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ORIGINAL RESEARCH ARTICLE

Tensile and physical properties of *Piliostigma thonningii* (camel's foot) and *Hyphanea thebaica* (doum palm) hybrid fibre reinforced epoxy resin composites

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ABSTRACT

The morphological, mechanical, and physical attributes of novel hybrid epoxy polymers reinforced with fibres from camel's foot and doum palm, treated with alkali, have been carefully investigated. FTIR spectroscopy demonstrated the efficacy of the NaOH treatment by the partial elimination of non-cellulosic constituents, evidenced by an upward shift in the O–H excitation peak from 3297.30 to 3323.28 cm-1, along with a reduction in the C–H and C=O bands. The mechanical evaluation demonstrated that hybridization significantly enhanced performance, achieving an ultimate tensile strength of 41.67 MPa and a tensile modulus of 3.459 GPa at an optimal filler ratio of 4.0D to 1.0P. This optimal ratio was validated by SEM morphological analysis, which showed reduced gaps and improved adhesion between fibres and the matrix. Composites maintained a low density of 0.96-1.27 g/cm^3 and absorbed minimal water (up to 2.07%). The results indicate that the two natural fibres effectively combined to produce a composite material with enhanced mechanical strength and significant potential for use in environmentally friendly construction and vehicles.

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Hybrid composites, Tensile test, Hand lay-up, Epoxy resin, camel's foot and doum palm fibres.

INTRODUCTION

Sustainable economic growth, increasingly used as an alternative across sectors. In a developed association, ancient products from metals, plastics, rubber, and steel are being discarded due to the advent of modern composite materials in many aspects of our lives. A composite is formed by merging different resources that fairly differ in their properties. Also, constituents work together to form a unique property, with different materials determining their ability to mix, dissolve, or blend. Composite materials can exist from natural or synthetic fibres.

Natural fibers are present in plants and animals and can be modified and synthesized into different materials. Fibres from jute, Sisal, flax, and oil palm are utilized in harvest new composites; this concept has attracted considerable attention towards the exploration of natural sources in the last decade (Muhammed and Isyraf, 2015).

Mostly, natural fibres are classified as primary fibres, alongside secondary fibres. Fibres like jute fibre, oil palm/doum palm, and others are mostly grown for their fibre content. Secondary fibres like agro residues, coir fibres, and pineapple fibres are fibres obtained from plant by-products. Fibres can be obtained in many classes, such as bast fibres (including leaf and seed fibres), kernels, grasses, and reed fibres, which are all supplementary types (Aravindh et al., 2022; Ramesh, 2014; Prabhu et al., 2020; Karthi et al., 2020).

The concept of biodegradation of natural fibres can relate to physical, mechanical, chemical, thermal, and humidity settings, which have expanded their role in numerous applications (Dittenber and GangRao, 2012; Ramesh, 2014; Farouk et al., 2012). They are biodegradable, readily available, and very easy to obtain. Examples of fibres include bagasse, sisal, coir, cotton, hemp, jute, flax, ramie, pineapple fibre, palm kernel, and maize husk.

The fibres are typically surface-treated to increase adhesion (El-shekeil et al., 2012). It was observed that chemical treatment (alkali treatment) of fibres improved the mechanical properties of epoxy-reinforced composites, thereby suggesting improved water absorption capacity (adhesion) (Farouk et al., 2012). The mechanical properties of the composites were found to

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improve due to alkali treatment of the natural fibres, which led to improved adhesion. Additionally, other silanes can be added to the alkali treatment (Doan et al., 2012).

The impact of fibre size and fibre weight ratio may result in the increase or decrease in the mechanical properties of rice husk fibre reinforced polyester composites as investigated by (Aboshora et al., 2017) which confirmed that both fibre size/fibre ratio have a significant effect on the tensile and impact strength of the composites, these mechanical properties may increase/decrease upon increase in fibre loading. Krishan et al. (2019) found that fibre orientation in some composite materials tends to confer good mechanical properties, such as micro-hardness, tensile strength, flexural strength, inter-laminar shear strength, and impact strength. Ondeik et al. (2018) studied the behaviour of selected fibres, including doum palm fibre, luffa gourd fibre, and baobab plant fibre. The result indicated that the doum palm fibre had the highest strength and is expected to be more crystalline than the luffa gourd fibres or baobab fibres, which have lower crystallinity.

Alkali treatment will be applied to the doum fibres to clean their surfaces and improve surface quality, enabling better interaction between the fibres and the matrix. To determine how fibre composition affects the composites' properties, tensile and rheological characteristics will also be examined.

In modern times, doum palm fibres are used to fabricate composites for construction, automotive, furniture, and structural applications. However, the trunk, leaves, and other parts can be used to make ropes, canvas, pulp, paper, and, lately, insulation and mats (Krishan et al., 2019; Ondeik et al., 2018). Natural fibres as reinforcements offer advantages over synthetic fibres. This is due to the alignment of carbon-carbon bonds, which also significantly affects their strength and stiffness (Justiz-Smith et al., 2008). They also offer low density, low cost, and biodegradability, which have been designated in a study as a fortification in low-density polyethylene (LDPE). not for their strong resistivity as well as their strength (Ondeik et al., 2018). The study also examines how doum fibres are used at several weight proportions to assess the impact of a supplementary doum on thermal and mechanical features.

The basic chemical components of lignocellulose fibres in camel's foot (*Piliostigma thonningii*) fibre are cellulose, hemicellulose, and lignin (Mohammed et al., 2015). The use of *Piliostigma thonningii* (camel's foot) fibres in the production of ceiling boards. By combining the fibres with styrofoam adhesive as a binder, the study produced composite boards under varying fibre-to-binder ratios, pressures, and temperatures. The optimal conditions yielded boards with desirable properties, including low density, minimal water absorption, adequate tensile strength, and low thermal conductivity, suggesting their suitability as insulating ceiling materials (Mohammed et al., 2015) .

Hybrid composites are made up of reinforced phases, a single matrix reinforcing phase, and various matrix phases. Hybrid composites can be designed by combining a natural fibre and a synthetic fibre (bio fibre) in a matrix, or by combining two natural fibre/biofibre in a matrix, which affects the fabrication of many mixtures with specified natures and is comparable to a single fibre armored compound. Natural fibres like bamboo, when mixed with synthetic fibres such as glass, form a hybrid compound that plays an important role in achieving combinations with desired properties at a lower cost. The behavior of hybrid composites is a weighted sum of their individual components, with a more favorable balance between their inherent advantages and disadvantages. The properties of all the composites are obvious through different factors, including fibre content, fibre length, alignment, and extent of mixture of fibres, fibre medium (Siddika et al., 2013). Hybrid composite materials have better all-round combinations of properties than composites containing only one fibre type. Hybrid composites may replace or reduce the use of synthetic fibres in applications in the automotive, building, and aircraft industries (Jawaid et al., 2012).

Composite materials of E-glass, Jute, and coconut fibres were analysed to determine their microstructural and mechanical properties. The results showed that coconut fibres had better impact strength, tensile strength, and hardness values than those reinforced with jute (Gopinath et al., 2008).

According to Jha et al. (2018), a hand lay-up technique was used to fabricate a hybrid composite of jute and E-glass fibres to measure the mechanical properties of the resulting composite. The fabricated composites would help achieve the desired mechanical parameters of the composite material, with improved erosion or wear resistance in the materials formed from the hybrid composite of jute and E-glass fibres.

Natural fibres can serve as essential reinforcing phases in advanced structural composites, with the potential to have major positive effects on the economy, environment, and society. This is due to their many benefits, including low density, cost-effectiveness, durability, reduced greenhouse gas emissions, high recyclability, and carbon neutrality (Mohammed et al., 2015). A composite containing two or more types of fibre is referred to as a hybrid. Depending on the goal of hybridization, the polymeric material's requirements, or the building's design, the components that comprise the hybrid composite are considered. The assets of single-fibre mixtures are enhanced by crossing with other fibres, reducing the disadvantages of each individual fibre while preserving their advantages.

