

Tensile Behavior of Date and Banana Fiber-Reinforced Sustainable Green Hybrid Composites

Abstract

Natural fiber-based composites have gained significant attention due to their biodegradable nature, cost-effectiveness, and potential as sustainable alternatives to synthetic materials. These composites are widely applicable in industries such as automotive, aerospace, construction, recreation, and sports, owing to their favorable mechanical properties and simple, economical processing. This study focuses on developing and evaluating the tensile strength of a hybrid natural composite reinforced with banana and date fibers in an epoxy resin matrix. Prior research highlights the excellent mechanical properties of banana and date fibers individually. The findings reveal that composites with date fiber reinforcement exhibit the highest Young's modulus compared to other material compositions. Moreover, using a single layer of banana fiber yielded better tensile results than double layers. The study concludes that combining date and banana fibers in a hybrid configuration enhances tensile properties compared to single-fiber composites, demonstrating the potential for tailoring this combination to achieve optimized mechanical performance.

Keywords: *Epoxy resin, date fiber, banana fiber, tensile strength, young's modulus. hybrid composite*

1. Introduction

The United Nations issued a red alert in 2021, stating that the current rise in global temperatures is unacceptable. If current levels maintained, the future of humans on Earth become uneasy to live. Human activities are to blame, with the increasing use of plastics and synthetic waste materials among the most significant contributors [1]. Natural based composite can be considered as an alternative for plastic based material, synthetic materials have increased in use in many of the applications we know today. Composites become essential material in material's family as it acquire almost all areas of application.

The definition of a composite material is "a macroscopic combination of two or more distinct materials with a finite interface between them" (Karbhari, 2007). Properties and molecular arrangement of atoms of composites are unlike alloys. Composites developed by reinforcing reinforcement element into matrix element. Natural fibers combine with matrix to form composite, which held together by a substance known as binder. Strong bonds formed between the matrix and the reinforcements. Composites are typically isotropic and heterogeneous in nature (Siti et al., 2019). Abedom et al. (2021) fabricated a sugarcane-bagasse natural hybrid composite. Sugarcane is a common crop in tropical regions and grown in large quantities each year. Bagasse is the residue left over after sugarcane crushed in mills to produce sugar or alcohol. Bagasse made up of 45% fiber, 45% cellulose, 33% hemicelluloses, and 20% lignin. The mechanical properties such as tensile strength, flexural strength, impact strength, and hardness improved by increasing the volume of reinforcements in powdered form of sugarcane, jute, ramie, banana, pineapple fiber, and seashell powder developed by fused deposited modeling (FDM) machine is modified by combining with the shape deposition modeling (SDM)[5].

Composites can produced using a variety of techniques. Some of the methods based on polymer manufacturing techniques, such as injection molding. The figure below depicts the most common

polymeric composite fabrication techniques. The fiber loading has significant effect on mechanical properties, date palm fibres (DPF) loaded with (0%, 40%, 50%, and 60% by wt%) and it was seen 50% DPF composites have better mechanical properties with better interfacial bonding between fibres and matrix [6].

