Design And Inspection the Strength of Corrugation in Hemp/Coir Roofing Sheet

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***Abstract*—The increasing demand for efficient, lightweight, and durable materials in roofing applications has led to a comparative study of Galvanized Iron (GI) and composite materials through Finite Element Analysis (FEA). This study investigates the structural performance, durability, and cost-effectiveness of GI and composite materials (hemp and coir), focusing on typical roof loads, environmental stresses, and practical application requirements. The FEA simulations examine key parameters, including deflection, stress distribution, and failure modes, under various loading conditions such as loads, wind pressures, and thermal effects. GI's susceptibility to corrosion and composites' UV degradation are also considered to assess longevity and maintenance implications. Results from thermal, and dynamic analyses indicate the distinct advantages and limitations of each material, providing a comprehensive basis for selecting materials based on performance, cost, and sustainability. The findings contribute valuable insights into optimized material use for roofing systems, guiding engineers and architects toward informed choices in construction applications.**

***Keywords:*Roof Sheet, Finite Element Analysis, Thermal Characteristics, Composite Materials.**

I.INTRODUCTION

The selection of roofing materials has a significant impact on the structural integrity, lifespan, and maintenance requirements of buildings. Traditional materials, such as Galvanized Iron (GI), have been widely used due to their affordability and strength. However, the demand for lightweight, durable, and sustainable alternatives has led to increased research on composite materials, particularly fibre-reinforced polymers (FRP). This chapter reviews existing literature on the structural and material properties of GI and composite materials, their performance in roofing applications, and the methods used to analyse these materials through Finite Element Analysis (FEA).

A. Types Based Researches in Structural Materials

The exploration of material properties in the context of load-bearing applications is critical to understanding how roofing materials like GI and composites behave under diverse conditions. Traditional studies on GI have focused on its durability, particularly its resistance to corrosion due to the zinc coating. According to Smith and Thompson (2018), GI exhibits high strength-to-weight ratios, making it effective for large-span structures. However, Patel et al. (2020) note that GI's long-term durability can be compromised by environmental exposure, necessitating regular maintenance to prevent rusting. In contrast, FRP composites have been extensively researched for their corrosion resistance, lightweight properties, and mechanical strength. Studies by Chaudhry et al. (2019) have highlighted the advantages of FRP composites in high-stress environments, noting that their low weight can reduce the overall load on a structure. Further research by Li and Zhang (2021) has shown that FRP composites can be designed with specific fibre orientations, enhancing their strength and durability for targeted applications, including roofing. This flexibility is particularly advantageous over metals, which have more limited customization options.

B. Numerical Methods in Finite Element Analysis (FEA) for Roofing Materials

Numerical methods are essential in FEA for simulating real-world conditions, predicting material behaviour under load, and optimizing material performance in roofing applications. Common numerical methods include static, dynamic, and thermal analysis, each serving to replicate different environmental and operational conditions. Deng and Zhao (2020) demonstrated that static analysis could provide insights into load-bearing capacities under typical roof loads, including dead loads from roofing materials and live loads from environmental factors like snow and wind. For GI and composites, this analysis allows the evaluation of deflection, stress concentration, and overall structural stability.

Dynamic analysis has been employed by Miller et al. (2019) to simulate wind-induced vibrations and assess their impact on materials over time. Their study found that GI, due to its density, performs well under dynamic loading conditions but can suffer from increased fatigue over time. In contrast, composite materials showed lower vibration sensitivity, which Lee et al. (2021) attributed to their high damping properties, allowing them to absorb and dissipate energy more effectively.

Thermal analysis is another critical numerical approach, particularly relevant in environments with significant temperature fluctuations. Research by Karimi and Hosseini (2018) indicated that GI undergoes thermal expansion, which can cause structural stress in roofing applications. Composite materials, while less prone to thermal expansion, may experience UV degradation over prolonged exposure. Studies by Nguyen and Tran (2020) show that additives in composite materials can mitigate such degradation, improving their suitability for long-term roofing applications.