The objective of hybridizing two natural fibres is often to improve the balance of their physical, chemical, and mechanical properties rather than to maximize the hybrid effect. Polymer composites based on natural fibres are inexpensive materials with minimal environmental impact. However, the problem with the use of natural fibres is their low adhesion with the polymeric matrix (Ngueho-Yemele et al., 2013).

Development of new hybrid epoxy-based composites that are capable of replacing traditional materials for domestic, automotive, and construction applications. There is a need to optimise the performance of hybrid epoxy-based composites for automotive, aerospace, and personal protective equipment, providing a blend of properties such as stiffness, strength, and ductility that mono-fibre reinforced composites cannot achieve.

MATERIALS AND METHODS

Materials

The two natural fibres of camel's foot (*Piliostigma thonningii*), and doum palm (*Hyphanea thebaica*) were obtained from Koreye village, Sabon Gari, Zaria local government. Epoxy Resin and Hardener (grades 3554A and 3554B) were used as the matrix from Lagos State, while sodium hydroxide (NaOH) and Distilled Water were also used for fibre treatment from the chemistry department. Table 1 shows the equipment used.

Fibre extraction

Camel's foot bark was obtained locally from Koreye village, Sabon Gari Local Government, Kaduna State, Nigeria. Doum palm fibres were removed from the doum palm tree by separating them from the fruit husk and processing them to obtain continuous fibres. Camel's foot and doum fibres were cleaned to remove impurities and dried to achieve a moisture content suitable for composite processing. The fibres were treated with a suitable surface treatment method to enhance fibre-matrix adhesion. Different sizes were cut at the nodes for the upper skin by detaching or scraping the fibre without damaging its surface. Between the nodes, 200 mm was cut. The upper skin of the doum palm was removed without damaging the fibre surface. After removing the skin, the bark was soaked in water for 3-4 weeks to extract fibre. After soaking, the fibres were detached. Fresh camel's foot and doum palm fibres were obtained after careful drying.

Table 1: List of equipment and their sources

S/NO	EQUIPMENT	MODEL	SOURCE
1	Tensile strength test machine	TM2102-T7	Department of Polymer and Textile Engineering, A.B.U. Zaria
2	Fourier transform infrared spectroscopy (FTIR) machine	Caray 630 FTIR Agilent Technologies	Multi-User Science Research Laboratory, Department of Chemistry, A.B.U. Zaria
3	Scanning Electron Microscopy Machine	Thermo Fisher Prima	Dicon, Kaduna State

Table 2: Design of Experiment (Formulation) for Camel's foot (*Piliostigma thonningii*)/Doum Palm (*Hyphanea thebaica*) Hybrid Fibre Reinforced Epoxy Composites

S/N	wt. % of camel's foot fibre, P. (g)	wt. % epoxy (g)	wt. % doum palm, D. (g)	wt. % hardner (g)	total mass of composites (g)
1.	0.00	112.50	0.00	37.50	150
2.	5.00	112.50	0.00	32.50	150
3.	4.50	112.50	0.50	32.50	150
4.	4.00	112.50	1.00	32.50	150
5.	3.50	112.50	1.50	32.50	150
6.	3.00	112.50	2.00	32.50	150
7.	2.50	112.50	2.50	32.50	150
8.	2.00	112.50	3.00	32.50	150
9.	1.50	112.50	3.50	32.50	150
10.	1.00	112.50	4.00	32.50	150
11.	0.50	112.50	4.50	32.50	150
12.	0.00	112.50	5.00	32.50	150

Alkali treatment

Because alkali treatments account for the majority of treatments used for natural fibres in which the process makes the surface of natural fibres rougher and eliminates the lignin, oil, and wax coating them, which improves better fibre interlocking with the polymer matrix; in this study, a solution of 5% sodium hydroxide (NaOH) was prepared, and the camel's foot (*Piliostigma thonningii*) fibre was immersed in the solution for one hour. The same procedure was repeated for doum palm fibres. After one hour, the fibre was thoroughly cleaned with acetic acid, then distilled water, and finally dried in an oven at 60°C for 24 hours.

Composite fabrication

A mould was used for casting the composite. A hand lay-up technique was used for the preparation of the samples. A calculated amount of epoxy resin and hardener (ratio of 112.5 cm^3 and 37.5 cm^3) was thoroughly mixed with gentle stirring to minimize air entrapment. For quick and easy removal of the composite from the mould, petroleum jelly was used as a releasing agent. The essential quantity was distributed through the mixture. Hybrid combination of camel's foot and doum palm fibres in the ratio (0 wt. %

and 5 wt. %) was prepared with the matrix for fabrication, after careful mixing, the whole mixture was poured into the mould for a treatment which was kept at room temperature for twenty four hours, subsequently , the samples were removed out of the mould, it was then proceed for cutting and supplementary tests based on the ASTM standards. Table 2 shows the Design of Experiment (Formulation) for Camel's foot (*Piliostigma thonningii*)/Doum Palm (*Hyphanea thebaica*) Hybrid Fibre Reinforced Epoxy Composites

Fourier Transform Infrared Spectroscopy (FT-IR)

FTIR Spectroscopic analysis observed on camel's foot (*Piliostigma thonningii*) and doum palm fibres was carried out using an Agilent infrared spectrophotometer, which weakened the total reflectance (ATR) at 650-4000 cm^{-1}.

Physical properties

Density

The mass of each sample was measured with an analytical balance, and the volume was determined by displacement. Water was poured into a measuring cylinder, and the initial volume was recorded. The composite sample was then carefully placed into the cylinder, and the new reading on the cylinder was recorded as the final volume. The density of the sample is to be calculated as the ratio of the masses of the sample to the amount/volumes of the samples in g/cm^3. The densities of the samples were determined using the expression below according to the ASTM D790 standard method.

$$Density = \frac{Mass\ (g)}{Volume\ (cm^3)} \quad (1)$$

Where mass is measured in grams (g) and volume in a cubic centimetre (cm^3)

Water absorption

The samples were weighed and recorded and then immersed in water in a container for 24hours. The test samples were initially measured using a digital weighing balance as M_1; they were then removed and reweighed, recorded as M_2. The same procedure continues, with records taken every 24 hours for 30 days, until the sample stops absorbing water completely. Water absorption was carried out in accordance with ASTM D570. Water absorption is measured using the equation.

$$Water\ absorpton = \frac{m_2 - m_1}{m_1} \times 100 \quad (2)$$

Where M_1 is the initial weight before immersion, and M_2 is the final weight after immersion

Mechanical Properties

Tensile strength

The fabricated composite samples were cut into a dumbbell shape. The specimen was clamped in the tensile test machine's grip and held firmly to prevent slippage. Readings were recorded, and the procedure was repeated for the remaining composites to obtain the load-extension graph. The tensile test was carried out in accordance with ASTM D638. Triplicate specimens of each composite were cut into a dumbbell shape, and the average values recorded were used to calculate the tensile test parameters such as;

i. Ultimate Tensile strength (UTS) is the load (N) applied per square area to break the material, which is expressed in (MPa)

$$UTS = \frac{Average\ Force}{Cross\text{-}section\ Area} \quad (3)$$

ii. Tensile strain is the ratio of the change in length in millimeters per gauge length. This shows that the tensile strain is unitless

$$Strain = \frac{\Delta l}{l} \quad (4)$$

iii. Percentage elongation is the percentage increase in the length of the material before it breaks. It is usually obtained by multiplying the tensile strain by 100%

$$\%\ Elongation = \frac{\Delta l}{l} \times 100 \quad (5)$$

Morphological properties

Micrographical analysis (SEM)

The morphological properties of the specimens were examined using a Thermo Fisher Prima scanning electron microscope at DICON, Kaduna. Micrographs were acquired at ambient temperature. A field-emission gun operated at 5 kV was used for analysis. Magnification was increased, and morphological data for the samples were recorded. Microstructural details were captured at various magnification levels. The cracked surfaces of the analysed samples were coated with gold in an orthogonal direction to the cracks.

RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy (FTIR)

The importance of alkali treatment to the fibres derived from doum palm and camel's foot fibres was examined using FT-IR spectroscopy. The spectral data for the treated and untreated fibres are depicted in Figures 1, 2, and 3, which illustrate a decrease in the intensity of the O-H stretch, with a discernible shift in peak intensity observed at 3297.30 cm-1, 3305.71 cm^{-1}, and 3323.28 cm^{-1} for the untreated fibre (UT). This validates the impact of the hydroxide process, which has partially diminished the level of non-cellulose polysaccharides within the fibre (Tisserat et al., 2014).

This phenomenon is predominantly attributed to hydrogen bonding between the O-H groups of cellulose and hemicellulose within the fibre (Yang et al., 2019; Kokot et al., 2022). Peaks identified at (2889.44 cm^{-1}), (2818.61 cm^{-1}), and (2762.65 cm^{-1}) across spectral analyses mainly emanate from or after C-H vibrational stretching, which are associated with the aliphatic group, while an observed diminution in their stretching intensity signifies the elimination of hemicellulose (Andreeva et al., 2002). It verifies that the therapy has partially eradicated hemicelluloses. Hemicelluloses provide the hydrophilic properties of fibres (He et al., 2017). The absorption peak at 1600.92 cm^{-1} is attributed to the carbonyl (C=O) stretching of acetyl groups in hemicellulose (Gumel and Tijjani, 2015). In the spectral representation of untreated fibre, the absorbance recorded at 1428.92 cm^{-1} corresponds to the –CH_3 group. In the treated sample at 5%, the peak at 1320.61 cm-1 is assigned to the asymmetric deformation of lignin, and its attenuation corroborates the removal of both lignin and hemicellulose (Lawal et al., 2023).

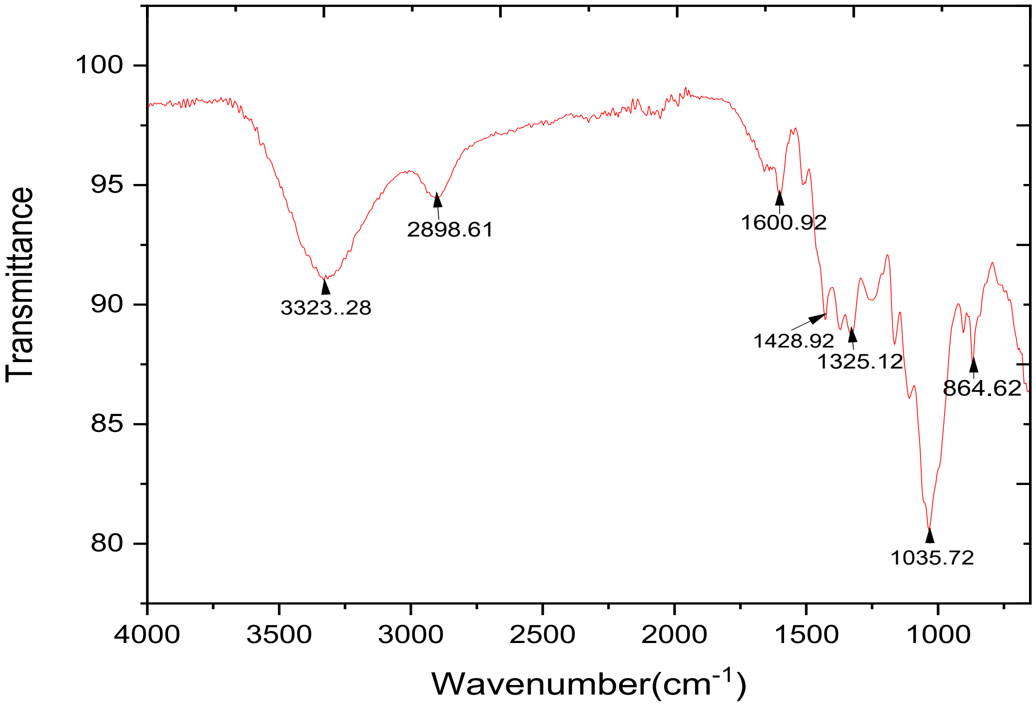

Figure 1: Fourier Transform Infrared Spectroscopy of untreated fibre

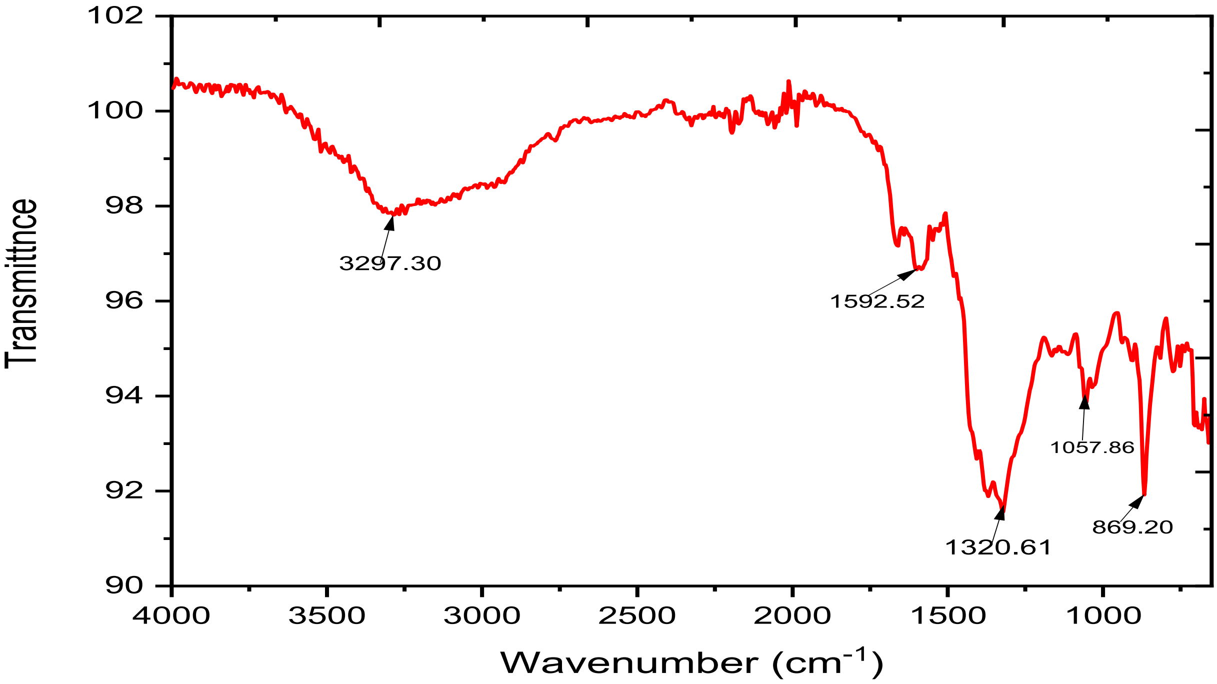

Figure 2: Fourier Transform Infrared Spectroscopy (FT-IR) of treated *Piliostigma thonningii* (Camel's foot) Fibre

