LAYERED HYBRIDISATION OF FLAX AND GLASS FIBRE COMPOSITES FOR AUTOMOTIVE INTERIOR APPLICATIONS

Dr. Chandrasekaran P[1], Karunya A[2]

1. Assistant professor II, Department of Textile Technology, Kumaraguru College of Technology, Coimbatore-49, Tamilnadu ,India

2. Final year M.Tech student, Department of Textile Technology , Kumaraguru College of Technology, Coimbatore-49, Tamilnadu ,India

ABSTRACT

The growing demand for lightweight, sustainable, and high-performance materials in the automotive industry has accelerated the development of hybrid natural fibre composites. In this study, a layered hybridization approach using flax and glass fibres reinforced with epoxy resin is proposed for automotive interior applications. Two laminate configurations are designed and compared: a glass skin laminate (G–F–G–F–F–G) and a graded functionally graded material (FGM) laminate (G–F–G–G–F–G). A total of eighteen specimens is planned, with nine specimens fabricated for each configuration using compression moulding as the consolidation technique. The influence of processing pressure and fibre orientation angles (0°, 45°, and 90°) on the mechanical and thermomechanical behaviour of the composites will be investigated. Mechanical testing including tensile, flexural, and impact tests will be carried out to evaluate strength, stiffness, and toughness. Microscopy analysis will be used to examine fibre distribution, interfacial bonding, and possible defects such as voids and delamination. Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA) will be performed to assess the thermal stability and dynamic mechanical performance of the laminates under conditions relevant to automotive interiors.

Keywords: Flax fibre, Glass fibre, Hybrid composites, Layered hybridization, Compression moulding, Automotive interiors, DMA, DSC

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1. INTRODUCTION

The automotive industry is undergoing a significant transformation driven by the demand for lightweight, energy-efficient, and environmentally sustainable materials. The increasing focus on reducing vehicle weight is directly associated with improved fuel efficiency and lower greenhouse gas emissions. Conventional synthetic fibre composites such as glass and carbon fibre reinforced polymers are widely used in automotive components due to their excellent mechanical performance. However, these materials are associated with high energy consumption during production, limited recyclability, and environmental concerns. As a result, natural fibre reinforced composites have emerged as promising alternatives for semi-structural and interior automotive applications.

Natural fibres such as flax, jute, hemp, and sisal offer several advantages including low density, renewability, biodegradability, cost-effectiveness, and reduced carbon footprint. Among them, flax fibre has attracted considerable attention because of its high specific strength and stiffness compared to other natural fibres. Flax fibre composites exhibit good vibration damping properties and acoustic insulation, making them highly suitable for automotive interior components such as door trims, dashboards, seat backs, and roof liners. However, despite these advantages, flax fibre reinforced composites suffer from limitations such as lower impact resistance, reduced moisture resistance, and lower mechanical strength when compared to synthetic fibre composites.

The performance of hybrid composites strongly depends on fibre arrangement, stacking sequence, and fibre orientation. Layered hybridization enables the tailoring of composite properties by strategically placing different fibres within the laminate.

For automotive interior applications, materials are not only required to possess adequate mechanical strength but also withstand thermal variations inside the vehicle cabin. In tropical climates, cabin temperatures can rise to 70–80 °C, which may lead to softening or degradation of polymer- based materials. Therefore, thermal stability and dynamic mechanical performance are critical parameters in material selection. Techniques such as Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA) are essential to evaluate the glass transition temperature, thermal behaviour, and vibration response of composite materials under service conditions.

In this study, layered hybrid flax–glass fibre reinforced epoxy composites are proposed for automotive interior applications using compression moulding as the fabrication technique. Two laminate configurations are designed: a glass skin laminate with stacking sequence G–F–G–F–F–G and a graded FGM laminate with stacking sequence G–F–G–G–F–G. A total of eighteen specimens will be fabricated, with nine specimens for each configuration. The influence of compression moulding pressure and fibre orientation angles (0°, 45°, and 90°) on the mechanical and thermomechanical behaviour of the composites will be investigated. Mechanical testing, microscopy, DSC, and DMA will be employed to comprehensively assess the suitability of the proposed hybrid composites for sustainable and reliable automotive interior components.

2. LITERATURE REVIEW

Hybrid natural fibre composites have gained significant attention in recent years due to their potential to combine the mechanical advantages of synthetic fibres with the sustainability benefits of natural fibres. Several researchers have reported that flax fibre reinforced composites exhibit good specific strength, stiffness, and vibration damping characteristics, making them suitable for automotive interior applications. However, the inherent limitations of flax fibres, such as lower impact resistance and moisture sensitivity, necessitate hybridization with synthetic fibres like glass to enhance overall performance.

