American Journal of Mechanical and Industrial Engineering
2026, Vol. 11, No. 3, pp. 45–56
https://doi.org/10.11648/j.ajmie.20261103.12

Research Article

Fabrication and Mechanical Feasibility of Fan Blade Using Alkaline Treated Hybrid Enset-Bamboo Fiber Reinforced Polyester Composite

Abera Ayza Anebo[1,*], Mubarek Sebre[2], Temesgen Haile Giorgis[1]

[1]Department of Mechanical Engineering, Wolaita Sodo University, Wolaita Sodo, Ethiopia
[2]Department of Mechanical Engineering, Enterprise and Manufacturing Office, Silte, Ethiopia

Abstract

This study explores the development of eco-friendly, high-performance fan blades using a hybrid composite of Enset and Bamboo fibers reinforced with unsaturated polyester resin. An Enset-Bamboo reinforced composite was fabricated by using hand layup method. The easiest method for preparing polymers is hand layup. Above all, in order to prevent polyester tar from adhering to the surface, the shape surface of the previously created mold was cleaned by applying discharge gel or wax. To achieve a high-quality surface finish on the item, smooth-surfaced Polyethylene Plastic was utilized at both the upper and lower portions of the form plate. The Enset - bamboo fiber reinforced polyester composite was fabricated using a hand lay-up process. An Enset-Bamboo reinforced fiber composite is the best material based on the result of strength and low weight ratio and safe for ceiling fan blade. To improve mechanical interlocking, fibers underwent alkaline (NaOH) treatment, and an optimal composition of 25% Enset, 20% Bamboo, and 55% polyester was determined through systematic analysis. The result of the composite blades achieved excellent durability, exhibited a low water absorption rate of 1.38%, and offered a significant 31% weight reduction compared to traditional aluminum alternatives, demonstrating their viability for aerodynamic applications. So, generally Enset-bamboo fiber reinforced composite matrix material is the suitable weight ratio, strength and durability for the ceiling fan blade.

Keywords

Bamboo Fiber, Enset Fibers, Fan Blade, Hybrid Composite, Natural Fiber, Polyester

1. Introduction

Ceiling fans serve as vital, energy-efficient devices for maintaining thermal comfort in various industrial, commercial, and residential spaces. Traditionally manufactured from aluminium, these blades offer corrosion resistance but suffer from a poor strength-to-weight ratio and difficulties with surface finishing. To address these limitations, there is a growing shift toward fiber-reinforced composite materials. By combining a matrix typically, a thermosetting polymer like unsaturated polyester with reinforcing fibers, engineers can create blades that are lighter and more efficient, ultimately reducing the energy required for rotation and improving overall performance [6].

*Correspondence: Abera Ayza Anebo (abera.ayza@wsu.edu.et), Abera Ayza Anebo (aberaayza4@gmail.com)

Received: 14 June 2026; **Accepted:** 6 July 2026; **Published:** 6 August 2026

Natural fibers have emerged as an excellent sustainable alternative for these reinforcements, offering benefits such as cost-effectiveness, biodegradability, and high specific strength. Materials like false banana, hemp, jute, and bamboo provide impressive mechanical properties, largely driven by their cellulose, hemicellulose, and lignin content. For example, false banana fiber exhibits high tensile strength and favourable crystallite orientation, making it a promising candidate for bio-composites. While natural fibers present challenges regarding moisture absorption and interfacial bonding with the resin, these issues are increasingly managed through advanced material engineering to ensure stability and durability [10].

To optimize these new designs, researchers are increasingly relying on computational tools such as Finite Element Modelling (FEM) and Computational Fluid Dynamics (CFD). By using software like ANSYS, engineers can accurately simulate stress distribution, deformation, and airflow patterns before physical production. These numerical simulations allow for the precise evaluation of natural fiber-reinforced composites against traditional materials, ensuring that the resulting blades meet structural requirements while minimizing weight. This integration of sustainable natural fibers and advanced simulation techniques represents a significant step toward more efficient, eco-friendly, and high-performance ventilation technology [4].

2. Statement of the Problem

The primary practical challenge in hybrid or advanced reinforced composites lies in the critical trade-off between achieving high-performance lightweight characteristics and ensuring long-term resistance to fluid ingress. Whether dealing with natural fiber-reinforced polymer composites or metal matrix composites, the presence of internal voids, interfacial gaps, or the inherently hydrophilic nature of certain reinforcement phases can lead to significant water absorption, which degrades the composite's internal structure and increases its effective service weight. This accumulation of moisture not only causes volumetric swelling or oxidative corrosion, which compromises structural reliability, but it also fundamentally threatens the weight-saving advantages for which these materials were selected. Consequently, the core problem is to engineer a highly dense, homogeneous matrix-reinforcement interface that effectively repels moisture and maintains dimensional stability without sacrificing the low-density profile essential for high-efficiency structural applications.

