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# Fabrication and Mechanical Evaluation of Hybrid Composites Using Pineapple Leaf Fiber and Water Hyacinth Filler

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## Abstract

Natural fibers, pineapple leaf fiber (PALF) and water hyacinth fiber (WHF) are promising reinforcements due to their high tensile strength, availability, and eco-friendly nature. When combined with a polymer matrix, such as epoxy resin(10:1), these fibers enhance the mechanical properties of the composite while maintaining environmental sustainability. The fibers undergo Alkali treatment(7% NaOH for 1 hr at 80°C) to improve interfacial adhesion with the epoxy matrix, ensuring better load transfer and enhanced adhesion between layers.Varying the fiber loading and fiber ratio four samples are made including 2% FL (1:1), 2% FL (4:1), 5% FL (4:1) and 7% FL (4:1).The composite specimens are then subjected to various mechanical tests, including tensile, flexural.5%FL outperforming all of the samples rated MoE (2.436 MPa),UTS (43.932MPa), Elongation 25.355 and Flexural Stress (86.027 MPa) showing balanced mechanical properties.

## Keywords

Pineapple Leaf Fiber, Water Hyacinth Fiber, Hand-Layup, Epoxy-resin composite and sustainable materials.

## 1. Introduction

Natural fiber-reinforced polymer composites have drawn a lot of interest because of its advantageous physical properties, ecological responsibility, and lightweight design. These composites are made of a polymer matrix that is reinforced with natural fibers In a composite material the fibers give the composites strength and stiffness, while the matrix transfers the load. Numerous variables affect these composites characteristics such as fiber length, fiber loading, fiber-matrix interaction and processing techniques(Motaleb, 2018).

Two naturally available, renewable fibers with promising mechanical qualities are pineapple leaf fiber (PALF) and water hyacinth fiber (WHF). Pineapple leaf fiber contains high cellulose content, making it a strong reinforcement in composite material, whereas, water hyacinth- one of the fastest growing aquatic plants contains fibers with good flexibility and better bonding- making them complementary to each other in the composite. Utilizing these two fibers not only improves the performance but also provides environmental sustainability by converting agricultural waste into value added materials.

Epoxy resin, a widely used thermosetting polymer, serves as an excellent matrix material due to its superior mechanical properties, good adhesion to fibers, and resistance to environmental degradation. However, natural fibers often require chemical treatment to improve fiber-matrix adhesion and reduce moisture absorption. Alkali treatment (NaOH) is one of the most effective methods for modifying the fiber surface, removing impurities, and enhancing interfacial bonding, ultimately leading to improved mechanical performance of the composite(S et al., 2015).

In this research, pineapple leaf fiber and water hyacinth fiber were used as reinforcements in an epoxy matrix to fabricate composite materials using the solution casting method. Different fiber loadings (2%, 5%, and 7%) were used to study the effect of fiber content on the mechanical properties of the composites. The main objectives of this study is to explore the potential of these natural fibers as sustainable reinforcement materials in polymer composites, offering a cost-effective and eco-friendly alternative to synthetic fibers.

### 1.1 Objectives

- Eco-friendly Natural fiber composite fabrication using Water Hycinth Fiber (WHF) and Pineapple Leaf Fiber (PALF) as reinforcement and Epoxy resin as Hardener.
- Observing the changes of mechanical properties with the variation of fiber ratio and fiber loading .

## 2. Literature Review

According to Murugan Sethupathi et al. (2024), Natural-fibre reinforcements such as pineapple-leaf fiber (PLF) have high cellulose content, good specific strength, and promising mechanical properties that make them attractive, low-cost alternatives to synthetic fibres in polymer composites (Sethupathi et al., 2024).Similarly, Hoque et al. (2021) reported that PLF-reinforced epoxy composites exhibit significantly improved tensile and flexural strengths compared to neat epoxy. They further observed that alkali treatment enhances fiber surface roughness, which improves interfacial adhesion and promotes more efficient stress transfer within the composite(Hoque et al., 2021).

