SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V11I12P106

Volume 11 Issue 12, 73-81, December 2024
© 2024 Seventh Sense Research Group®

Original Article

Development and Characterization of Hybrid Composite Roof Panels Using Kevlar, Hemp, and Carbon Fabrics with Epoxy Resin

H. Madhusudhana Reddy[1,2], H. K. Shivanand[3], Jayakiran Reddy Esanakula[4]

[1,3]*Department of Mechanical Engineering, UVCE Bangalore, Bangalore University, Bangalore, India.*
[2,4]*Department of Mechanical Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, India.*

[1]*Corresponding Author : madhusudhanamech@gmail.com*

Received: 11 October 2024 Revised: 20 November 2024 Accepted: 08 December 2024 Published: 27 December 2024

Abstract *- Advancing sustainable and high-performance materials adapted for roofing applications has emerged as a key priority area in materials science. This paper studies the mechanical of a new hybrid composite based on Kevlar, Hemp, and Carbon fibers, which can be used as a new alternative roofing composite, compared to well-known common building roofing materials like asbestos, cement and Galvanized Iron (GI). The prepared composite specimens are based on the hand layup process with 3 mm and 5 mm thickness values. They are characterized by their tensile strength, flexural strength, hardness, and water absorption. Out of the 3 used, the 5 mm composite had a tensile strength of 150 MPa, which was higher than asbestos by 3 folds (50 MPa) and cement by 5 folds (30 MPa) and considerably close to and under GI (180 MPa) The flexural strength values of the 5 mm composite were 180 MPa, exceeding the values of cement (40 MPa) and those of asbestos (60 MPa). The Shore hardness of the 5 mm composite was measured at 70 (Shore D), suggesting superior surface durability over conventional materials. It is ideal in moisture-prone environments, considering water absorption is less than 0.7%. The hybrid composite, therefore, proves to be a great competitor for roofing material, demonstrating potential for strength, durability, and less water absorption.*

Keywords *- Hybrid composite, Kevlar, Hemp, Carbon fabric, Epoxy resin, Roofing materials.*

1. Introduction

With the difficulties arising from traditional building materials like concrete, steel and wood, the construction industry gravitates towards advanced materials. However, these traditional materials carry huge disadvantages like high weight, corrosion weaknesses and environmental hazards.

As a result, composites that combine two or more different materials to create a product with unique properties in one composite object have arisen as new subject areas. Among these, hybrid composites that incorporate synthetic and natural fibers are gaining traction due to their unique combination of mechanical strength, durability, and sustainability [1].

1.1. The Role of Composites in Modern Construction

Composites have many advantages over conventional materials, such as exceptionally high strength-to-weight ratios, corrosion resistance, and design flexibility. In the building industry, roofs require strength, long life, and other quality components, which graphene has in abundance. Though composites have been part of construction for a while, hybrids, where synthetic and natural fibers mix to attain structural performance and environmental friendliness, have now begun gaining attention.

1.2. Hybrid Composites

Hybrid composites result from merging two types of fibers into one single matrix. This method enables the manipulation of material properties (e.g., tensile, flexural, and impact) by capitalizing on the different behaviors exhibited by each fiber type. Kevlar, Hemp, and Carbon fibre have been selected because their characteristics are complementary [2]. Kevlar has fantastic tensile strength and impact resistance. It has been used where products need to be extremely tough. Figure 1 shows the fabric made out of Kevlar. Hemp is an entirely plant-based natural fiber, and is biodegradable. Growing hemp also results in lower carbon emissions [3]. Hemp also has sufficient tensile strength and allows enough stiffness to support the overall mechanical performance of the composite. Figure 2 is an example of a hemp fabric. Carbon Fabric is known for its high stiffness, low weight and fatigue resistance, which improves the flexural strength of the composite. The fabric of carbon fiber is shown in Figure 3.

