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Preparation and Characterisation of Camel's Foot *(Piliostigma Thonningii)* and Doum Palm *(Hyphanea Thebaica)* Hybrid Fibre Reinforced Epoxy Resin Composites

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Abstract **Original Research Article**

The polyester resin / Camel's Foot and Doum Palm hybrid fibre composites were fabricated using a hand layup method at a fibre ratio of 5/0, 0.5/4.5, 1.0/4.0, 1.5/3.5, 2.0/3.0, 2.5/2.5.wt%. Physical properties such as density, water absorption and mechanical properties such as flexural strength, impact strength, tensile strength, and also morphological test (SEM) of the different composition of the prepared sample were investigated. Tensile strength was recorded to be maximum for 4.0/1.0 fibre ratio at 30.17 MPa and the minimum to be 20.55 MPa at 0.5/4.5 fibre ratio, the decrease could be due to the weak interfacial adhesion between the hybrid fibres and the epoxy resin matrix. The water absorption was 2.83 % as maximum, and increased as the filler loading increases until it became saturated. The density of the hybrid composites obtained was 1.27 g/cm3 as maximum for 4.5/0.5 filler ratio. SEM micrograph of the composite showed little interfacial interaction, few voids and little micro-pores were revealed, this could be due to air trap during the composite fabrication.

Keywords: Hybrid, Composites, Polyester Resin, Filler, Palm, Fiber,

1. INTRODUCTION

Natural fibres are now frequently utilized in place of synthetic fibres because of their many benefits, which include high specific mechanical qualities, low weight, low cost, and biodegradability. Although they are far more expensive than natural fibre composites, synthetic fibre composites are only appropriate for military and aircraft applications due to their superior mechanical qualities. Researchers have been focusing on the requirements of both home and industrial applications since the invention of composites. Scientists and engineers are becoming increasingly interested in the study and development of natural fibres as reinforcement for the automotive industry. Nowadays, the most popular fibre in composite technology is natural fiber, which is an intriguing alternative. Several natural studies on keraf, bagasse, jute, ramie, hemp, and oil palm (Hemant *et al*., 2016). Natural fillers, such as groundnut shell particle, wood flour, rice husk, coconut husk, wheat husk, sisal particles, etc., are agricultural resources that are available in many countries. Many researchers have attempted to develop and characterize composites using natural fillers as reinforcement in particle or powder form. These materials are inexpensive, renewable, and biodegradable, which has reduced the use of expensive, non-biodegradable traditional reinforcement materials like ceramic fillers and synthetic fibers in applications (Tisserat et *al*., 2014; Baskhar *et al*., 2013; Herrera-Franco and Valadez-González 2004).

When natural fibre reinforcement is used instead of synthetic fibres in thermosetting matrices, such as epoxy resins, weight, density, and costs are decreased while biodegradability and renewability are improved (in the case of bio epoxy matrices) (Wang and Schuman 2013). Because of these benefits, bio fibers are desirable alternatives to the widely used synthetic fibres such as; carbon, glass, or aramid fibers by (Dittenber *et al*., 2011). However, the comparatively low interaction of the fibre and matrix interphase is a significant disadvantage of natural fibre reinforced composites (Yousif *et al*., 2012). The fibres are typically surface treated to increase adherence (El-shekeil *et al* 2012). It was observed that alkali treatment of natural fibres improved the mechanical properties of epoxy composites, suggesting improved adhesion (Yousif *et al*., 2012). The mechanical characteristics of the composites were found to improve due to the alkali treatment of natural fibres which revealed improved adhesion. Additionally, other silanes can be added to the alkali treatment (Doan *et al*., 2012).

Natural polymer composites are less costly materials that have a small environmental impact. But the issue with using natural fibers is that they don't stick to the polymeric matrix effectively. Numerous researchers have examined the impact of particle/filler loading, fiber length, fiber orientation, and fiber orientation on the mechanical behavior of polymer composites (Biswas *et al*., 2011, Clark, 2002). Fibres from doum palms are an eco-friendly way to strengthen polymer composites. Their abundance and mechanical qualities make them suitable for usage as a novel material composite. Alkali treatment will be applied to the doum fibres in order to clean their surface and improve the connection between the polymer fibers. In order to determine how the fibre composition affects the composites' qualities, tensile and rheological characteristics will also be examined. Doum Palm fibres are traditionally used in making ropes, canvas, pulp, paper and lately for insulation and mats (Bessadok *et al*., 2007; Majibur Rahman Khan *et al*., 2011; Hattalli *et al*., 2002), they have been selected in this study as reinforcement in LDPE not only because of their good strength and resistivity (Majibur Rahman Khan *et al*., 2011). In this study, alkali treated doum fibers were used at various weight ratios to evaluate the impact of added Doum on the mechanical and thermal properties of composites.

Camel's foot (*piliostigma thonningii*) is a plant which content lignocellulose fibre, which is growing abundantly as a wild uncultivated tree in many parts of Nigeria. The basic chemical component of lignocellulose fibres in camel's foot (*piliostigma thonningii*) are cellulose, hemicellulose and lignin (Lange, 2013). The cellulose consists of high molecular weight polymers accounts for 40 wt% of the lignocellulose. Hemicellulose consists of shorter polymers usually accounts 25 wt% of the lignocellulose, while lignin accounts 20 wt. % lignocellulose (Lange, 2013).

Hybrid composites are made up of one reinforcing phases and a single matrix or single reinforcing phase and multiple matrix phases. Hybrid composites can be designed by the combination of a natural fibre and synthetic fibre (biofibre) in a matrix or a combination of two natural fibre/biofibre in a matrix. Hybrid composite provide greater freedom when it comes to designing composites for specific properties as compared to single fibre reinforced composites. Recently, natural fibres such as bamboo, jute etc. have been mixed with synthetic fibres such as glass to form hybrid composite which plays important role in the composites with desired properties at low cost. The behavior of hybrid composites is a weighed sum of individual components in which there is a more favorable balance between the inherent advantages and disadvantages. The properties of all the composites are decided by many factors such as fibre content, fibre length, orientation, extent of intermingling of fibres, fibre matrix bonding (Siddika *et al*., 2013). Hybrid composites materials have better all-round combination of properties than composites containing only one single fibre type. Hybrid composites may replace or reduce the utilization of synthetic fibres in applications of automotive, building industries, aircraft, (Jawaid *et al*., 2012). In addition to being used in the transportation industry as seat and backrest backings in buses, jute-coir hybrid composites are also used in railway coaches for sleeper berth backing and for building interiors, doors, and windows (Baley et al., 2006). Natural fibers can be used as the essential reinforcing phases in advanced structural composites, which have the potential to have major positive effects on the economy, environment, and society. This is due to their many benefits, which include low density, cost-effectiveness, durable properties, reduced greenhouse gas emissions, high recyclability, and carbon neutrality. According to

Jones (1994), the phenomenon of an apparent synergistic improvement in the qualities of a composite containing two or more types of fiber has been referred to as the hybrid effect. Depending on the goal of hybridization, the polymeric material's needs, or the design of the building, the components that comprise the hybrid composite are considered. The properties of single-fiber composites were improved by hybridizing with other fibers, reducing the disadvantages of each individual fiber while maintaining its advantages. The objective of hybridizing two natural fibers is often to improve the balance of their physical, chemical and mechanical properties rather than to maximize the hybrid effect.

1.1 Statement of the research Problem

1. The mechanical performance of natural fibers, has led researchers to develop techniques for the extraction and modification of cellulose (the main component of natural fibers) from such fibers (Lai and Chen 2008). Polymer composites based on natural fibers are an inexpensive material with minimal impact on the environment. However, the problem with the use of natural fibers is their low adhesion with the polymeric matrix (Ngueho Yemele *et al*., 2013).
2. The use of natural filler material has been the subject of intensive research and it is experiencing significant development. Composites reinforced with natural filler materials are in considerable high demand though not readily available because of their low cost, renewability and biodegradable nature, (Tisserat *et al*., 2014).
3. Although, so many works have been reported on natural fibre composites, no any work reported yet on the mechanical, physical and morphological characterization on doum Palm/camels foot (*piliostigma thonningii*) hybrid reinforced epoxy resin composites.
4. There is need to optimise the performance of hybrid epoxy-based composites for automotive, aerospace and personal protective equipment which provide a blend of properties such as stiffness, strength and ductility, which cannot be achieved by mono-fibre reinforced composites.