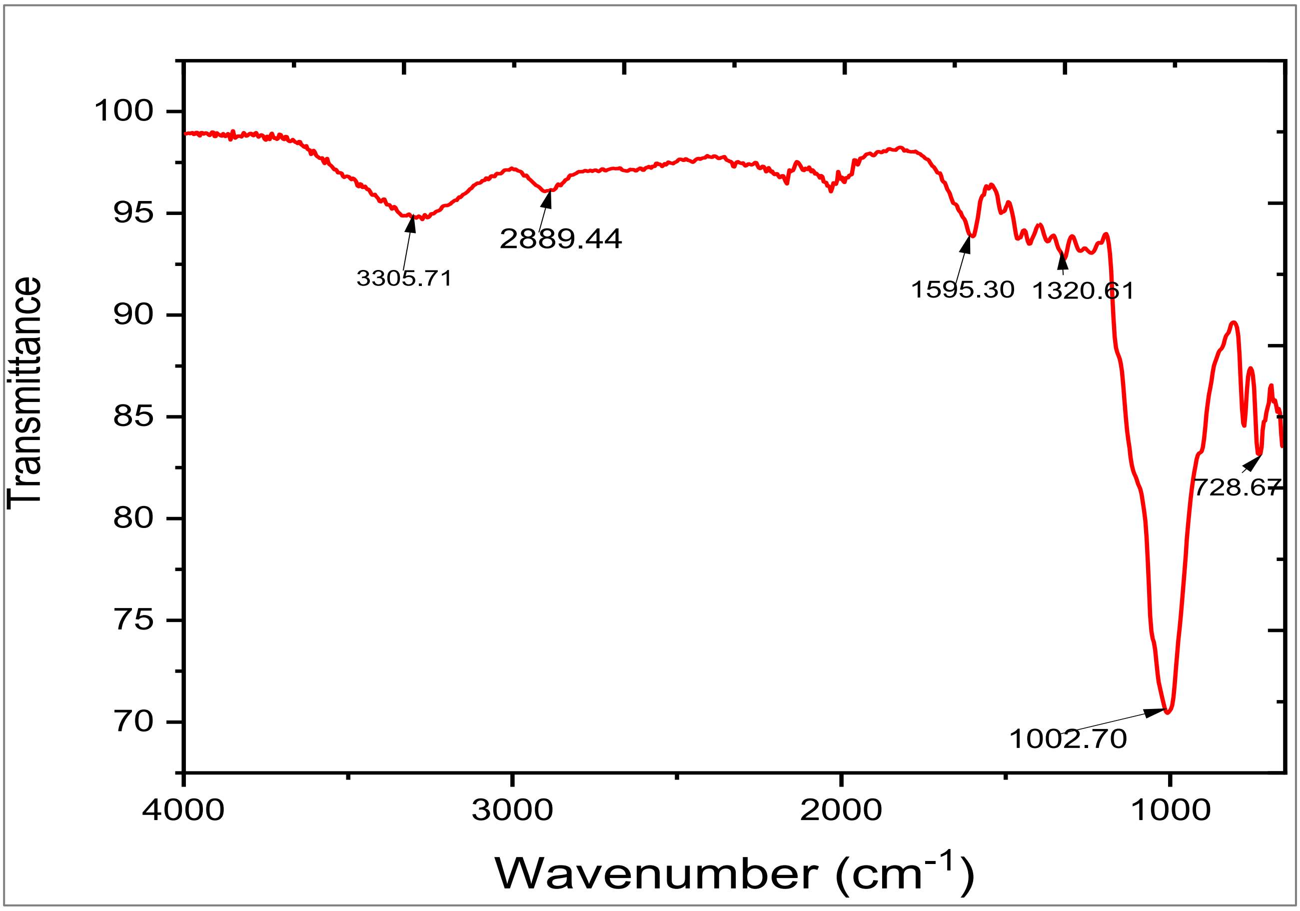

Figure 3: Fourier Transform Infrared Spectroscopy (FT-IR) of treated Doum Palm Fibre at 5% NaOH

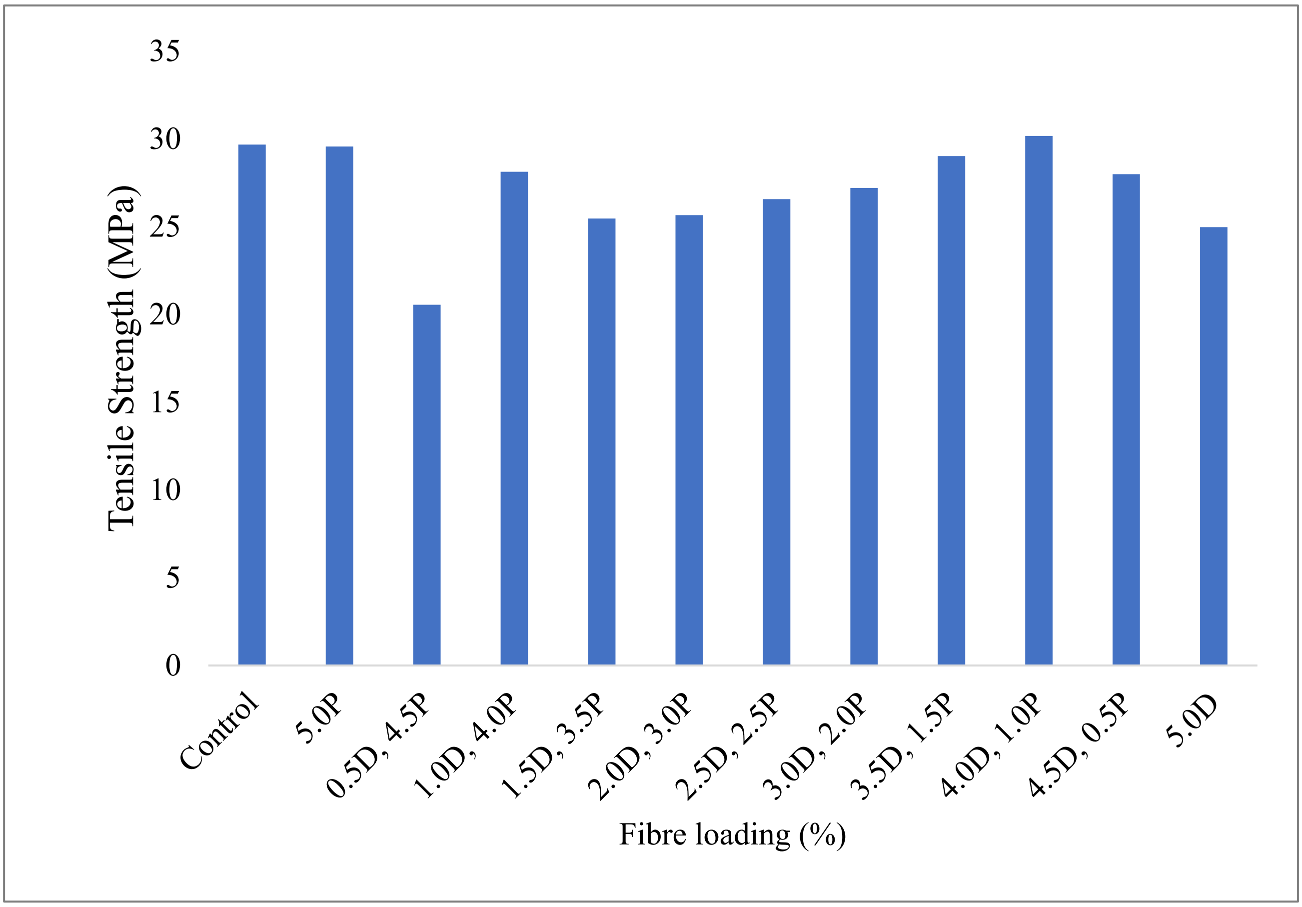

Figure 4: Tensile Strength of Hybrid Camel's foot (Piliostigma thonningii) and Doum Palm Reinforced Epoxy Resin Composites

