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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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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 experimental design utilized four different combinations, including the base matrix, single date fiber, and hybrid fiber

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ratios. The fabrication process was carried out using the hand layup technique. Tensile tests were performed on all the developed samples to evaluate their strength and Young's modulus.. 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 tensile strength.

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 are sustainable 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 macr oscopic combination of two or more distinct mate rials with a finite interface between them" [2]. Properties and molecular arrangement of atoms of composites are unlike alloys. Composites developed by reinforcing reinforcement element into matrix element. [3] 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 [4]. 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 [5]. Incorporating natural fibers can improve mechanical, thermal, and dielectric properties of composites, making them more effective for various applications.

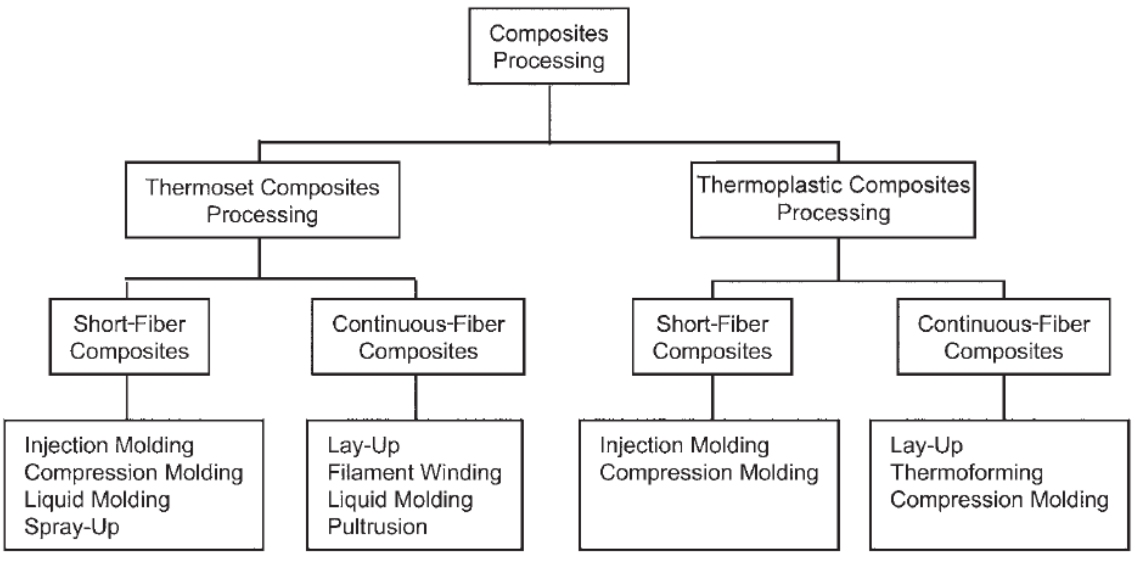


Fig. 1. Polymer composites method of formation [7]

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 [6]. studied 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.

Natural fiber-based composites are becoming increasingly popular because they are biodegradable and less expensive than synthetic material. 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 (Elanchezhian et al., 2018). The current goal of the research is to create a banana, date fiber reinforced hybrid natural composite, and evaluate its tensile properties. Hand lay-up technique adopted for fabrication process. Banana fiber (BF) is known for its high tensile strength, which contributes to the overall strength of bio composites when used as a reinforcement material (Balaji et al., 2024) . Date palm fibers are a renewable resource, making them an eco-friendly alternative to conventional materials in composites, and exhibit competitive mechanical, physical, and chemical properties, enhancing the performance of polymer composites (Abdellah et al., 2023)

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.

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.