In 2021 a research article on study of mechanical and thermomechanical properties of flax/glass fiber hybrid-reinforced epoxy composites investigated the mechanical and thermomechanical behaviour of flax/glass fibre reinforced epoxy composites and reported that hybrid laminates showed significantly higher tensile and flexural strength compared to pure flax composites. Their study highlighted the synergistic effect between flax and glass fibres improves load transfer efficiency and stiffness. The authors also observed enhanced thermal stability in hybrid composites, making them suitable for applications subjected to temperature variations.

The mechanical durability of pinned hybrid glass–flax composite laminates under salt-fog ageing conditions and reported that the presence of glass fibre layers improved environmental resistance and mechanical retention.

In the year 2023 they further demonstrated that glass skin hybrid laminates exhibited better recovery in mechanical performance after exposure to salt-fog and dry cycles. These findings suggest that glass skin configurations are effective in protecting natural fibre layers from environmental degradation and improving long-term durability.

The mechanical behaviour of hybrid glass–flax–carbon fibre reinforced polymer composites under static and dynamic loading was analyzed. Their results showed that hybridization significantly enhances impact resistance, stiffness, and energy absorption capability compared to single fibre composites. This study emphasized the importance of fibre stacking sequence in controlling stress distribution and damage propagation within laminates.

This paper investigated the influence of alkaline surface treatment on flax/glass hybrid composites and found that improved fibre–matrix interfacial bonding resulted in higher tensile strength, flexural strength, and impact resistance. Their work highlighted that interfacial adhesion plays a critical role in determining composite performance and failure mechanisms.

3. MATERIALS AND METHODS

3.1 MATERIALS

In the present study, woven flax fibre and woven glass fibre are selected as reinforcement materials. Flax fibre is chosen due to its low density, renewability, biodegradability, and good vibration damping characteristics, which are desirable for automotive interior applications. Glass fibre is incorporated to enhance mechanical strength, stiffness, and impact resistance of the composite laminates. The combination of flax and glass fibres in a hybrid configuration is expected to provide balanced performance in terms of sustainability and mechanical reliability.

Epoxy resin is used as the matrix material because of its excellent adhesion to both natural and synthetic fibres, high mechanical strength, good thermal stability, and low shrinkage during curing.

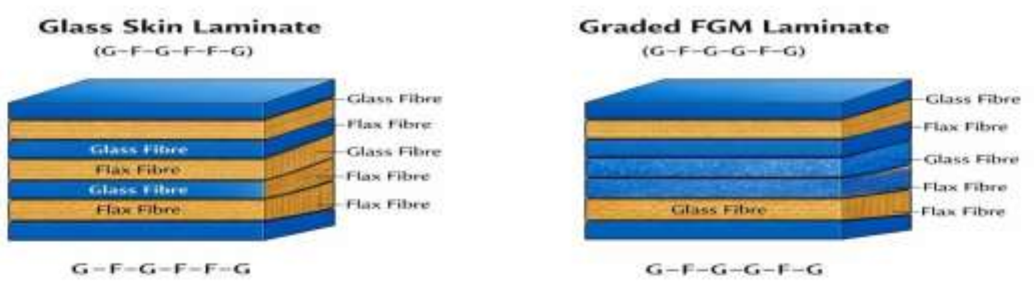
3.2 LAMINATE DESIGN AND STACKING SEQUENCES

Two different layered hybrid laminate configurations are proposed in this work:

1. Glass skin laminate:
   Stacking sequence: G–F–G–F–F–G
   In this configuration, glass fibre layers are placed on the outer surfaces of the laminate, while flax fibre layers are positioned in the core. The glass skin is expected to provide improved surface strength, impact resistance, and protection to the inner flax layers.

2. Graded FGM laminate:
   Stacking sequence: G–F–G–G–F–G
   This configuration represents a functionally graded material (FGM) structure, where the fibre composition changes gradually across the thickness of the laminate. Such an arrangement is intended to improve stress transfer, reduce interlaminar stress concentration, and enhance vibration damping characteristics.

Here,
G = Glass fibre layer F = Flax fibre layer



1.1 Laminate sequence of Glass skin and Graded FGM

4. FABRICATION PROCESS

Compression moulding will be employed as the consolidation technique for the fabrication of all hybrid's composite laminates. This method is selected due to its ability to produce composites with uniform thickness, improved fibre–matrix bonding, reduced void content, and superior surface finish. These characteristics are highly desirable for automotive interior components, where dimensional accuracy, mechanical reliability, and aesthetic quality are important.