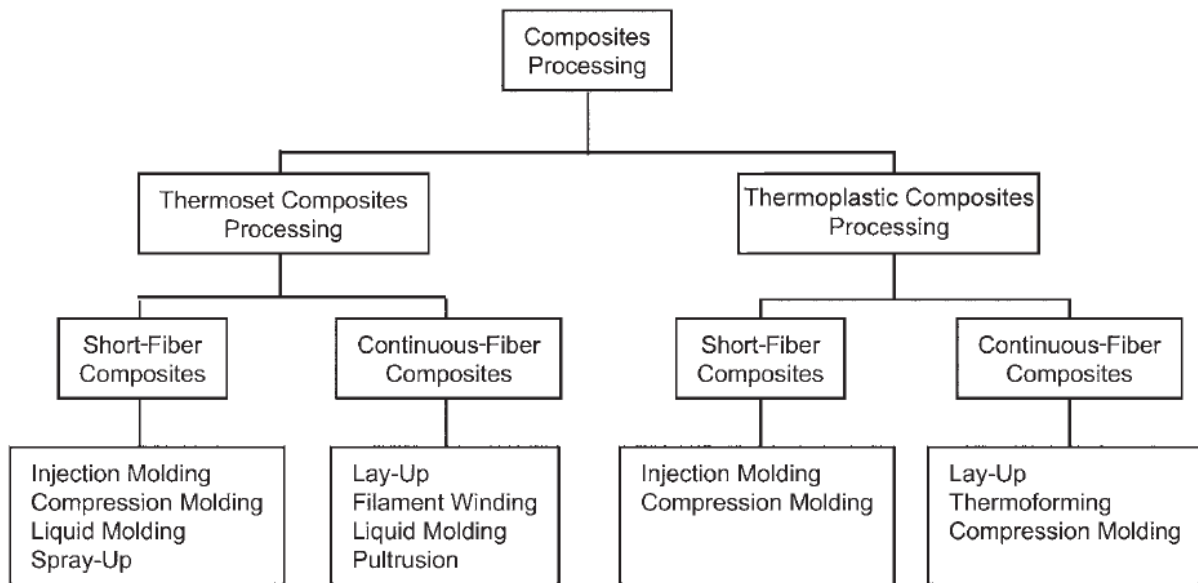


Figure 1: Polymer composites method of formation (Campbell, 2010)[7].

Natural fiber-based composites are becoming increasingly popular because they are biodegradable and less expensive than synthetic materials[8]. Also, manufacture natural fiber-based composite materials can achieve sufficient mechanical strengths for a variety of applications. To achieve the desired performance and interface, these materials must be prepared using chemical treatments or other processes. The current goal of the research is to create a banana, date fiber reinforced hybrid natural composite, and evaluate its mechanical properties. Hand lay-up technique adopted for fabrication process.

2. Methodology

The experimental study is to evaluate the tensile strength of prepared natural hybrid fiber composites using date fiber and banana fiber. The details for the experiments discussed in detail in the following sections.

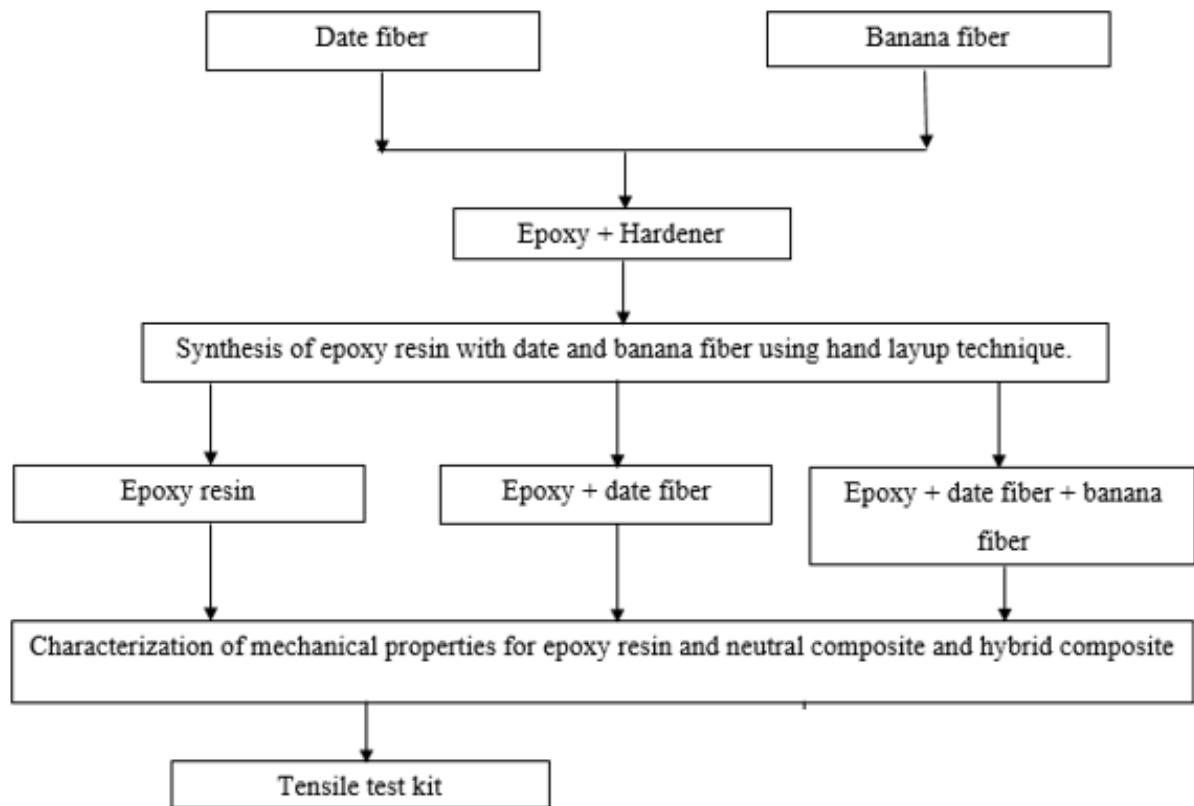


Figure 2:Research flow process

2.1. Material selection

2.1.1 Epoxy resin

Epoxy LY556 as matrix, a polymeric resin compound from the Epoxide family, selected. The epoxy resin was added to the prepare composites with maximum of 100% and a minimum of 80%, with a resin-to-hardener ratio of 2:1.