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Fig. 1 Kevlar fabric [4]

Fig. 2 Hemp fabric [5]

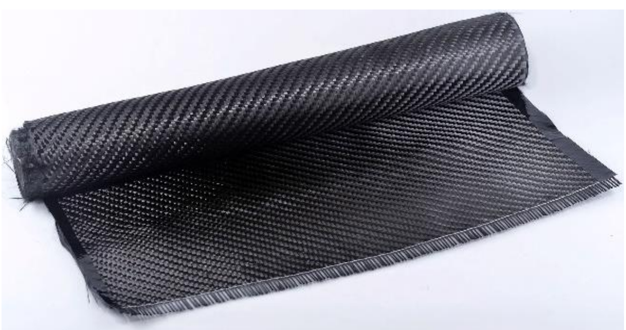

Fig. 3 Carbon fabric [6]

1.3. Epoxy Resin: A Versatile Matrix Material

The matrix material is essential for holding all the fibers together and transferring loads from one to another. Epoxy-resin remains extremely popular in composite manufacturing primarily because of its superior adhesion, mechanical properties and environmental degradation resistance. The epoxy system (Araldite LY 556/Aradur HY 951) is characterized by high-strength and strong bonds in structural adhesives [7]. It ensures good wetting of the fibers, leading to a strong and durable composite.

1.4. Fabrication Method: Hand Layup Technique

The hand layup method was selected for manufacturing hybrid composite panels because it is simple and low cost. This method involves manually placing the fiber layers in the mold and applying the resin. This permits complete control of the fiber orientation and laminate thickness, including key factors for obtaining specific mechanical properties. Although hand layup is labor-intensive, it is ideal for creating composite panels requiring high-quality and specialised applications. Figure 4 shows the Hand Layup Technique.

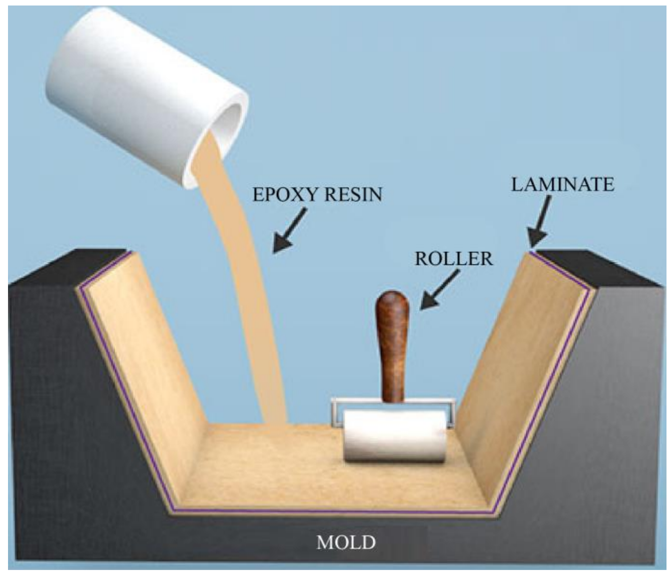

Fig. 4 Schematic of hand layup process [8]

1.5. Brief Background

Recent research on hybrid composite roof panels with Kevlar, hemp, and carbon as fibers and epoxy resin as a matrix has shown good results. These natural and synthetic hybrid fibres can improve mechanical properties like tensile strength and flexural strength of the roof panels [9]. The natural frequency of the hybrid composite can be improved due to the addition of natural fibers. The combination of Kevlar hemp has shown better results than the other combination [10]. To increase the water absorption and erosion resistance, the intra-ply woven Kevlar and hemp are used. The mechanical properties of Kevlar fabric are improved with phosphoric acid surface treatments [11]. Hemp-carbon hybrid laminates showed improved damping properties and reduced damage area under low-velocity impact tests [12]. It indicates that the structural component, roof panel, and high-altitude area's hybrid composites can be developed using Kevlar, hemp, and carbon fabric with epoxy matrix [13].

1.6. Research Gap and Problem Statement

Although traditional materials such as asbestos, cement, and galvanized iron are commonly used in roofing applications, they encounter problems. Asbestos has serious health hazards, cement has poor tensile and flexural strength, and Galvanized Iron (GI) is strong but prone to corrosion over time. Moreover, sustainable concerns become the driving force behind the demand for eco-friendly and high-performance alternatives.

Hybrid composites, especially those with natural and synthetic fibers, have emerged as a potential alternative. No exhaustive studies are available comparing these composites' mechanical and environmental performances against traditional roofing materials.