1.2 Aim and objectives

The aim of this work is to prepare and investigate the physical, mechanical and morphological properties of hybrid composites of camel's foot (*piliostigma thonningii)* and doum palm reinforced epoxy resin composites

Objectives:

1. Prepare hybrid composites of Doum palm and camel's foot (*piliostigma thonningii*) fibres.
2. Carry out test on physical properties; density, water absorption of the composites.
3. Carry out test on mechanical properties; tensile test, flexural test, hardness and impact tests on the hybrid composites.
4. Determine the morphology of the composites using scanning electron microscope (SEM)

1.3 Justification

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

- Hybrid epoxy-based composites also provide an alternative to synthetic fibres in some applications like lower densities and higher impact energy absorption capacity (Beckwith 2003). There is an abundance of camel's foot (*piliostigma thonningii*) and doum fibres due to their availability, low cost, value addition, light weight and unique mechanical properties which provide potential properties for a synergistic effect to the development of sustainable materials.

- Natural fibres are not reliant on petroleum-based precursors such as polyacrylonitrile or silica and they do not consume significant power to manufacture. Natural fibres are available in abundance, they are comparatively cheaper to produce, manufacture and are eco-friendly. They can also provide an alternative to synthetic fibres in some applications. The use of natural fibres as reinforcement in composite materials is justified as a way to exploit a local resource in industry (Sobczak *et al*., 2008).

1.4 Scope

The scope of the study include;

1. The preparation of the matrix with the natural fibres
2. The development of the hybrid composite material by adding the fillers into the resin matrix
3. The preparation and characterisation of the camel's foot (*piliostigma thonningii)* and Doum fibres, including chemical, mechanical properties, and morphological characteristics
4. The evaluation of the mechanical and morphological properties of the hybrid composites

The potential applications of the hybrid composite material in various applications such as automotive, construction, and packaging. However, there are some limitations to this topic, which include:

1. Epoxy resin was used as matrix in this research work
2. Doum Palm and Camel's foot fibres were used as reinforcements.
3. Hand lay-up/casting technique was used to fabricate the composites.
4. Physical Properties (Density and water absorption) were studied
5. Mechanical properties such as tensile, flexural were investigated
6. SEM was used to study the morphological properties of the composite

2.0 MATERIALS AND METHODS

2.1 Materials

Table 2.1: List of equipment and instrument

S/N	Materials	Source
1	Camel's foot (*Piliostigma thonningii*)	Koreye village, Sabon Gari local government
2	Doum Palm	Koreye village Sabon Gari local government
3	Epoxy Resin and Hardener	Lagos State
4	Distilled Water	Chemistry Department, A.B.U. Zaria
5	Tensile Strength test Machine (TM2102-T7)	Polymer and Textile Engineering Department, A.B.U. Zaria
6	Scanning Electron Microscopy Machine	Dicon, Kaduna State

2.2 Methods

2.2.1 Fibre Extraction

Camel's foot Bark was obtained locally from Koreye village, Sabon Gari local government, Kaduna state Nigeria. Doum palm fibres was 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 be dried to attain a moisture content suitable for composite processing. The fibres will be treated with a suitable surface treatment method to enhance fibre-matrix adhesion. They were cut to sizes between two nodes. The upper skin was removed by scrapping without damaging the fibre surface. Then they were cut to sizes of 200mm length. The upper skin of the doum palm was removed without damaging the fibre surface. After removing the skin, the bark was soaked into water for a period of 3-4 weeks to extract fibre. At the end the fresh doum palm fibre was obtained after careful drying.

2.2.2 Alkali Treatment

The camel's foot (*piliostigma Thonningii*) and Doum Palm fibre were immersed in 5% sodium hydroxide (NaOH) for one hour. The fibre was first washed several times, then washed thoroughly with acetic acid and finally with distilled water, then dried in an oven at 60°C for twenty four hours.

2.2.3 Composite Fabrication

A mould was used for casting the composite sheet. The hand lay-up technique was used for preparation of the samples. A calculated amount of epoxy resin and hardener (ratio of 2:1 by volume) was thoroughly mixed with gentle stirring to minimize air entrapment. For quick and easy removal of composite sheets, a petroleum jelly was used as a releasing agent. The required amount of fibre was then distributed on the mixture. The remaining mixture was then poured into the mould, care was taken to avoid formation of air bubbles. The mould was allowed to cure at room temperature for twenty four hours after which the samples were taken out from the mould and kept for further tests based on the ASTM standards.

2.3 Characterisation

2.3.1 Fourier Transform Infrared Spectroscopy (FT-IR)

FTIR analysis of camel's foot (*piliostigma thonningii*) and doum palm fibres using an Agilent infrared spectrophotometer at Multi-User Science Research Laboratory, Ahmadu Bello University, Zaria was conducted. The untreated and treated fibres were analysed in an attenuated total reflectance (ATR) detector over a 650-4000 cm^{-1} (wave number) range at a resolution of 4 cm^{1}

2.4 Physical properties

2.4.1 Density

The mass of each sample was determined using analytical weighing balance and the volume was determined using displacement method. Water was poured into a measuring cylinder and reading was recorded as the initial volume. 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 was computed as the ration of the mass of the sample to the volume of the sample in g/m3. The densities of the samples were determined using the expression below according to ASTM D790 standard method;

$$\text{Density} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}} \ldots\ldots\ldots\ldots\ldots\ldots \text{i}$$

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

2.4.2 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 $\mathbf{M_1}$, They were removed and re weighed again and recorded as $\mathbf{M_2}$. The same procedure continues and recorded after every 24 hours for 30days until the sample stop absorbing the water completely. Water absorption was carried out in accordance with ASTM D570. The water absorption is measured using the equation;

$$\text{Water Absorption} = \frac{M_2 - M_1}{M_1} \times 100 \ldots\ldots\ldots\ldots\ldots \text{ii}$$

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

2.5 Mechanical Properties

2.5.1 Tensile Strength

The fabricated composite samples were cut into a dumb-bell shape. The specimen was held in the grip of the testing machine and tightened firmly to prevent slippage. The reading was recorded and the procedure was repeated for the remaining composites and the load extension graph was obtained. The tensile test was carried out in accordance with ASTM D638. Triplicate specimen of each composites were cut in a dumbbell shape and the average values recorded were used to calculate the tensile test parameters as;

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

$$\text{UTS} = \frac{\text{Average Force}}{\text{Cross−sectional Area}} \ldots\ldots\ldots\ldots\ldots\ldots \text{iii}$$

ii. Tensile strain is the ratio of change in length in millimetre per gauge length this shows that the tensile strain is unit less

$$\text{Strain} = \frac{\Delta l}{l} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{iv}$$

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

$$\%\ \text{Elongation} = \frac{\Delta l}{l} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{v}$$

iv. Young modulus is the ratio of ultimate tensile stress to tensile strain usually expressed in (GPa).

2.6 Morphological properties

2.6.1 Scanning Electron Microscopy (SEM)

The morphological characteristics of the specimens were examined utilizing a Thermo Fisher Prima scanning electron microscope located at Dicon, Kaduna. The micrographs were acquired under ambient temperature conditions. A field emission gun, coupled with an accelerating voltage of 5 kV, was employed for the analysis. The magnification levels were enhanced, and the morphological data of the samples were recorded in electronic format. Microstructural details were captured at various magnification levels. The fractured surfaces of the specimens were subjected to a gold coating, and the samples were analyzed in a direction orthogonal to the fractured surfaces.

3.0 RESULTS AND DISCUSSION

3.1 Fourier Transform Infrared Spectroscopy (FTIR)

The influence of alkali treatment on the fibres derived from the doum Palm and camel's foot was examined utilizing FT-IR Spectroscopy. The spectral data pertaining to the untreated fibers is depicted in figures 1, 2, and 3, which illustrate a decrease in the intensity of O-H stretching, with a discernible shift of the absorption peak observed at 3297.30 cm-1, 3305.71 cm-1, and 3323.28 cm-1 for the untreated fiber (UT). This phenomenon is predominantly attributable to the lack of hydrogen bonding between the O-H groups of cellulose and hemicellulose inherent in the fiber (Gumel and Tijjani, 2015; Usman et al., 2021). Peaks identified at 2889.44 cm-1, 2818.61 cm-1, and 2762.65 cm-1 across all spectral analyses predominantly emanate from C-H stretching vibrations associated with the aliphatic group, while the observed diminution in their stretching intensity signifies the elimination of hemicellulose (Jayamani et al., 2020). The absorption peak noted at 1600.92 cm-1 is attributed to the carbonyl C=O stretching of acetyl groups present in hemicellulose (Liu et al., 2019). In the spectral representation of untreated fiber, the absorbance recorded at 1428.92 cm-1 corresponds to the –CH3 group. For the treated sample at 5%, the peak observed at 1320.61 cm-1 is ascribed to the asymmetric deformation of lignin, and the attenuation of this peak corroborates the removal of both lignin and hemicellulose (Jin et al., 2022).