According to Singh et al. (2023), pineapple leaf fiber used as fabric reinforcement improves toughness and stiffness of polypropylene-based hybrid composites, showing that PLF can function effectively in both thermoplastic and thermoset systems. They also reported that stacking sequence and fiber arrangement greatly influence the final mechanical performance (Singh & Mishra, 2023).

For water hyacinth (WH), Thuc et al. (2021) demonstrated that chemical treatments—particularly alkaline treatment—lead to a significant improvement in fiber–matrix bonding by removing lignin and increasing surface roughness. The treated WH composites achieved compressive strengths comparable to fiberglass-based systems, showing strong potential as an eco-friendly reinforcement (Thuc et al., 2022). Likewise, Flores-Ramirez et al. (2015) reported that polyester composites reinforced with 5–10 wt% water hyacinth fibers showed the best flexural and compressive properties. Their FT-IR and DSC analyses confirmed that adding WH fibers does not negatively affect the matrix, and they concluded that WH fibers perform competitively with jute, abaca, and rice straw(Ramirez et al., 2015).In addition, Gnanadurai et al. (2021) found that water hyacinth fiber content has the highest impact on the strength of WH/HDPE composites. Using Taguchi optimization, they observed that moderated alkali treatment (5% NaOH) and higher WH loading improved tensile and flexural strength. Their optimized composite (30% WH fiber) was suitable for applications such as furniture, tiles, and partition boards (R et al., 2021).

By reviewing these studies, it becomes clear that although a considerable amount of research has been conducted separately on pineapple leaf fiber (PLF) and water hyacinth (WH), there is very limited work—and in many cases no direct studies—that investigate a hybrid composite combining both PLF and WH in a single system. Only a few papers mention WH in combination with other natural fibers, and almost none explore the synergistic effects of PLF (as reinforcement) and WH (as filler) together. Therefore, the present work addresses an important research gap by evaluating the combined influence of PLF and WH in composite materials, contributing new insights into hybrid natural-fiber composite development.

## 3. Materials

The extraction of fibers can be done using manual, chemical, or mechanical methods. Among these, mechanical extraction is preferred as it provides high-quality fibers in an eco-friendly manner. In this study, pineapple leaves were collected from the CUET campus, and water hyacinth was sourced from a local pond.

### 3.1 Pineapple Leaf Fiber Extraction

Pineapple leaf fibers were extracted using a mechanical scraping method. The leaves were first washed thoroughly to remove dirt and then manually scraped to separate the fibers. After extraction, the fibers contained residual moisture, so they were oven-dried at 70°C to ensure proper drying before use (Figure 1).

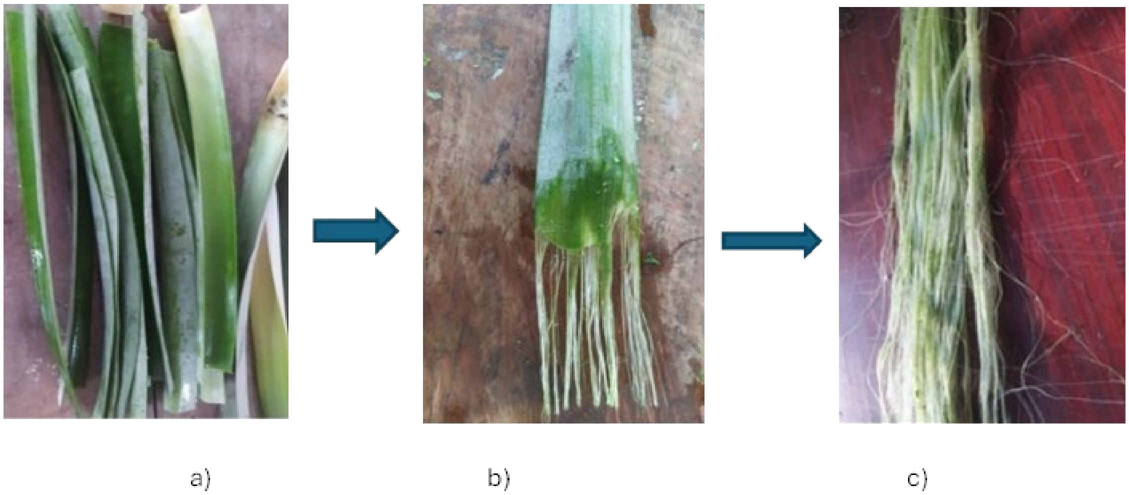


Figure 1. Manual Extraction of Pineapple Leaf Fiber

**3.2 Water Hyacinth Filler Preparation:** Water hyacinth was collected and chopped into small pieces. These pieces were then washed with detergent to remove impurities. After washing, the fibers were oven-dried at 70°C to remove moisture. Once dried, the water hyacinth was ground into a fine powder using a grinder to be used as a filler in the composite fabrication (Figure 2).