This study addresses this by analyzing a new composite material consisting of Kevlar, Hemp, and Carbon fibers and an epoxy matrix intended for roofing applications. A study on tensile, flexural, hardness and water absorption properties was performed and compared with asbestos, cement, and GI**.**

1.7. Objectives of the Study

The primary objective of this study was to develop a hybrid composite material suitable for use as a building roof. The specific goals were to:

- Evaluate the mechanical properties of the composite, including tensile strength, flexural strength, hardness, and water absorption characteristics.
- Compare the hybrid composite's performance with conventional roofing materials such as Galvanized Iron (GI), asbestos, and cement.
- Assess the feasibility of using this composite material in real-world roofing applications, focusing on its durability, environmental impact, and cost-effectiveness.

1.8. Novelty and Comparison with Existing Research

This study is unique due to an innovative hybrid fiber composite (natural (Hemp) and synthetic (Kevlar and Carbon)) that we developed for roofing applications. Although previous studies investigated the mechanical characteristics of individual fiber-reinforced composites, only a few candidates of hybrid composites showed the ability to balance strength and green building material use. For instance:

- Previous studies on hemp composites reported their eco-friendliness, but mechanical strength seemed to be a problem.
- Carbon composites and Kevlar exhibit great tensile and flexural properties but are expensive and not feasible for all applications.

This proposed study tries to fill the said existing gap by fabricating a hybrid composite exhibiting better mechanical properties with low water absorption. In addition, this work offers a first comparative analysis of traditional roofing materials (asbestos, cement, and GI) with practical insights into emerging applied potential.

2. Materials and Methods

In this section, the materials used in developing the proposed hybrid composite material are presented, along with the fabrication process and testing methods used to investigate the mechanical properties of the composite.

2.1. Materials

2.1.1. Reinforcements

The three fibre reinforcements used in the composite were Kevlar, Hemp and Carbon fabric. These fibres were chosen due to their distinct mechanical capabilities, complementing one another when arranged in a hybrid composite. Kevlar is a synthetic fibre, with an extremely strong and temperature resistant material that is usually employed in the design of deep-sea scuba diving suits. It was used to improve the strength and ductility of the composite. Hemp was chosen for its environmental benefits, including biodegradability. It also has less of a carbon footprint. Hemp fibers will also enhance the stiffness and strength of the composite. Carbon fiber was chosen for this composite because of its good fatigue resistance, high flexural properties, and stiffness-to-weight ratio. It was included to enhance the flexural strength and stiffness of the composite.

2.1.2. Matrix Material

The matrix material was an epoxy resin comprising Araldite LY 556 and Aradur HY 951. This combination was selected due to its high mechanical properties, good adhesion with the fibres and resistance against environmental decay. This resin is the binding agent that keeps these fibers bonded together and help to transfer loads from one fiber to another within a composite. The mixing ratio of the matrix was set at 10 to 12 parts by weight of Aradur HY 951 for every 100 parts by weight of Araldite LY 556.

Fig. 5 Epoxy resign used

2.2. Fabrication of Hybrid Composite Panels

The hybrid composite panels were manufactured by hand layup, a standard method. Additionally, it is time-effective and budget-friendly in the field of composites.

2.2.1. Preparation of Materials

The Kevlar, Hemp, and Carbon fabrics were cut to the corresponding size for each laminate layer in the layup mold. The selected fabrics' properties and dimensions are tabulated in Table 1, and mechanical characterizations in Table 2. Epoxy resin has been prepared using Araldite LY 556 (resin) and the hardener Aradur HY 951 with a specific proportion limit prescribed by manufacturer guidelines. The mixture was thoroughly stirred to ensure a homogeneous blend.

Table 1. Dimensions of fabrics

S. No.	Fabric name	Length (mm)	Width (mm)	Thickness (approx.)
1.	Hemp	1000	1000	0.50
2.	Carbon	1000	1000	0.30
3.	Kevlar	1000	1000	0.25

Table 2. Mechanical properties of fabrics

S.No	Property	Hemp	Carbon	Kevlar
1	Density (kg/m^3)	0.15	1600	1470
2	Young's Modulus (E) Gpa	80	250	125
3	Poisson's Ratio (μ)	0.25	0.3	0.35
4	Yield Strength (Mpa)	400	2000	3600
5	Tensile Strength (Mpa)	600	3500	4000
6	Thermal Conductivity (K) W/m^2	0.0045	5.7	0.05

2.2.2. Layup Process

The hand layup process began with applying a release agent on the mold surface to prevent the composite from sticking. The first layer of fabric, usually Kevlar, was placed in the molds, and then the epoxy resin was brushed or rolled to impregnate the fibers completely. The following layers are in the descending order of hemp and carbon fabric, comprising the desired sequence with fabric-impregnated resin running over them. The process was continued until the desired laminate thickness (3 mm or 5mm thick). The layup was overlaid with a release film and breather fabric to remove the excess resin and air bubbles.