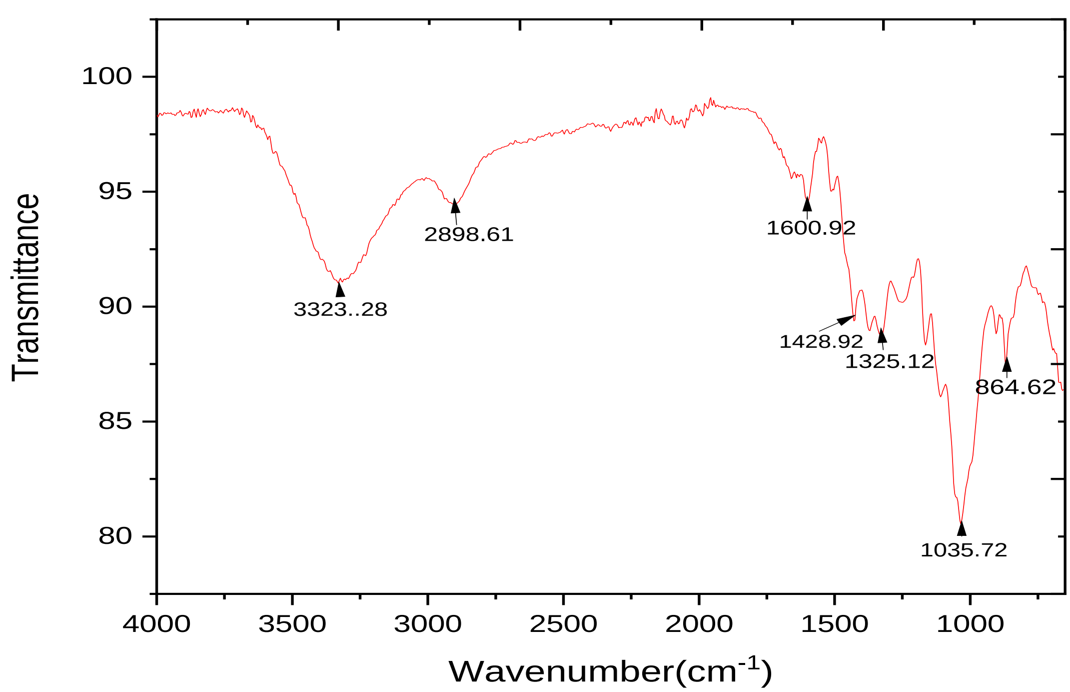

Figure 1: Fourier Transform Infrared Spectroscopy (FT-IR) of untreated Doum Palm fibre

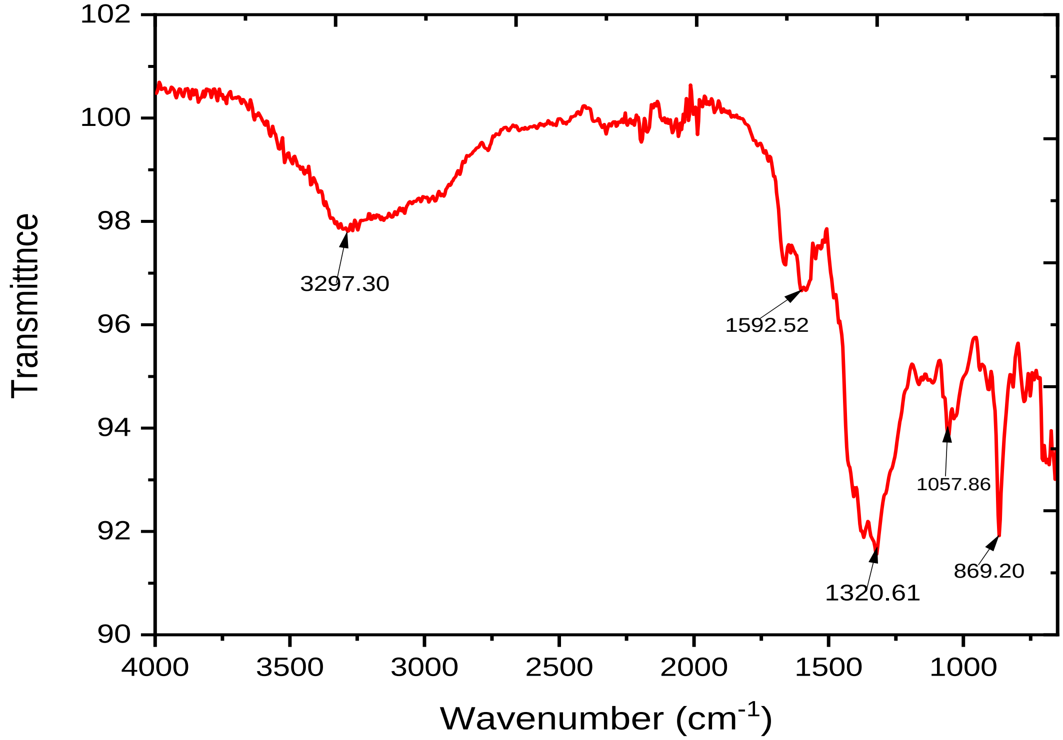

Figure 2: Fourier Transform Infrared Spectroscopy (FT-IR) of treated camel's foot (*Piliostigma Thonningii*) fibre at 5% NaOH

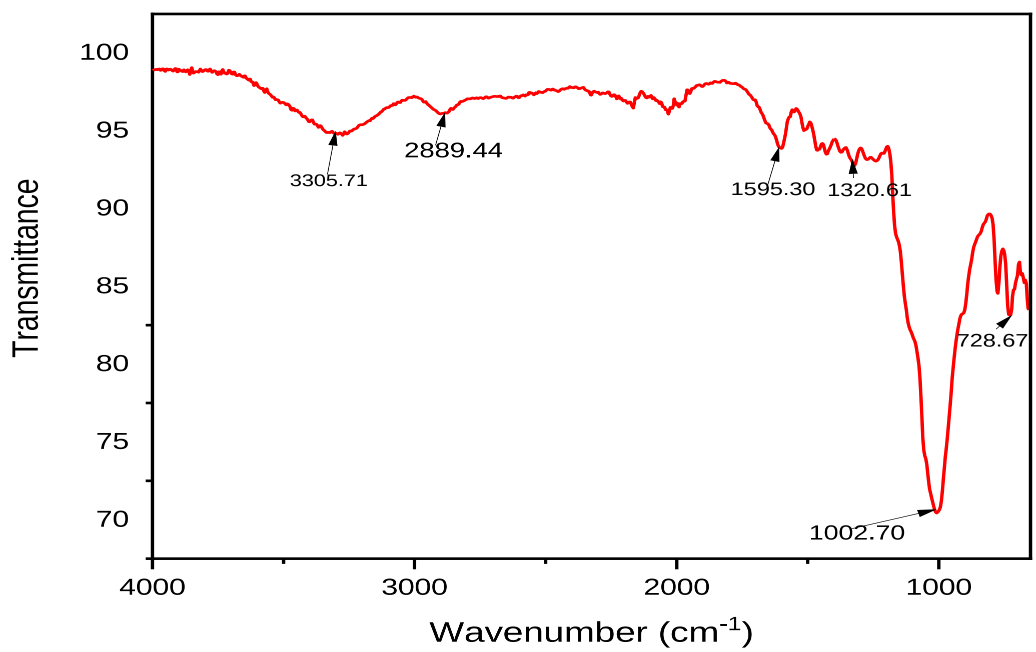

Figure 3: Fourier Transform Infrared Spectroscopy (FT-IR) of treated Doum Palm fibre at 5% NaOH