3. Objectives

3.1. General Objective

The general objective of the study was to fabricate and mechanical feasibility of Fan Blade using Alkaline treated Hybrid Enset-Bamboo Fiber Reinforced Polyester Composite.

3.2. Specific Objectives

1) To develop and fabricate hybrid enset - bamboo fiber reinforced polyester composite in different proportion.
2) To design the experiment by using Taguchi method.
3) To evaluate the density and water absorption.

4. Materials and Methods

4.1. Materials Used

The material utilized in the current thesis work were Bamboo, Enset fiber alongside polyester resin and hardener.

4.2. Bamboo Fiber

Bamboo fiber is chosen for this research project because it has many benefits over other natural fibers, including high mechanical strength, high tensile strength, low specific weight, high modulus of elasticity, and availability locally [7].

The classification of natural fiber sources uses bamboo plant fiber source under leaf category Enset plant and grass/reed category bamboo plant. Bamboo fiber selected for this study is highland bamboo (Yushania alpina) due to its relatively high tensile strength, good stiffness, low density, and excellent fatigue resistance, which are critical requirements for rotating components such as ceiling fan blades. Compared to other natural fibers, it provides a better strength-to-weight ratio and good interfacial bonding with polyester resin. Mature bamboo culms aged 2 - 3 years were specifically chosen, as this age range provides optimal mechanical performance with higher fiber strength and reduced moisture content. The bamboo was sourced from a highland area with stable environmental conditions, and fibers were carefully extracted by experienced personnel using controlled manual methods to ensure consistency in fiber quality. These factors collectively make the selected bamboo suitable and reliable for hybrid composite development in this application.

Figure 1. *Bamboo Extraction Procedure.*

Enset Fiber

For many Ethiopian smallholder households, enset (Ensete ventricosum welw Chessman) is a crop of significant economic and sociocultural significance. More than 20 - 25% of Ethiopia's population depends on enset as a staple and costrate food source and traditional medicinal. The methods used to process Enset for food vary depending on the Enset growing area and are based on the traditional indigenous knowledge of the people.

Enset (Ensete ventricosum) fiber was selected because of its good toughness, biodegradability, and local abundance; mature enset plants aged four years were used to ensure better fiber strength. The extraction was carried out by skilled local processors using traditional scraping methods, where the scraper (sharp-edged bamboo tool) condition (new and well-maintained) was controlled to minimize variability and ensure consistent fiber quality.

Figure 2. *Enset Extraction Process.*

4.3. Polyester Resin

Polyester resins are widely used in the composite industries. The more alluring aspect of polyester resin is its affordability in comparison to epoxies, which exhibit superior performance. According to Gao et al. the unsaturated polyester resin has an ester bond and a C = C double bond created via polycondensation. This unsaturated polyester resin allows for complex casting [3].

Cobalt naphthalene was employed as a catalyst and methyl ethyl ketone as an accelerator for the curing process. Polyester resins are widely accessible and typically less expensive than other resins. Polyester resin has superior mechanical qualities among the thermosetting polymer family. It is one of the resins that may be readily utilized as a matrix for polymer composites, and its composition can be altered to suit the needs [1].

Polyester resin-reinforced natural fiber composites are typically made by hand using the layup technique. Alkalization improves the adhesiveness between the polyester reinforcement and the natural fiber matrix, boosting the composite's strength [5].

Figure 3. *Polyester general-purpose resin.*

5. Calibration & Density Calculation

Density of Specific Gravity bottle (Pycnometer)

Density: Specific gravity bottle (Pycnometer) was used to determine the density of both Enset and Bamboo.

A Specific gravity bottle is a device that determines density by using a liquid having a recognized density for current study water was used.

To compute the density of fibers in this thesis, water was used. To determine the specific gravity/ density of the fibers Specific gravity bottle was used. The following steps are used [2].

$$\text{Weight of the empty Specific gravity bottle} = W_1$$

$$\text{Weight of the Specific gravity bottle + sample} = W_2$$

$$\text{Weight of the Specific gravity bottle + sample + water} = W_3$$

$$\text{Weight of the Specific gravity bottle + water} = W_4$$

The following procedures were followed to calibrate pycnometer device for fiber density measurement.

1) The pycnometer underwent cleaning, drying, and washing.
2) The Pycnometer's weight was determined without the addition of fibers or water.
3) The pycnometer was filled with distilled water, and the total weight was determined.
4) By subtracting the pycnometer's weight from the overall weight, the mass of water was determined.
5) Using mass and density, the volume of water was also computed (density of water at room-temperature (25°c) is 0.997g/ml [10].
6) The actual volume that the pycnometer holds was determined by measuring the volume of water it contains, and the two volumes were compared.

W_{bottle} - Wieght of the empty, clean, and dry pycnometer.

