

Material Optimization for Door Trim of Automobile to Check Impact Strength

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Abstract—The trend in modern vehicles is the use of material and manufacturing techniques that increase fuel economy and reduce the weight of cars [1]. The traditional petroleum-based plastics such as ABS and PP cause waste disposal problems, added weight, and high environmental cost [1]. In this research, we intend to develop, optimize and experimentally evaluate the design of bio-composite material to replace petroleum-based plastic for automotive interior door trims [1]. We will test the impact resistance of a bio-composite made from fast-growing Areca and Bamboo fibers with bio-resins under door-hit velocities [1]. The experiments show that natural fiber composites, especially Bamboo fibers with epoxy resins, are very flexible and can be very useful in automotive parts reduction [1].

Index Terms—Automotive interior components, Bio-composite materials, Bamboo fiber, Impact strength testing, Sustainable manufacturing.

I. INTRODUCTION

Lightweight engineering in the automotive sector relies on low-density materials and advanced joining technologies to improve performance and efficiency [1]. Automotive door panels provide controlled access and structural security to the vehicle cabin, featuring exterior and interior surfaces that differ sharply in design, finish, and function [1]. The door trim incorporates a three-stage sealing system: a primary seal that dampens door closing velocity and reduces exterior noise intrusion, a secondary weather seal protecting the cabin from water entry, and a striker that locks the door in position against the elastic energy stored in both seals [1].

The closing sound of a car door is a critical subjective quality indicator for consumers, despite being objectively unrelated to vehicle performance [1]. Common sources of door noise include rattling caused

by irregular gaps inside the housing of wire connectors, buzzing resulting from the vibration of the structure itself, and squeaking produced by loosely assembled internal panels [1]. Replacing traditional plastics with sustainable alternatives like Areca and Bamboo fibers turns agricultural waste into high-value materials, offering reduced carbon footprints and better end-of-life biodegradability [1].

II. SUMMARY OF THE PREVIOUS STUDIES

Table 1 highlights key research findings from prior peer-reviewed studies regarding the structural optimization and crashworthiness of automotive door components.

No.	Authors	Title	Publication & Year
1	Vijayan P.	Design and impact analysis of lightweight door panel	IJRRASE & 2016
2	Bundele & Bindu	Structural optimization of front door with ULSAB concept	Global J. Eng. & 2012
3	Tan Wei	Vehicle door structure based on FEM	ICASM Conf. & 2012
4	Dalavi S.	Crashworthiness of car interior door trims in side impact	IJESIT & 2015
5	Bazios P.	Door components for two-seater EV in side impact	BETA CAE & 2015
6	K.M Faridul Hasan	Bamboo fibre reinforced biocomposites	Elsevier & 2023

III. RESEARCH GAP

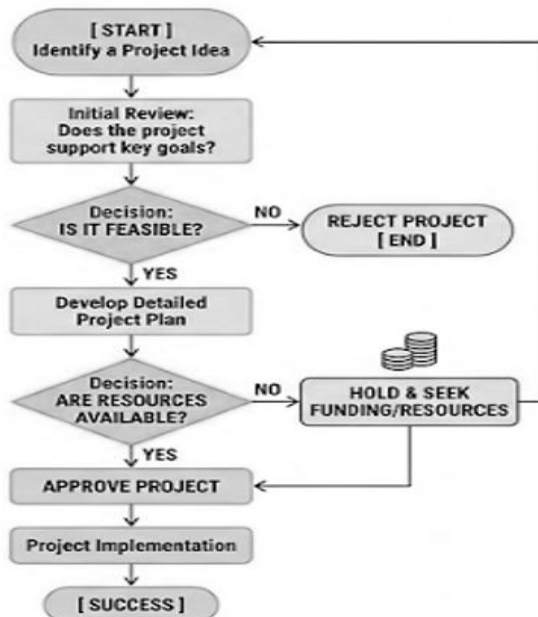
While existing literature validates that composite materials with natural fibers and polymer matrices

offer synergistic strength, high rigidity, and superior thermal or sound insulation for interior applications, significant gaps remain [1]. Most documented literature focuses exclusively on uniform composition panels, utilizing single-phase natural fiber composites with consistent fiber loading throughout [1]. Functionally graded structures are significantly underexplored [1]. The layer-by-layer tailoring of material properties remains an open design space, as graded architectures possess the potential to offer targeted performance without the trade-offs typical of monolithic structures [1].

