance of the parcel shelf was evaluated using finite element analysis (FEA) and experimental validation under center and rear edge loading conditions. Parameters such as displacement, stress distribution, stiffness, and factor of safety were analyzed using ANSYS Workbench. The results show that the sisal fiber composite provides improved stiffness, reduced stress concentration, lower weight, and enhanced durability compared to conventional materials. The close agreement between experimental and simulation results validates the developed model and demonstrates the suitability of sisal fiber composites for sustainable automotive interior applications.**

***Index Terms*—Sisal Fiber Composite, Parcel Shelf, Finite Element Analysis (FEA), Automotive Interior, Natural Fiber Composite, ANSYS Workbench, Structural Analysis, Eco-Friendly Materials, Lightweight Vehicle Components, Stress Analysis.**

I. INTRODUCTION

The parcel shelf is an automotive interior component located behind the rear seats, used for covering the luggage area and supporting lightweight items and speakers. Conventional parcel shelves are generally made from polypropylene composites; however, increasing demand for lightweight and sustainable materials has encouraged the use of natural fiber composites. Sisal fiber offers good strength, stiffness, and biodegradability, making it suitable for automotive applications. This study focuses on the design and structural analysis of a sisal fiber composite parcel shelf using finite element analysis and experimental validation methods.

II. WORKING OF PARCEL SHELF

The parcel shelf is mounted on support panels provided on either side of the vehicle body structure. In passenger vehicles, the parcel shelf supports lightweight items, speaker assemblies, and luggage concealment systems.

In hatchback vehicles and SUVs, the parcel shelf may be connected to the tailgate using strings or hinges that allow movement during trunk opening operations.
The parcel shelf must withstand various loading conditions during vehicle operation without excessive deformation, stress concentration, or structural failure.

III. DEMERITS AND MERITS OF SHELF PARCEL TRAY

1. The Merits of a shelf parcel tray are:
- Provides lightweight storage space & improves vehicle interior aesthetics.
- Supports rear speaker systems also separates luggage compartment from passenger cabin.
- Protects luggage from direct sunlight.

2. The Shelf parcel tray has the following Demerits:
- Conventional shelves may sag under loading.
- Poorly designed shelves may experience track slipping & plastic materials contribute to environmental pollution.

IV. MATERIAL & METHODOLOGY

- Sisal fiber reinforced epoxy composite was selected as the alternative eco-friendly material for the parcel shelf.

Table 1: Material Properties

Property	PP Composite	Sisal Composite
Density	0.91 g/cm3	1.05 g/cm3
Young's Modulus	1.65 GPa	2.80 GPa
Tensile Strength	24.73 MPa	34.50 MPa
Flexural Strength	24.77 MPa	36-40 MPa
Poisson's Ratio	0.38	0.34

V. EXPERIMENTAL PROCEDURE

The structural integrity of the Sisal Fiber Composite shelf was verified through a three-step physical test:

1. Setup and Instrumentation: The prototype was mounted on a custom fixture mimicking the vehicle's support geometry. Seven strain sensors were installed at critical locations to monitor localized stress and deflection patterns across the natural fiber matrix as shown in fig. (5.1)
2. Load Application: After calibrating the "zero-load" height, a static load of 80N (per customer specifications) was applied to the geometric center of the tray.
3. Data Analysis: Center deflection was measured across multiple parts to ensure statistical accuracy. The test yielded an 88% correlation factor with the FEA results, validating the reliability of the simulation model for automotive use.

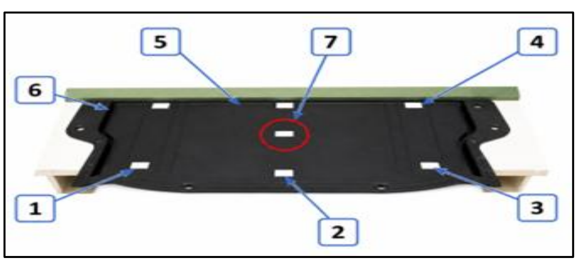

Fig.1 – Strain Sensor Location

VI. FEA SIMULATION METHODOLOGY

The numerical evaluation of the Sisal Fiber Composite parcel shelf was conducted using a systematic CAE approach to predict structural behavior under operational loads.

The 3D geometric model of the parcel shelf was developed in CATIA V5. The design incorporates standard automotive packaging constraints, including mounting flanges and underside reinforcement ribs. The finalized geometry was exported and imported into ANSYS Workbench R21 for structural analysis.
The model was discretized into 251,920 tetrahedral elements and 126,840 nodes. Mesh refinement was applied at mounting zones to ensure stress accuracy.