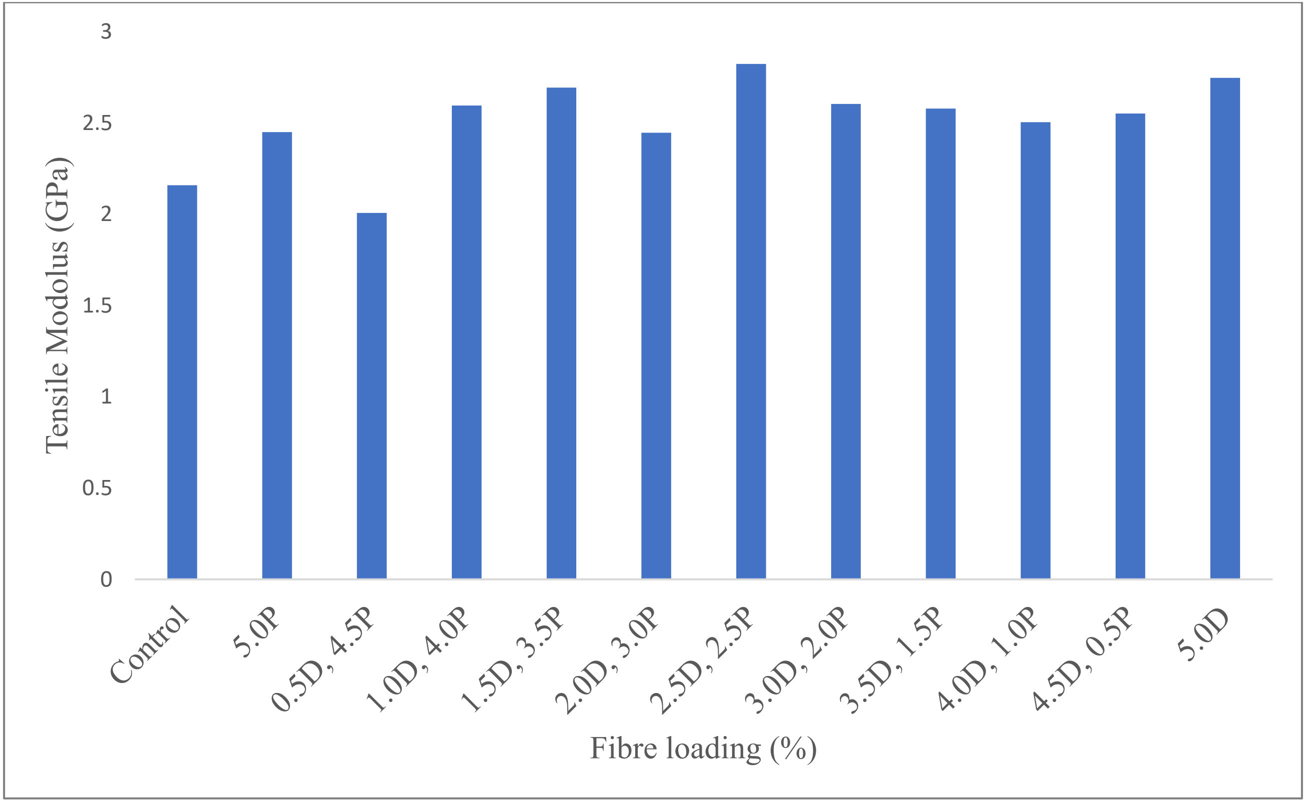

Figure 5: Tensile Modulus of Hybrid Camel's foot (Piliostigma thonningii) and Doum Palm Reinforced Epoxy Resin Composites

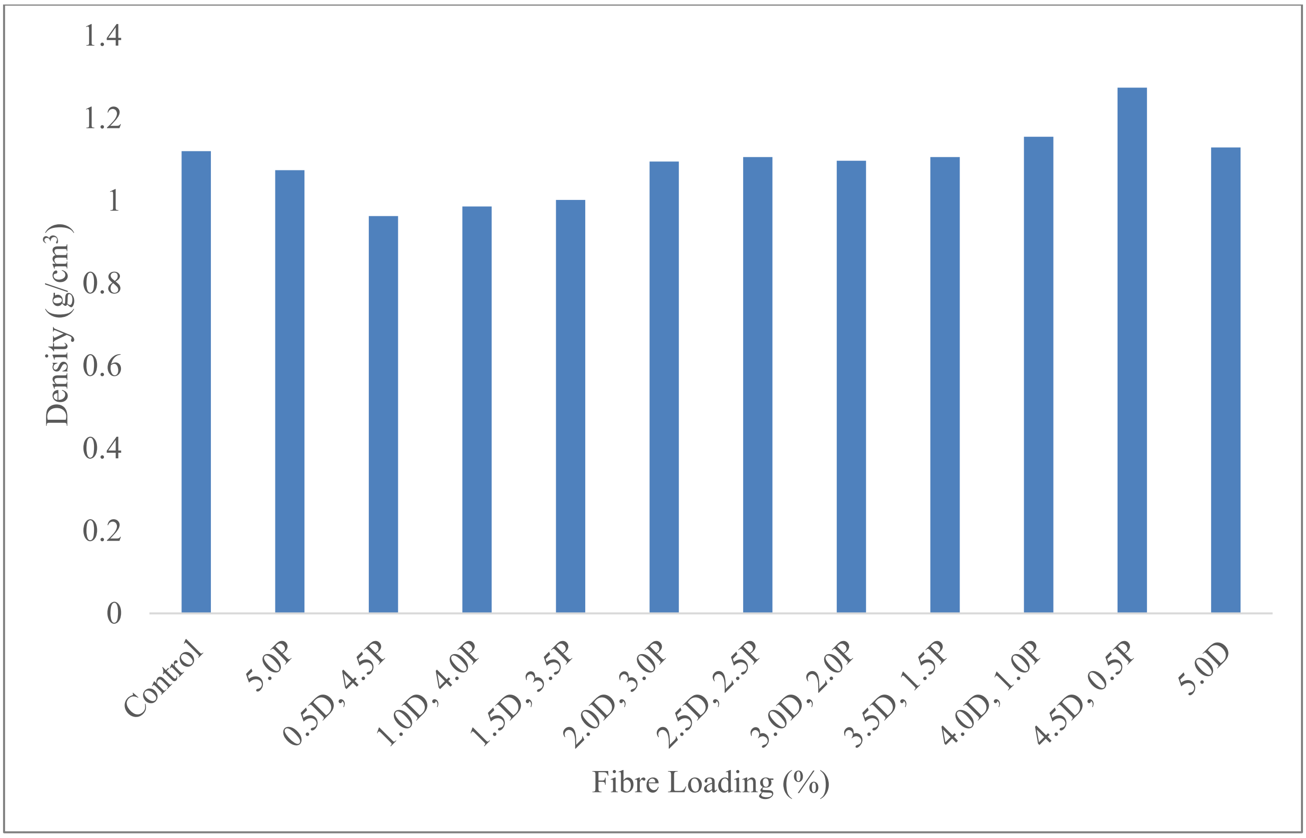

Figure 6: Density of Hybrid Camel's foot and Doum Palm Reinforced Epoxy Resin Composites

Mechanical Properties

Tensile strength

From Figure 4 below shows the tensile strength of the composites at different filler ratio of 5P, 0.5D/4.5P, 1.0D/4.0P, 1.5D/3.5P, 2.0D/3.0P, 2.5D/2.5P, 3.0D/2.0P, 3.5D/1.5P,4.0D/1.0P, 4.5D/0.5P, and 5.0D. It is shown that increasing the filler ratio from 0.5D/4.5P to 3.0D/2.0P decreased tensile strength. The highest tensile strength was recorded to be 41.67 MPa for a

4.0D/1.0P filler ratio, and the lowest tensile strength was 20.55 MPa for a 0.5D/4.5P filler ratio, respectively. This decrease in tensile strength with an increase in some filler ratio was due to the lower surface area provided by the larger particle size, which led to an irregular distribution of fibre particles and reduced efficient stress transfer from the polymer matrix to the filler particles. Similar trends were reported by Alewo et al. (2015), Montagna and Santana (2012), Kamalbabu and Mohankumar (2014), and Njoku et al. (2011).