Table 1. Properties of epoxy resin and hardener

	Epoxy resin	Hardener
Type	Solvent-modified	Polyamide
Appearance	Milky white/Yellow liquid	Colorless
Viscosity (27⁰C)	650	650
Specific gravity	1.15	0.98
Density	1.142 g/cm ³	0.987 g/cm ³



Figure 3: Epoxy Resin

2.1.2 Date and banana fiber

The fibers derived from palm trees resemble naturally woven fiber mat and appear as a mesh with single cross patterns. The multicellular date palm fiber has aggregate sizes ranging from 2 to 5 microns. Banana fiber is extracted from the banana plant's stem. Both banana and date palm fibers are sourced from local farms in Oman. The collected fibers are then uniformly cut using a cutter for use in the experiment.

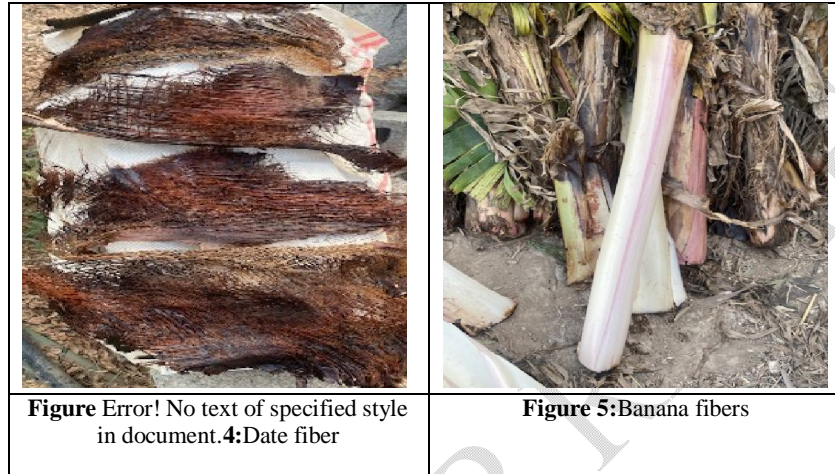


Table 2: chemical and physical properties of date fiber

Chemical properties		Physical properties	
Constituent	Percentage	Property	Value
Cellulose	27	Density	0.9 to 1.2 kg/m ³
Hemi cellulose	43	Length of fiber	20 to 250 mm
Lignin	27.4	Diameter	100 to 1000 microns
Extractives	1.8	Thermal conductivity	0.83 mK
Other	0.70		

Table 3: chemical and physical composition of banana fiber

Chemical properties		Physical properties	
Constituent	Percentage	Property	Value
Cellulose	27	Density	950 kg/m ³
Hemi cellulose	43	Length of fiber	2000 to 3000 mm
Lignin	27.4	Diameter	0.080 to 0.250 mm
Extractives	1.8	Water absorption	60%
Other	0.70	Aspect ratio (l/d)	1.5

3. Experimental details

To improve the design of experiments (DOE) for testing the natural fiber-based composites, a more systematic and controlled approach can be adopted. The goal is to better understand the impact of fiber type, fiber content, and matrix composition on the mechanical properties of the composites. By varying

the fiber type and content, the influence of each variable on mechanical properties can be isolated. A basic epoxy resin and three different variations of the natural fiber based composites were tested.