IV. METHODOLOGY

The research followed a structured framework to evaluate and validate the bio-composite material for door trim application:

1. Force Analysis: Study the force distribution across the interior door trim panel under various impact loading conditions [1].
2. Standard Model Study: Develop a mathematical model to accurately characterize the slamming mechanism of the door system [1].
3. Material Study: Evaluate the aesthetics and mechanical properties of the selected bio-composite formulations intended for the door trim [1].
4. Fabrication & Testing: Fabricate the bio-composite panels utilizing a hand layup method and test them experimentally for tensile and impact strength [1].



5. Finalizing the Product: Analyze the experimental data to finalize the actual product design and material composition [1].

V. EXPERIMENTAL STEPS

A proposed bio-composite material formulation was developed to serve as a replacement for conventional plastic trims [1]. The composition of the candidate material was formulated as follows:

Material / Component	Percentage	Reference
Epoxy/Bio-Resin	40%	[1]
Areca Fiber	33%	[1]
Bamboo Fiber	22%	[1]
Nano Clay	3%	[1]
Silane Coupling Agent	2%	[1]
Additives (UV Stabilizers)	-	[1]

B. Graded Architecture Creation

A functionally graded three-layer architecture was designed to optimize performance [1]:

- Outer Layer: Formulated with high bamboo fiber content to provide structural stiffness and surface durability [1].
- Middle Layer: Composed of a lightweight foam core designed for mass reduction and thermal insulation [1].
- Inner Layer: Engineered with an Areca-rich composition specifically for impact absorption and energy dissipation [1].

VI. RESULT AND DISCUSSION

1. Experimental Test Results Overview

The physical and mechanical testing of Bamboo fiber/Epoxy and Areca fiber/Epoxy composites was conducted in accordance with ASTM standards. The individual specimen results and evaluated mean values are summarized.

2. Analysis of Mechanical Properties

2.1 Flexural Performance (Bamboo / Epoxy)

Under three-point bending tests (ASTM D790), the Bamboo fiber composite demonstrated exceptional structural rigidity, reaching an average flexural

strength of 326.67 MPa. The failure modes observed were localized fractures at the outer tension fibers (center and corner breaks). This remarkably high flexural capacity significantly exceeds standard literature baselines for untreated natural fibers (130 - 190 MPa) and vastly outperforms traditional unreinforced automotive interior polymers such as ABS or Polypropylene (60 MPa).

Mater ial Comp osite	Test Stan dard	Evalu ated Para meter	Speci men 1	Speci men 2	Speci men 3	Mea n Val ue
Bamb oo / Epox y	AST M D24 44	Dama ge Area (mm ²)	1430 .20	1644 .03	1570 .17	154 8.13
Bamb oo / Epox y	AST M D24 44	Dama ge Depth (mm)	2.6	3.6	3.8	3.33
Bamb oo / Epox y	AST M D79 0	Flexu ral Stren gth (MPa)	320. 0	335. 0	325. 0	326. 67
Areca / Epox y	AST M D24 44	Dama ge Area (mm ²)	3605 .06	3565 .26	3747 .56	363 9.29
Areca / Epox y	AST M D24 44	Dama ge Depth (mm)	2.0	2.8	2.6	2.47
Areca / Epox y	AST M D63 8	Tensi le Stren gth (MPa)	13.5 2	14.1 1	13.1 1	13.5 8
Areca / Epox y	AST M D63 8	Yield Stren gth (MPa)	15.3 9	15.7 7	14.9 9	15.3 8
Areca / Epox y	AST M D63 8	Elong ation at Break (%)	4.4	4.2	4.2	4.27

2.2 Tensile Behavior (Areca / Epoxy)

Uniaxial tensile testing (ASTM D638) of the Areca fiber composite yielded an average ultimate tensile strength of 13.58 MPa and a yield strength of 15.38 MPa, with an average elongation at break of 4.27%. The low elongation at break confirms a classic brittle fracture mode typical of untreated bio-composite structures. The lower tensile performance indicates weak interfacial adhesion between untreated raw Areca fibers and the epoxy matrix. Fiber pull-out rather than fiber fracture was the primary driver of failure.