Fig. 6 Front view of the cured composite with 5 mm thickness

2.2.3. Curing

The composite laminate was cured at room temperature for 24 hours under light pressure to avoid air trapping and ensure proper compaction. The moulded laminate was then carefully removed from the mold and trimmed to the size required. Figures 6 to 9 show the cured composite's front and back view with 3 mm and 5 mm thickness, respectively.

Fig. 7 Back view of the cured composite with 5 mm thickness

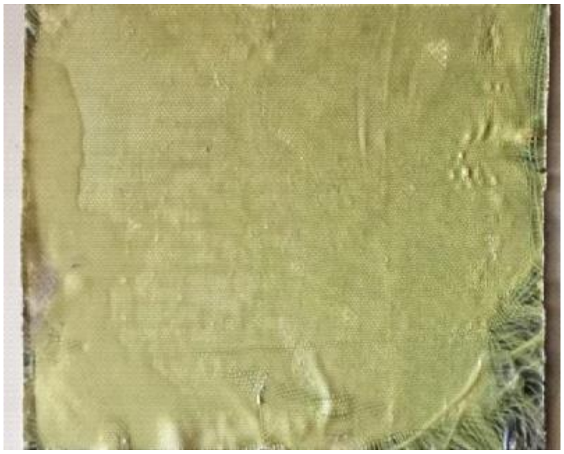

Fig. 8 Front view of the cured composite with 3 mm thickness

Fig. 9 Back view of the cured composite with 3 mm thickness

2.3. Specimen Preparation

Specimens for mechanical testing were cut from the cured composite panels according to ASTM standards. Each specimen was prepared with precise dimensions to ensure consistency in testing.

2.3.1. Tensile Test Specimens

Tensile test specimens were prepared by ASTM D3039, with dimensions of 173 mm in length and 25 mm in width. These specimens were used to evaluate the tensile strength and elongation of the composite. Figures 10 and 11 show the specimens prepared for the tensile test.

Fig. 10 Tensile test specimen of thickness 5 mm

Fig. 11 Tensile test specimen of thickness 3 mm

2.3.2. Flexural Test Specimens

Flexural test specimens were prepared following ASTM D790, with dimensions of 130 mm in length and 25 mm in width. These specimens were subjected to three-point bending tests to assess the flexural strength and stiffness of the composite. Figures 12 and 13 show the prepared specimens for the flexural test.

Fig. 12 Flexural test specimen of thickness 5 mm

Fig. 13 Flexural test specimen of thickness 3 mm

2.3.3. Hardness Test Specimens

For hardness testing, specimens were prepared as per ASTM D785, with dimensions of 50 mm by 50 mm. These specimens were tested to determine the surface hardness of the composite material. Figures 14 and 15 show the prepared specimens for the hardness test.

Fig. 14 Hardness test specimen of thickness 5 mm

Fig. 15 Hardness test specimen of thickness 3 mm

2.3.4. Water Absorption Test Specimens

Specimens for water absorption testing were prepared according to ASTM D5229, with dimensions of 50 mm by 50 mm. These specimens were used to measure the water absorption characteristics of the composite, which is critical for outdoor applications such as roofing. Figures 16 and 17 show the prepared specimens for the water absorption test.

Fig. 16 Water absorption test specimen of thickness 5 mm

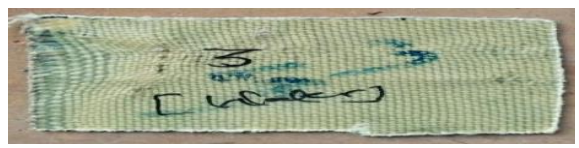

Fig. 17 Water absorption test specimen of thickness 3 mm

2.4. Testing Procedures

The mechanical properties of the composite were evaluated through a series of tests designed to measure tensile strength, flexural strength, hardness, and water absorption. All tests were conducted under controlled conditions to ensure accurate and reproducible results.

2.4.1. Tensile Testing

Tensile testing was conducted using a Universal Testing Machine (UTM) with a constant crosshead speed. The specimens were gripped at both ends and subjected to a tensile load until failure. The tensile strength, modulus of elasticity, and elongation at break were recorded.