Initially, the woven flax and woven glass fibre fabrics will be cut according to the required mould dimensions. The fibres will be cleaned and dried to remove any surface contaminants and moisture, which may otherwise affect the bonding with the epoxy resin. The epoxy resin system will be prepared by mixing the resin and hardener in the recommended ratio to ensure proper curing.

The laminate lay-up will be carried out by arranging the fibre layers in the desired stacking sequence inside the mould cavity. Two different configurations will be prepared:

- Glass skin laminate: G–F–G–F–F–G
- Graded FGM laminate: G–F–G–G–F–G

After placing each fibre layer, a uniform amount of epoxy resin will be applied to ensure complete impregnation. Care will be taken to avoid air entrapment between the layers. Once all the layers are stacked, the mould will be closed and placed inside the compression moulding press. The laminate will then be subjected to controlled temperature and pressure for a specified curing time.

4.1 MECHANICAL TESTING

Mechanical testing will be carried out to determine the strength, stiffness, and toughness of the fabricated laminates.

a) TENSILE TEST

Tensile testing will be performed to evaluate the tensile strength and modulus of the composites. This test reflects the load-bearing capability of the material when subjected to axial forces. For automotive interior design, tensile properties are essential to ensure that panels, trims, and structural inserts can withstand handling loads and operational stresses without failure.

Expected outcome:

- Glass skin laminates are expected to show higher tensile strength due to the presence of glass layers on the outer surfaces.
- Graded FGM laminates may show improved stress distribution and reduced interlaminar stress.

b) FLEXURAL TEST

Flexural testing will be conducted to assess bending strength and flexural modulus. Automotive interior components such as door panels, dashboards, and seat back panels primarily experience bending loads.

Expected outcome:

- Glass skin configuration is expected to perform better in flexural loading due to the high stiffness of glass fibres at the outer layers.
- Graded FGM laminates may demonstrate balanced stiffness with improved energy absorption.

c) IMPACT TESTING

Impact testing will be carried out to study the energy absorption capacity and impact resistance of the composites. This is important for safety and durability in automotive interiors, where accidental impacts and vibrations are common.

Expected outcome:

- Hybrid laminates are expected to show improved impact resistance compared to pure flax composites.
- Flax layers may contribute to better damping and crack arresting behaviour.

4.2 DIFFERENTIAL SCANNING CALORIMETRY (DSC)

DSC will be performed to analyze the thermal behaviour of the composite laminates. It provides information about:

- Glass transition temperature (Tg)
- Thermal stability
- Degree of curing of epoxy resin

For automotive interiors, materials must withstand cabin temperatures ranging from 40–80 °C without deformation or loss of mechanical properties.

Expected outcome:

- A stable Tg well above cabin temperature indicates good thermal reliability.
- Similar Tg values for both laminates confirm consistent curing.

DSC = stability under temperature changes in car interiors.

4.3 DYNAMIC MECHANICAL ANALYSIS (DMA)

DMA will be used to study the viscoelastic behaviour of the composites under dynamic loading conditions. It provides:

- Storage modulus (stiffness)
- Loss modulus (energy dissipation)
- Damping factor (tan δ)

DMA is extremely important for automotive applications because interior components are continuously subjected to vibrations, cyclic loads, and temperature variations.

Expected outcome:

- Glass skin laminates may show higher stiffness (higher storage modulus).
- Graded FGM laminates may show improved damping characteristics due to flax fibre content.

DMA = performance under real driving stress.

4.4 RELEVANCE TO AUTOMOTIVE INTERIOR APPLICATIONS

The combination of mechanical testing, microscopy, DSC, and DMA ensures that the developed hybrid composites satisfy both performance and safety requirements for automotive interiors:

Tab 1.1 Requirements for Automotive interiors:

Test	Automotive Relevance
Tensile, Flexural, Impact	Strength, stiffness, and durability
Microscopy	Quality control and defect detection
DSC	Thermal stability under cabin heat
DMA	Vibration resistance and comfort

5. EXPECTED RESULTS AND DISCUSSION

Since this work is proposed as a pre-experimental research study, the following results are anticipated based on existing literature and the selected laminate design.

5.1 EFFECT OF STACKING SEQUENCE

The stacking sequence is expected to have a significant influence on the mechanical and thermomechanical properties of the hybrid composites.

- The glass skin laminate (G–F–G–F–F–G) is expected to exhibit:
  - Higher tensile and flexural strength
  - Improved surface hardness
  - Better impact resistance

  This is because glass fibres possess higher stiffness and strength, and their placement on the outer layers helps resist bending and tensile stress more effectively.