$W_{bottle} + W_{H2O}$ - Represents the total weight of the pycnometer filled completely with distilled water.

$$W_{H2O} = (Wbottle + W_{H2O}) - W_{bottle} \quad (1)$$

Equation (1) was used to calculate the weight of water contained in the pycnometer by subtracting the empty bottle mass.

$$Density = \frac{m}{v} \quad (2)$$

Defines density as the ratio of mass to volume.

$$V_{bottle} = V_{H2O} \quad (3)$$

Indicates that the pycnometer volume is equal to the mea ured volume of the water it contains.

$$V_{H2O} = \frac{m_{H2O}}{\rho_{H2O}} \quad (4)$$

This is the exact volume of Specific gravity bottle.

Density of Bamboo Fiber

The mass and volume calculation method, with the procedures listed below, was used to determine the density of bamboo and Enset fibers.

1) The weight of Specific gravity bottle was measured.
2) After adding the fiber to the bottle with the specific gravity, the total weight was calculated.
3) Water was poured into the fiber-holding specific gravity bottle, and the weight was recorded.
4) The water density at room temperature, which is 0.997g/ml, was used to compute the volume of water and fibers.

W_{bottle} - Represents the mass of the empty specific gravity bottle.

$W_{bottle} + W_{bamboo}$ - Represents the combined mass of the bottle and dry bamboo fiber.

$W_{bottle} + W_{bamboo} + W_{H2O}$ - Represents the total mass of the bottle containing bamboo fiber and filled with water.

$$W_{bamboo} = (W_{bottle} + W_{bamboo}) - W_{bottle} \quad (5)$$

W_{bamboo} - Determines the mass of bamboo fiber alone.

$$W_{H2O} = (W_{bottle} + W_{bamboo} + W_{H2O}) - (W_{bottle} + W_{bamboo}) \quad (6)$$

W_{H2O} - Calculates the mass of water added to the fiber-filled bottle.

$$V_{H2O} = \frac{W_{H2O}}{\rho_{H2O}} \quad (7)$$

V_{H2O} - Computes the volume of water inside the bottle using the density of water; V_{bamboo} - Determines the volume of bamboo fiber by subtracting the water volume from the bottle volume.

$$V_{bamboo} = V_{bottle} - V_{H2O} \quad (8)$$

$\rho_{bamboo} = \frac{W_{bamboo}}{V_{bamboo}}$ - Calculates the density of bamboo fiber from its mass and volume.

Density of Enset Fiber

W_{bottle} - Represents the mass of the empty specific gravity bottle.

$W_{bottle} + W_{enset}$ - Represents the combined mass of the bottle and dry Enset fiber.

$W_{bottle} + W_{enset} + W_{H2O}$ - Represents the total mass of the bottle containing Enset fiber and water.

$$W_{enset} = (W_{bottle} + W_{enset}) - W_{bottle} \quad (9)$$

W_{enset} - Determines the mass of Enset fiber alone.

$$W_{H2O} = (W_{bottle} + W_{enset} + W_{H2O}) - (W_{bottle} + W_{enset}). \quad (10)$$

W_{H2O} - Calculates the mass of water added after inserting the Enset fiber.

$$V_{H2O} = \frac{W_{H2O}}{\rho_{H2O}} \quad (11)$$

V_{H2O} - Computes the volume of water using the known density of water; V_{enset} - Determines the volume of Enset fiber by displacement; ρ_{enset} - Calculates the density of Enset fiber based on its measured mass and volume.

$V_{enset} = V_{bottle} - V_{H2O}$;

$$\rho_{enset} = \frac{W_{enset}}{V_{enset}} \quad (12)$$

Sample size

Sample size for this study was selected from initial stand point that by ASTM standard; Mechanical test machines have their own sample dimension limit. Depending on that volume of sample was prepared for all samples, then samples were prepared by using prepared mold. Finally manufactured samples were shaped for each test as per their test standards and Tested.

The following sample compositions are outlined for this research work. Fiber is the primary load-bearing component in fiber-reinforced composites, while the resin matrix ensures fiber bonding, load transfer, and structural integrity. Therefore, these specific ratios represent low, moderate, and high fiber volume fractions commonly used in composite research to identify the optimal balance between mechanical strength, stiffness, and adequate matrix wetting. For both treated and untreated composites, the compositions were chosen. According to the majority of researchers, this range of volume fractions produced composite specimens with good mechanical qualities. The rule of mixing analytical approach was used to prepare the fiber to resin ratios [5].

The following calculations were made for the density, fiber volume, fiber weight, matrix volume, and matrix weight of the composite materials.

Designation of Composite Materials

Carefully determining the weight percentages of these components, the resulting material is engineered to optimize mechanical properties, such as strength, durability, and stability. The focus on integrating natural materials highlights the potential for sustainable and high-performance solutions.