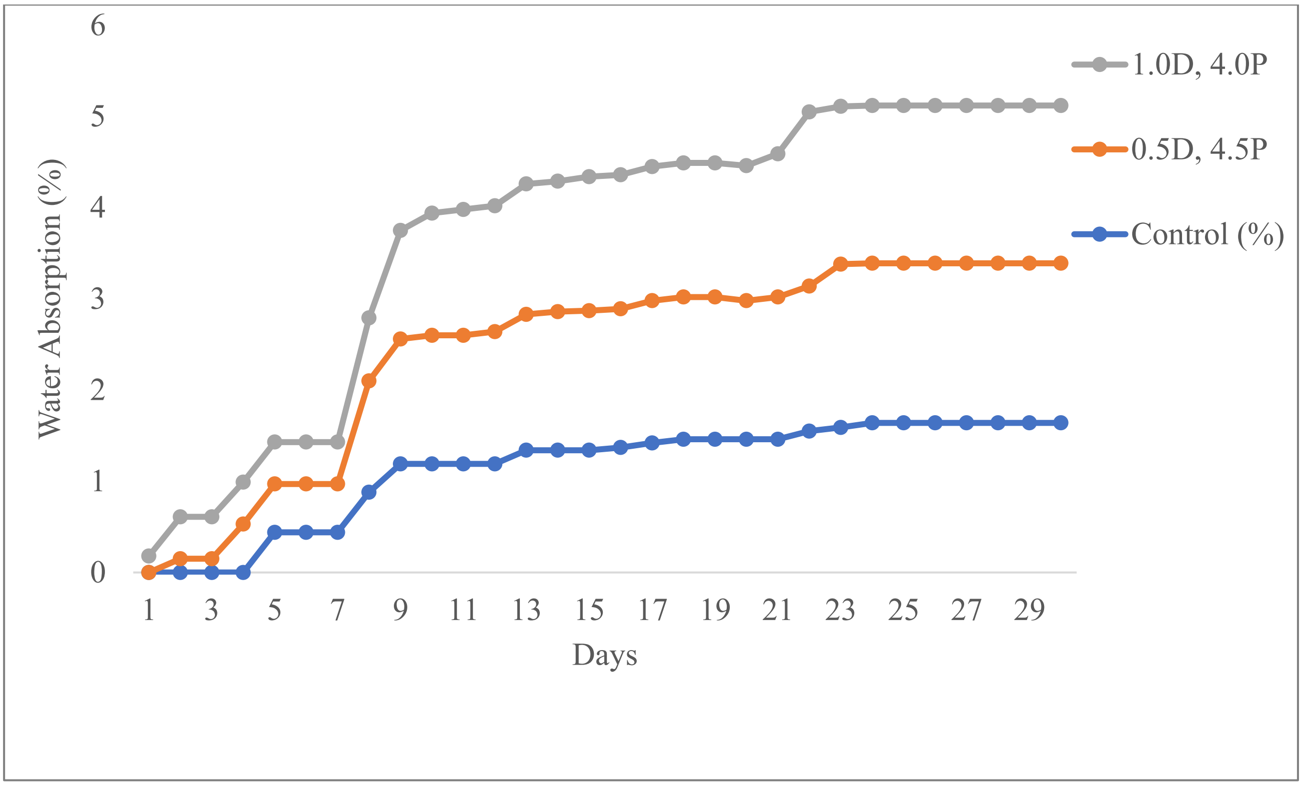

Figure 7: Water Absorption of Hybrid Camel's foot (*Piliostigma thonningii*) and Doum Palm Reinforced Epoxy Resin Composites

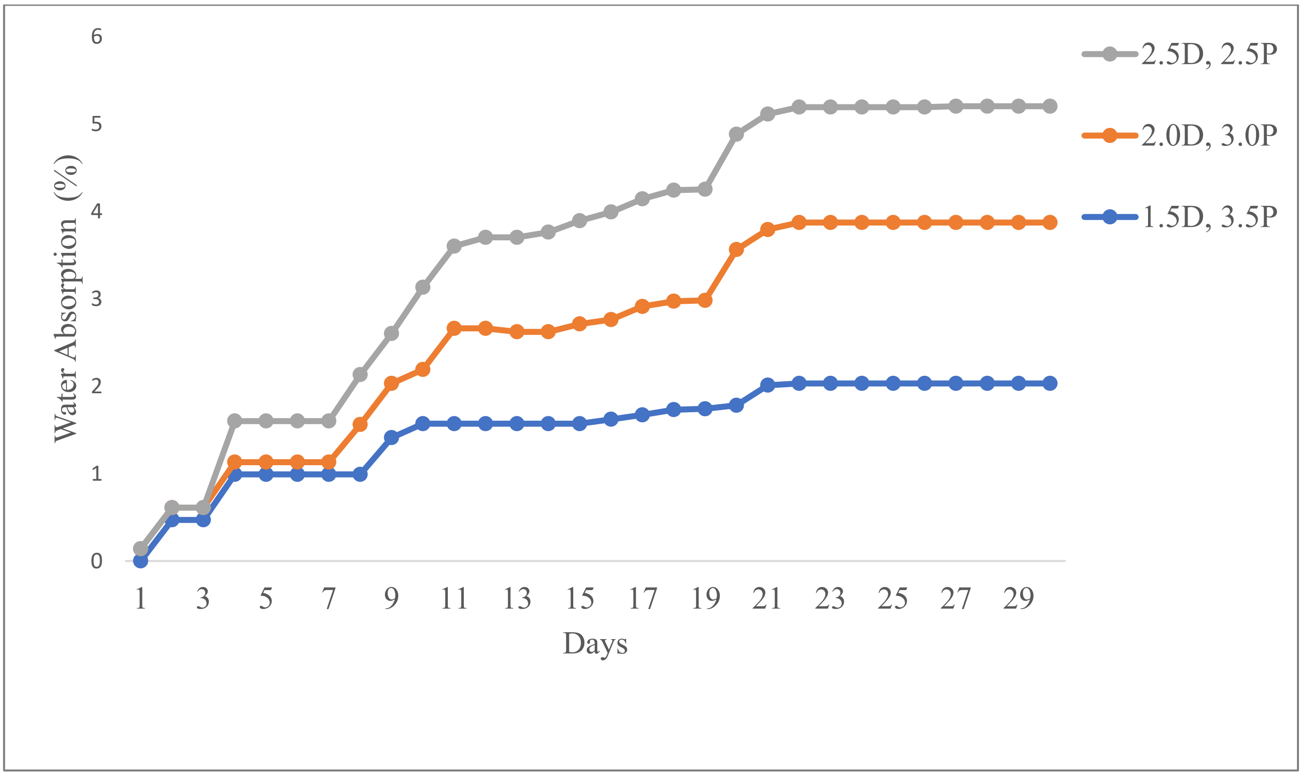

Figure 8: Water Absorption of Hybrid Camel's Foot (Piliostigma thonningii) and Doum Palm Reinforced Epoxy Resin Composites

An alkaline solution purifies the filler and eliminates impurities, thereby enhancing bonding between the surface layers. This is consistent with the findings of Olcay and Kocak, (2021). According to Praveena et al. (2022), a similar study found that the enhancement in tensile strength occurs due to the incorporation of stronger doum palm and camel's foot (*Piliostigma toningii*) fibres into the epoxy resin matrix, which had a significant effect on tensile strength with increasing and decreasing fibre content during composite fabrication. The trend in the tensile strength results is similar to that reported by Rakesh et al. (2011).

