Experimental Investigation on the Mechanical and Tribological Behavior of Hybrid Natural Fiber and HDPE Reinforced Composite

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***Abstract*—The use of composite materials incorporating natural fibres is gaining traction in engineering fields like automotive, marine, and aerospace due to their advantages, including high specific strength, renewability, non-abrasiveness, cost-effectiveness, and biodegradability. Among the various natural fibres explored as alternatives to glass fibre, banana and kenaf stand out as favourable options due to their low cost, high strength, high aspect ratio, excellent insulating properties, and low thermal conductivity. The purpose of this work is to study the influence of Banana fiber, kenaf fibre, Coir fiber and combined with HDPE same volume of epoxy resin is-70%. But the content of fiber Ratio -1 Banana fiber is -10%, kenaf fiber is-10%, Coir fiber is-5% and HDPE is-5%. In Ratio-2 Banana fiber is -7.5%, kenaf fiber is-10%, Coir fiber is-7.5% and HDPE is-5%. Ratio -3 Banana fiber is -7.5%, Kenaf fiber is-7.5%, Coir fiber is-10% and HDPE is-5%. From this research analysis identified that greater impact energy, tensile strength, and flexural load were produced by a higher banana, kenaf fiber and a lower cotton fibre content. More compressive strength and low percentages of water absorption have been achieved by the equal percentages of banana, cotton fibre and the most amount of cotton fibre.**

***Index Terms*—Natural fiber, Flexural strength, Impact load, Tensile strength.**

I. INTRODUCTION

In the ongoing pursuit of enhanced performance-defined by factors such as reduced weight, increased strength, and lower costs-conventional materials often reach their functional limits. Consequently, researchers, engineers, and scientists are committed to developing either advanced version of traditional materials or entirely new materials. Composites fall into the latter category. Over the past three decades, composite materials, along with plastics and ceramics, have emerged as dominant contenders in innovative material development. Their applications have steadily expanded, consistently breaking into new markets. Present-day composite materials, which range from commonplace items to extremely specialized applications, now make up a sizeable portion of the engineered materials market. While composites are well-established as lightweight materials, the current challenge lies in enhancing their cost-effectiveness. Efforts to achieve this have led to several groundbreaking manufacturing techniques now utilized within the composites industry. Furthermore, the industry has recognized that marketable applications of composites offer far greater business potential than the aerospace sector, particularly due to the vast scale of the transportation industry.

India, blessed with an abundant supply of natural fibers such as bamboo, ramie, jute, sisal, pineapple, coir, and banana, has focused on developing natural fiber composites to unlock value-added applications. These composites are especially suited as wood alternatives in the construction and housing sectors. The Indian strategy for natural fiber composites revolves around two primary goals: conserving forest resources and providing economic benefits to natural fiber cultivators. After addressing the challenges of aerospace applications, advancements in composite materials have increasingly catered to domestic and industrial needs.

Traditional materials like wood and metals have been largely replaced by composites, which are praised for their stiffness, high strength-to-weight ratio, and lightweight nature. Material experts worldwide are now concentrating on natural composites to reduce raw material costs, driving further innovation in this promising field. This research focuses on the preparation of Banana fiber, Kenaf & Coir fibers matrix as an Epoxy resin-based hybrid composites. Further, the mechanical, tribological and water absorption behaviour of the composites are to be investigated. Hence, the collection of information related to the aforementioned work is vital to identify the research gap and planning of research work. This section covers recent studies on the hybrid composites fabricated using natural fibers.

Huyen Bui et al. [2024] conducted a study that encompassed the preparation and characterization of fibers, cutting them to the required length, and creating the mixtures. The process also involved optimizing fiber distribution, as well as monitoring and ensuring the quality of the fiber-reinforced material. The methodology was demonstrated through two examples: a coconut fiber-reinforced mortar (a hardened cementitious mix) and an eco-friendly brick made from sediment and oil palm fibers. Diego M. et al. [2024] examined the characteristics of PALF obtained from plants that were 11 and 18 months old, as well as from the base, middle, and tip of the leaves. The study evaluated Azores PALF's tensile strength, elongation at break, linear density, diameter, and Young's modulus, among other physical-mechanical characteristics. The fibers' chemical makeup and morphological characteristics were further examined using ATR-FTIR, XRD, TGA/DTG, and FESEM. Significant changes were found among fibers collected from different leaf sections, however there were negligible differences in fiber qualities between plant ages.