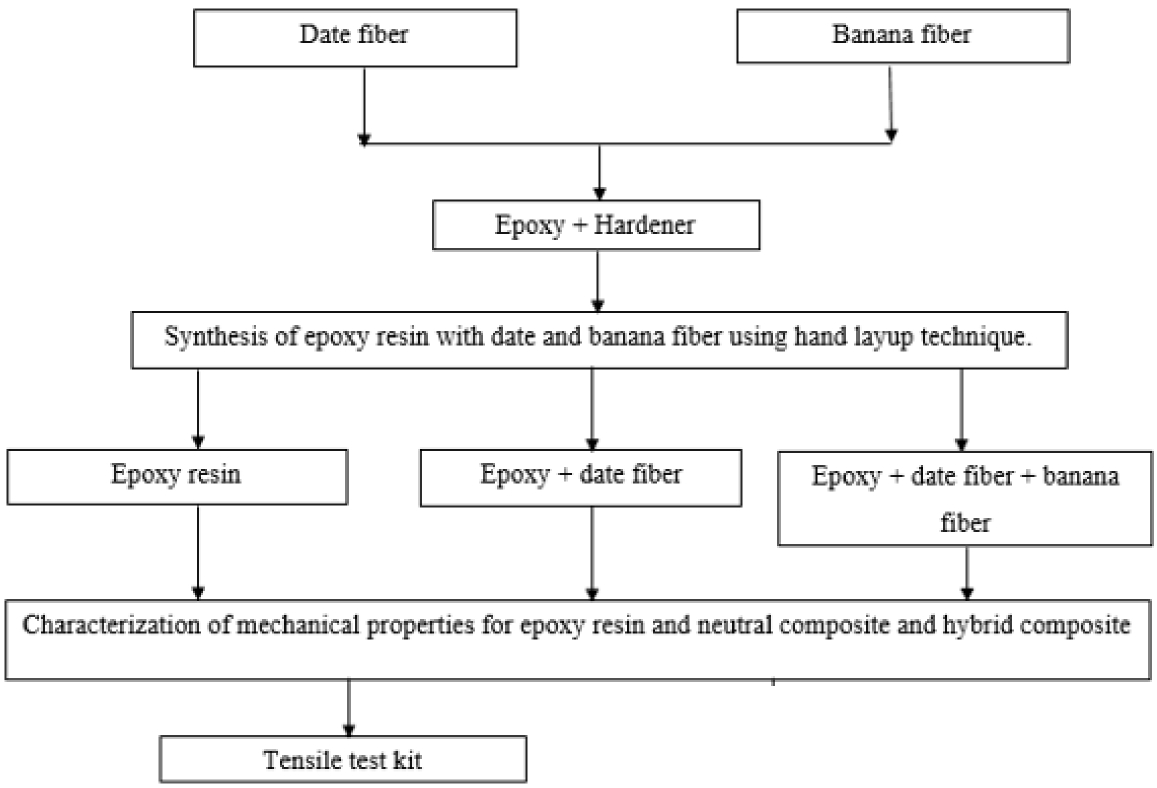


Fig. 2. Research flow process

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 1. Properties of epoxy resin and hardener

	Epoxy resin	Hardener
Type	Solvent-modified	Polyamide
Appearance	Milky white/Yellow liquid	Colorless
Viscosity (27^{0}C)	650	650
Specific gravity	1.15	0.98
Density	1.142 g/cm^3	0.987 g/cm^3

Fig. 3. Epoxy Resin

Fig. 04. Date fiber

Fig. 5. Banana fibers

Table 2. chemical and physical properties of date fiber

Checmical 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 tensile properties of the composites. By varying the fiber type and content, the influence of each variable on tensile strength 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.

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.

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 [11].

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

Extraction the reinforced (Banana fiber)