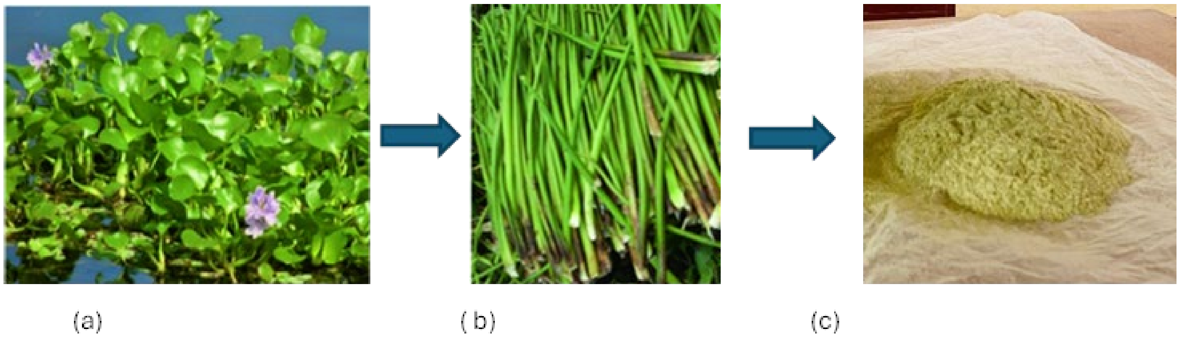


Figure 2. Steps of Water Hyacinth Filler Preparation

Commercial-grade epoxy resin was collected from the local market of Chattogram. The epoxy resin used in this study was selected for its strong adhesion properties and mechanical stability in composite applications.

## 3.3 Mold Making and Design

Molds were designed and fabricated following ASTM standard dimensions to ensure consistency and accuracy in sample preparation. The molds were prepared to accommodate the composite samples during the casting process, allowing for uniform thickness and shape. According to ASTM size the mold box was length of 27cm, width of 6 cm and thickness of 0.5 cm (Figure 3).