Taweechai Amornsakchai et.al. [2023] were were incorporated at 10 and 20% wt. levels. After two-roll mill mixing, uniaxially aligned prepreg sheets were compression molded into composites. At 10 wt.%, PALF and flax exhibited virtually the same stress–strain curve. Interestingly, PALF excelled at 20 wt.%, defying its inherently lower tensile properties compared to flax. PALF/PBS reached 70.7 MPa flexural strength, 2.0 GPa flexural modulus, and 107.3 _C heat distortion temperature. For flax/PBS, comparable values were 57.8 MPa, 1.7 GPa, and 103.7 C. Both composites' matrix orientations were identical, according to X-ray pole figures. Ridhwan Jumaidin et al. [2023] The increasing accumulation of non-biodegradable plastics has posed significant environmental challenges, leading to a growing demand for eco-friendly alternatives like thermoplastic starch (TPS). Despite its environmental benefits, Low mechanical strength and high moisture sensitivity are two drawbacks of TPS that limit its usefulness. Through the use of coconut fiber as reinforcement, this study aims to improve the mechanical and thermal characteristics of TPS.

Aifa Mahammad Asri and Nur Liyana et al. [2022] Particles of kenaf, which were obtained from a plantation in Chendor, Cherating, Pahang, ranged in size from 0.5 mm to 2.0 mm. A 2% NaOH solution was used to treat these particles. The particles were bonded together using phenol formaldehyde (PF) glue, which had resin concentrations of 8% and 10%. The purpose of the study was to evaluate the effects of different resin contents on the mechanical and physical characteristics of particleboards made of kenaf. Suresh Gosula et al. [2022] Using a computerized UTM machine in accordance with ASTM guidelines, the mechanical characteristics of recently created composites were experimentally investigated. The mechanical behavior of the composites was examined using a scanning electron microscope (SEM). The results showed that adding jute fiber reinforcement significantly improved the mechanical characteristics of rice straw-jute-coconut-palm fiber composites. Furthermore, the improvements were more noticeable as the amount of jute fiber rose.

Md. Ariful Alam et al. [2022] Polymer composites have emerged as a dynamic and innovative area of research, with a growing emphasis on biodegradable fibers as reinforcements. Given the rapid depletion of petroleum resources and the demand for environmentally sustainable materials, natural fiber composites play a crucial role in addressing ecological concerns. This study developed a composite using glass fiber and rice straw as reinforcements with an epoxy resin matrix, investigating its mechanical properties, including impact and flexural strength. Bains, Sandeep et al. [2021] Burning rice straw in fields has caused pollution, nutrient loss, and negative impacts on beneficial soil microbes, making it a significant environmental problem. This study, carried out at Punjab Agricultural University in Ludhiana, assessed how well rice straw works as a mulch to reduce weeds and increase papaya crop yield and quality.

Sachin G. Ghalme et al. [2021] This study aimed to optimize the proportions of rice husk (RH) and rice straw (RS) to maximize the tensile and flexural strength of polymer composites. Experimental analysis and grey relational methods determined that incorporating 5% RS and 8% RH into bio-epoxy resin yielded a composite with simultaneously enhanced tensile and flexural properties.

Zakia Hussein et al. [2019] Insulation plays a critical role in reducing energy consumption and CO2 emissions throughout the lifecycle of buildings. To support sustainable construction globally, developing ecological insulating materials and evaluating their technical performance is essential. The tensile and compressive strengths, modulus of rupture (MOR), modulus of elasticity (MOE), and thermal conductivity of particleboards derived from agricultural waste were examined in this study. Particleboard density, resin type, resin content, processed rice straw utilization, and waste type (rice straw or flax shives) all had an impact on the attributes.

The following are the main goals of the present study:

1. Fabricating epoxy resin-based hybrid composites reinforced with various fibers, including banana, kenaf, coir, and HDPE, in different ratio percentages.
2. Evaluating the mechanical and tribological properties, such as tensile strength, flexural strength, compressive strength, hardness, and wear behavior.
3. Assessing the water absorption characteristics of the developed composites.
4. Identifying potential applications for the hybrid composites and exploring their practical implementation.