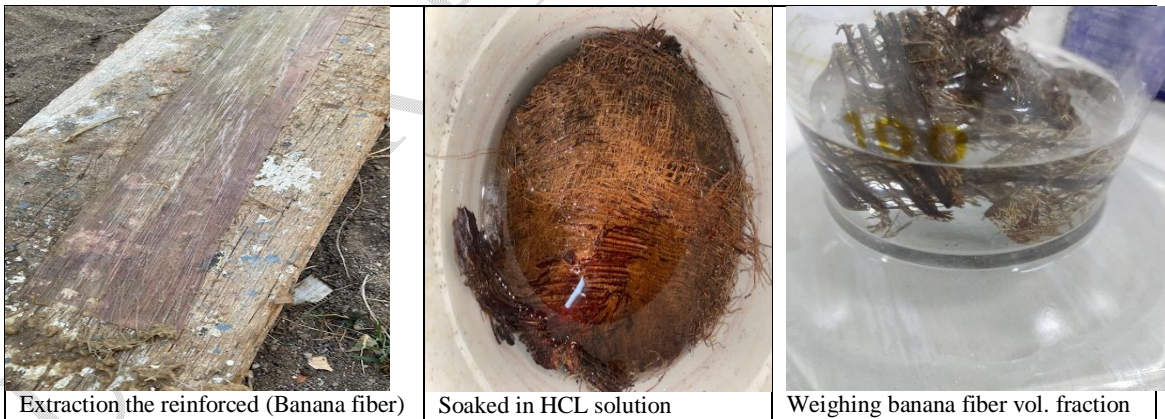
The following table shows the formulation of the composites used for this project.

Table 4: Formulation of composite

Composite Formulation	Epoxy resin (%)	Date fiber (%)	Banana fiber (%)	Layer Configuration
Group 1 (Base Matrix)	100	0	0	
Group 2 (15% Date Fiber)	85	15	0	
Group 3 (10% Date + 5% Banana Fiber)	85	10	5	2 layers of Banana
Group 4 (10% Date + 10% Banana Fiber)	80	10	10	2 layers of Banana

3.1 Fabrication of Hybrid natural composite

First the fiber from date and banana tree are extracted and further cleaning process begins, the process of cleaning the fibers (date fiber and banana fiber), with a 2-liter of water in a container and extracted fibers are washed and soaked for 12 hours in water to clean fibers from dust particles. Next, a 40 ml solution of hydrochloric acid (HCL) is mixed with 2 liters of water, then soaked that fiber for 6 hours, finally, again clean it by water and dry in room temperature for 24 hours. Once dried, the fibers are chopped into small pieces and further processed into powder form. The blending process is carried out using a blending machine, and after blending, the fibers are placed in an automatic sieve shaker machine. This machine segregates the fibers into required sizes. Once the fibers and matrix material is ready next steps is to prepare mold, in current work the mold material selected is high-density foam. The extracted fibres are not usable directly due to high moisture content, which will affects the binding with epoxy resin and affect the strength of composite. The fibres are fully dried before reinforced in an epoxy resin matrix material to improve wettability.