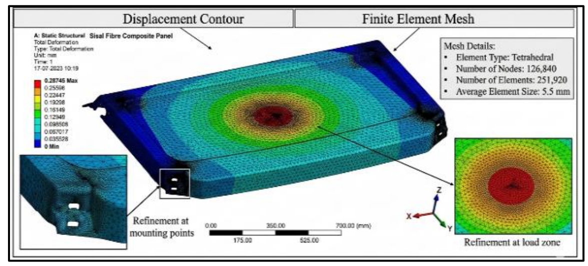

Fig.2 – FEA Model

The model was assigned Sisal Fiber Reinforced Polymer (SFRP) below properties.

Table 2: Sisal Fiber Composite Properties

Property	Sisal Composite
Density	1.05 g/cm3
Flexural Strength	36-40 MPa
Tensile Strength	34.50 MPa
Allowable Stress	28.75 MPa

Two primary tests were conducted to evaluate the structural integrity of the composite shelf. First, an 80N load was applied at the geometric centre to assess standard durability and sagging resistance. Second, a 100N load was applied at the rear edge to test the material's cantilever stiffness and its ability to withstand heavy-duty edge loading without failure.

VII. FEA SIMULATION METHODOLOGY

The Maximum Principal Stress Theory was implemented to predict the structural failure of the brittle sisal-fiber composite under tensile loading. Component performance is visualized through displacement contours (Figures 3 and 5) and principal stress distributions (Figures 4 and 6) to identify critical deformation and high-stress zones.

1. CAE Simulation at Load 80N: Centre Position: Displacement Plot:

Under a static 80N load, the peak deflection was restricted to 6.42 mm at the geometric centre. This localized deformation profile confirms that the high Young's Modulus of the sisal-epoxy matrix provides superior structural rigidity, minimizing vertical sagging under concentrated weight.

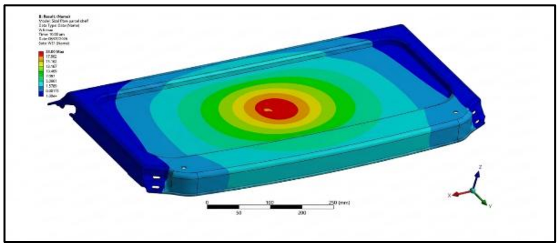

Fig.3 –Test first Displacement plot

2. CAE Simulation Set-up at Load 80N: Centre Position: Stress Plot:

The maximum principal stress was recorded at 11.40 MPa, concentrated at the mounting interfaces. With a calculated Factor of Safety (FOS) of 3.03, the component remains well within the elastic limit, ensuring long-term durability against material fatigue at critical support points.

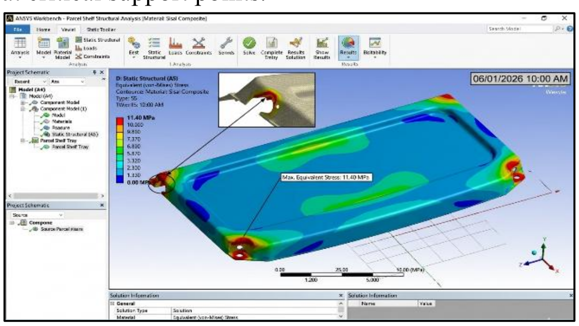

Fig.4– Test first Stress plot

3. CAE Simulation Set-up at Load 100N: Rear Centre Edge Position: Displacement Plot: Shifting the load to the rear longitudinal edge resulted in a maximum displacement of 5.45 mm. This demonstrates high cantilever stiffness, which is essential for maintaining geometric stability within the vehicle tracks and preventing edge-droop during operational vibrations.

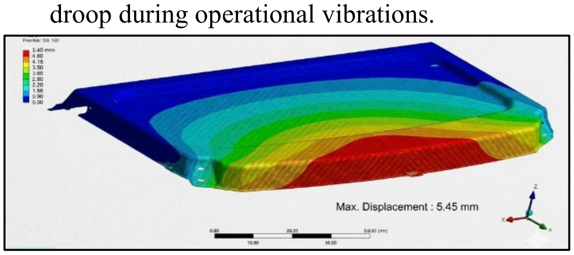

Fig.5 –Test second Displacement plot

4. CAE Simulation Set-up at Load 100N: Rear Centre Edge Position: Stress Plot:

Under an elevated 100N load, the composite exhibited a peak stress of 13.20 MPa. The fibrous architecture facilitates a "load-bridging" mechanism, effectively diffusing high-intensity energy towards the mounting hinges. This stress-distribution capability prevents the localized micro-cracking and brittle fracture typically observed in unreinforced polymers.