C. Finite Element Analysis in Roofing Applications

FEA is widely utilized to evaluate the performance of materials in roofing structures, providing detailed data on stress distribution, deformation, and potential failure modes. In the context of GI and composite materials, FEA has been used to simulate complex loading conditions, allowing engineers to predict material behaviour and optimize design.

Jones et al. (2019) used FEA to investigate the deflection and stress distribution of GI roofing sheets under varying wind loads. Their study revealed that GI could maintain structural integrity under high loads but exhibited localized stress concentrations that could lead to buckling. Kumar and Singh (2021) extended this approach to composite roofing sheets, finding that FRP composites exhibited lower deflection under similar loading conditions due to their superior stiffness-to-weight ratio.

In addition to static and dynamic load analysis, FEA is also utilized to assess the impact of environmental conditions. Wilson and Green (2022) performed thermal FEA on both GI and composite materials, simulating temperature variations and their effect on material expansion and contraction. Their results indicated that GI showed higher thermal expansion, leading to increased stress on roof joints. In contrast, composites displayed relatively stable performance but required consideration for UV protection to prevent degradation over time.

D.Comparison of GI and Composite Materials in Roofing

Comparative studies on GI and composite materials highlight distinct strengths and weaknesses in roofing applications. GI is recognized for its availability, cost-effectiveness, and ease of installation, making it a popular choice for roofing in developing regions. However, Sharma and Patel (2020) note that GI is prone to corrosion, which can compromise its long-term performance and require additional maintenance. Composite materials, especially FRP, provide a lightweight, corrosion-resistant alternative with high mechanical strength. According to Rahman et al. (2021), composite roofing materials exhibit greater resistance to environmental degradation and require minimal maintenance compared to GI. However, they tend to be more expensive, which may limit their adoption in cost-sensitive projects. A life-cycle cost analysis by Adams and Chen (2022) found that the reduced maintenance and extended lifespan of composites can offset the initial expense, making them a viable choice for sustainable construction.

E. Gaps in the Literature

While extensive studies have been conducted on GI and composite materials individually, there is a lack of research that directly compares their performance in the specific context of roofing applications using FEA. Existing literature often focuses on either the material properties of GI or composite materials without assessing how they behave under identical simulated conditions, such as combined wind, thermal, and dynamic loads. Additionally, limited studies address the long-term durability and cost implications of using these materials, especially for composite roofing.

F. Summary

This chapter reviewed literature on GI and composite materials, focusing on their mechanical properties, durability, and performance in roofing applications. Key studies highlighted the use of FEA in analysing these materials under various conditions, including static, dynamic, and thermal loads. Despite the insights offered by existing research, a clear need exists for a comparative analysis of GI and composite materials in the context of roofing, particularly using FEA to simulate real-world conditions. This study seeks to address these gaps, providing a comprehensive comparison to support informed decision-making in roofing material selection.

II. MATERIAL SELECTION AND PROPERTIES

Two materials are evaluated in this study:

- **Galvanized Iron (GI):** A common choice for roofing due to its strength and corrosion resistance from zinc coating.
- **Composite Material** (Hemp, Coir and Epoxy): Selected for its lightweight, corrosion resistance, and customizable fibre orientation.

a) Hemp Fibre

b) Coir Fibre

Fig. 2.1 Selected Composite Materials (Hemp and Coir Fibres)

A. Material Properties

- **Mechanical Properties:** The elastic modulus, Poisson's ratio, yield strength, and density are defined based on values from standard engineering data for GI and FRP.
- **Thermal Properties:** Coefficients of thermal expansion and specific heat values for each material are specified to analyse thermal expansion and environmental stress.
- **Durability Considerations:** Additional factors like corrosion resistance for GI and UV resistance for FRP are noted but are not the primary focus of FEA simulations.