3.2 Mechanical Properties

3.2.1 Tensile Strength

The tensile testing determines the tensile characteristics of the composite specimens. The experimental results for tensile strength shown in figure 4 that the tensile strength increased after reinforcement with 4.0D/1.0P wt% fibres to the matrix which leads to an increase in tensile strength. The composite having a hybrid ratio of 4.0P/1.0D wt. % shows slightly lower tensile strength of 28.12MPa than the tensile strength of (30.17 MPa) for the 4.0D/1.0P wt. % hybrid composite. The composite material began to elongate linearly in response to the stress exerted as the loading continued, with the deviation of the matrix material reaching the point of submission while the fibres continued to lengthen and resist until resistance collapsed, as the fibre loading increases, the tensile strength also increases as a result of the incorporation of stiffer fibres into the epoxy matrix. The tensile strength tends to reduce when the ratio of the doum palm fibre is slightly higher than that of piliostigma thonningii fibre as can be seen in 4.5D/0.5P wt% to be 27.98MPa, 5.0D/0P wt. % to be 24.97MPa. These weight fractions also favour the production of composites with a higher volume fraction of the matrix with enhanced mechanical performance. The characterization of the composites composition reveals that hybridization has significant effect on the mechanical properties of composites having the highest tensile strength of 30.17 MPa while the fibre ratio of 4.5P/0.5D wt. % fibres showed the lowest tensile strength of 20.55 MPa. Consequently, there exists a significant enhancement in the tensile characteristics of doum palm when it is amalgamated with camel's foot (*piliostigma thonningii*) fibers within the reinforced epoxy hybrid composite framework. The augmentation in tensile strength can be attributed to the integration of more robust doum palm and camel's foot (*piliostigma thonningii*) fibres into the epoxy matrix. The observed pattern of the tensile strength results aligns closely with those documented by Abbasi and Sarfraz (2003).

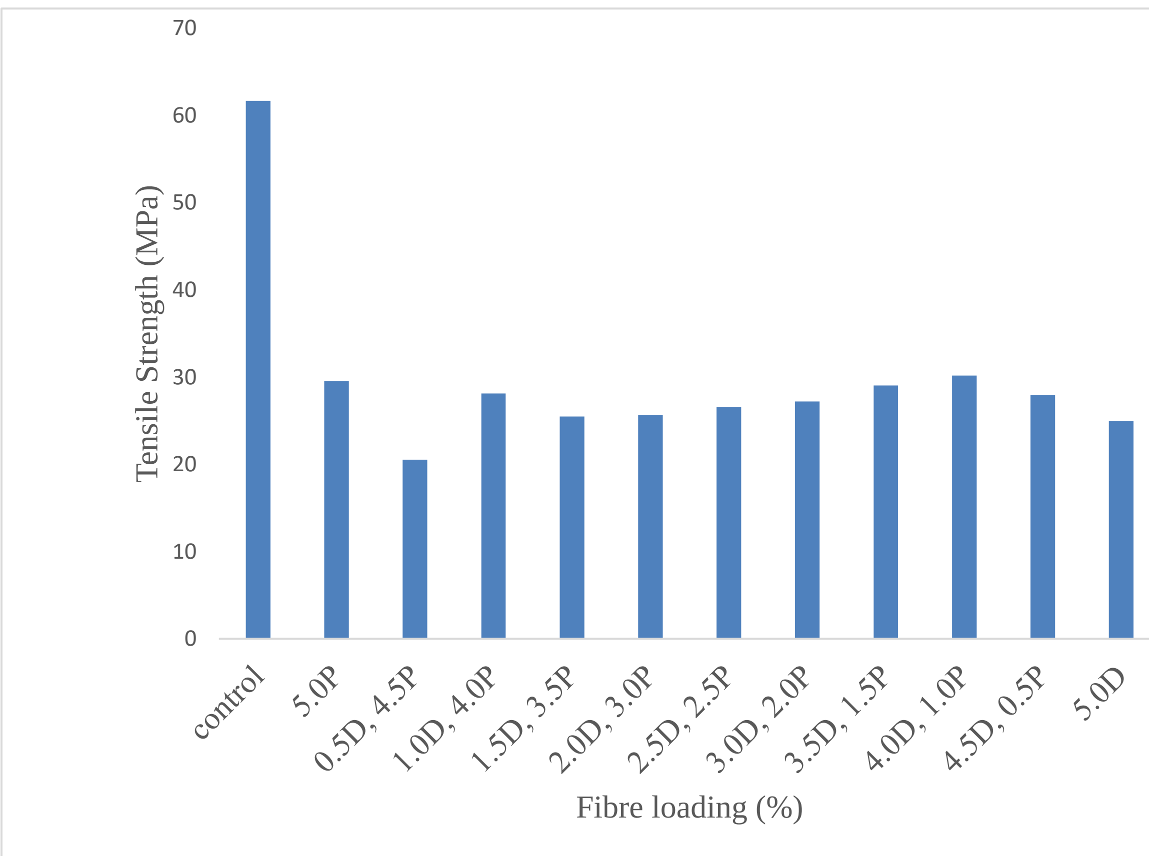

Figure 4: Tensile Strength of Hybrid camel's foot (*piliostigma thonningii*) and Doum Palm reinforced Epoxy resin Composites

3.2.2 Tensile Modulus

From figure 5 below, the tensile modulus gives the measure of the stiffness of the composite. The tensile modulus constitutes a critical parameter for composite materials, with the addition of fibers enhancing both the yield stress and the tensile modulus of the specimens by an impressive 50%, alongside an augmentation of toughness characteristics. Consistent with expectations the integration of fibers significantly enhanced the elastic modulus (stiffness) of the reinforced epoxy matrix composites. From the experiments, the tensile modulus is found to be maximum at 2.82GPa for the composites 2.5P/2.5D wt. % and lowest at 2.0 GPa for the composites of ratio 0.5D wt. % and 4.5P wt. %.

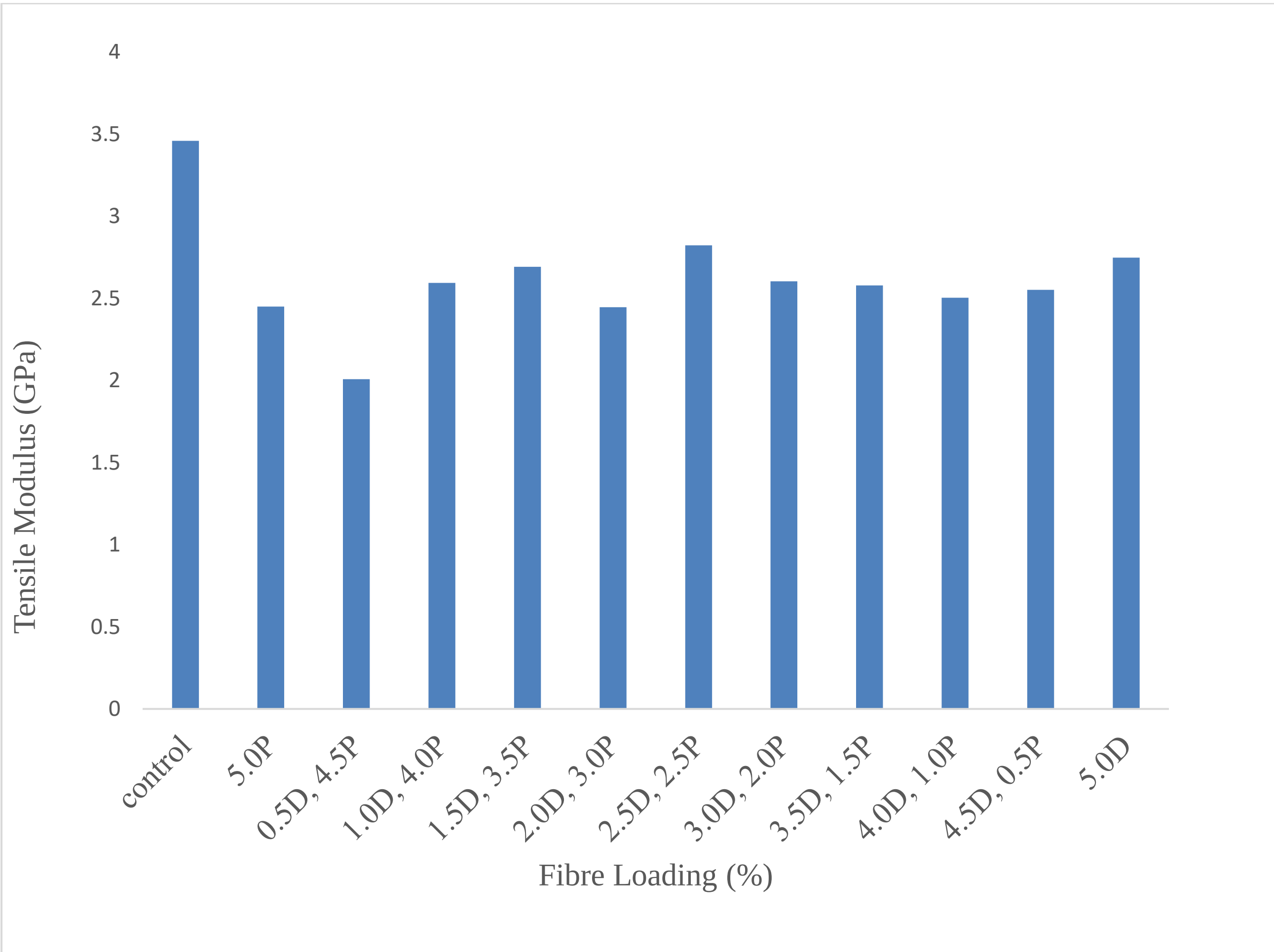

Figure 5: Tensile Modulus of hybrid camel's foot (*piliostigma thonningii*) and Doum Palm reinforced Epoxy resin Composites