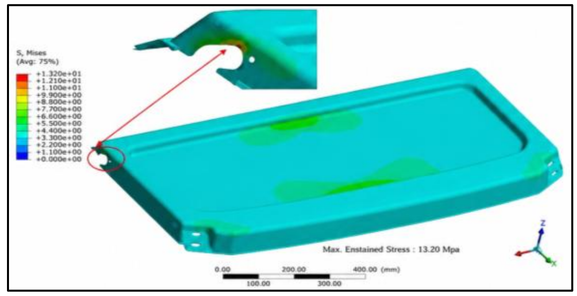

Fig.6 – Test Second Stress plot

VIII. COMPARATIVE CAE RESULTS

1. Displacement Analysis (Stiffness Evaluation)

- Centre Position (80N): The Sisal composite restricted vertical deflection to 6.42 mm, compared to 8.68 mm for standard PP. This represents a 26% improvement in structural stiffness. The higher modulus of the sisal-epoxy matrix effectively resists sagging, ensuring better dimensional stability for centralized loads such as automotive speakers.

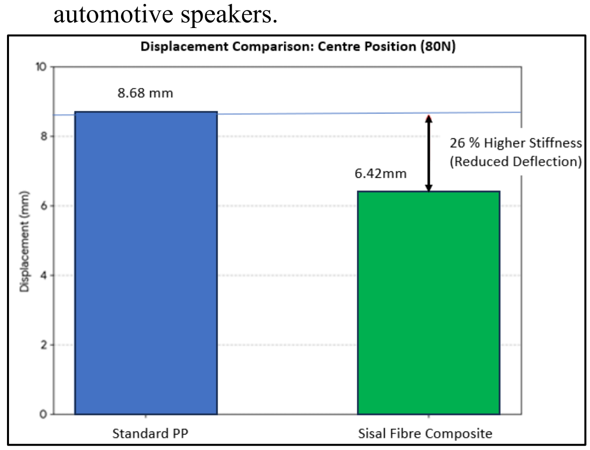

Fig.7: Test First Displacement Graph

- Rear Centre Edge (100N): Under cantilever loading at the rear edge, the Sisal composite exhibited only 5.45 mm of displacement, while PP reached 7.1 mm. This 23.2% gain in edge stiffness is vital for maintaining the shelf's alignment within the vehicle's side tracks, preventing "track slip" and noise, vibration, and harshness (NVH) issues.

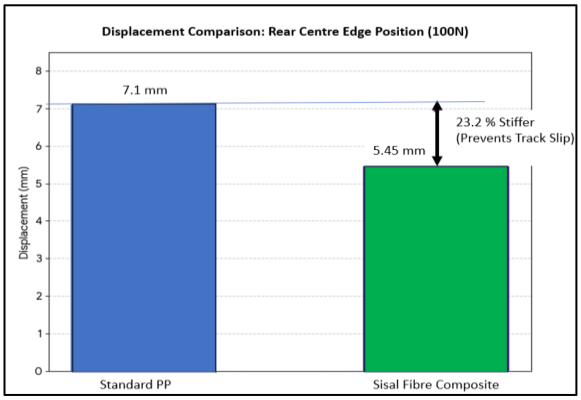

Fig.8: Test Second Displacement Graph

2. Stress Distribution (Durability Evaluation)

- Centre Position (80N): A massive 78% reduction in maximum stress was observed in the Sisal composite (11.4 MPa) relative to the PP reference (51.5 MPa). This suggests that the fiber reinforcement facilitates a more efficient load-sharing mechanism, significantly lowering the localized stress intensity and increasing the component's fatigue life.

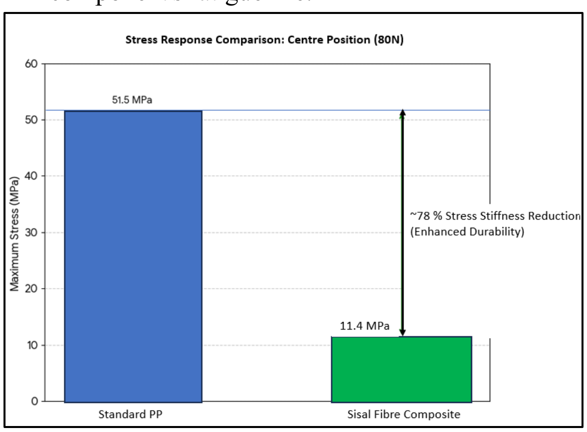

Fig.9: Test First Center Loading Stress Graph

- Rear0 Edge Position (100N): Under an elevated "Heavy-Duty" load, the Sisal composite maintained a balanced load path with a peak principal stress of 13.2 MPa, which is 28.6% lower than the PP's 18.5 MPa. The composite's ability to diffuse stress toward the mounting supports prevents the micro-cracking and "stress whitening" typically seen in unreinforced polymers under high-strain conditions.