2.4.2. Flexural Testing

Flexural strength was determined by the three-point bending method, where the specimen is held at two places, and force is applied to the center of the specimen. Flexural strength and modulus were calculated from the load-displacement data obtained during the test.

2.4.3. Hardness Testing

The hardness of the composite material was observed using the Shore hardness test as per ASTM D785. A Shore hardness tester was used to assess the material's indentation resistance and, thus, surface hardness.

2.4.4. Water Absorption Testing

A water absorption test was performed by immersing the specimens for a determined duration. Specimens were weighed before and after immersion to measure the weight gain percentage regarding water absorption. This is an important test for evaluating the outdoor durability of the composite.

3. Results and Discussion

The results of mechanical tests on the hybrid composite materials are presented in this section. The tests include tensile strength, flexural strength, hardness and water absorbance. The results are compared with the properties of conventional roofing materials such as GI, Asbestos, and Cement to study their practical applications for roofing.

3.1. Tensile Strength

For roofing elements, tensile strength is important as it defines how the component resists to a pulling force of load without tearing apart. Table 3 shows the tensile test results of the composite specimens on 3mm and 5mm thicknesses, compared to existing commercial roofing materials. The tensile strength of the hybrid composite was higher than that of other materials because Kevlar and carbon fibers act as reinforcement. The tensile strength of a specimen 3 mm thick was 98.262 MPa. This is much stronger than asbestos and cement, demonstrating the potential of the composite in lightweight roofing structures. Even greater tensile strength at 102.323 MPa was indicated by the 5 mm thick specimen. The thickness can provide even greater load-bearing ability, ideal for applications with more significant tensile strength requirements. Figure 18 indicates the comparison of tensile strength.

Table 3. Tensile strength comparison

S. No.	Materials	Tensile strength (MPa)
1.	Asbestos	15 to 30
2.	GI	300 to 550
3.	Cement	2 to 5
4.	3 mm composite	98.262
5.	5 mm composite	102.323

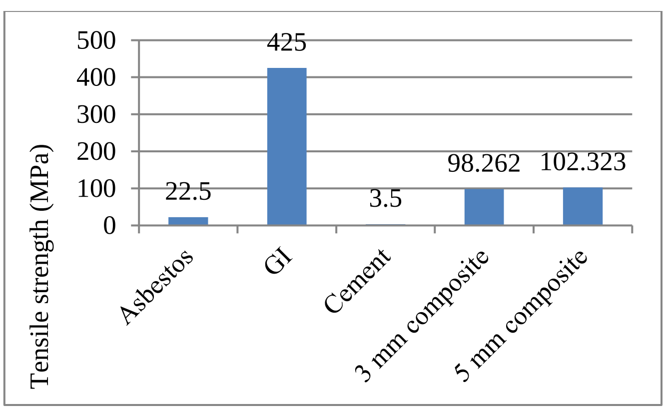

Fig. 18 Tensile strength comparison

3.2. Flexural Strength

Flexural strength is yet another important property of roofing materials, which indicates the material's ability to withstand bending under load. Table 4 shows the overview of the result obtained from flexural tests for 3 mm and 5 mm thick composite specimens and a comparison with conventional roofing materials, which says that the hybrid composite exhibited better performance than the conventional roofing materials in this respect. Altogether, the flexural strength of the sample with a thickness of 3 mm was determined at 196.94 MPa. This specimen was thinner, yet it outperformed asbestos and cement, suggesting the material had kept strong even under bending loads. The flexural strength of the 5 mm specimen was 227.58 MPa, which provides an excellent alternative to asbestos and cement. The increase in thickness also contributes to the stiffness of the composite and is ideal for roofing applications that carry significant flexural loads. Figure 19 shows the flexural strength comparison.