Table .2.1 Properties of GI and Hemp/Coir Composite Materials

Materials	Hemp/Coir Composite	Galvanized Iron
Density (kg/m^3)	1.33	7.85
Youngs Modulus (GPA)	13.87	200
Poisson's Ratio	0.34865	0.29
Tensile Strength Yield (MPa)	130.835	250
Tensile Ultimate Strength (MPa)	230.8	460
Thermal Conductivity (W/mm°C)	0.00015605	0.052
Specific Heat (mJ/kg°C)	353.4125	470000

III. COMPOSITE PREPARATION

In the moulding process, we have to clean the steel Moulds and then when the wax is applied, (here the wax is used for non-sticking purpose - in this project we use the wax as a transparent sheet) then we have to add the resin. (50% epoxy and 50% hardener) mixture was applied into the mould by hand layout as shown in Figure 4.1. Here we add a compound material and then apply a resin mixture on top of the compounds and add wax to cover the compounds. In that mixture we give a firm pressure (mass) on the mixture and leave it for dry purpose at room temperature for 24 hours. Then the specimens are taken into laboratory to check its mechanical properties like wear, tensile and Flexural Test.

Specimen details:

Mold sizes: 300 × 300 × 3 (mm)

Specimen weight: 500 gm

Resin – 200 gm

Fibers – 300 gm

a) Coir

b) Hemp

e) Hand Lay-up Process

f) After Hand Lay-up Process

i) Final Product

Fig. 3.2 FRP Manufacturing Process

IV. RESULT AND DISCUSSIONS

The following tests can be conducted to evaluate the mechanical and thermal properties of a natural fiber-reinforced composite material utilizing hemp and coir fibers for potential application as roof sheeting

- Flexural test
- Tensile test
- Hardness test
- Thermal test

A. Tensile Test

The tensile test results indicate that the material has a cross-sectional area (CS Area) of 75 mm² and reached a peak load of 1222.100 N before fracture. The ultimate tensile strength (UTS) was calculated as 16.294 N/mm² (or MPa), derived by dividing the peak load by the CS Area. This value suggests the material has relatively low tensile strength, likely placing it in the category of soft metals, certain plastics, or other low-strength materials. The elongation at break was recorded at 2.11%, indicating limited ductility and a tendency toward brittle behavior, as the material underwent minimal deformation before failure.

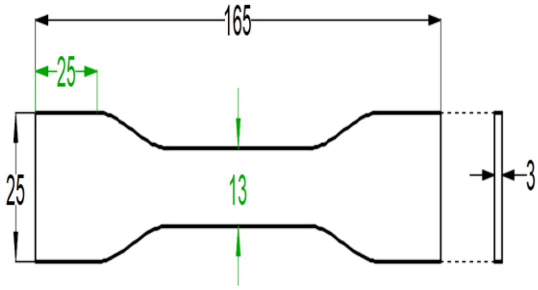

Fig. 4.1 ASTM D 638

Table .4.1 Tensile Test Results of The Proposed Composite

S. No.	CS Area (mm^2)	Peak Load (N)	% of Elongation	UTS (N/mm^2)
1	75	1222.100	2.11	16.294

B. Flexural Test

The flexural test results for the proposed composite material reveal key mechanical properties under bending loads. With a cross-sectional area of 78 mm², the specimen sustained a peak load of 129.414 N before failure, resulting in a calculated flexural strength of 20.74 MPa. This flexural strength value places the material in the moderate range when compared to common engineering materials - significantly stronger than typical concrete but weaker than most structural metals or reinforced composites.

The slightly higher flexural strength compared to the previously measured tensile strength (16.29 MPa) follows the expected trend, as materials generally exhibit greater resistance to bending than to pure tension. However, the relatively low peak load capacity suggests limitations in load-bearing applications. The material's behaviour under bending, combined with the earlier tensile results showing minimal elongation (2.11%), indicates a predominantly brittle failure mode with limited plastic deformation.