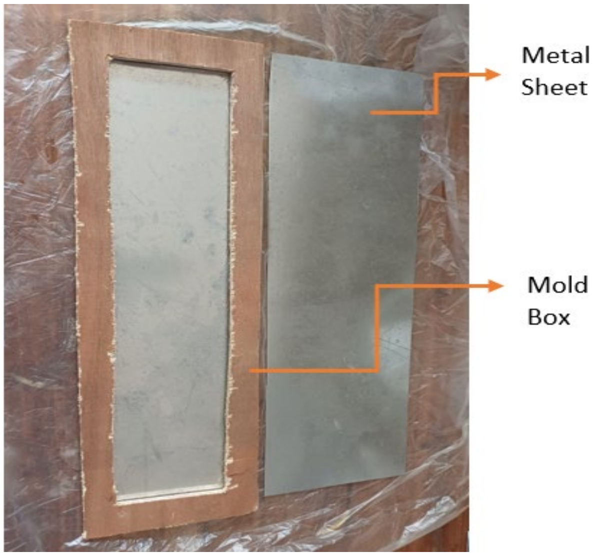


Figure 3. Mold Design

## 4. Methodology

Pineapple leaf fiber (PLF) and water hyacinth powder (WHP) reinforced epoxy composites were prepared by the hand lay-up technique. PLF was extracted, cleaned, and dried, while water hyacinth was processed into fine powder through drying, grinding, and sieving. The mold was placed on a proper working surface and coated with a releasing agent. According to the required fiber loading, the PLF and WHP were weighed and mixed in specified ratios (1:1 and 4:1). Epoxy resin was taken in a beaker, and hardener was added in a fixed ratio of 10:1. The mixture was stirred slowly to avoid bubble formation. A thin layer of the epoxy and hardener mixture was first poured on the mold surface and spread uniformly using a plastic spreader. The prepared reinforcement layer was then placed on the resin-coated surface and gently rolled with a hand roller to ensure proper wetting. Again, a portion of the epoxy–hardener mixture was poured over the reinforcement and rolled to remove entrapped air. The same process was repeated for all samples, maintaining the respective fiber loadings and PLF:WHP ratios. After the lay-up, the composite was covered with a second release sheet and compressed using a roller to achieve uniform thickness. The whole arrangement was then pressed with a dead weight for several hours to complete the curing. Once cured, the weight was removed, and the composite sheet was separated from the release surface. The same procedure was followed for all samples to obtain PLF and WH powder reinforced epoxy composites.

### 4.1. Sampling

The fiber loading and matrix ratio for each composite sample are presented in the following Table 1.

Table 1. Material Composition of Prepared Samples

| Sample No | Reinforcement Loading(%) | PLF:WHP | Matrix (Epoxy+Hardener)% | Epoxy:Hardener |
|---|---|---|---|---|
| S1 | **2%** | **1:1** | **98%** | **10:1** |
| S2 | **2%** | **4:1** | **98%** | **10:1** |
| S3 | **5%** | **4:1** | **95%** | **10:1** |
| S4 | **7%** | **4:1** | **93%** | **10:1** |

Here are the images of composite materials incorporating pineapple leaf and water hyacinth fibers, illustrating the effects of fiber loading and chemical treatment on overall strength and flexibility (Figure 4).

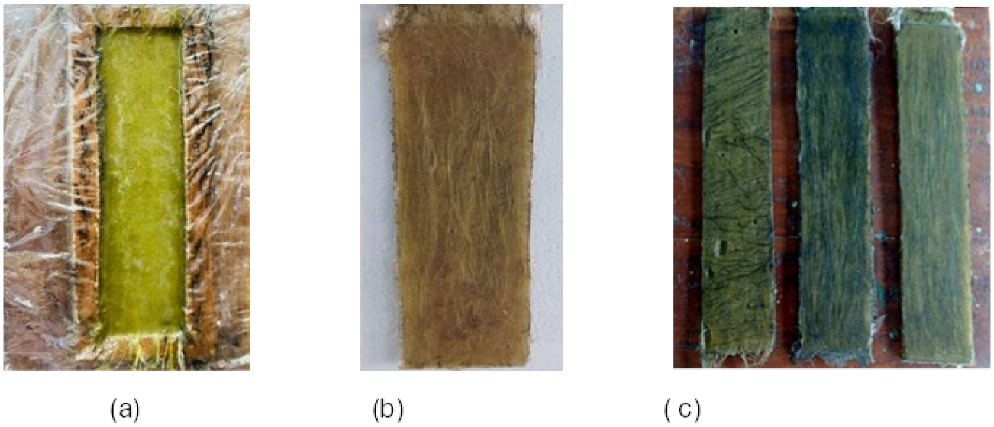


Figure 4. Final Composite Sample

## 5. Testing and Results

Four samples of composite were made by the Hand Layup method by varying fiber loading. The first sample containing 2% fiber (1:1) showed some voids and a rough surface due to air entrapment. The bubbles formed because of using polyethylene on the mold box. Fibers were placed unidirectionally in one layer. The second sample, 2% fiber (4:1), showed a better surface texture, and the fibers were uniformly distributed in three layers. The 5% and 7% fiber samples exhibited uniform surface appearance, and void formation was reduced by applying pressure twice. These four samples were then tested in the Universal Testing Machine.