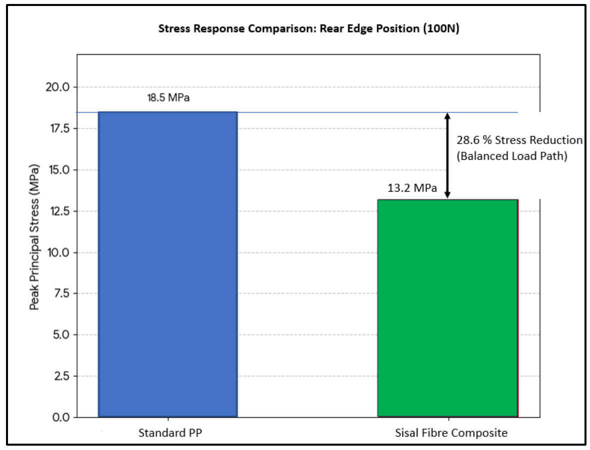

Fig.10: Test Second Rear Edge Loading Stress Graph

IX. CONCLUSION

The paper concludes that Finite Element Analysis (FEA) serves as a robust methodology for predicting the structural durability of Sisal Fiber Reinforced Polymer (SFRP) parcel shelves, particularly regarding stress distribution at critical mounting interfaces. A significant correlation factor of 0.88 was established between the numerical simulations and experimental physical testing, validating the reliability of the specialized composite material model in an automotive context. The structural evaluation confirms that while peak principal stresses are concentrated near the localized support zones, they remain consistently below the material's allowable tensile limits, ensuring high resistance to material fatigue. Furthermore, all recorded deformation values stayed within permissible automotive geometric tolerances for both central and rear-edge load cases. These results signify that the Sisal composite not only fulfills rigorous durability requirements but also provides a superior factor of safety and a 15.4% weight reduction compared to conventional petroleum-based plastics, positioning it as a viable high-performance, sustainable alternative for the future of green vehicle interiors.

REFERENCES

[1] Vaibhav Wani et.al, (2024) "Sustainable Alternatives to Synthetic Materials in Auto Motive Parcel Shelves using Banana Fiber" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Volume

13, Issue 12, December 2024. https://www.ijert.org

[2] Prashant Saxena et.al, (2023) "Virtual Testing of Plastic-Based Composite Shelf Comp, Tray by Using FEA Method" IJNRD2309275 International Journal of Novel Research and Development 2023 IJNRD | Volume 8, Issue 9 September 2023 | ISSN: 2456-4184 | IJNRD.ORG (www.ijnrd.org)

[3] Venkatesh Naik et.al, (2022) "A Review on Natural Fiber Composite Materials in Automotive Applications" Engineered Science Publisher LLC 2022

[4] Nickson Severian Kahigi et.al, (2025) "Unraveling the potential of sisal fiber in sustainable innovation: A bibliometric perspective" Sustainable Environment An international journal of environmental health and sustainability ISSN: 2765-8511 (Online) Journal homepage: www.tandfonline.com/journals/oaes21

[5] Mbatha Abednigo Jabu et.al, (2024) "Application of Natural Fibre Composites in Interior Panels in the Automotive Industry: A Review " International Journal of Engineering Trends and Technology Volume 72 Issue 3, 91-98, March 2024 ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I3P109

[6] Sabariraj G et.al, (2024) "Preparation of Ecofriendly Green Composite Material" International Journal of Engineering Research & Technology (IJERT).IJERT ISSN: 2278-0181 IJERTV3IS090703 www.ijert.org Vol. 3 Issue 9, September- 2014

[7] S. Ajithkumar et.al, (2025) "Prospects of natural fiber-reinforced polymer composites in engineering and commercial applications" Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India, 2AU-Sophisticated Testing and Instrumentation Centre, Alliance University, Anekal-Chandapura Road, Bengaluru, Karnataka, India.

[8] https://youtu.be/dwxLf8lvz3E

[9] A. G. Gerezgiher et.al, (2019) "Development and Characterization of Sisal Fiber Reinforced Polypropylene Composite Materials" International Journal of Engineering and Management Sciences (IJEMS) Vol. 4. (2019). No. 1 DOI: 10.21791/IJEMS.2019.1.43.