Polyester resin is calculated to fit a 100% composition for each sample.

$$\text{Polyester (\% in Volume)} = 100 - (\text{EF} + \text{B}) \tag{13}$$

The study employs a factorial design of experiments to systematically investigate the effects of Enset and Bamboo fibers on the mechanical properties. For both Enset and bamboo fibers, Compositions (15%, 20% & 25%), were used for current study. The design considers all possible combinations of filler levels, enabling a comprehensive evaluation of their impacts.

Table 1. Designed weight percent combination of the composite [9].

Enset Fiber	Bamboo Fiber	Polyester	Composite variants
15	10	75	15 EF+10 BF+75 EF
15	15	70	15 EF+15 BF+70 EF
15	20	65	15 EF+20 BF+65 EF
20	10	70	20 EF+10 BF+70 EF
20	15	65	20 EF+15 BF +65 EF
20	20	60	20 EF+20 BF+60 EF
25	10	65	25 EF+10 BF+65 EF
25	15	60	25 EF+15 BF+60 EF
25	20	55	25 EF+20 BF+55 EF

For specimen one = $\frac{1}{\rho_{C1}} = 0.1\left(\frac{1}{1.38}\right) + 0.1\left(\frac{1}{0.84}\right) + 0.8\left(\frac{1}{1.4}\right)$

$$\frac{1}{\rho_{C1}} = 0.10 + 0.11 + 0.46 = 0.67 \tag{14}$$

$\rho_{C1} = 1.49\ \mathrm{g}/cm^3$, and in similar way the remaining samples density are calculated.

Table 2. Composite density.

Enset Fiber	Bamboo Fiber	Polyester	Composite variants	Density of each sample (g/cm^3)
15	10	75	15 EF+10 BF+75 EF	1.35
15	15	70	15 EF+15 BF+70 EF	1.29
15	20	65	15 EF+20 BF+65 EF	1.26
20	10	70	20 EF+10 BF+70 EF	1.33
20	15	65	20 EF+15 BF +65 EF	1.29
20	20	60	20 EF+20 BF+60 EF	1.26
25	10	65	25 EF+10 BF+65 EF	1.26
25	15	60	25 EF+15 BF+60 EF	1.29
25	20	55	25 EF+20 BF+55 EF	1.25

I. Density and mass of each composite

The mass of the composite is the product of volume, and density of the composite. So firstly, the volume and the density are determined [8].

$$\text{Mass} = \text{Density} * \text{Volume}$$

$$\text{Volume of die} = \text{Length} * \text{width} * \text{thickness} \tag{15}$$

Volume of die = 205mm * 65mm * 5mm = 66625mm^3 = 66.625cm^3

$$\text{Volume of composite} = V_{EF} + V_B + V_P \tag{16}$$

$$\frac{M_C}{\rho_C} = \frac{\text{Mass of EF}}{\rho \text{ of EF}} + \frac{\text{Mass of B}}{\rho \text{ of B}} + \frac{\text{Mass of P}}{\rho \text{ of P}}$$

$$M_C\left(\frac{1}{\rho_C}\right) = \text{M EF}\left(\frac{1}{\rho \text{ of EF}}\right) + \text{M of B}\left(\frac{1}{\rho \text{ of B}}\right) + \text{MP}\left(\frac{1}{\rho \text{ of P}}\right) \tag{17}$$

The combined mass of the Enset Fiber, Bamboo and polyester, calculated using the given ratio, equals the total mass of the composite.

Densities of the natural fibers are studied using Archimedes' principle [11].

The density of Enset Fiber 1.38 g/cm^3, bamboo fiber 0.84 g/cm^3, and polyester 1.4 g/cm^3.

$$\text{For specimen one} = \frac{1}{\rho_{C1}} = 0.1\left(\frac{1}{1.38}\right) + 0.1\left(\frac{1}{0.84}\right) + 0.8\left(\frac{1}{1.4}\right)$$

$$\frac{1}{\rho_{C1}} = 0.072+0.119+0.571 = 0.762$$

$\rho_{C1} = 1.312\ g/cm^3$

For 10% Enset fiber, 10% of Bamboo fiber and 80% of polyester Composite material, ρ_{C1}=1.312 g/cm^3. It is density of composite for sample one. It was computed for the other specimen of Composite material in a similar way for sample 2, 3, 4, 5, 6, 7, 8, and 9.

$$M_C = \rho_C \times V_C \tag{18}$$

For sample one $M_{C1} = \rho_{C1} \times V_C = 1.35\frac{g}{cm^3} \times 66.625cm^3 = 89.94\ g$.