### 5.1. Tensile Strength

At 2% (1:1 ratio), the tensile strength is 27.364 MPa. When the fiber ratio changes to 4:1 at the same 2% loading, the tensile strength slightly improves to 29.159 MPa. This indicates that modifying the fiber ratio influences composite strength, likely due to better fiber interaction or load distribution. Increasing the fiber loading to 5% (4:1) results in a substantial rise in tensile strength to 43.942 MPa (Figure 5). This suggests that optimal fiber content enhances stress transfer, making the composite stronger because the fibers effectively reinforce the matrix, improving mechanical performance(P et al., 2023). At 7% (4:1), the tensile strength drops slightly to 39.943 MPa. This decrease may be due to fiber agglomeration or poor matrix wetting, where excess fibers lead to weaker bonding with the matrix, causing stress concentration points and reducing overall strength. Higher fiber loading can also introduce voids or irregularities, negatively impacting mechanical properties (Article et al., 2022).

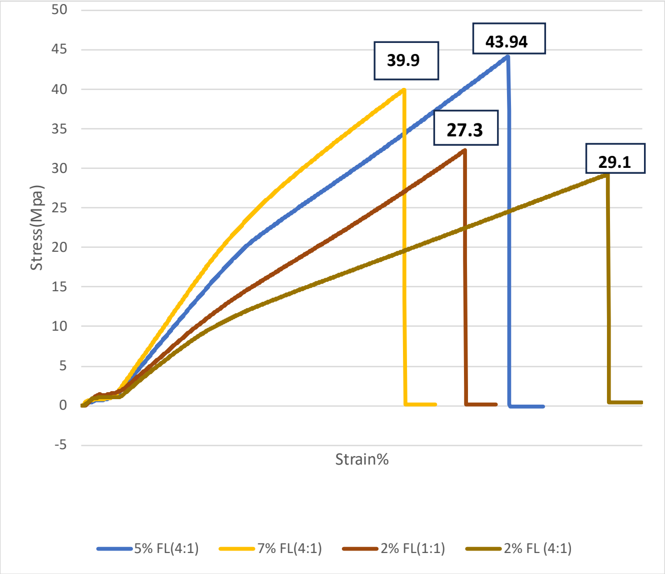


Figure 5. Tensile strength of the PLF-WH composite

## 5.2. Modulus Of Elasticity

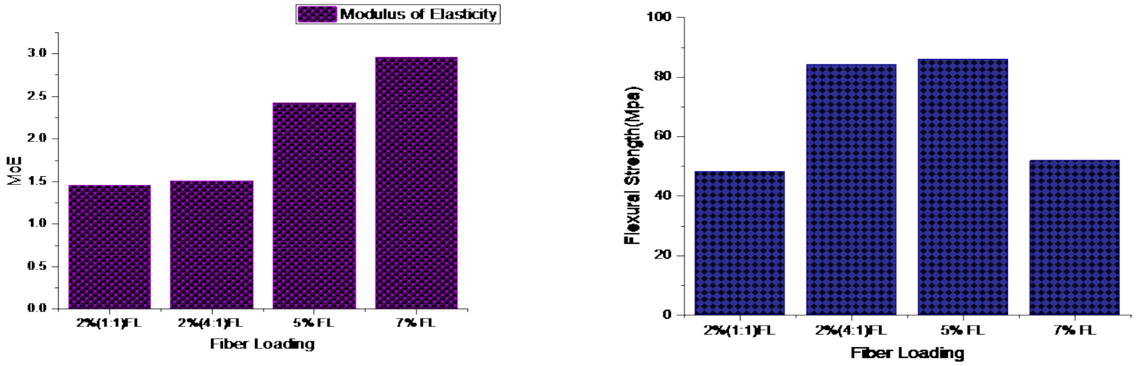
In the case of MoE, the modulus of elasticity increases with fiber loading, and initially it remains approximately constant because the fiber percentage is the same, only the ratio is different for 2% FL (1:1) and 2% FL (4:1). When fibers are incorporated into the matrix, they help bear the load and resist deformation, improving the overall stiffness of the material. As the fiber content increases, there are more fibers to share the load.The MoE increases from 2.436 to 2.96 MPa as the fiber loading increases from 5% to 7%. This reduces strain (deformation) for a given stress, leading to an increase in modulus, which is a measure of the material's stiffness. The orientation of the fibers also plays a role. If fibers are well aligned and uniformly distributed, they can carry more load effectively. As the fiber loading increases, this alignment tends to improve, further enhancing stiffness (Ku et al., 2011).

