Biodegradable Composite from Coconut Husk and Cotton Fibre: A Sustainable Material for Aerospace Applications

*Nikhita M[1], Sarvika Raju Chamarthy[1], Nandini C[2], K Y Hemalatha[2] and G Vijay Kumar[3]

[1]*Department of Aerospace, R.V. College of Engineering, Bengaluru*

[2]*Department of AIML, R.V. College of Engineering, Bengaluru*

[3]*Department of Biotechnology, R.V. College of Engineering, Bengaluru*

Abstract

The development of biodegradable composites using natural fibres has become an area of significant interest due to increasing concerns about environmental sustainability and plastic waste. This study focuses on the fabrication and characterization of a biodegradable composite material reinforced with coconut husk (coir) and cotton fibres, bound together using epoxy resin. The composite was evaluated for its mechanical, thermal, and acoustic properties, with a particular focus on its applicability in aerospace components such as cabin wall insulation, engine compartments, and cargo bays. The results indicate that these bio-composites present a promising sustainable alternative, although further research is required to overcome challenges like dimensional stability and fire resistance.

Keywords*: bio-composite; coconut husk; cotton fibres; epoxy resin; compressive strength; thermal analysis; sustainable materials; Aerospace applications.*

1. Introduction

The aerospace industry is increasingly adopting natural fibre composites (NFCs) like coconut coir and cotton reinforced with epoxy resin for interior applications, driven by the need for sustainable, lightweight, and cost-effective materials. Compared to traditional synthetic composites and aluminium alloys, NFCs offer lower density, reduced environmental impact, and sufficient mechanical, thermal, and acoustic performance for non-structural components such as panels, seat frames, and tray tables. These biodegradable, renewable materials contribute to fuel efficiency, lower emissions, and enhanced cabin safety through improved fire behaviour. As processing techniques advance, NFCs are emerging as viable alternatives that align with aviation's goals of innovation, sustainability, and operational efficiency.

2. Objective

The primary objective of this research is to engineer a composite material utilizing coconut husk fibre, with the intent of advancing its application within the aerospace sector. This study undertakes a rigorous examination of the physicochemical and mechanical behaviour of coir fibres when integrated with various reinforcing and binding agents, such as epoxy resin. A key focus is placed on optimizing the volume fraction and spatial distribution of the coconut husk fibres to achieve targeted mechanical and dynamic properties, including tensile strength, flexural modulus, and vibration damping. The research also evaluates the composite's effectiveness as a thermal and acoustic insulator, which are critical performance parameters for aerospace interior components.

*Corresponding author: Nikhita M, nikhitamahadevappa@gmail.com

3. Background And Motivation

A significant aspect of this work is the valorisation of coconut husk, an agricultural by-product that is typically discarded as waste. By repurposing coconut husk fibres as a primary reinforcement in composite materials, this research not only diverts substantial organic waste from landfills and open burning but also aligns with global efforts to promote resource efficiency and circular economy principles. The utilization of coir fibres in composite fabrication leverages their inherent renewability, biodegradability, and low environmental impact compared to conventional synthetic fibres, thereby offering a sustainable alternative for high performance engineering applications.

The experimental methodology systematically investigates the interfacial bonding mechanisms between the coir fibres and the polymer matrix, employing advanced characterization techniques to correlate microstructural features with macroscopic performance. In addition to mechanical testing, the thermal and acoustic insulation capabilities of the developed composites are rigorously assessed to ensure compliance with the stringent requirements of aerospace environments. The study further explores the effects of fibre treatment and processing variables on the durability and long-term stability of the composites, addressing potential challenges associated with natural fibre heterogeneity.

Ultimately, this research aims to demonstrate that coconut husk fibre-reinforced composites can serve as an environmentally responsible alternative to traditional synthetic materials in aerospace interiors, without compromising on essential performance metrics. By facilitating the reuse of agricultural waste and reducing reliance on non-renewable resources, the adoption of such bio-composites contributes to a reduction in environmental pollution and supports the development of greener, more sustainable industrial practices within the aerospace industry.

4. Material Selection and Processing

For the prototyping phase, the research team utilized coconut coir, shredded cotton fibre, and a commercially available epoxy resin as the primary materials. The coconut coir was initially extracted by carefully removing it from the outer shell of the coconut.