Table 3. *Calculated mass of each composite in this study.*

Enset Fiber	Bamboo Fiber	Polyester	Density (g/cm3)	Calculated mass (g)
15	10	75	1.35	89.94
15	15	70	1.29	83.94
15	20	65	1.26	83.94
20	10	70	1.33	88.61
20	15	65	1.29	85.94
20	20	60	1.26	83.94
25	10	65	1.26	83.94
25	15	60	1.29	85.94
25	20	55	1.25	83.28

II. Mass of the fiber and matrix in each composite sample

In composite material engineering, precise calculation of the filler, fiber, and matrix masses is essential for understanding and optimizing the composite's properties and performance. The weight of the filler, fiber, and matrix material must be calculated, because it is used to determine how many grams of filler, fiber, and matrix material are added in each sample composite. It is determined by using the formula below.

$$W_{EF} = \text{Mass percent of EF} * M_C$$

$$W_B = \text{Mass percent of B} * M_C$$

$$W_p = \text{Mass percent of p} * M_C \tag{19}$$

Table 4. Mass of the fiber, and matrix contents of the composite for each sample.

Sample	Composite variant	Mass of the fibre and matrix contents		
		EF	B	P
1	15 EF+10 BF+75 EF	14.89	9.92	64.52
2	15 EF+15 BF+70 EF	12.89	12.89	60.15
3	15 EF+20 BF+65 EF	11.59	15.45	57.96
4	20 EF+10 BF+70 EF	17.72	8.86	62.02
5	20 EF+15BF +65 EF	15.85	11.89	59.46
6	20 EF+20 BF+60 EF	15.99	15.99	59.96
7	25 EF+10 BF+65 EF	20.15	8.06	60.45
8	25 EF+15 BF+60 EF	20.48	12.29	53.26
9	25 EF+20 BF+55 EF	18.15	14.52	50.83

III. Compute the volumes of fiber and matrix in each composite sample

In the design of composite materials, calculating the volume proportions of fiber and matrix is vital for assessing and predicting the composite's performance. Each component plays a crucial role in influencing the mechanical properties and overall behavior of the composite. Accurate measurement of these volumes for each sample is necessary for optimizing performance, maintaining consistency, and achieving the desired material properties [13].

$$\text{The fiber (BF) volume} = V_{BF} = \frac{w_{BF}}{\rho_{BF}}$$

$$\text{The fiber (EF) volume} = V_{EF} = \frac{w_{EF}}{\rho_{EF}}$$

$$\text{The matrix (P) volume} = V_p = \frac{w_p}{\rho_p}$$

Calculated total volume;

$$\mathrm{V_C = V_{EF} + V_{BF} + V_P} \tag{20}$$

Table 5. The volume of fibers and matrix for each sample.

Sample	Composite variants	Volume (cm^3)			
		EF	BF	P	V_{Total}
1	15 EF+10 BF+75 EF	10.78	11.8	46.08	68.66
2	15 EF+15 BF+70 EF	9.34	15.34	42.96	67.64
3	15 EF+20 BF+65 EF	8.39	18.39	41.4	68.18
4	20 EF+10 BF+70 EF	12.84	10.54	44.3	67.68
5	20 EF+15 BF +65 EF	11.48	14.15	42.47	68.1
6	20 EF+20 BF+60 EF	11.58	19.03	42.82	73.43
7	25 EF+10 BF+65 EF	14.6	9.59	43.17	67.36
8	25 EF+15 BF+60 EF	14.84	14.63	38.04	67.51
9	25 EF+20 BF+55 EF	13.15	17.28	36.30	66.73

IV. Compute the volume fraction of the fiber and matrix in each composite sample

Understanding the volume fraction of filler, fiber, and matrix in composite materials is essential for customizing the material's properties to achieve desired performance levels. The volume fraction reveals the proportion of each component, affecting the composite's overall strength, stiffness, and durability. To calculate these fractions, start by determining the volume of each component based on its mass and density. Then, divide the volume of each component by the total volume of the composite. These calculations are critical for fine-tuning the material composition and ensuring consistent performance across different samples [12].

$$\text{The fiber (EF) volume fraction } = V_{fEF} = \frac{v_{EF}}{v_C}$$

$$\text{The fiber (BF) volume fraction } = V_{fBF} = \frac{v_{BF}}{v_C}$$

$$\text{The matrix (P) volume fraction } = V_{fP} = \frac{v_P}{v_C} \quad (21)$$

***Table 6.** The volume fraction of fibers and matrix for each sample.*

Sample	Designation (Samples)	Volume fraction (%)		
		EF	BF	P
1	15 EF+10 BF+75 EF	16.18	17.71	69.16
2	15 EF+15 BF+70 EF	14.01	25.02	64.48
3	15 EF+20 BF+65 EF	12.59	27.6	62.13
4	20 EF+10 BF+70 EF	19.27	15.81	66.49
5	20 EF+15 BF +65 EF	17.23	21.23	63.74
6	20 EF+20 BF+60 EF	17.38	28.56	64.27
7	25 EF+10 BF+65 EF	21.91	14.39	64.79
8	25 EF+15 BF+60 EF	22.27	21.95	57.09
9	25 EF+20 BF+55 EF	19.73	25.93	54.48

Weight percentages for each sample are given in Table 5 above.