3.3 Physical Properties

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

3.3.1 Density

Figure 6 below revealed that increase in wt. % of reinforced epoxy hybrid fibre composites from 0.5D/4.5P wt. % to 2.5D/2.5P wt. % resulted to increase in the density from 0.90 to 1.11 g/cm³ from the Figure.., showed a slight decrease in density, with increasing reinforcement from 2.5D wt. % to 3.0D wt. % of doum palm fibres, It means that density decreases with increase in the wt. % of doum palm fibre. For the two fibre hybrid composite system containing doum palm and piliostigma thonningii fibres reinforced epoxy, the density was found to increase as the % doum palm fibre ratio increases from 0.5D wt. % to 2.5D wt. % at 0.90 g/cm³ to 1.11 g/cm³.

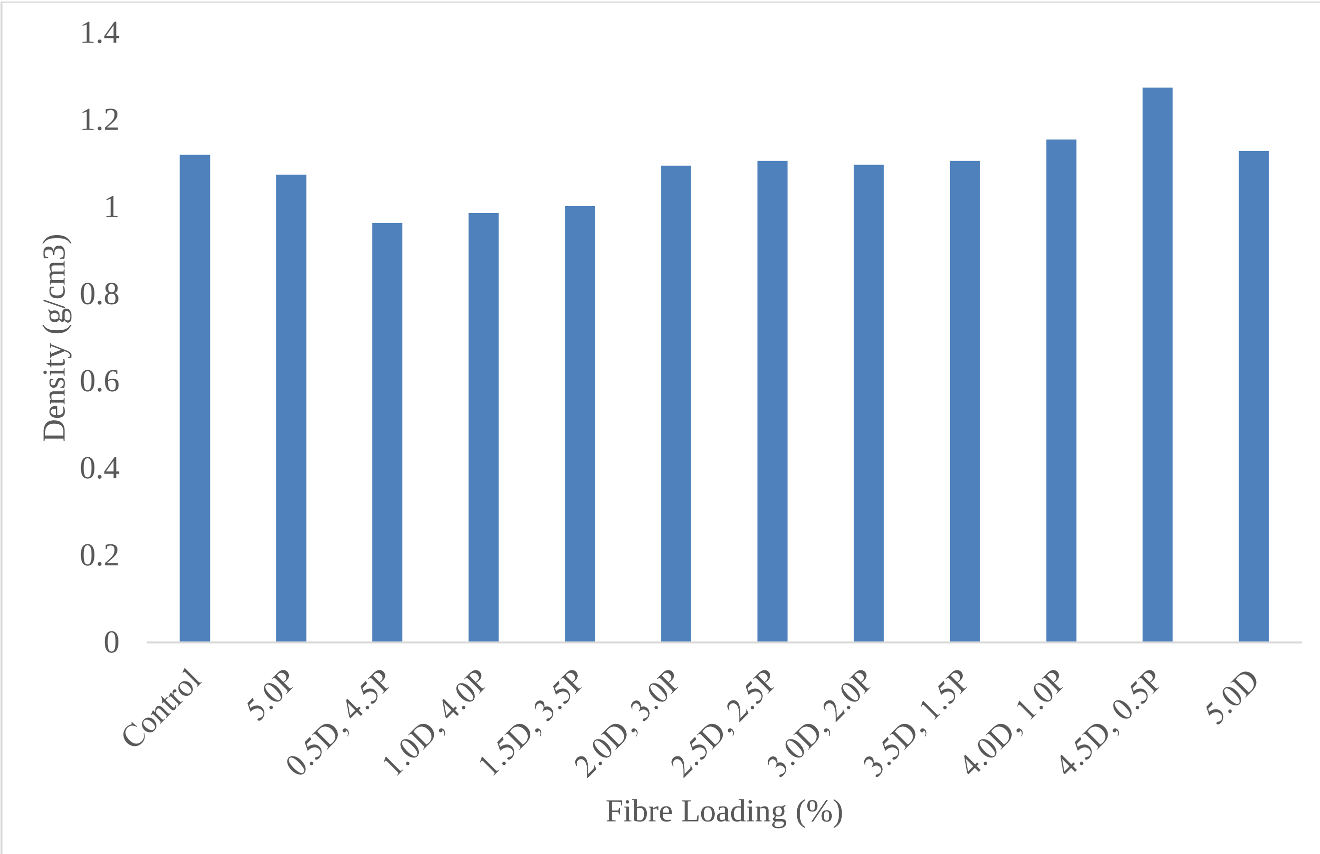

Figure 6: Density of hybrid camel's foot and doum Palm reinforced Epoxy resin Composites

However, as the fibre loading ratio of doum palm fibre increases while that of camel's foot decreases at 3.0D/2.0P wt. % at 1.10 to 1.27 g/cm³. Thus, the increase in the density to be maximum at 1.27 g/cm³ is as a result of the decrease in the fibre loading of camel's foot (*piliostigma thonningii*) and increase in the doum palm fibre loading in hybrid composites ratios. However, proper combination of doum palm and camel's foot (*piliostigma thonningii*) fibre reinforced epoxy composites material have a variety of industrial applications when weight and strength would be considered and desired.

3.3.2 Water Absorption

Water absorption is one of the major concerns in using natural fibre composites in many applications. The water absorption rate was measured by the weight change method for the composites for a period of 30 days.

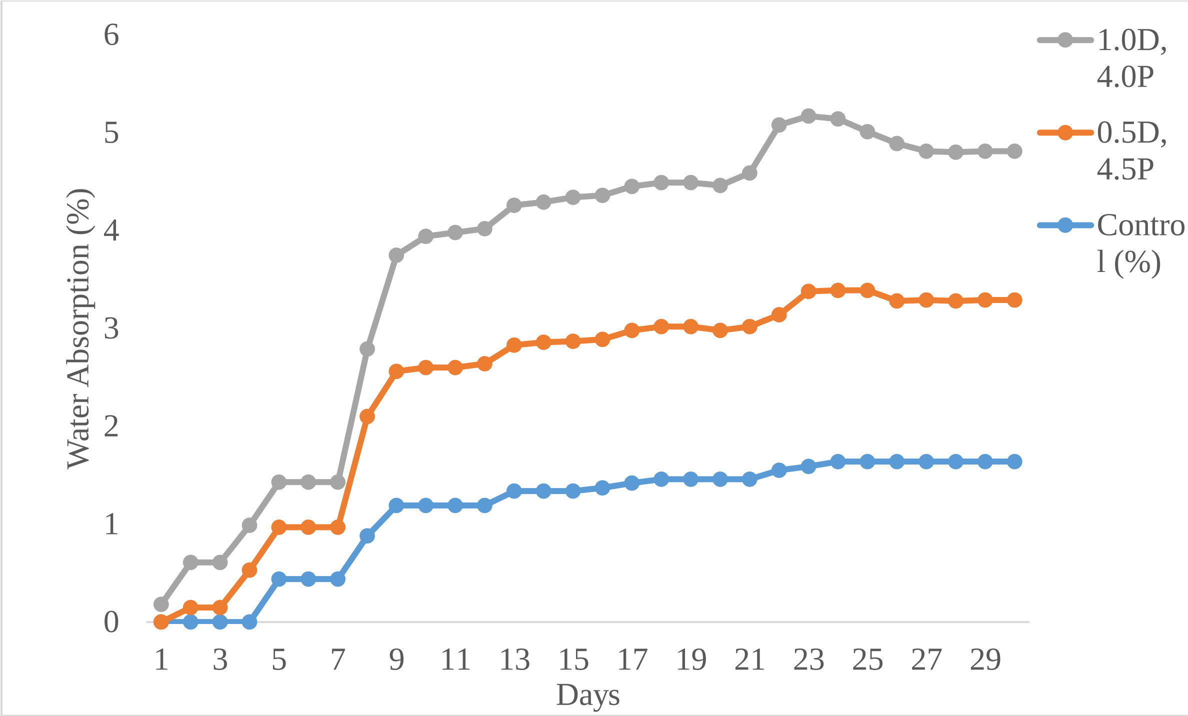

Figure 7: Water Absorption of Hybrid camel's foot (*piliostigma thonningii*) and Doum Palm reinforced Epoxy resin Composites