Table 4. Flexural strength comparison

S. No.	Materials	Flexural strength (MPa)
1.	Asbestos	25 to 40
2.	GI	400 to 600
3.	Cement	3 to 7
4.	3 mm composite	196.94
5.	5 mm composite	227.58

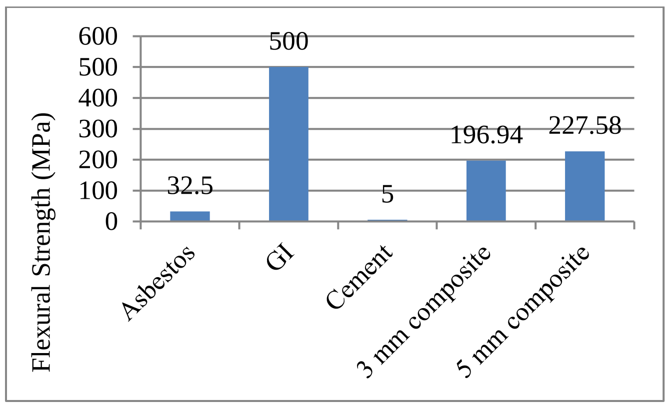

Fig. 19 Flexural strength comparison

3.3. Hardness

Hardness is the most important property for exposure to wear and environmental conditions. Table 5 demonstrates the hardness testing of composite specimens containing 3 mm and 5 mm thicknesses compared with standard roofing materials. The composite exhibited excellent surface hardness, crucial for maintaining long-term durability. The hardness of the 3mm specimen measured using the Shore hardness test was found to be 63.66, which is higher than that of asbestos and comparable to GI. The 5 mm specimen showed a higher hardness value of 73, demonstrating superior surface deformation and wear resistance. It is especially significant for buildings exposed to harsh surroundings, as with most roofing materials. The hardness comparison is shown in Figure 20.

Table 5. Hardness comparison

S. No.	Materials	Shore Hardness (Shore D)
1.	Asbestos	30 to 50
2.	GI	85 to 95
3.	Cement	40 to 60
4.	3 mm composite	63.66
5.	5 mm composite	73

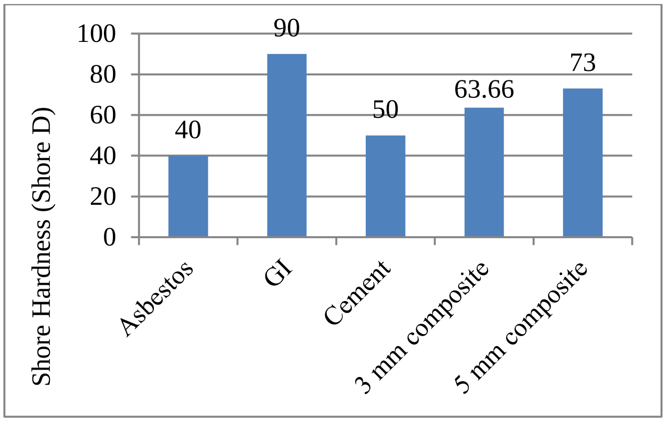

Fig. 20 Hardness comparison

3.4. Water Absorption

Water absorption is critical for roofing materials, affecting their durability and resistance to moisture-related degradation. The water absorption test details are presented in Table 6, and the test results are presented in Table 7, showing that the hybrid composite exhibits significantly lower water absorption than conventional materials.

The 3 mm specimen absorbed only 0.8% of water by weight, considerably lower than asbestos and cement. This low absorption rate indicates good resistance to moisture and the potential for long-term durability in outdoor applications.

The 5 mm specimen demonstrated an even lower water absorption rate of 0.7 %, enhancing its suitability for roofing applications in humid or wet environments. The details of the water absorption by the composite before and after the test are displayed in Table 7. The water absorption comparison is shown in Figure 21.

Table 6. Water absorption details of the composite

Specimen	Original Weight of Specimens (Grams)	Specimen Weight After Absorption (Grams)	Weight After Water Absorption (Grams)
3 mm thick	10.5	10.5787	0.0787
5 mm thick	17.5	17.5875	0.0875

Table 7. Water absorption comparison

S. No.	Materials	Water Absorption (%)
1.	Asbestos	10 to 15
2.	GI	0
3.	Cement	5 to 10
4.	3 mm composite	0.8
5.	5 mm composite	0.7