- The graded FGM laminate (G–F–G–G–F–G) is expected to:
  - Show more uniform stress distribution across layers
  - Reduce interlaminar stress concentration
  - Improve vibration damping performance

  The gradual transition of fibre types through the thickness helps minimize abrupt stiffness mismatch.

5.2 EFFECT OF FIBRE ORIENTATION ANGLE

The fibre orientation is expected to strongly affect anisotropic mechanical behaviour:

- 0° orientation:
  - Maximum tensile and flexural strength
  - Best load transfer efficiency

    - Suitable for components requiring high stiffness
- 45° orientation:
    - Improved shear resistance
    - Better energy absorption
    - Balanced mechanical response
- 90° orientation:
    - Lower tensile strength
    - Higher transverse strength

5.3 EFFECT OF COMPRESSION MOULDING PRESSURE

Increasing moulding pressure is expected to:

- Improve fibre wetting
- Reduce void content
- Enhance fibre–matrix bonding
- Increase mechanical strength and stiffness However,

extremely high pressure may cause:

- Excessive resin squeeze-out
- Fibre distortion
- Reduced interlaminar bonding

Thus, an optimum pressure range is anticipated for best laminate quality.

5.4 MECHANICAL PERFORMANCE

Tab 1.2 Required mechanical properties:

Property	Expected Better Performance
Tensile Strength	Glass skin laminate
Flexural Strength	Glass skin laminate
Impact Resistance	Hybrid laminates > pure flax
Energy Absorption	Graded FGM laminate
Stiffness	Glass skin laminate
Damping	Graded FGM laminate

5.5 MICROSCOPY OBSERVATIONS

Microscopic examination is expected to show:

- Uniform fibre distribution

- Minimal voids at higher pressures
- Strong fibre–matrix adhesion
- Reduced delamination in graded FGM laminates
- Failure modes such as fibre pull-out, matrix cracking, and interlayer separation

5.6 THERMAL BEHAVIOUR (DSC RESULTS)

DSC analysis is expected to indicate:

- A glass transition temperature (Tg) well above 80 °C
- Good thermal stability of epoxy matrix
- Complete curing of resin
- Suitability for automotive cabin environments

5.7 DYNAMIC MECHANICAL BEHAVIOUR (DMA RESULTS)

DMA is expected to reveal:

- Higher storage modulus for glass skin laminates
- Higher damping factor (tan δ) for graded FGM laminates
- Stable viscoelastic behaviour across operating temperature range This confirms:

DMA = performance under real driving stress
DSC = stability under temperature changes in car interiors

5.8 SUITABILITY FOR AUTOMOTIVE INTERIOR COMPONENTS

Based on the expected outcomes:

- Glass skin laminates are ideal for:
  - Door panels
  - Seat backs
  - Structural interior supports
- Graded FGM laminates are ideal for:
  - Dashboard panels
  - Trim components
  - Noise and vibration damping parts

6. CONCLUSION

This study proposes the development and characterization of layered hybrid flax–glass fibre reinforced epoxy composites fabricated using compression moulding for automotive interior applications. Two different laminate configurations, namely glass skin (G–F–G–F–F–G) and graded FGM (G–F–G–G–F–G), are designed to evaluate the influence of stacking sequence, fibre orientation, and moulding pressure on the overall performance of the composites.

The incorporation of flax fibre offers environmental sustainability, reduced weight, and enhanced vibration damping, while glass fibre contributes superior mechanical strength and stiffness. The hybridization of these fibres is expected to achieve an optimized balance between mechanical performance and eco-friendliness, which is highly desirable in modern automotive design.

The proposed experimental methodology involving tensile, flexural, and impact testing will provide insight into the load-bearing capability, stiffness, and toughness of the laminates. Microscopy analysis will ensure quality assessment by examining fibre distribution, bonding, void content, and delamination behavior.

It is anticipated that the glass skin laminates will exhibit higher tensile and flexural strength due to the placement of glass fibres on the outer surfaces, whereas the graded FGM laminates will demonstrate improved stress distribution and superior damping properties. The variation in fibre orientation angles (0°, 45°, and 90°) and moulding pressures is expected to further influence the anisotropic mechanical behavior and consolidation quality of the laminates.

Overall, this proposed research highlights the strong potential of hybrid flax–glass composites as sustainable, lightweight, and high-performance materials for automotive interior components such as door panels, dashboards, seat backs, and trim structures. The outcomes of this work are expected to contribute to the advancement of eco-friendly composite materials in the automotive sector while maintaining the required standards of safety, durability, and thermal stability.

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