Following extraction, the coconut husk was subjected to a dehydration process by exposing it to direct sunlight for a duration of 24 hours, thereby facilitating the removal of moisture content and rendering the material more amenable to subsequent grinding operations. Alternatively, to expedite the dehydration process, the coconut husk may be placed in a controlled-temperature oven for approximately 3 to 4 hours, achieving comparable moisture reduction in a significantly shorter timeframe. The coir then underwent a mechanical shredding process to reduce it to a fine powder presented in Figure 1. This step was specifically implemented to significantly increase the surface-to-volume ratio, thereby promoting improved interaction and bonding with the epoxy matrix in the composite structure. The processed coir powder was collected and stored under controlled conditions to prevent contamination prior to its incorporation into the composite.

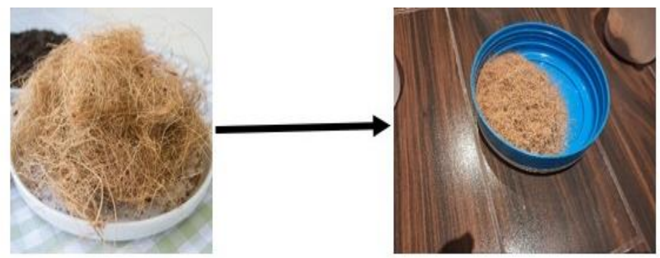

Figure 1: Coconut husk after grinding

In the preparation of the cotton fibre reinforcement, the team selected discarded cotton fabric, commonly sourced from rag materials, as the base material. The fabric was first cut into small, manageable pieces to facilitate further processing. These pieces were then subjected to mechanical shredding, a process designed to accelerate the breakdown of the woven fabric into discrete fibres as shown in Figure 2. This method produced fibres with morphological characteristics closely resembling those of raw, unprocessed cotton, which is advantageous for achieving uniform dispersion within the resin matrix.

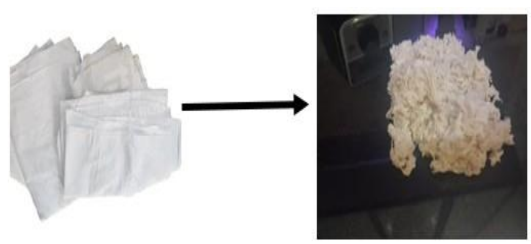

Figure 2: Cotton fibre after grinding

The primary objective of this fibre preparation technique was to maximize the available surface area of the cotton fibres, thereby enhancing the interfacial bonding and mechanical performance of the resulting composite material. All prepared fibres were subsequently collected and stored in a moisture-free environment until composite fabrication commenced.

5. Methodology

A layered composite fabrication approach was adopted, wherein alternating layers of cotton fibre and coconut husk were incorporated, each layer being thoroughly impregnated with epoxy resin. For the hand layup process, a plastic mould was selected to facilitate the easy demoulding of the composite material following the curing phase. The epoxy resin system utilized for prototyping consisted of a standard resin and hardener, mixed in a 2:1 ratio by volume, which was determined to yield optimal results in terms of mechanical properties and handling characteristics.

The fabrication sequence commenced with the application of a thin layer of resin onto the base of the mould. Subsequently, a layer of cotton fibre was placed and saturated with an additional amount of resin to ensure complete wetting and impregnation. This was followed by the addition of a layer of pre-processed coconut husk, which was similarly drenched with resin. This alternating process of layering cotton fibre, resin, coconut husk, and resin was repeated until a total of three cotton fibre–resin–husk assemblies were achieved within the mould.

Upon completion of the layup, the entire assembly was subjected to compression to expel any excess epoxy resin. This step is critical, as the presence of surplus resin can lead to the formation of a brittle composite matrix, thereby compromising the material’s mechanical integrity. The compressed setup was then placed under direct sunlight for a period of 24 hours to facilitate the curing of the epoxy resin. Exposure to sunlight not only accelerates the curing process through the provision of heat but also aids in the elimination of any residual microbial contaminants. After the curing period, the composite was demoulded, yielding a finished material ready for further evaluation and testing.