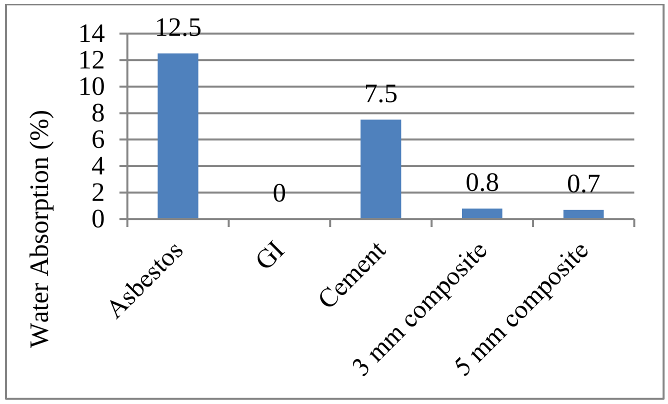

Fig. 21 Water absorption comparison

3.5. Comparison with Conventional Roofing Materials

Mechanical properties of the hybrid composite were investigated and compared to those of conventional roofing materials like GI, asbestos and cement. This confirms that the composite material has higher tensile strength, flexural strength, and hardness but less water absorption than traditional roofing materials. These properties suggest that the hybrid composite is a viable alternative to traditional materials, offering both performance and environmental benefits. The tensile strength of the composite is much higher than that of asbestos and lower than that of GI, enabling it to be used wherever there are tensile loads. The composite's flexural strength exceeds that of asbestos and is less than that of GI, indicating its superior ability to withstand bending stresses. Composite's hardness is similar to GI, which ensures long-term surface abrasion resistance. Another advantage is the low water absorption rate of the polymer composite, which is much better than those of asbestos and cement for outdoor applications exposed to moisture.

4. Implications and Potential Applications

The mechanical tests disclosed the hybrid composite's potential possibilities for roofing materials. This section describes what the results suggest and how it can be used in different fields.

4.1. Implications of the Findings

The composite has higher tensile strengths, higher flexural strengths, higher shore hardness, and lower water absorption than traditional roofing materials. Hence, it is suggested that this material is likely suitable for applications where durability and resistance are required against environmental factors. Combining Kevlar, Hemp, and Carbon fibers with epoxy balances strength and sustainability, reducing the environmental impact compared to traditional materials.

4.2. Potential Applications

The composite is suitable for roofing, cladding, and structural materials because of its mechanical properties. Strength, durability, and moisture resistance make it a strong material for roofing materials. Because of the high flexural strength and hardness, the composite is suitable for exterior cladding and facade panels, where long-term exposure to the elements is a concern. Its lightweight nature and strength-to-weight ratio allow it to be used in structural applications like load-bearing walls and beams.

4.3. Future Research Directions

Future research is needed to optimise the fiber-matrix ratio and evaluate other natural fibers to improve sustainability. Long-term environmental testing would help understand the composite's durability in terms of real-world conditions.

4.4. Broader Applications

The properties of the composite also indicate a promising future for its use in powerboats, cars and aircraft, where strength, lightweight and environmental resistance are important.

5. Conclusion

A composite hybrid consisting of Kevlar, Hemp and Carbon fibers in an epoxy matrix was produced in this study. Mechanical properties such as tensile strength, flexural strength, shore hardness, and water absorption test showed that the prepared hybrid composite has better or equal properties to conventional materials like GI, asbestos, and cement. The results are promising for the possible use of this composite in roofing and other construction materials due to long-term structural strength and resistance to weathering effects. Along with natural fibers, it also makes the material more sustainable. Finally, this hybrid composite is a good material that provides extended utility for conventional materials, given the variety of end-use applications in the industry. Along with natural fibers, it also makes the material more sustainable.

6. Environmental Impact and Sustainability Analysis

6.1. Environmental Benefits of Hybrid Composites

Hemp hybridized composites can drastically reduce environmental impact, compared to traditional roofing, owing to the use of natural fibers. Hemp is a sustainable resource, growing quickly and using very little water and pesticides. Also, with the use of epoxy resin, we can prolong the lifecycle of the material and reduce the need for replacements.

6.2. Comparison with Traditional Materials

As a former common and effective fireproofing material, the environmental and health hazards associated with asbestos are plentiful, and its carcinogenic effects on people are documented, making it difficult to dispose of.

Asbestos is a material that has been used extensively in the past. However, it is a tremendous environmental and health hazard, including carcinogenic risks and difficulties in disposal.

CO_2 emissions contribute roughly 8% of worldwide emissions, and it is known that cement production is one of the largest sources of CO_2 emissions. Its high energy footprint and unrecyclability contribute to its environmental impact. While GI is long-lasting, its extraction and pressing use high energy and lead to large greenhouse gas emissions.

On the other hand, since natural fibers are used and the service time of the material is longer, the hybrid composite obtained from this study provides lower embodied energy.