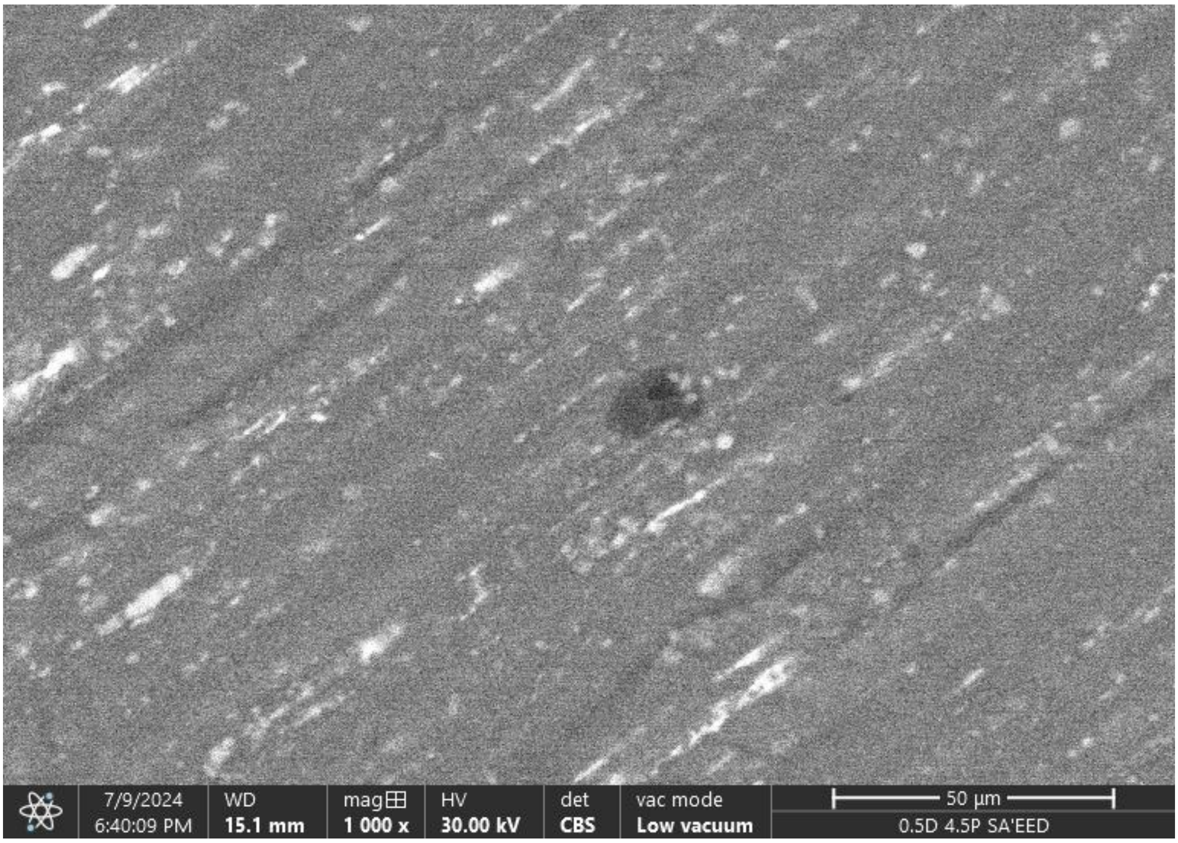

Plate 1: 0.5D/4.5P wt. % hybrid composites micrograph at magnification 1000x

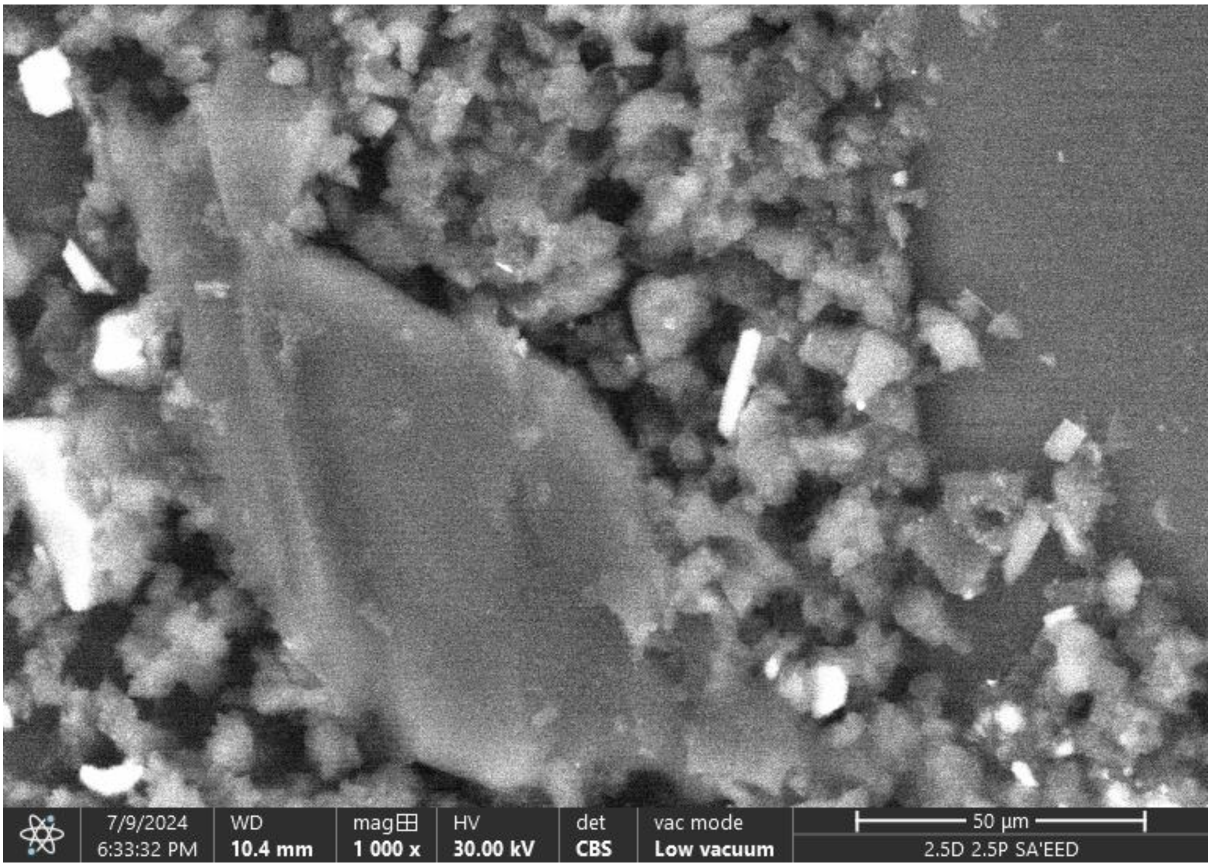

Plate 2: 4.0D/1.0P wt. % hybrid composites micrograph at magnification 1000x

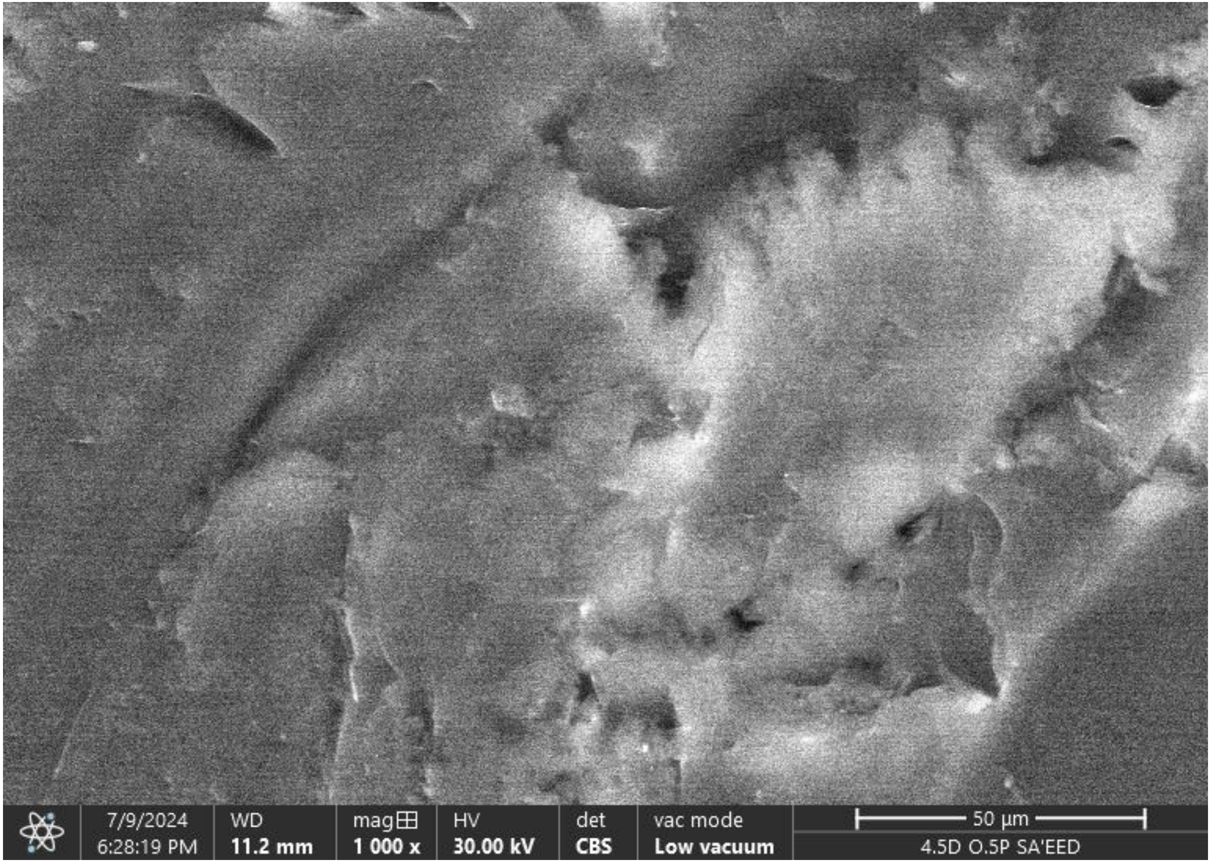

Plate 3: 4.5D/0.5P wt. % hybrid composites micrograph at magnification 1000x

Tensile modulus

From Figure 5, there was an increase in tensile modulus with increasing filler ratio, and a slight decrease when the piliostigma thonningii filler ratio was reduced, which could be due to inadequate mixing of the filler and the matrix. It is found at (3.459 GPa) maximum for 4.0D/1.0D wt. % and lowest at 2.07GPa for filler ratio 0.5D wt. % and 4.5P wt. % respectively. This could be due to irregular distribution within the matrix or to changes in the crystallinity of the cellulose structure during treatment, which will reduce the mobility of the polymer molecular chains. It is evident from the work of Genevieve and Isaac (2011).

Physical Properties

Physical parameters such as density, water absorption, and SEM were determined, and the results were discussed in this section.

Density

The density of doum palm composites in the epoxy resin was found to be 1.129 g/cm^3 for 5.0D wt. %, and 1.074 g/cm^3 of camel's foot for 5.0Pwt. %, and the pure epoxy resin to be 1.17 g/cm^3, respectively. Figure 6 revealed an increase in wt. % of reinforced filler ratio of doum/camel's foot in the epoxy resin matrix decreases the density from 1.120 g/cm^3 of epoxy to 1.074 g/cm^3 of camel's foot fibre. The reduction in density may result from the lightweight nature of the fibres, which can nevertheless occupy space. Consequently, there is an overall reduction in the bulk density of all composite components relative to epoxy resin (Sing et al., 2012).

The density was found to be maximum at 1.27 g/cm^3 for a 4.5D/0.5P filler ratio and minimum at 0.96 g/cm^3 for a 0.5D/4.5P filler ratio. It can be concluded that a reasonable amount of doum palm/camel's foot (piliostigma thonningii) hybrid composites would have different industrial applications when properties of strength, weight, and availability are to be considered in the design process.

Water absorption

Water absorption is a major concern when using natural fibre composites in many applications. The water absorption rate of the composites was measured using the weight change method over 30 days.

From Figure 7, when the percentage fibre loading increases, the water absorption rate of 0.5D/4.5P and 1.0D/4.0P slightly increased from 0-1.37% and 1.38% after 10 days until it reaches a maximum of 1.94% for the sample 0.5D/4.5P and 2.07% for 1.0D/4.0P after 20days. The increase is due to the incorporation of more hydrophilic cellulosic fibres into the epoxy matrix. Moreover, natural fibres derived from lignocellulose exhibit hydrophilic properties due to the presence of strongly polar groups; consequently, an increase in fibre content within a composition enhances water absorption capacity (Birniwa et al., 2023).