Figure 3: Materials utilised for the hand layup

Throughout the lay-up, care was taken to ensure uniform distribution and impregnation of the resin within each layer to promote optimal interfacial bonding. The flowchart of preparation of the composite is shown in Figure 4. Upon completion of the layering, the entire assembly was subjected to compression. This compression step is essential for expelling excess epoxy resin, which, if retained in large quantities, can lead to increased brittleness and diminished mechanical performance in the final composite. The controlled removal of surplus resin thus contributes to the production of a structurally robust and reliable composite material, as shown in Figure 5.

Figure 4: Flowchart of the layup

Figure 5: Compressing the composite to remove excess resin

After repeating this process such that we obtain 3 layers of cotton fibre- coconut husk layers, the composite is compressed under pressure to remove excess resin. All the materials used in fabricating the composite is shown in the Figure 3.

The below tables: Table 1 and Table 2 depicts certain characteristic properties of coconut husk and cotton fibres respectively

Table 1: Properties of coconut husk

Characteristics of coconut husk	Values
Average diameter	0.1 mm
Density	0.67 - 1.00 g/cm3
Lignin	45.84 %
Cellulose	43.44 %
Hemi-cellulose	0.25 %
Young’s modulus	2-8 GPa
Poisson’s ratio	0.3

Table 2: Properties of cotton fibre

Characteristics of cotton fibre	Values
Density	1.14 g/cm3
Lignin	0.40- 1.00 %
Cellulose	90%
Hemi-cellulose	85-95%
Young’s modulus	5-13 GPa
Poisson’s ratio	0.475

6. Testing

6.1 Compressive strength [Compression testing machine]

Figure 6: Compression testing on the specimen

Figure 7: Compression testing machine setup

Upon testing the specimen using a Compression Testing Machine (CTM), (as demonstrated in the Figure 6) it demonstrated the ability to withstand a compressive load of 1200 kN with minimal deformation. While neat epoxy resin is inherently brittle and typically exhibits a maximum compressive strength of approximately 100 MPa, the fabricated composite significantly exceeded this threshold, achieving a compressive strength of 165 MPa. This notable enhancement in mechanical performance indicates effective load distribution and reinforcement within the composite matrix. Additionally, the specimen exhibited slight plastic deformation during loading, suggesting a shift from the brittle failure mode typically associated with epoxy toward a more ductile response, likely due to fibre reinforcement or matrix modifications.

A minor surface crack approximately 5 mm in length was observed post-testing, indicating the onset of localized failure; however, this did not significantly affect the structural integrity under load. The measured compressive strength of 165 MPa is a considerable improvement over conventional resin systems and reflects the composite’s potential for load-bearing applications. Such mechanical characteristics make this material a viable candidate for structural components in aerospace interiors, where high strength-to-weight ratios, damage tolerance, and moderate ductility are essential design requirements. The comparision is depicted in the below Figure 7 and 8.

The Table 3 depicts a comparision between the bio-composite and other used materials in aerospace and other areas based on their compressive strengths and densities.

Figure 8: Specimen before and after compression testing respectively

Table 3: Comparision table

Material	**Compressive strength, MPa**	**Density, g/cm3**
Red brick	2.5-3.5	1.8-2.1
Cement	20-40	3.1-3.25
Concrete	20-40	2.3
Aluminium Alloy (e.g., 7075-T6)	450-500	2.7
Carbon Fibre Reinforced Polymer(CFRP)	150-250	1.6-1.9
Nomex® Honeycomb Core	3-5	0.05-0.1
Phenolic Resin Composite Panels	80-150	1.2-1.5
Polyetheretherketone (PEEK)	120-140	1.3
Polycarbonate (used in windows)	70-90	1.2
PVC Foam Core (used in sandwich panels)	1-3	0.03-0.1
Aramid Fibre Composites (e.g., Kevlar)	150-200	1.4-1.45
Bio-composite (the specimen)	**165**	**0.2-0.3**

6.2 Thermal properties [Digital Scanning Calorimeter]

The DSC curve, as shown in the Figure 9, shows a single sharp endothermic peak in the temperature range of 139.23°C to 140.88°C, with a peak at 139.70°C. This thermal event is indicative of the melting temperature (Tm) of a crystalline or semi-crystalline material.