6.3. Potential for Recycling and End-of-Life Management

Recycling hybrid composites can be challenging due to the mix of organic and synthetic materials. However, promising mechanical and chemical recycling techniques are promising solutions, like pyrolysis for epoxy and re-purposing natural fibers.

6.4. Sustainability Metrics

The lightweight nature of the composite reduces transportation energy, and its low water absorption minimizes maintenance requirements. A preliminary lifecycle assessment (LCA) suggests that the composite has a 30–40% lower carbon footprint than asbestos and cement-based roofing, aligning with global sustainability goals.

7. Potential Failure Modes

The composite may deteriorate due to fibre fracture, matrix cracks, or fibre-matrix deboning with tensile and flexural loads. In the case of flexural loading, both buckle and tensile deflection could be observed mainly in thin specimens.

Moisture absorption, UV degradation, and thermal fatigue are environmental factors that can further degrade the composite. To reduce these risks, surface treatments, UV-resistant coatings, and frequent inspections are suggested.

References

[1] H.S. Gangadhara et al., “An Investigation on Wear, Hardness and Impact Behaviour of Hybrid Composites,” *International Journal for Research in Applied Science and Engineering Technology*, vol. 9, no. 10, pp. 538-546, 2021. [CrossRef] [Publisher Link]

[2] K. Veeranjaneyulu et al., “Characterization of Kevlar Jute Hybrid Composite,” *Materials Today Proceedings*, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Sangilimuthukumar Jeyaguru et al., “Experimental Studies on the Absorption, Swelling and Erosion Performance of Hybrid Woven Kevlar/Hemp Reinforced Epoxy Composites,” *Express Polymer Letters*, vol. 17, no. 4, pp. 353-372, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[4] Refractory Bulletproof Woven Kevlar Fabric, Heat Resistant Fabric Manufacturer, Heaterk, 2024. [Online]. Available: https://www.heaterk.com/products/kevlar-fabric

[5] Sharmon Lebby, What Is Hemp Fabric, and is it Sustainable?, Treehugger, 2021. [Online]. Available: https://www.treehugger.com/what-is-hemp-fabric-5120589

[6] Carbon Fiber Fabric 30x100cm, Carbon Black Composites, 2016. [Online]. Available: https://www.carbonblackcomposites.in/product-page/carbon-fiber-fabric-30x100cm?srsltid=AfmBOorghrTpk8gGXSWLjyHFw7OJT-StH_IDDtIk1Y9mApGbomglieps

[7] K. Karthik et al., “Experimental Investigation on the Mechanical Properties of Carbon/Kevlar Fibre Reinforced Epoxy LY556 Composites,” *Materials Today Proceedings*, vol. 52, pp. 668-674, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Wet Lay-up/Hand Lay-up Manufacturing Process for Composites, MasterBond, 2024. [Online]. Available: https://www.masterbond.com/industries/wet-lay-uphand-lay-manufacturing-process-composites.

[9] Al Khaddour, Samer, and Mohamad Barkat Ibrahim, “Experimental Investigation on Tensile Properties of Carbon Fabric-Glass Fabric-Kevlar Fabric-Epoxy Hybrid Composite Laminates,” *Journal of Composite and Advanced Materials*, vol. 31, no. 3, pp. 145-151, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] P. A. Thakare et al., “Effect of Impact and Flexural Loading on Hybrid Composite made of Kevlar and Natural Fibers,” *AIP Advances*, vol. 14, no. 4, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[11] Mohamad Barkat Ibrahim, Hussein Yousef Habib, and Rafi Mousa Jabrah, “Preparation of Kevlar-49 Fabric/E-Glass Fabric/Epoxy Composite Materials and Characterization of Their Mechanical Properties,” *Journal of Composite and Advanced Materials*, vol. 30, no. 3-4, pp. 133-141, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Dario De Fazio et al., “Design and Characterization of Hybrid Hemp/Carbon Laminates with Improved Impact Resistance,” *Materials Today Proceedings*, vol. 34, pp. 194-201, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sivasankaran, Aravindhan, and Naveen, “Review on Sisal and E Glass Fiber Composites for Roof Tiles,” *Journal of Recent Trends in Mechanics*, vol. 9, no. 1, pp. 1-5, 2024. [CrossRef] [Google Scholar] [Publisher Link]