The absorption rate of the composites became constant after 25 days (Figure 8), reaching saturation. The water absorption rate of hybrid composites of doum palm/camel's foot/epoxy mostly increases from 0 to 1.41% after 10days until it reaches a maximum, then the water absorption rate decreases and increases until it reaches a saturation after 20-25days. The increase is a result of the incorporation of more hydrophilic cellulosic fibres into the epoxy resin system. The rate of absorption decreases systematically until it becomes saturated at 30 days. Nevertheless, this was elucidated by the observation that enhanced synthetic fibres exhibit stronger bonding and reduced water content compared with non-reinforced organic fibres (Olcay and Kocak, 2021).

Morphological Properties

Scanning Electron Microscopy (SEM)

In the micrographs from plate 1, agglomeration in the resin matrix has been observed due to poor dispersion of the doum palm/camel's foot composites. The debonding can be observed due to the inappropriateness between hydrophilic fibres and the hydrophobic epoxy matrix, leading to a poor interfacial bond (Birniwa et al., 2023). Hence, it can be concluded that due to poor dispersion of doum palm/camel's foot fibres in the epoxy resin, a remarkable effect on the mechanical properties may not be obtained.

From plate 2 , good fibre dispersion in the resin matrix has been observed. The micrographs show that the fibres are well dispersed in the epoxy resin matrix, with good adhesion between the fibres and the matrix, indicating enhanced mechanical properties of the hybrid composites. The absence of voids or little voids around the fibres indicates a good interfacial adhesion between fibres and the epoxy resin matrix (Lawal et al., 2023).

Plate 3 also shows a good fibre-matrix interaction in the composite. There are some observed voids. This defect may result from a homogeneous mixture. The observed voids in the micrograph indicate a point of fibre pullout after deformation due to the tensile strength. This defect may result from improper dispersion of the matrix during the composite's casting process (Dittenber and GangaRao, 2012).

CONCLUSION

This study successfully fabricated and experimentally evaluated blended doum palm/camel's foot fibre-strengthened synthetic epoxy compounds using a hand lay-up approach. The subsequent findings can be derived from the investigation:

i. A hybrid compound has been effectively developed and strengthened using both camel's foot and doum palm fibres.
ii. According to recent studies, integrating multiple fibre loads at varying weight rates within a matrix enhances the properties of distinct composites.
iii. The maximum tensile, tensile modulus, and density of the hybrid reinforced epoxy resin composites were found to be 41.67MPa, 3.47GPa, and 1.43kg/m^2, respectively. The mechanical performance is improved across all other composites with varying fibre weight ratios. Both camel's foot/doum palm natural fibres can be integrated into the epoxy matrix to improve some properties. The tensile results were also evident in SEM analysis, which showed the interfacial bonding of camel's foot/doum palm fibre with the matrix, and the composites produced can be utilized where certain mechanical properties are required for the manufacture of car parts, furniture, in aerospace, construction, and many more.

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