No noticeable **glass transition (Tg)** was observed in the lower temperature range, suggesting either:

- The material is highly crystalline (Tg not detectable due to minimal amorphous content), or
- Tg is below the scanning range (25°C) or too weak to be detected under the test conditions.

The Table 4 depicts all the observations from the obtained graph from the Digital Scanning Calorimeter.

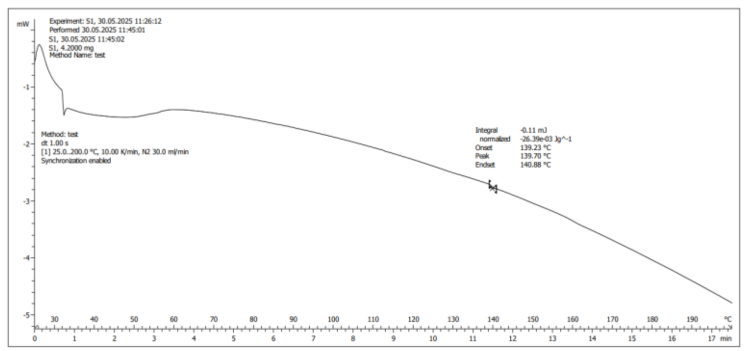

Figure 9: Graph obtained from DSC testing

6.2.1 Resin (likely thermoplastic or bio-based resin): The peak at 139.70°C is most likely the melting temperature (Tm) of the resin matrix. The narrow melting range (139.23–140.88°C) and relatively sharp peak suggest the resin has a semi-crystalline nature. This defines the processing temperature range for moulding or shaping.

6.2.2. Coconut Husk Fibre (Lignocellulosic): Coconut husk consists of lignin, cellulose, and hemicellulose. These do not have a sharp melting point; instead, they degrade thermally at higher temperatures (typically >200°C). Thus, they do not contribute to the observed peak but affect thermal stability and filler behaviour.

6.2.3 Cotton Fibre (Cellulose): Like coconut husk, cotton is mainly cellulose. Cellulose has no melting point—only degradation (>250°C). So again, cotton doesn't contribute to the peak but enhances mechanical reinforcement and thermal resistance.

Table 4: Interpretation from the DSC graph

Property	Observed value	Interpretation
Melting temperature (Tm)	139.70 °C	Indicates the material is semi-crystalline or crystalline. It melts at this temperature. Suitable for applications below this point.
Melting range (onset-endset)	139.23°C-140.88 °C	Narrow range shows high purity or well-defined crystalline structure.
Enthalpy of fusion	-0.11 mJ (-26.39 mJ/g)	The amount of energy absorbed during melting, normalized for mass. Indicates crystallinity.
Glass transition temperature (Tg)	Not observed in range of (25°C – 139 °C)	May be below 25°C or not present in detectable quantity. Indicates low amorphous content.
Material Mass	4.2 mg	Used to calculate normalized enthalpy.
Atmosphere	Nitrogen (30 ml/min)	Inert gas used to prevent oxidation during heating.
Heating rate	10K/min	Standard ramp rate for observing melting and other thermal transitions.

7. Improving The Performance Characteristics of The Composite

The mechanical properties of composites, such as tensile and flexural strength, are strongly influenced by the size and proportion of reinforcing fibres. Optimal fibre content (typically 10–20 wt.%) and smaller particle sizes enhance interfacial bonding and stress transfer, improving overall strength. However, excessive or large fibres can cause agglomeration and weaken the composite.

Surface treatments like alkali or silane enhance fibre-matrix adhesion by increasing surface roughness and removing impurities. Optimizing processing parameters—such as temperature, pressure, and curing time—ensures uniform dispersion and minimal voids. Hybridization with other fibres or fillers (e.g., nano-clays) can boost impact resistance and thermal stability. Additionally, aligning fibres along load paths and using layered laminates can further enhance directional strength, crucial for aerospace applications.