II. MATERIALS AND METHODS

The materials selected for the current study, along with their respective mixture compositions, are as follows:

Materials

Unsaturated polyester resin as the matrix, kenaf fiber, coir fiber, cobalt naphthalate (as the accelerator), methyl ethyl ketotone peroxide (MEKP) as the catalyst, cellophane leather to seal the mold and make it easier to remove the casting, and necessary equipment like a roller, scissors, water, a container, and a mold are among the materials used in this study. The material combination has mentioned in following table 3.1.

Fiber Extraction and Treatment

Coconut shells and kenaf plants were the sources of coir and kenaf fibers, respectively. The kenaf stalks and coconut shells were peeled in order to remove the fibers. The fibers had different physical properties; coir fibers were comparatively short, whereas kenaf fibers were lengthy.

Specimen Fabrication

Hand Lay-Up technique was used to fabricated the specimens. This process involved pouring a measured quantity of resin, mixed with 4% accelerator and 1% catalyst, into a mold. After allowing the mixture to pre-harden for approximately ten minutes, a cellophane leather sheet was placed over it, followed by the mold cover. Pressure was applied using a concrete block for 24 hours to ensure complete curing of the laminate. The cured laminate was subsequently machined to meet ASTM standards for testing. During fabrication, a roller was used to compress each fiber-matrix layer to eliminate trapped air within the specimen.

Cutting Laminates (Std. Sizes)

The fabricated specimens were trimmed into specific sizes required for various tests. This was accomplished using a hacksaw. The output specimen by hand layup method shown in figure 1.

Mechanical Testing of Specimens

The fabricated specimens underwent mechanical testing to evaluate their impact, flexural, and compressive properties. The mechanical characteristics of material hardness, impact strength, tensile strength, compression strength, water absorption and flexural strength respectively.

Table 3.1. Matrix Reinforcement Ratio

Mix Ratio / Specimen ID	R1	R2	R3
Epoxy Resin	70%	70%	70%
	210 gms	210 gms	210 gms
Banana	10%	7.5%	7.5%

Fiber	30 gms	22.5 gms	22.5 gms
Kenaf Fiber	10%	10%	7.5%
	30 gms	30 gms	22.5 gms
Coir Fiber	5%	7.5%	10%
	15 gms	22.5 gms	30 gms
HDPE	5%	5%	5%
	15 gms	15 gms	15 gms

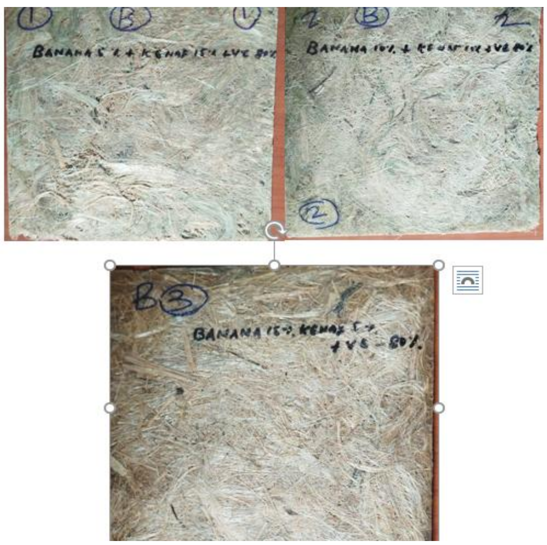

Fig 1. Composite Specimen

III. RESULTS AND DISCUSSION

Hardness test findings show that the maximum kenaf fiber (B2) and the medium banana and coir fiber have a maximum hardness strength of about 75 HRM, followed by R3 ratio results that shows 72 HRM (Figure 2). However, the smallest amount of hardness (66 HRM) is induced by the largest percentage of banana and kenaf coir fiber.

Similarly, the results of the tensile test showed that, in comparison to other fiber ratios, the maximum proportion of banana and kenaf minimum coir fiber results in a higher average tensile strength of 11.5 N/mm^2. The figure 3 represents the variance of tensile stress graphically.