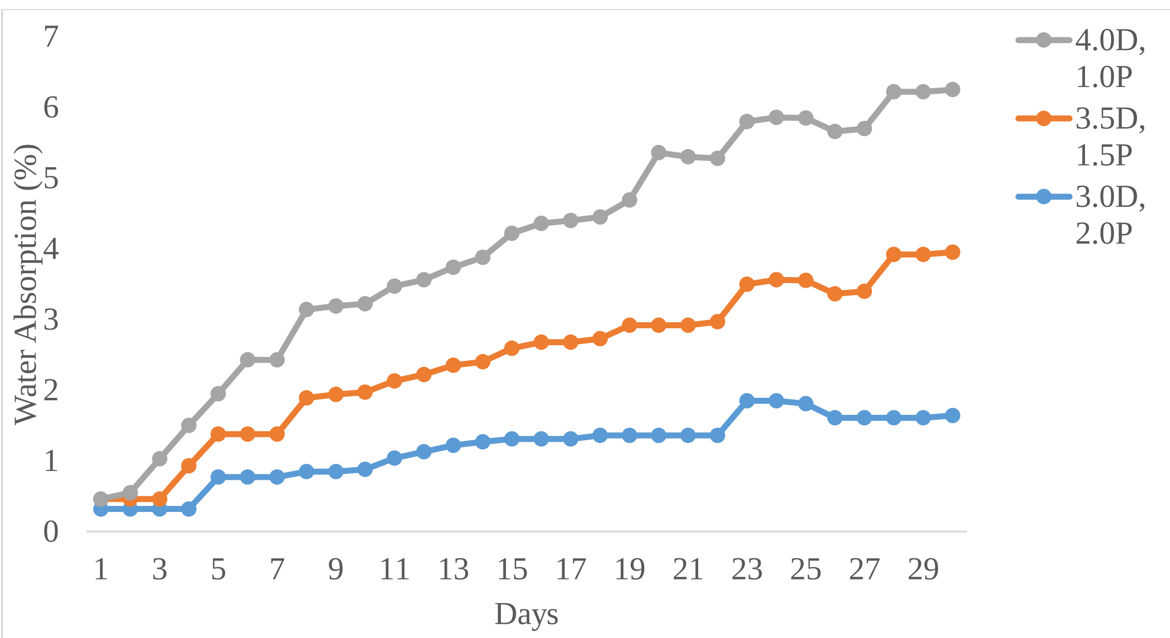

Figure 8: Water Absorption of hybrid camel's foot (*piliostigma Thonningii*) and Doum Palm reinforced Epoxy resin Composites

From the figure 7 above, the percentage fibre loading increases, the rate of water absorption rate of 0.5D/4.5P wt. %, 1.0D/4.0P wt. % slightly increased from 0 to 1.37% and 1.38% after 10 days until it reaches a maximum of 1.94% for 0.5D/4.5P wt. % and 2.07% for 1.0D/4.0P wt. % after 15days. The increase is as a result of the incorporation of more hydrophilic cellulosic fibres into the composite system. The composites became constant after 25days until it is saturated. The hybrid composites ratio of 1.5D/3.5P wt. %, 2.0D/3.0P wt. % and 2.5D/2.5P wt. % increases from 0 to 1.41% after 10days, 0 to 1.09% after 12days and 1.18% after 9days respectively until it reaches a maximum of 2.93% for 1.5D/3.5P wt. % hybrid composites after 15days, the water absorption rate decreases and increases until it reaches a constant after 25days. The trend of the hybrid composite is as follows; 3.0D/2.0P wt. %, 3.5D/1.5P wt. %, 4.0D/1.0P wt. %, 4.5D/0.5P wt. %, 5.0D/0P wt. % and 0D/5.0P wt. % having a maximum absorption rate of 1.85%, 2.55%, 2.83%, 2.43%, 2.01% and 1.56% after 10-15days respectively. The increase is as a result of the incorporation of more hydrophilic cellulosic fibres into the composite system as shown in Figure 3.4 thus, the rate of absorption decreases systematically until it reaches a constant up to the 30days time. The rate of water absorption in hybrid composites was found to be minimal within the initial 1 to 5 days. Additionally, it was noted that the composite typically reaches a state of equilibrium predominantly after a duration of 15 days. This phenomenon can be elucidated by the observation that reinforced natural fiber (RNF) composite materials exhibit a greater degree of bonded interactions and possess a lower water content in comparison to non-reinforced natural fibers.

3.4 Morphological properties

3.4.1 Scanning Electron Microscopy (SEM)

Plate 1: Dispersion of the resin observed is uniform as expected as the control sample due to the homogeneity of the hydrophobic matrix. The micrograph is almost plain because there are no distortions in the morphology of the resin since fibres were not embedded in it. The degree of dispersion of fibres within the resin matrix significantly influences the mechanical characteristics of the composite material. In the current study, Scanning Electron Microscopy (SEM) has been employed to analyze a hybrid composite that incorporates hybrid fibres at specified weight percentages reinforced within an epoxy resin matrix.

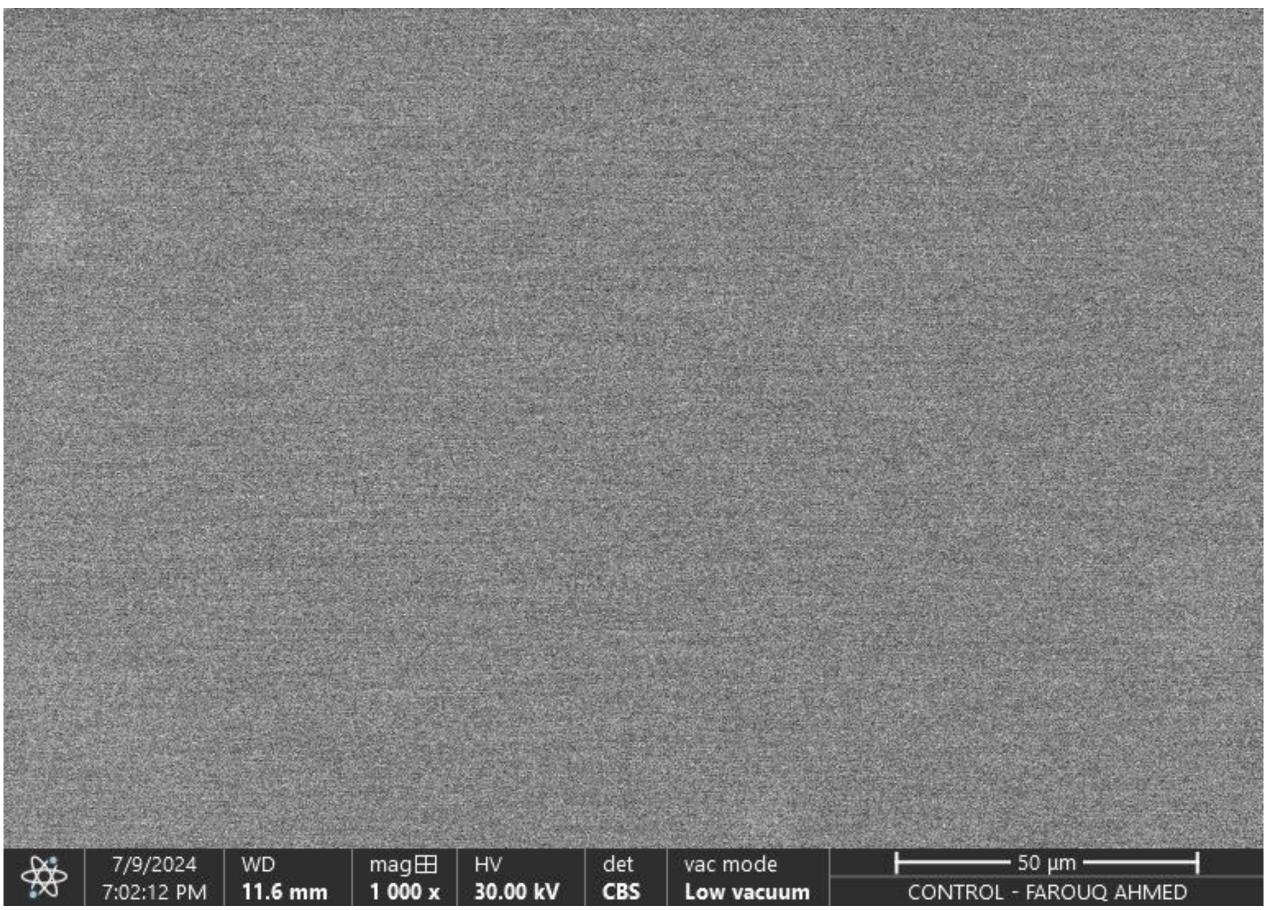

Plate 1: 0% Fibre (100% Epoxy Resin and Hardener) at magnification 1000x

In the micrographs, agglomerated fibres in the resin matrix has been observed due to poor dispersion of the Doum Palm/PT composites. Hence, it can be concluded that due to poor dispersion of Doum Palm/PT fibres in the epoxy resin, a remarkable effect on the mechanical properties may not be obtained.