Manufacturing of Composite Samples

Surface Treatment of Fibers

In order to decrease the hydrophilic nature of the fibers and improve their wettability with the polymer matrix by strengthening the interfacial linkage between the constituents, natural fiber surface modification is necessary for natural fiber-reinforced composites. Silane, acetylation, mercerization, etherification, and enzymatic treatment are among the various fiber modification techniques that are accessible. Because of its improved wettability, reduced fiber surface degradation, and lack of need for extra ingredients to neutralize the PH level, the mercerization (alkaline) kind of treatment was chosen for the current project.

The fiber surface treatment was required since it reduces the hydrophilic qualities of natural fibers by eliminating amorphous (water-soluble) components.

1) It helps the reinforced fibers more wettable and their surface rougher.
2) The interfacial connection between the fibers and matrix is strengthened.
3) To decrease the fiber's ability to absorb moisture and water.

Making an alkaline (NaOH) solution and soaking fiber;

Enset and bamboo fibers surface treatment were carried with NaOH concentrations of 5% for each and the soaking time was 2hr and 48hr respectively. The fibers surface treatment procedure variation occurred due to the fiber's chemical compositions (cellulose, hemicellulose, lignin, and pectin) and previous researches. The alkaline solution preparation and surface treatment were carried out at room temperature, because it was simple, not time consuming, and helps to reduce fibers degradation. Types of equipment used for fiber surface treatment were beakers, electronic scale balance, stirrer, scissor, plastic pan, and drier.

Figure 4. Alkaline treatment, Soaking and Extracted fiber.

The treatment procedures are written below,

1) The fibers were washed with water to remove dust and other impurities from superficial parts of the fibers (for a better hydrolysis process).
2) The amount of water (solvent) was added to a beaker and measured on the electronic scale balance and poured into the plastic pot. The required amount of NaOH was measured on an electronic scale balance (5% for each enset and bamboo fibers and added to the water.
3) The water and NaOH were stirred with a stirrer until a homogeneous solution was formed.
4) The fibers were submerged in the solution for the necessary amount of time two hours for Enset fiber and twenty- four hours for Bamboo fiber.
5) After the immersion, the fibers were taken out and washed with water to neutralize the PH from the fiber surface.
6) The fibers were placed in the dryer at 40°C for 24 hours. Once they were completely dry, they were removed and cut with 20mm-long scissors.

Fabrication Method

The easiest method for preparing polymers is hand layup. Above all, in order to prevent polyester tar from adhering to the surface, the shape surface of the previously created mold was cleaned by applying discharge gel or wax. To achieve a high-quality surface finish on the item, smooth-surfaced Polyethylene Plastic was utilized at both the upper and lower portions of the form plate. The Enset - bamboo fiber reinforced polyester composite was fabricated using a hand lay-up process. The procedure is detailed below:

Mold Preparation: The mold surface was coated with a release gel to prevent the epoxy resin from adhering during the curing stage.

Initial Layering: An aluminum foil base was placed on the mold, followed by a layer of glass fiber. This was saturated with a uniform application of resin and hardener mixture to ensure complete wetting. A bamboo layer was then positioned and coated with the same resin-hardener mixture.

Sequential Stacking: The layup continued with a repeating sequence of jute fiber and bamboo layers. The stacking order was carefully maintained to ensure the outermost layers consisted of glass fiber.

Compression and Bonding: An outer mold was placed over the stack. To ensure structural integrity and effective bonding between the fibers and the matrix, a uniform load was applied using a sand-covering technique.

Curing: The assembly was left undisturbed for 24-48 hours to allow the composite to set completely.

Finishing: After curing, the Enset - bamboo fiber reinforced polyester composite was removed from the mold. Excess material and uneven edges were trimmed, filed, and sanded to achieve the final shape and a refined surface finish.

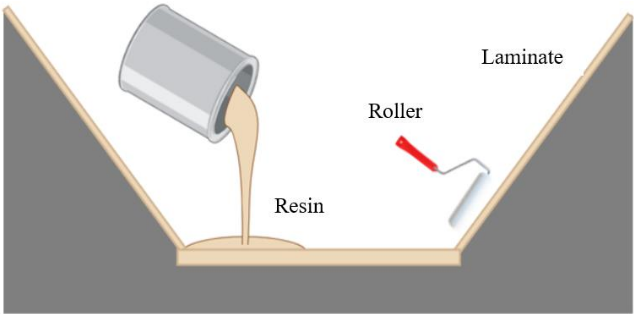

Figure 5. Hand lay-up process [6].

Mold Design

Mold was dimensioned and designed based on testing machines working on ASTM standard. It was modeled in AutoCAD and manufactured to be ready for Composite manufacturing.