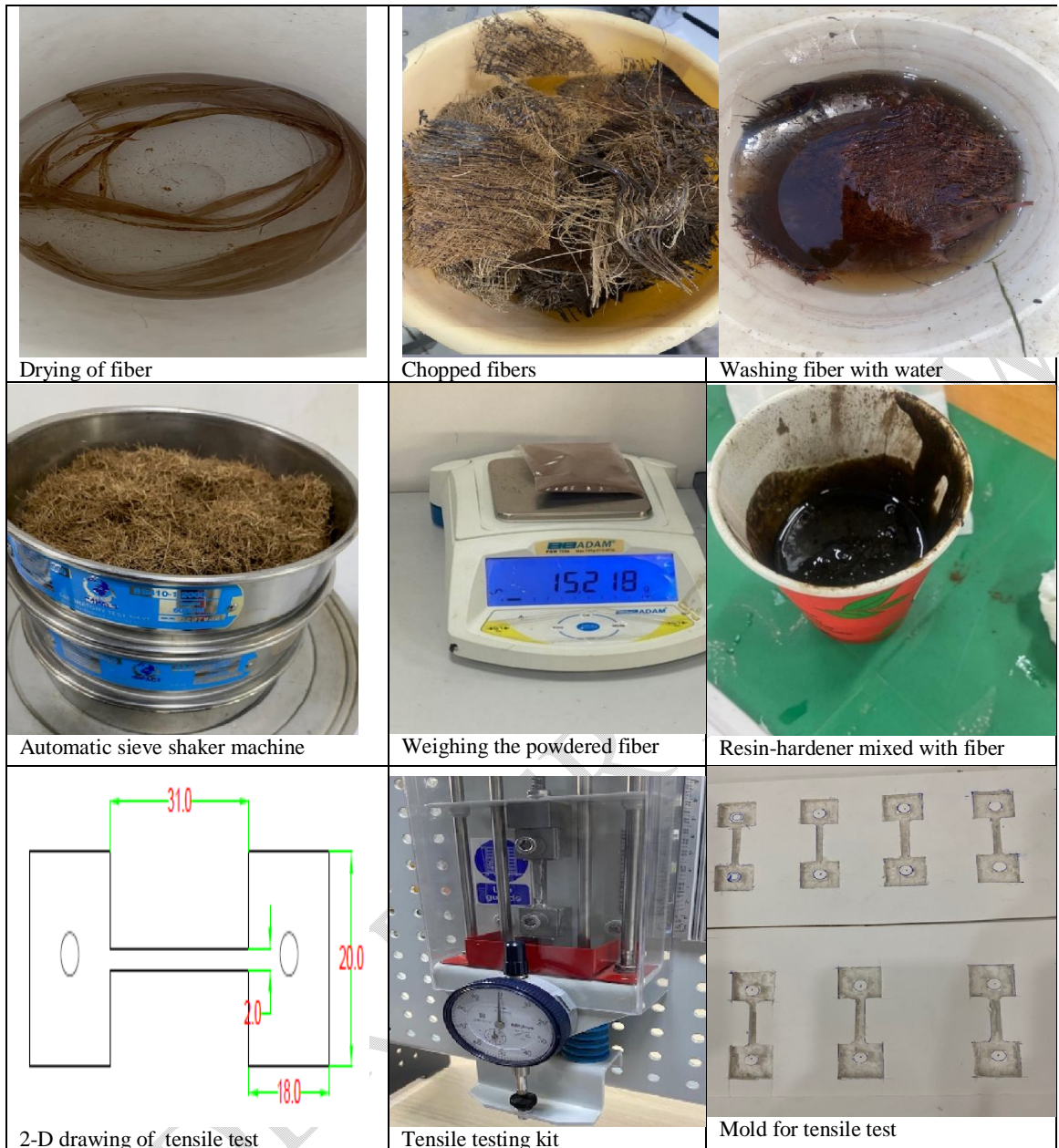


Figure 6:processing, assembly, and preparation of composite

In the current work, traditional hand lay-up technique was adopted for fabrication of composite material. The tensile test conducted as per ASTM E10 standard with tensile kit setup by applying uniaxial load on either sides of specimen [9].

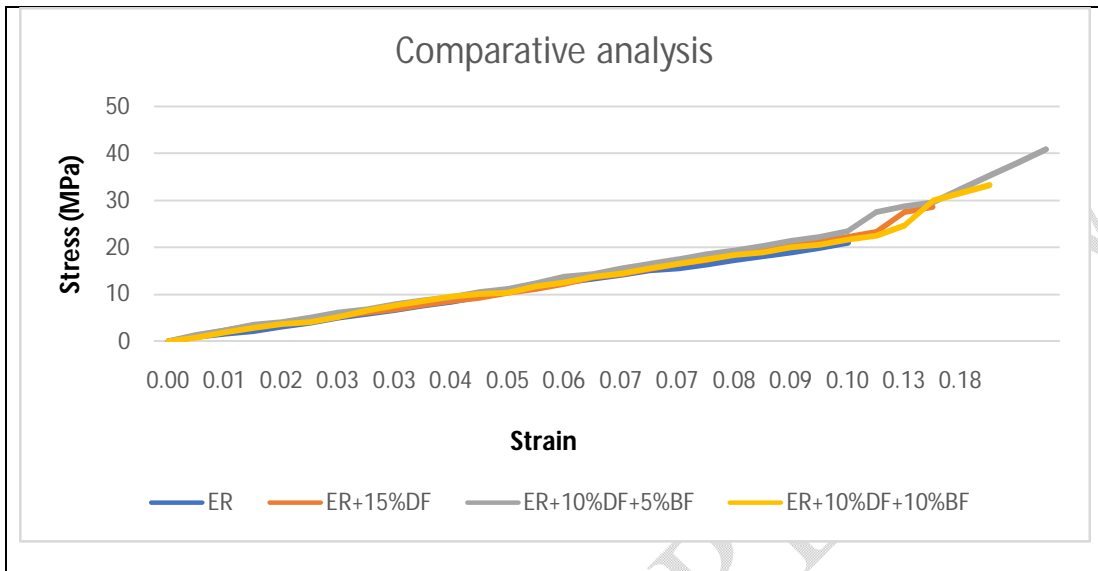
4. Result and Discussion

In this work, four different sets of composites investigated to understand the tensile behaviour and performance of composites with variation of reinforcement quantity and type of reinforcements. The standard test specimen dimensions for tensile test is length 30mm, width 4mm and thickness of 2mm.