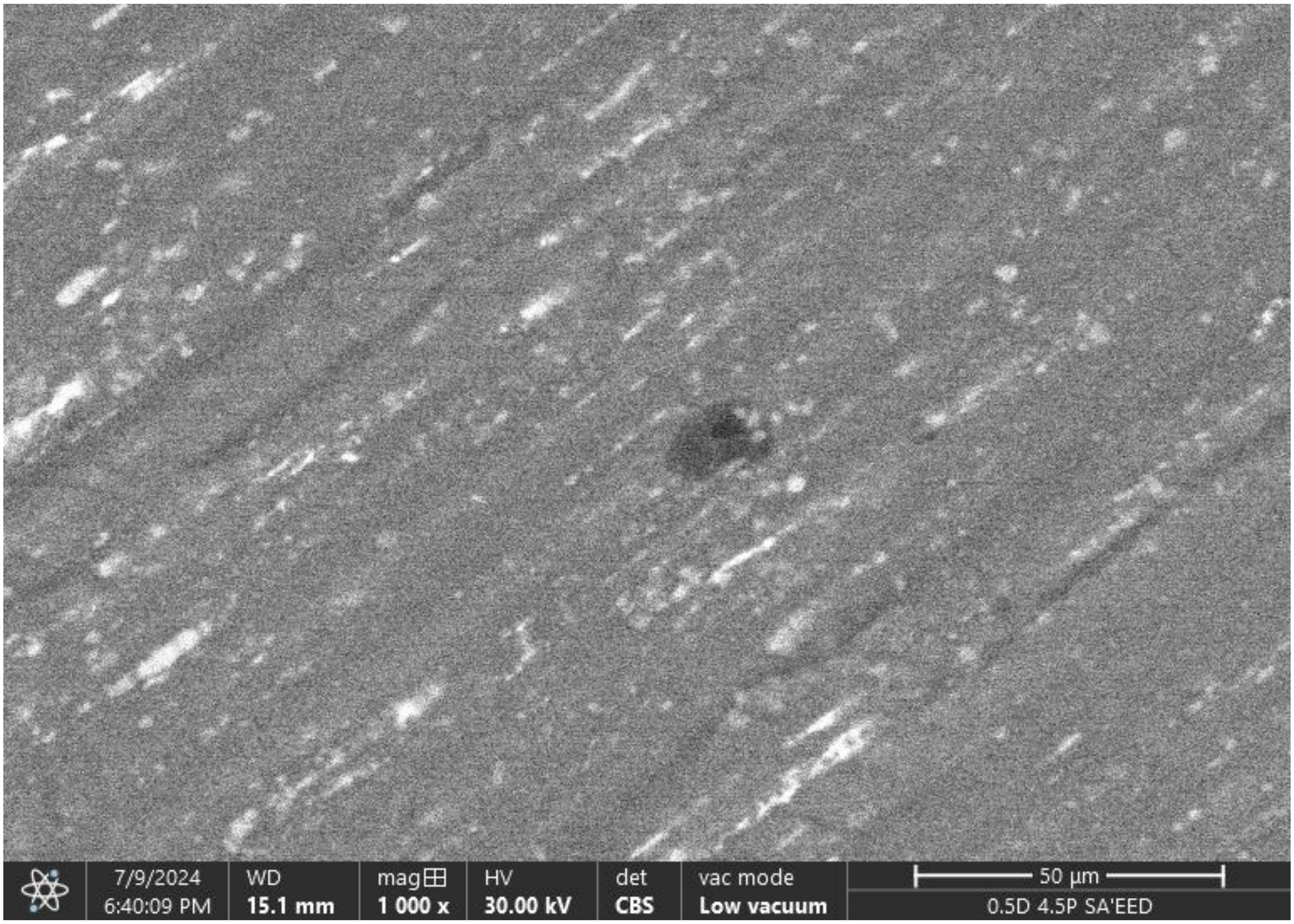

Plate 2: 0.5D/4.5P wt. % hybrid composites micrograph at magnification 1000x

Plate 2 shows the vertical cut section of the hybrid composites 2.5D/2.5P wt. % camel's foot/doum palm fibre composites material. In this case, good dispersion of the fibres in the resin matrix has been observed. It was seen from the micrographs that fibres are well dispersed in the epoxy resin matrix reveals 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.