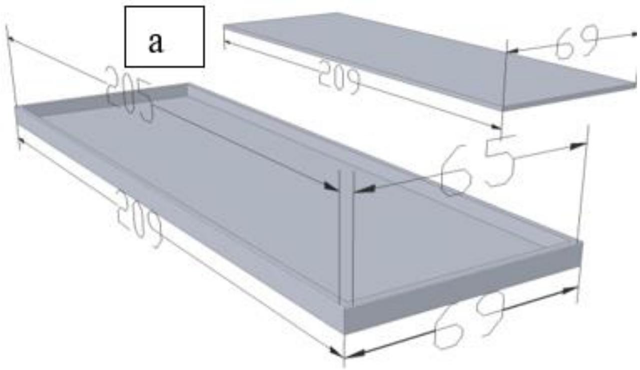

Figure 6. Mold Design.

After that, a second layer of unidirectional bamboo fiber was applied to the gum surface, and to remove any air pockets that may have formed due to the quantity of gum, a roller was gently rolled over the enset fiber-sap layer. The cycle of steps described above was repeated to create sandwiched structures by stacking the required layers.

Figure 7. Samples Prepared for Test.

Water Absorption Test

The water absorption test of composite specimen was done to examine the material's ability to resist water penetration.

Figure 8. Water Absorption Test.

The specimens were tested at room temperature condition (21- 23°C).

The test procedures for the specimen are listed below.

1) An electronic scale balance was used to determine each specimen's weight.
2) Every specimen spent 48 hours submerged in the water.
3) The specimens were removed from the water after two days, and their weight was determined.

6. Results and Discussion

The design and fabrication of fan blades using alkaline-treated hybrid Enset-Bamboo fiber reinforced polyester composites represent a significant step toward sustainable engineering. Below are the typical results and discussions expected in such studies, based on current research into natural fiber-reinforced polymer composites (NFRPCs).

1). Effect of Alkaline Treatment

Alkaline treatment (typically using NaOH) is a critical processing step for natural fibers like Enset and Bamboo.

Surface Modification: The treatment effectively removes non-cellulosic impurities such as lignin, hemicellulose, and waxes from the fiber surface. This process increases surface roughness, which facilitates better mechanical interlocking between the fibers and the hydrophobic polyester resin.

Interfacial Adhesion: By exposing hydroxyl (-OH) groups, the treatment improves chemical compatibility between the hydrophilic fibers and the matrix. This enhanced adhesion is vital for efficient stress transfer from the matrix to the fibers, directly improving the density and water absorption of the blade.

2). Mechanical and Physical Performance

The resulting composite blades generally demonstrate a favorable balance between water absorption and weight.

Mechanical Strength: Hybridization allows the composite to combine the specific strengths of both Enset (known for high cellulose content and flexibility) and Bamboo (known for rigidity). Research on similar natural fiber composites indicates that treated hybrid composites can achieve substantial improvements in mechanical properties—often up to 30% compared to untreated counterparts.

Weight Reduction: A primary benefit of transitioning from conventional materials (like aluminum and other composite fibers ratio) to natural fiber composites is weight reduction. Studies have shown that composite blades can be significantly lighter (e.g., ~31% lighter) than aluminum blades while maintaining structural safety under operational stress.

Environmental Stability: While natural fibers are inherently hydrophilic and susceptible to moisture absorption, the alkaline treatment and proper encapsulation in a polyester matrix help mitigate swelling, dimensional instability, and degradation.

3). Discussion on Design and Utility

Sustainability: Using Enset and Bamboo both abundant in regions like Ethiopia aligns with circular economy principles by reducing reliance on synthetic, non-biodegradable materials and lowering the carbon footprint associated with metal extraction and processing.

7. Conclusion and Recommendation

This research focused on developing a composite material for ceiling fan blades, utilizing locally sourced Enset and Bamboo fiber and unsaturated polyester, manufactured through a manual hand lay-up approach. The optimum ratio of reinforcement to matrix in the ceiling fan blade was established based on physico-mechanical properties, utilizing Design of experiment and AutoCAD software. The optimum result was achieved with 25% Enset and 20% Bamboo fiber and 55% unsaturated polyester. The optimal physico- mechanical properties resulted for density is of 1.25 g/cm^3 and Water absorption was 1.38% over 24 to 48 hours was obtained. Furthermore, the Enset-bamboo fiber-reinforced ceiling fan blade achieved a weight reduction of 6% compared to the glass fiber-reinforced ceiling fan blade and 31% compared to the conventional aluminium ceiling fan blade.

7.1. Conclusion

The study successfully demonstrates the viability of utilizing an alkaline-treated hybrid Enset-Bamboo fiber-reinforced polyester composite as a sustainable alternative for ceiling fan blade manufacturing.

Mechanical Performance of the alkaline treatment proved instrumental in cleaning the fiber surfaces and enhancing the interfacial adhesion between the Enset-Bamboo fibers and the polyester matrix. This led to significant improvements in the density and Water absorption of the composite.