Soaked in HCL solution

Weighing banana fiber vol. fraction

Drying of fiber

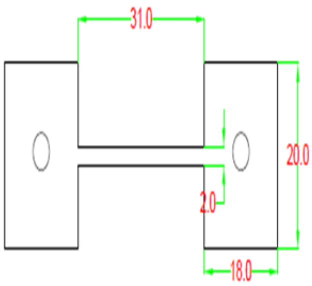
Chopped fibers

Washing fiber with water

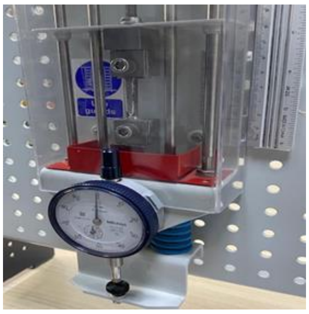
Automatic sieve shaker machine

Weighing the powdered fiber

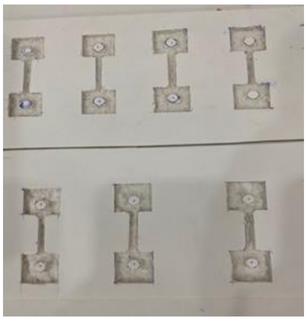
Resin-hardener mixed with fiber



2-D drawing of tensile test



Tensile testing kit



Mold for tensile test

Fig. 6. processing, assembly, and preparation of composite

4. RESULTS 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.

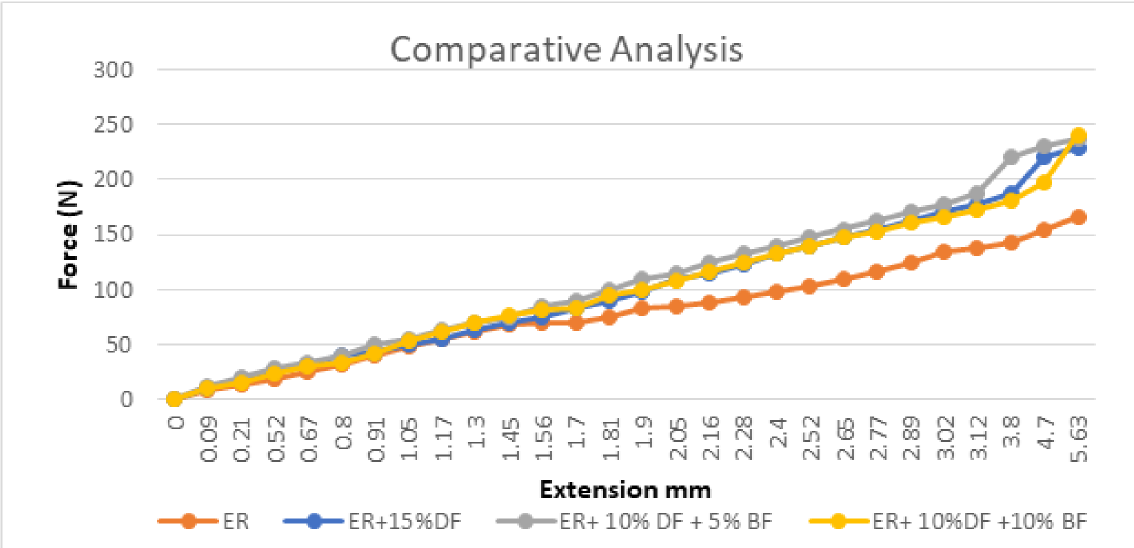
Stress = Force / cross-sectional area

Strain = Increase in length / original length

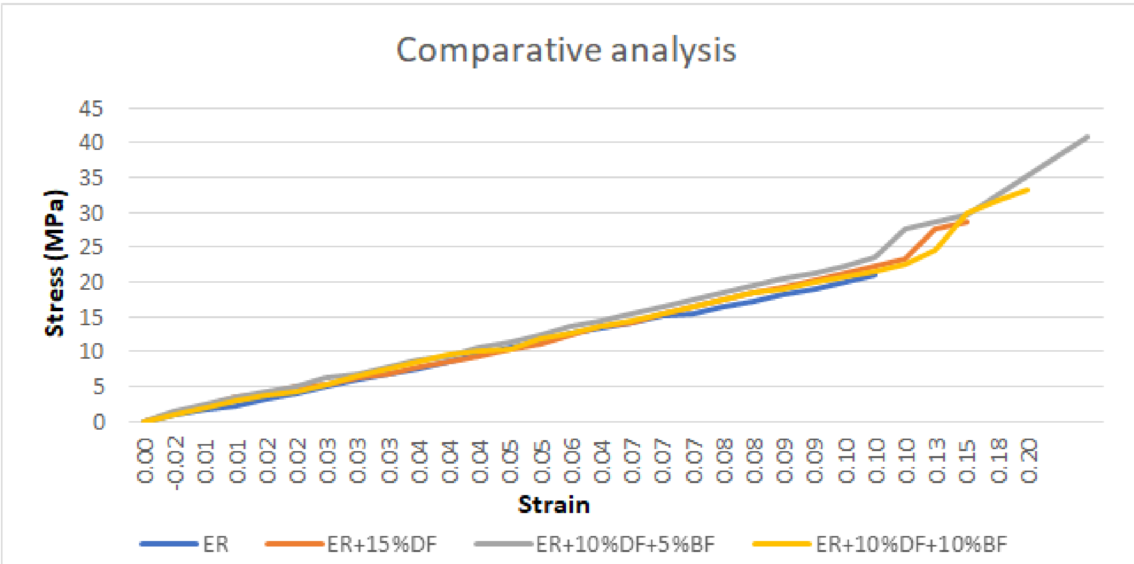
The load nut increased in 0.4 mm load steps for 28 times. The results below shows for each sample variation.

4.1 ANALYSIS

The analysis of the Graph 1 reveals that the tensile load caused a gradual elongation of the pure epoxy resin composite by 4.24 mm under a

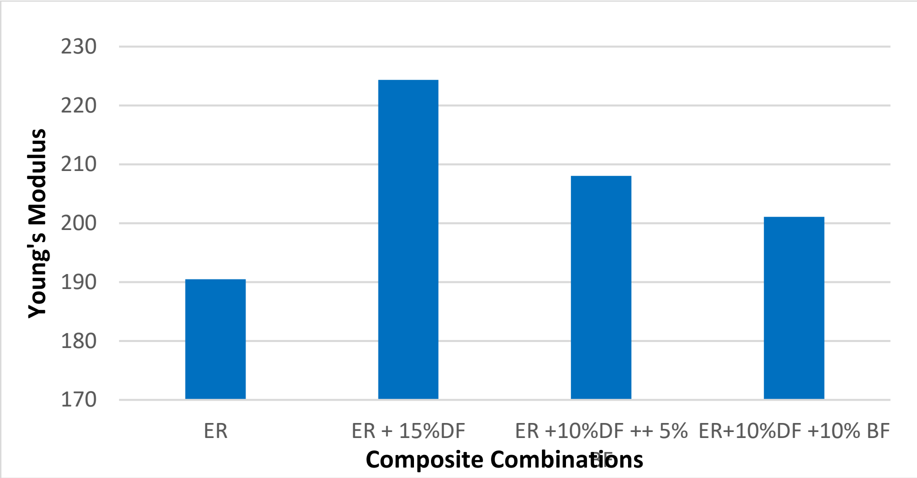


(A)



(B)

Graph 1(A-B) . 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

maximum applied force of 165 N. With the addition of 15% date fiber, the elongation increased to 4.71 mm, corresponding to a maximum force of 229 N. In the hybrid configuration containing 10% date fiber and 5% banana fiber, the composite exhibited a further elongation of 5.63 mm under a maximum force of 237 N. Additionally, increasing the fiber ratio resulted in an elongation of 5.47 mm in the date fiber-banana fiber-epoxy resin composite, with a maximum force of 253 N. These results clearly demonstrate that incorporating natural fibers enhances the tensile performance of the composite, as indicated by increased elongation and load-bearing capacity.

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 [12;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 [13]. Proper proportioning of fibers with different properties is essential for achieving optimal results in hybrid composites.

Additionally, the fabrication techniques used are cruial 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.

5. CONCLUSIONS

Base on this study, we can concluded as follows

- 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 tensile properties.
- The inclusion of date fiber significantly enhanced the Young's modulus, emphasizing the superior tensile performance of natural fiber-based composites.
- The research concludes that natural fiber-reinforced composites, when designed with appropriate fiber ratios and proper

fabrication techniques, result in composites with enhanced tensile properties.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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