8. Challenges and Risk Management

Developing composites using natural fibres presents several challenges, the most prominent being variability in fibre properties. Unlike synthetic fibres, which can be manufactured to uniform specifications, natural fibres exhibit variations in length, diameter, 3 and strength. This inconsistency can lead to unpredictable behaviour in the final composite. To mitigate this issue, standardized treatment processes and strict quality control measures are implemented during fabrication. Another significant challenge lies in ensuring uniform dispersion and wetting of fibres in the matrix. Poor fibre distribution can result in weak points and reduce the overall mechanical performance of the composite. The hand lay-up and compression moulding technique, though labour intensive, allows for better control and even distribution of fibres, thereby minimizing these risks. Environmental stability is also a concern when working with natural fibre composites. Exposure to moisture and ultraviolet rays can degrade the fibres over time. To counter this, hybridization with cotton and the application of protective coatings are explored. These methods enhance the composite's resistance to environmental factors and extend its usable life in aerospace settings.

9. Conclusion

This study demonstrates that coconut husk and cotton fibres, when appropriately treated and combined with suitable binding and reinforcing materials, can be used to develop bio-composites with mechanical and thermal properties that are promising for non-critical aerospace applications. The material exhibits commendable strength-to-weight performance and acceptable thermal stability, making it a cost-effective and environmentally friendly alternative to conventional synthetic composites. Notably, such bio-composites are especially suitable for aerospace interior components or structural regions where minimal heat is generated, such as cabin panels, insulation structures, or auxiliary housings. The findings underscore the critical role of fibre surface treatment and optimized composition in enhancing interfacial bonding and overall performance. Although challenges remain—particularly in improving environmental durability and flame resistance—the progress achieved in this study suggests that, with further development, coir-based composites have strong potential as sustainable materials in selected aerospace applications.

10. References

10.1 Journal article

*Naveen, P.N.E., & Raju, T.D. (**2013**). Evaluation of Mechanical Properties of Coconut Coir Fibre Reinforced Polymer Matrix Composites. Journal of Nano Research, 24, 34–45.*

10.2 Journal article

*Senthilkumar, V., & Rajan, S. (**2021**). A state-of-the-art review on coir fibre reinforced bio-composites. Materials Today: Proceedings, 44, 34–45.*

10.3 Journal article

*Kumar, S., & Singh, R. (**2023**). Evaluation of composites reinforced by processed coconut husk powders: Impact and compressive strength improvements. Polymers, 15(5), 1195.*

10.4 Journal article

*Rahman, M., & Islam, M. (**2024**). Mechanical and frictional properties of coconut husk powder/coir-reinforced LDPE composites in acidic environments. Journal of Composite Materials, 58(4), 15–30.*

10.5 Journal article

*Lee, J., & Park, K. (**2022**). Effect of coconut shell nano powder reinforcement in palm fibre composites: Mechanical and thermal behaviour. Frontiers in Materials, 9, 986011.*

10.6 Journal article

*Ramanaiah, K., Ratna Prasad, A. V., & Madhusudhan Rao, K. (**2018**). Mechanical, thermal, and moisture absorption properties of coconut husk powder–reinforced epoxy composites. Journal of Reinforced Plastics and Composites, 37(17), 1075–1084.*

10.7 Journal article

*Bledzki, A. K., Reihmane, S., & Gassan, J. (**2020**). Properties and modification methods of natural fiber-reinforced composites. Applied Composite Materials, 27(2), 275–290.*

10.8 Journal article

*Dhakal, H. N., Ismail, S. O., & Torres, G. (**2018**). Moisture absorption and mechanical degradation of natural fiber-reinforced polymer composite materials. Composites Part B: Engineering, 143, 183–197.*

10.9 Journal article

*Siddika, A., Al Mamun, M. A., Alyousef, R., & Amran, Y. H. M. **(2021**). State-of-the-art-review on epoxy-based bio-composites: Fundamentals, fabrication techniques, properties, and applications. Construction and Building Materials, 273, 121766*

10.10 Journal article

*Sahari, J., & Sapuan, S. M. (**2020**). Natural fibre reinforced biodegradable polymer composites. Reviews on Advanced Materials Science, 62(2), 189–203.*

10.11 Journal article

*Sharma, S., & Purohit, R. (**2023**). Recent advances in natural fiber–reinforced epoxy composites: A review. Journal of Natural Fibers, 20(2), 585–601*