As fiber content rises, the matrix material (which is typically more flexible) contributes less to deformation under stress. This means more of the load is carried by the stiffer fibers, increasing the overall elastic modulus. Because the contributions of the matrix and fiber are balanced, elongation rises with fiber ratio but falls with fiber loading. The composite can stretch more readily at lower fiber ratios because the matrix, which is flexible, controls the elongation behavior. The material can initially retain good elongation because the fibers support the matrix and prevent premature failure. For 2% FL (4:1) and 5% FL (4:1), the elongation values were 31.2 and 25.35, respectively.

However, as fiber loading increases further, the stiff fibers restrict matrix deformation, making the composite less ductile and stiffer. Higher fiber loadings cause the composite to become more brittle and less able to elongate before failure, resulting in a significant drop in elongation. As a result, although fiber ratio can initially promote elongation, high fiber loading eventually decreases it due to increased stiffness and reduced matrix flexibility . For fiber loading exceeding 5%, elongation drops to 19.1.

## 5.3 Flexural Strength

Flexural strength also follows the same trend. Because the fibers improve the composite material's resistance to bending, increasing fiber loading usually results in an increase in flexural stress (Leaf et al., 2023). However, fiber agglomeration or weakening of the fiber–matrix interface at high fiber loadings may reduce flexural stress, lowering the composite's overall performance under bending forces. Excessive fiber loading beyond the material's optimal range often causes these effects (Figure 6).



(a) (b)

Figure 6. a) Modulus of Elasticity of the PLF-WH composite b) Flexural Strength of the PLF-WH composite

## 5.4 Testing Result Summary

The mechanical results indicate that increasing fiber loading initially enhances the composite performance. The 2% (4:1) sample shows better strength than 2% (1:1) due to improved fiber–matrix interaction. The 5% (4:1) composite exhibits the highest MoE, UTS, and flexural strength, confirming it as the optimum loading. However, property deterioration at 7% fiber is observed, likely from fiber agglomeration and poor wetting. Overall, 5% fiber loading provides the best mechanical performance among all samples (Table 2).

Table 2. Results for Tested Sample

| **Sample No** | **Fiber Loading** | **MoE (MPa)** | **UTS (MPa)** | **Elongation** | **Flexural Stress (MPa)** |
|---|---|---|---|---|---|
| 1. | 2% FL(1:1) | 1.461 | 27.364 | 22.693 | 48.24 |
| 2. | 2%FL(4:1) | 1.519 | 29.159 | 31.208 | 84.359 |
| 3. | 5% FL(4:1) | 2.436 | 43.942 | 25.355 | 86.027 |
| 4. | 7% FL(4:1) | 2.96 | 39.943 | 19.1 | 51.9 |

## 6. Conclusion

In conclusion, the results of this study demonstrate that the fiber loading percentage plays a crucial role in determining the mechanical properties of pineapple leaf fiber (PALF) and water hyacinth fiber (WHF) reinforced epoxy composites.

- Based on the findings, an optimal fiber loading percentage of 5% was identified as providing the best balance between strength, flexibility, and processability than others.
- At this range, the composites exhibited improved tensile and flexural strength without compromising too much on impact resistance or workability.
- 5% Fiber loading (4:1) showing MoE (2.436 Mpa),UTS (43.932Mpa),Elongation 25.355 and Flexural Stress (86.027 Mpa).
- Higher fiber loadings led to increased brittleness and poor resin impregnation, while lower fiber content resulted in reduced mechanical performance.
- 7%(w/v)NaoH treatment for 1 hr at 80°C followed by washing until the neutralization enhance the mechanical properties.

Therefore, a fiber loading of 5%(4:1) is recommended for achieving high-performance and durable composites in practical applications.

## 7. Future Work

In this work, the fibers were placed unidirectionally. Further works can be done by placing fiber in both cross directions and compare the mechanical properties with the previous one.

- Water absorption, Impact test, Picnometry density measurement of the composite can be done.
- With the variation of NaOH percentage alkali treatment, how the mechanical properties changes can be observed.

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