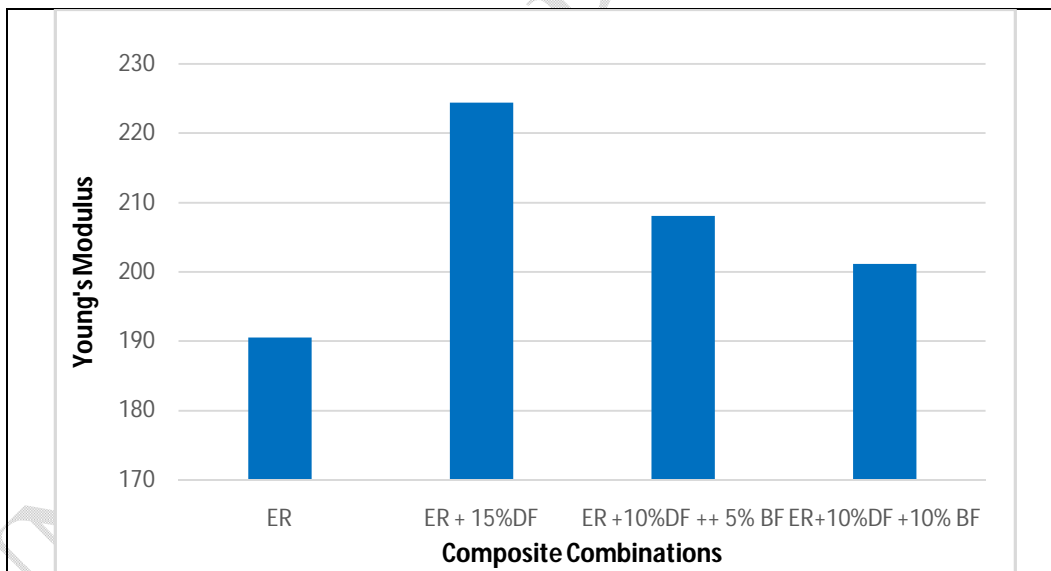
$$\text{Stress} = \text{Force} / \text{cross-sectional area}$$

Strain = Increase in length / original length

The load was increased in 0.4 mm load steps for 28 times. The results below show for each sample variation.



Graph 1: load vs displacement and stress vs strain diagrams for epoxy resin and all developed composite systems



Graph 2: Comparison of the Young's Modulus for epoxy resin and all developed composite

4.1 Analysis

The stress-strain curves indicate that the maximum stress observed was 22 MPa at a strain of 0.12. With the addition of 15% by weight of natural date fiber as reinforcement, the load at fracture increased by 52%, and the strength improved by 36.7%. This demonstrates that reinforcing the matrix with natural fibers has a significant positive effect on the material's strength, consistent with findings from other researchers [10-11].

When hybrid composites of date and banana fibers were tested, with a composition of 10% date fiber and 5% banana fiber, there was a notable improvement in load at fracture by 113% and strength by 118% compared to the base matrix material. This highlights that using fibers of different nature, with better wettability, can substantially enhance the material's strength.

However, when the fiber composition was adjusted to 10% date fiber and 10% banana fiber, the strength and fracture load decreased in comparison to the 5% banana fiber reinforcement. This suggests that a single layer of 5% banana fiber provides better reinforcement than two layers, which is in line with observations in other studies [12-13]. Proper proportioning of fibers with different properties is essential for achieving optimal results in hybrid composites.

Additionally, the fabrication techniques used are crucial in determining the final properties of the composites. Overall, the tensile strength of all composite systems developed, incorporating natural fibers, was significantly higher than that of the base matrix resin. This demonstrates the potential of date and banana fibers for developing composite materials with enhanced tensile strength.

CONCLUSIONS

- The current study demonstrates that the developed natural hybrid composites exhibit better strength compared to the base matrix material (epoxy resin). Among the different fiber combinations, the composite with 10% date fiber, 5% banana fiber (two layers), and 85% epoxy resin showed the best mechanical properties.
- The composite with date fiber in an epoxy matrix exhibited the highest Young's modulus, highlighting the superior mechanical properties of natural fiber-based composites compared to other materials.
- The tensile strength of the material showed significant improvement when natural fibers were incorporated, in contrast to the composite with only epoxy resin.
- The research concludes that natural fiber-reinforced composites, when designed with appropriate fiber ratios and proper fabrication techniques, result in composites with enhanced mechanical properties.

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