Material Efficiency of the hybrid composite design effectively leverages the high cellulose content and flexibility of Enset with the rigidity of bamboo, creating a blade that is both durable and significantly lighter than traditional metallic counterparts.

Sustainability by utilizing locally available natural fibers, this research provides a pathway toward reducing the environmental impact associated with conventional industrial materials, supporting the transition toward greener, circular manufacturing practices.

7.2. Recommendations

To further advance the development and industrial application of these hybrid composite fan blades, the following recommendations are proposed:

Optimization of Fiber Ratio by Conduct further research to determine the "optimum" in different volume fraction ratio between Enset and Bamboo fibers to achieve the perfect balance between stiffness, weight, and vibration dampening.

Long-Term Durability Studies Since natural fibers can be sensitive to environmental fluctuations, it is recommended to perform accelerated aging tests. This includes testing the blades under varying levels of humidity and temperature over extended periods to ensure long-term structural reliability.

Surface Coating Implementation to the further enhance resistance to moisture absorption and surface degradation, integrate a hydrophobic nano-coating or a thin protective varnish layer to the final blade surface.

Abbreviations

B	Bamboo Fiber
CAD	Computer-Aided Design
CM	Composite Material
EF	Enset Fiber
FRCM	Fiber Reinforced Composite Materials
hr	Hour
NaOH	Sodium Hydro-oxide
NF	Natural Fibers
°C	Degree Celsius

Author Contributions

Abera Ayza Anebo: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Mubarek Sebre: Methodology, Supervision

Temesgen Haile Giorgis: Methodology, Supervision, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Adeeb, E., Sohn, C. H., Maqsood, A., & Afaq, M. A. (2018). Design optimization of ceiling fan blades with nonlinear sweep profile. *Journal of Applied Fluid Mechanics*, *11*(5), 1153-1162. https://doi.org/10.29252/jafm.11.05.27857

[2] Adier, M. F. V., Sevilla, M. E. P., Valerio, D. N. R., & Ongpeng, J. M. C. (2023). Bamboo as Sustainable Building Materials: A Systematic Review of Properties, Treatment Methods, and Standards. *Buildings*, *13*(10). https://doi.org/10.3390/buildings13102449

[3] Akter, M., Uddin, M. H., & Anik, H. R. (2024a). Plant fiber-reinforced polymer composites: a review on modification, fabrication, properties, and applications. In *Polymer Bulletin* (Vol. 81, Issue 1). Springer Berlin Heidelberg. https://doi.org/10.1007/s00289-023-04733-5

[4] Al., A. A. et. (2018). Hydrophobic treatment of natural fibers and their composites—A review. *Journal of Industrial Textiles*, *47*, *n* (SAGE Publications Ltd), 2153-2183.

[5] Amjad, A. I. (2024). Advances in Bamboo Science Bamboo fibre : A sustainable solution for textile manufacturing. *Advances in Bamboo Science*, *7*(January), 100088. https://doi.org/10.1016/j.bamboo.2024.100088

[6] Andrew, J. J., & Dhakal, H. N. (2022). Composites Part C : Open Access Sustainable biobased composites for advanced applications : recent trends and future opportunities - A critical review. *Composites Part C: Open Access*, *7*, 100220. https://doi.org/10.1016/j.jcomc.2021.100220

[7] Ayele, A., & Sahu, O. (2014). Extension of Enset Plant Product for Rural Development in Ethiopia. *Journal of Agricultural Economics*, *2*(3), 31-40.

[8] Ayyappa Atmakuri, A. P. & G. J. (2025). Properties of Natural Fiber-Reinforced Epoxy Hybrid Composites. *Fiber-Based HYbrid Composites for Engineering*.

[9] B. S. U. R. Ao and Arayana, K. S. A. N. (2017). Composite Material Analysis of Axial Flow Fans. *IJSETR.*, *06*, *n*, 5859-5865.

[10] Barman, P., Dutta, P. P., Bardalai, M., & Dutta, P. P. (2024). Experimental investigation on bamboo fiber reinforced epoxy polymer composite materials developed through two different techniques. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *238*(6), 2185-2204. https://doi.org/10.1177/09544062231195474

[11] Behera, D., Pattnaik, S. S., Nanda, D., Mishra, P. P., & Manna, S. (2024). A review on bamboo fiber reinforced composites and their potential applications. *Emergent Materials*, *0123456789*. https://doi.org/10.1007/s42247-024-00832-9

[12] Bernard Miranda Campos, Serge Bourbigot, Gaëlle Fontaine, Bonnet, F. (2022). Thermoplastic matrix-based composites produced by resin transfer molding: A review. *Polymer Composites*.

[13] Chigbu, U. E., Atiku, S. O., & Plessis, C. C. Du. (2023). The Science of Literature Reviews : Searching, Identifying, Selecting, and Synthesising. *Publ. 11 (2023): 2.*