3. Impact Damage Resistance Analysis

The falling-tup impact test (ASTM D2444) revealed distinct energy dissipation mechanisms between the two bio-composite formulations. The Damage Area Ratio is calculated as:

$$\text{Damage Area Ratio} = \text{Areca Area} / \text{Bamboo Area} = 3639.29 \text{ mm}^2 / 1548.13 \text{ mm}^2 \approx 2.35$$

Localized Toughness (Bamboo): The Bamboo composite confined the impact energy to a small surface region (mean 1548.13 mm²), though it experienced a slightly deeper indentation depth (3.33 mm). This indicates high fracture toughness and strong internal interlaminar shear strength.

Surface Delamination (Areca): The Areca composite exhibited a 135% larger damaged surface area (mean 3639.29 mm²) while restricting penetration depth to 2.47 mm. The energy dissipated primarily through lateral matrix cracking and boundary delamination rather than deep perforation.

4. Feasibility & Suitability for Door Trims

Automotive interior door trims demand a combination of high bending rigidity, side-impact energy absorption, and lightweighting.

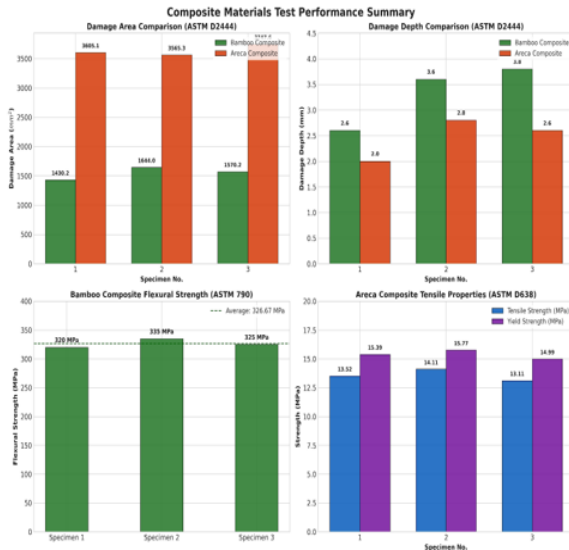
Outer Layer: Bamboo Composite (Flexural Rigidity)
Core Layer: Areca Composite (Acoustic Damping/Weight)
Outer Layer: Bamboo Composite (Impact Resistance)

4.1 Functional Allocation

Primary Substrate & Armrest (Bamboo Composite): Due to its 326.67 MPa flexural strength, the Bamboo composite easily surpasses OEM minimum structural targets (~100 MPa). It prevents panel sag, resists

handle cyclic fatigue, and localizes impact forces during collisions.

Secondary Core & Map Pocket (Areca Composite): While unsuitable as a standalone primary structural load-bearer in its untreated state, the Areca composite's low density and higher ductility make it ideal for non-structural acoustic insulation cores and lower trim covers.



4.2 Chemical Optimization Strategy

To utilize Areca fiber structurally, pre-treating the raw fibers with an alkali (NaOH) solution is recommended. Literature demonstrates that surface washing removes hemicellulose and lignin, enhancing surface roughness and increasing tensile strength from 13.58 MPa up to ~45 MPa, meeting OEM structural standards (≥ 30 MPa).

VII. CONCLUSION

In addition to natural fiber reinforced composites, both have mechanical properties that can be used to develop products in the field of automotive interior and door trims [1]. The Areca fiber composite is a sustainable alternative which offers adequate tensile properties but needs improvement in order to cope with higher loads [1]. Contrary to the Areca fiber composite, the Bamboo fiber and epoxy composite showed high flexural properties and was lightweight as well [1]. Considering the experimental results, the Bamboo fiber composite seems to be the most appropriate

substitute for conventional automobile door trim materials [1].