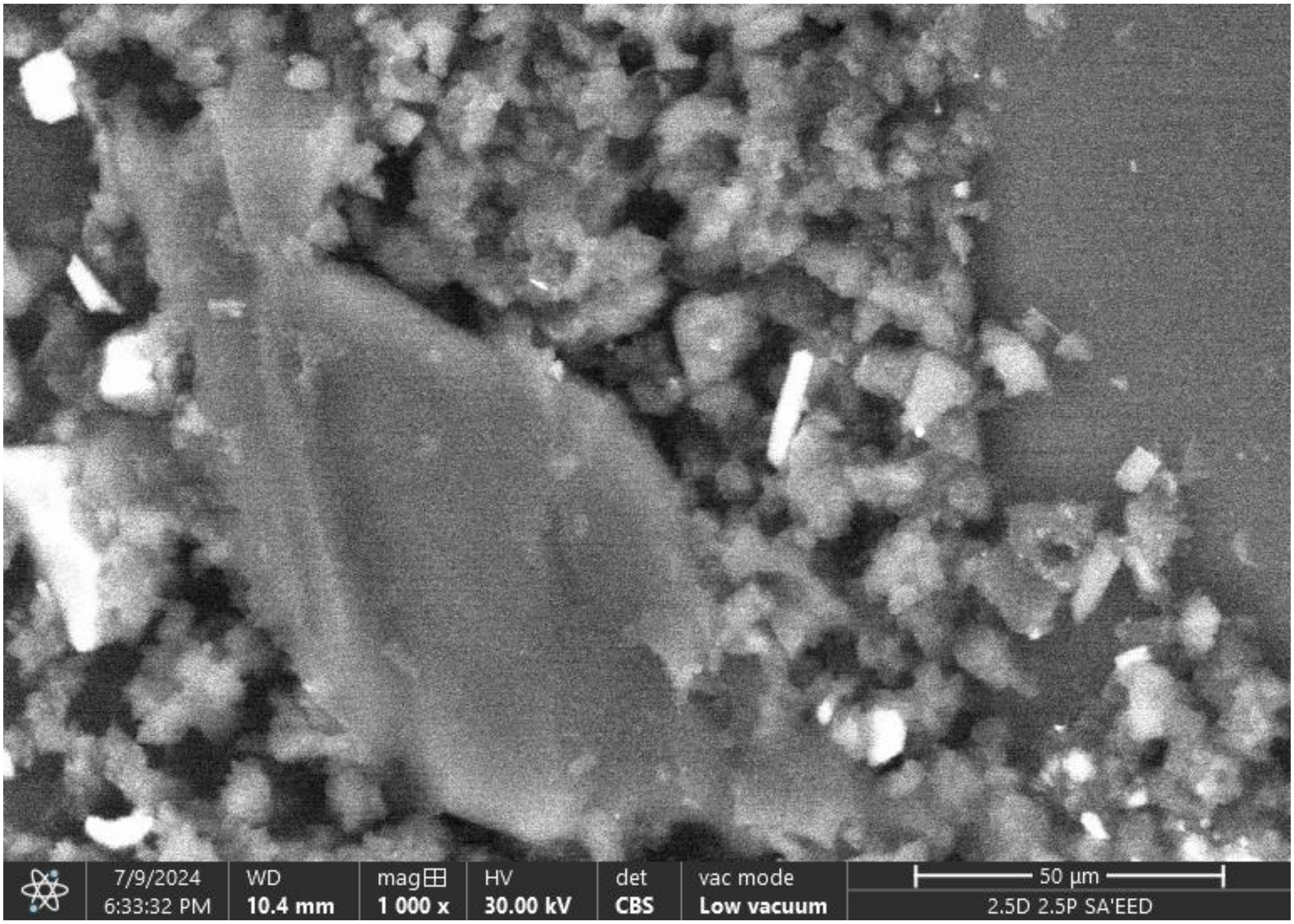

Plate 3: 4.0D/1.0P wt. % hybrid composites micrograph at magnification 1000x

Plate 3 shows a poor fibre-matrix interaction in the composite. There are some observed voids. This defect may be as a result of homogeneous mixture. The observed voids in the micrograph indicate a point of fibre pull out after deformation by the tensile testing. However, there is a point of loose bonding. This defect may be as a result of improper dispersion of the matrix during the casting process of the composite. It can be concluded that there is no proper interaction between the fibres and epoxy resin matrix thus, the bonding between the fibres and epoxy resin was not strong and shows little or no improved strength.

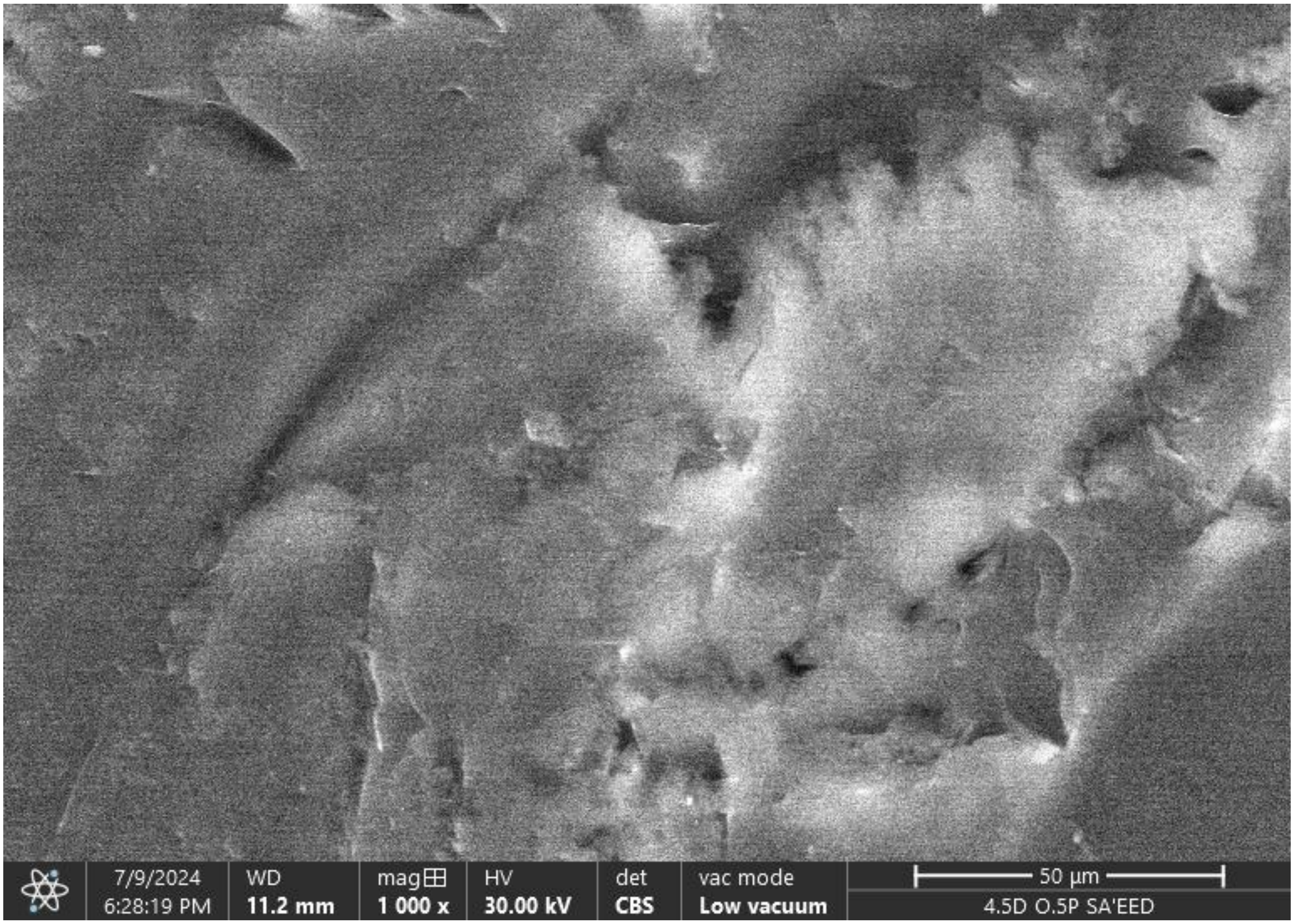

Plate 4: 4.5D/0.5P wt. % hybrid composites micrograph at magnification 1000x

4.0 CONCLUSION

This work resulted in the successful fabrication of hybrid doum palm/camel's foot (*piliostigma thonningii*) fibre reinforced epoxy composites using hand lay-up technique. The resultant composites were subjected to physical, mechanical, and morphological properties. An eco-friendly and unpolluted environment is essential for the survival of humanity. Therefore, material scientist and technologists are manufacturing advanced commercial products that are biodegradable, sustainable, and compatible with the environment. The Natural fibre based composite materials have a high commercial acceptance in structural and non-structural applications. Currently, the Natural fibre based composites are widely used in construction and building, automotive/transport, aircraft, and marine industries. The important requirements for these applications are high strength, renewability, stiffness, and low weight (Jawaid *et al*., 2017). The result of experimental investigation of the mechanical, physical, and morphological behaviour made the following conclusions:

i. The chemical composition of camel's foot (Piliostigma thonningii) and doum palm fiber was enhanced through sodium hydroxide treatment, which facilitated a superior interfacial interaction with the matrix materials, consequently eliminating impurities from the fibers and resulting in a diminished fiber diameter. As the concentration of the alkali treatment escalated, a slight increase in the density of the fibers was observed for both camel's foot and doum palm. This phenomenon can be attributed to the elimination of non-cellulosic constituents, such as hemicellulose and lignin.

ii The mechanical behavior of untreated and chemically treated camel's foot (*piliostigma thonningii*)/doum palm fiber reinforcement differs significantly. The rougher fiber surface of a chemically treated fiber promotes interfacial adhesion between the fibres and matrix, resulting in mechanical interlocking and less pullout.

iii the tensile property of camel's foot(*piliostigma thonningii*) and doum palm fibre epoxy resin hybrid composites, showed superior results in terms of tensile strength. However, a tensile property varies with the decrease in the percentage of weight fibre loading. Maximum tensile strength is achieved at 4.0D/1.0P wt. % fiber loading, the tensile fractography results were also evident using SEM analysis, which shows the interfacial-bonding of Camel's foot (*piliostigma thonningii*) /doum palm fibre/epoxy hybrid composite.

iv Alkali treatment considerably enhances the hybrid composite's flexural performance in comparison to untreated camel's foot (*piliostigma thonningii*) fibre/doum palm fibre/epoxy resin. Flexural strength initially increases when the fiber weight percentage rises from 3.5D/1.5P wt. % to 5.0P wt. %; however, flexural strength barely decreases at 3.5D/1.5P wt. % fiber loading. The maximum flexural strength is attained.

v Scanning electron microscopy (SEM) of the fabricated hybrid composite sample was carried out to examine the surface topography, phase-distribution, bonding of fiber/matrix interface of camel's foot fibre/doum palm fibre/epoxy resin hybrid composite.

vi According to the mechanical test findings of the created Camel's Foot (*piliostigma thonningii*) Fiber/Doum Palm Fiber/Epoxy Resin Hybrid Composite, the concept of utilizing two different fibers is viable for use in sports goods, flooring, roofing, protective shield and helmet shell applications. But, in order to get the better mechanical qualities, there is a chance to maximize the volume percentage of natural fibers used as reinforcements. Additionally, the mechanical capabilities of natural fiber reinforcement are well-established and on par with those of conventional composite materials.

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