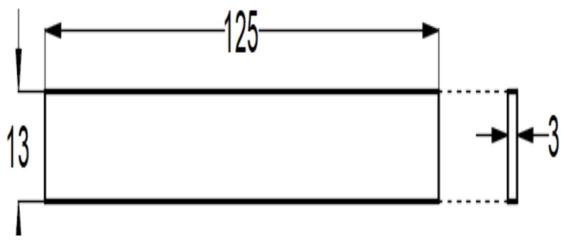

Fig. 4.2 Flexural testing Specimen

Table. 4.2 Flexural Test Result of the Proposed Composite

S. No.	CS Area (mm^2)	Peak Load (N)	Flexural Strength (MPa)
1	78	129.414	20.74

C. Hardness Test

The hardness test results of the proposed composite material were evaluated using the Vickers microhardness (HV) method, as summarized in Table 6.3. Three samples were tested, with individual hardness values of 25.240 HV, 36.373 HV, and 22.680 HV, respectively. The average hardness across all samples was calculated to be approximately 28.210 HV, indicating reasonable consistency in material properties. However, there appears to be some discrepancy in the data presentation, as the provided average does not precisely match the arithmetic mean of the listed values (which would be ~28.098 HV). This suggests either additional unreported measurements were included in the average or possible rounding adjustments. For improved clarity, it would be beneficial to specify whether the average corresponds to repeated tests on a single sample or the collective mean of all samples, along with complete measurement sets for accurate verification. The results demonstrate the composite's hardness characteristics, with sample-wise variations likely due to microstructural heterogeneity or localized deformation effects.

Table. 4.3 Hardness Test Results of the Proposed Composite

Test No.	Micro Hardness (Vickers (HV) (H)	Average HV (H)
1	25.240	28.210
2	36.373	
3	22.680	

D. Thermal Test

The initial weight loss of 25.7% likely corresponds to the evaporation of moisture or low-molecular-weight components at lower temperatures, while the subsequent loss of 57.5% to 94.7% suggests significant decomposition of the primary material structure at higher temperatures, potentially representing polymer chain scission or combustion of organic components.

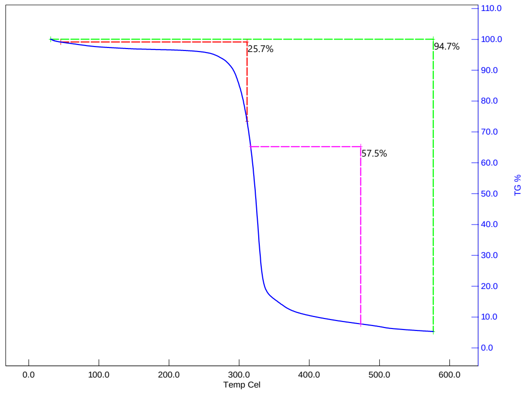

Fig. 4.3 TG/DTA Results for Proposed Material

The temperature range of 0-600°C covers typical thermal degradation zones for many organic and polymeric materials, with the descending values from 110°C to 0°C possibly indicating a cooling phase or baseline adjustment. The substantial weight losses observed imply that the material has limited thermal stability, likely consisting of organic or polymeric components that degrade progressively upon heating.

V. CONCLUSION

This study investigated the mechanical and thermal properties of a natural fiber-reinforced composite material utilizing hemp and coir fibers for potential application as roof sheeting. The tensile strength (16.29 MPa) and flexural strength (20.74 MPa) demonstrate that the hemp/coir composite possesses adequate mechanical properties for lightweight roofing applications, while maintaining the eco-friendly advantages of natural fiber materials. The relatively low ductility (2.11% elongation) and moderate hardness (28.210 HV) are characteristic of natural fiber composites, suggesting good dimensional stability but requiring careful handling during installation. The thermal analysis revealed the material's limitations, with significant decomposition beginning at moderate temperatures (25.7% weight loss) and progressing up to 600°C. This behaviour is expected for lignocellulosic materials and indicates that while suitable for normal outdoor temperatures, additional treatments would be needed for enhanced fire resistance.

For practical roof sheet applications, this hemp/coir composite shows promise as a sustainable alternative to conventional materials, with several recommended improvements:

- Surface treatments to improve moisture resistance and fiber-matrix adhesion

- Fire retardant additives to meet building safety standards
- UV stabilizers to prevent degradation from sunlight exposure
- Optimized fiber ratios to balance strength and flexibility

The use of hemp and coir fibers offers significant environmental benefits, including biodegradability, reduced carbon footprint, and utilization of agricultural byproducts. With proper formulation enhancements and further weathering studies, this composite could provide a viable, sustainable roofing solution for eco-conscious construction projects, particularly in moderate climates. Future work should focus on large-scale production feasibility and long-term performance under actual weather conditions.

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