REFERENCES

- [1] Vijayan P., "Design and impact analysis of light weight door panel of the car", IJRRASE, Vol. 8, No. 1, 2016.
- [2] Mr. Sandeep Bendre, Dr. Iravli, Rups B. Bhide, "Automotive Door Design & Structural Optimization...", Global J. Res. Eng., Vol. 12, Issue 2, 2012.
- [3] Tan Wei, "Design of the Vehicle Door Structure Based on Finite Element Method", ICASM, 2012.
- [4] Sandeep Dalvi, "Crashworthiness of Car Interior Door Trims in Side Impact", IJESIT, Vol. 4, Issue 5, 2015.
- [5] Panagiotis Blazios, "Design and study of door components for a two-seater electric vehicle...", 6th BETA Cell Int. Conf., 2015.
- [6] O.M. Terzioğlu, "FEM modeling of an automotive door trim panel...", 4th Int. Conf. Adv. Compos. Mater., 2012.
- [7] K. Veeraswamy, "Design and analysis of a composite beam...", IRJET, Vol. 3, Issue 02, Feb 2016.
- [8] M. Raghuvaran, "Design and Impact Analysis of a Car Door", IJMERE, Vol. 4, No. 9, 2014.
- [9] Finite Element Analysis of Internal Door Panel of a Car by Considering Bamboo Fiber Reinforced Epoxy Composite - ResearchGate
- [10] Mechanical Properties and Biodegradability of Areca Nut Fiber-reinforced Polymer Blend Composites - kyushu
- [11] Chopped Areca Nut Fibers as Filler in Epoxy Matrix: Mechanical and Tribological Studies - Walailak Journal of Science and Technology
- [12] K. M. Faridul Hasan, P. G. Horváth, Z. Kóczán, L. Bacsárdi, T. Alpár, "Bamboo fibre reinforced biocomposites: A review of manufacturing techniques and mechanical properties", Composites Part B: Engineering (Elsevier), Vol. 250, 2023.
- [13] S. Wasti, S. Adhikari, B. Sharma, S. J. T. S. E. S. Research, "Bamboo fiber reinforced polypropylene composites for transportation applications", Frontiers in Materials, Vol. 9, 2022.
- [14] M. Capretti, A. Integrated, D. Structural, "Natural Fibre and Hybrid Composite Thin-Walled

- Structures for Automotive Crashworthiness: A Review", MDPI Materials, Vol. 17, No. 10, p. 2246, 2024.
- [15] H. Abedsoltan, "Applications of plastics in the automotive industry: Current trends and future perspectives", Polymer Engineering & Science, Vol. 64, No. 3, pp. 929–950, 2024.
- [16] S. Jeyaguru, S. M. K. Thiagamani, S. M. Rangappa, S. Siengchin, S. Krishnasamy, C. Muthukumar, "Lightweight and sustainable materials for automotive applications", Lightweight and Sustainable Composite Materials (Elsevier), pp. 143–156, 2023.
- [17] E. Oh, M. M. Godoy Zúniga, T. B. Nguyen, B. H. Kim, T. Trung Tien, J. Suhr, "Sustainable green composite materials in the next-generation mobility industry: review and prospective", Advanced Composite Materials, Vol. 33, No. 6, pp. 1368–1419, 2024.
- [18] D. O. Kazmer, "Design of Plastic Parts for Automotive Interior Trim Modules", Applied Plastics Engineering Handbook (Elsevier), pp. 639–662, 2024.
- [19] F. Zhao, X. Liu, T. Feng, J. Zhao, W. Guo, "Forming performance and environmental impact of bamboo fiber reinforced polypropylene composites based on injection molding process for automobiles", Polymer Composites, Vol. 46, No. 1, pp. 567–578, 2025.
- [20] H. Negi, A. Vedrtam, K. Kalauni, "A comprehensive review on natural fiber-reinforced polymer composites: Surface treatments, mechanical performance, and sustainable applications", Journal of Thermoplastic Composite Materials, 2025.
- [21] S. Rahman, M. Z. Rahman, J. Tasnim, B. Saha, M. J. Abedin, "Biobased composites reinforced with natural fibers: Design, manufacturing techniques, and parameters influencing properties", Comprehensive Materials Processing (Elsevier), pp. 589–621, 2024.
- [22] S. J. Skosana, C. Khoathane, T. Malwela, "Driving towards sustainability: A review of natural fiber reinforced polymer composites for eco-friendly automotive light-weighting", Journal of Thermoplastic Composite Materials, Vol. 38, No. 2, pp. 754–780, 2025.
- [23] U. V. Akhil, N. Radhika, B. Saleh, S. Aravind Krishna, N. Noble, L. Rajeshkumar, "A comprehensive review on plant-based natural fiber reinforced polymer composites: Fabrication, properties, and applications", Polymer Composites, Vol. 44, No. 5, pp. 2598–2633, 2023.