The maximum impact load of 0.90 joules is shown by the reading of the impact test investigation, which shows a higher percentage contribution of banana and kenaf fiber and a lower percentage of coir fiber. The result of the equal weight banana, kenaf, and lower-level percentage coir ratio fiber is 0.80 joules. Higher coir fiber percentages, however, produced a minimum impact load of 0.75 Joules (figure 4).

Figure 5 represents the effects of flexural strength test indicate that the maximum flexural strength of almost 0.08 KN/mm^2 is achieved with banana and kenaf fiber and a lower percentage of coir fiber. This is followed by equal weight percentages of banana and kenaf fiber ratio and higher percentages of coir fiber, which yield 0.06 KN/mm^2.

According to the results of the compressive load test (figure 6), the maximum compressive load of around 0.14 KN is displayed by reading lower percentages of banana kenaf and higher percentages of coir fiber. This is followed by equal minimum weight percentages of banana, coir and maximum kenaf fiber ratio results, which show 0.10 KN.

All hybrid fiber composites water absorption were evaluated with the periodical gap 24 hours for the 3 days. According to the water absorption test results, the more coir fiber present, the lower the water absorption, which is 18%. The greatest water absorption, on one another present, is 47% for higher weight percentages of kenaf fiber. The figure 7 shows the variance of water absorption range for proposed specimens.

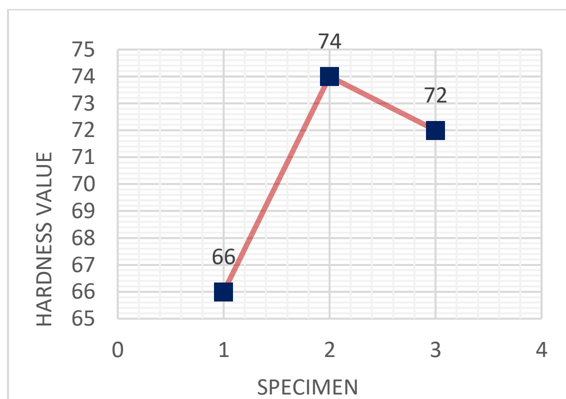

Fig 2. Hardness Test Comparison

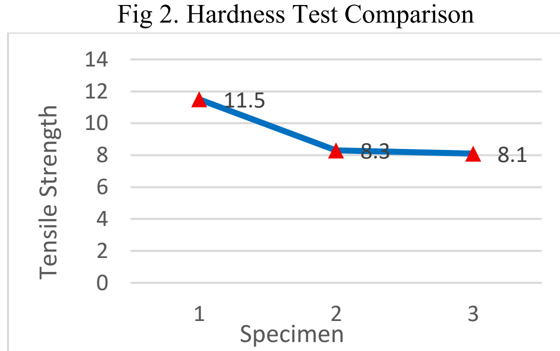

Fig 3. Comparison of Tensile Stress

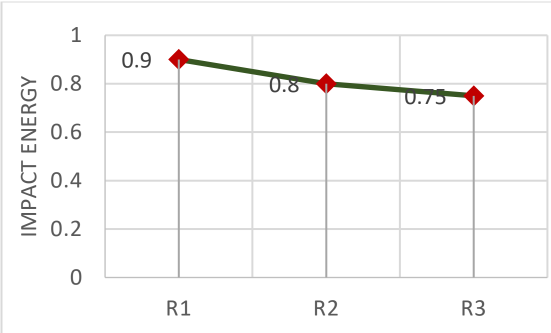

Fig 4. Effects of Impact Test

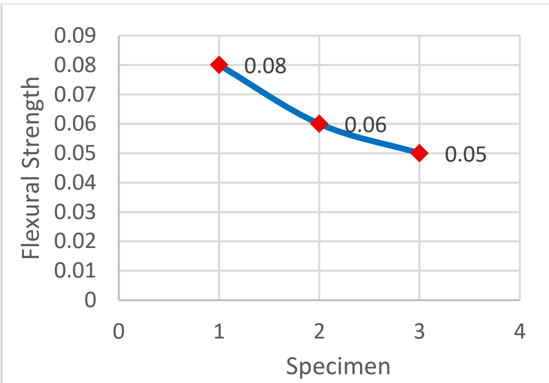

Fig 5. Flexural Test Results

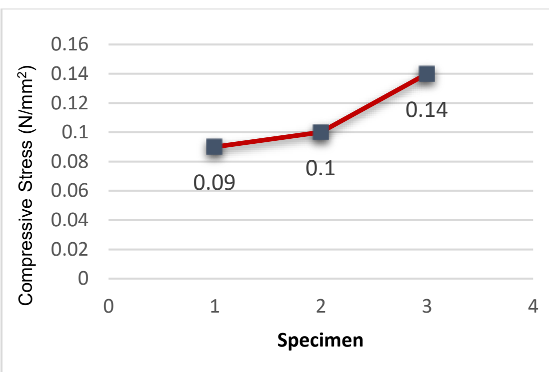

Fig 6. Compression Test Result Comparison

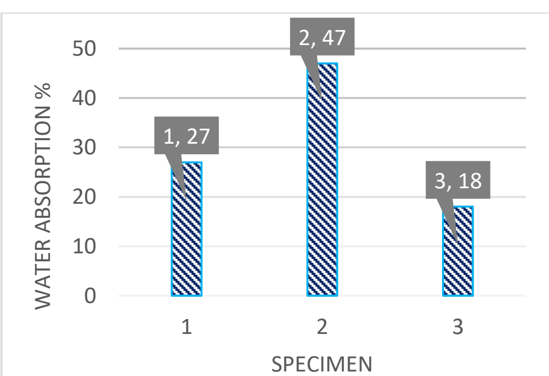

Fig 7. Water Absorption Results

V. CONCLUSION

This project successfully developed hybrid natural fiber composites, and their mechanical properties-including tensile, impact, flexural, and compressive strengths-were examined and analyzed. The study found that the compression molding technique is an efficient way to create hybrid natural fiber-reinforced composites. The composite samples proved suitable for evaluating mechanical properties, particularly tensile strength. The findings demonstrate the potential of hybrid fibers as a reinforcement material in epoxy matrix composites. Additionally, natural fiber-reinforced (NFR) composites require a higher fiber content for equivalent performance, thereby reducing the use of the more environmentally harmful base epoxy resin. The following points were concluded from the experimental research analysis.

- Hardness test findings show that the maximum kenaf fiber (B2) and the medium banana and coir fiber have a maximum hardness strength of about 75 HRM, followed by R3 ratio results that shows 72 HRM. However, the smallest amount of hardness (66 HRM) is induced by the largest percentage of banana and kenaf coir fiber.
- The results of the tensile test showed that, in comparison to other fiber ratios, the maximum proportion of banana and kenaf minimum coir fiber results in a higher average tensile strength of 11.5 N/mm^2.
- The maximum impact load of 0.90 joules is shown by the reading of the impact test investigation, which shows a higher percentage contribution of banana and kenaf fiber and a lower percentage of coir fiber. The result of the equal weight banana, kenaf, and lower-level percentage coir ratio fiber is 0.80 joules. Higher coir fiber percentages, however, produced a minimum impact load of 0.75 Joules.
- The results of the flexural load test indicate that the maximum flexural load of almost 0.08 KN/mm2 is achieved with banana and kenaf fiber and a lower percentage of coir fiber. This is followed by equal weight percentages of banana and kenaf fiber ratio and higher percentages of coir fiber, which yield 0.06 KN/mm^2.
- According to the results of the compressive load test, the maximum compressive load of around

0.14 KN is displayed by reading lower percentages of banana kenaf and higher percentages of coir fiber. This is followed by equal minimum weight percentages of banana, coir and maximum kenaf fiber ratio results, which show 0.10 KN.

- According to the water absorption test results, the more coir fiber present, the lower the water absorption, which is 18%. The greatest water absorption, on one another present, is 47% for higher weight percentages of kenaf fiber.

Finally concluded from the experiment that greater impact energy, tensile strength, and flexural load (B1) are produced by a higher banana kenaf and a lower coir fiber content. More compressive strength obtained through low percentages of water absorption have been achieved by the equal percentages of banana, coir fiber and the most amount of coir fiber.

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