ANALYSIS OF ZARIA BAOBAB POD FIBRES AS A POTENTIAL NATURAL FIBRE FOR ENGINEERING APPLICATIONS

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Abstract: Natural fibres are gradually replacing synthetic materials because of their availability, low cost, biodegradability and eco-friendly characteristics. Despite several researches in natural fibre applications and improving biodegradability, experimental work is very rare involving Baobab pod fibres.This study was carried out to extract and prepare the raw baobab fruit fibre from the pod and analyze and characterize the fibres for their physical, chemical, mechanical and thermal properties to see if they are viable for engineering applications. Even though Baobab pod fibres is readily available, environmentally friendly and have been commonly used in Nigeria by local farmers for making several materials such as rope, basket nets, snares, fishing lines and is even used for weaving, its potential for use for engineering applications has not been fully harnessed. In this study, an effort has been made to carry out physical, chemical, mechanical and thermal analysis on Baobab pod fibres, its composition, properties and its applications in engineering and curtailing environmental pollution. From the analysis, moisture content was found to be 9.4%, fixed carbon 71.9% and Cellulose content of 53.2%. It can be concluded that, Baobab pod fibres have excellent potential to be used in various engineering applications ranging from reinforced composites which has lot of significance in automotive industries, chemical industries and construction industries. Hence, it is recommended that consideration be given to producing cellulose nanocrystals from the fibres and reinforcing them with polymer matrix for manufacture of composites for engineering applications.

Keywords: Applications, Baobab-fibres, Biodegradability, Composition

1.0 Introduction

Natural fibre`s availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative to man-made fibres, they are more environmentally friendly, and are used in transportation, military applications, building and construction industries, packaging and consumer products (Ubi and Abdurrahman, 2019). There have been global researches by scientist to develop biodegradable polymers as a waste management option to curtail plastic pollution which is amongst the biggest environmental disasters of modern era (Anteneh *et al*., 2021).

Natural fibres reinforced polymer composites represent an opportunity to partially minimize on the environmental impacts by integrating biodegradable fibres such as baobab in place of synthetic fibres in composite materials production. Although composites reinforced with synthetic fibres possess superior mechanical properties, they have some severe drawbacks that include high cost, poor recyclability and non-biodegradability (Adesina et al., 2019).

These engineering composites are desired due to their low density, high corrosion

resistance, ease of fabrication, and low cost (Ubi and Abdurrahman, 2019). The performance of a fibre composite is judged by its length, shape, orientation, composition and the mechanical properties of the matrix (Nissen and atutz, 1985).

Adansonia digitata called the baobab tree in both English and French is very characteristic of the Sahelian region and belongs to the Malvaceae family. The plant is a very massive tree with a very large trunk (up to 10m diameter) which can grow up to 25m in height and may live for hundreds of years. The plant is widespread throughout the hot and drier regions of tropical Africa (FAO, 1988). The fruit consists of large seeds embedded in a dry, acidic pulp and shell (Russo et al., 2021). Studies have been carried out using different natural fibres reinforcement for polymers, little attention had been given to the potential use of baobab pod fibre as reinforcement for polymer matrix.

The Baobab, popularly called Kuka among the dominant Hausa speaking populace of northern Nigeria is widely distributed and is found in all parts of the region. Photo of a Baobab tree is shown in Figure 1.

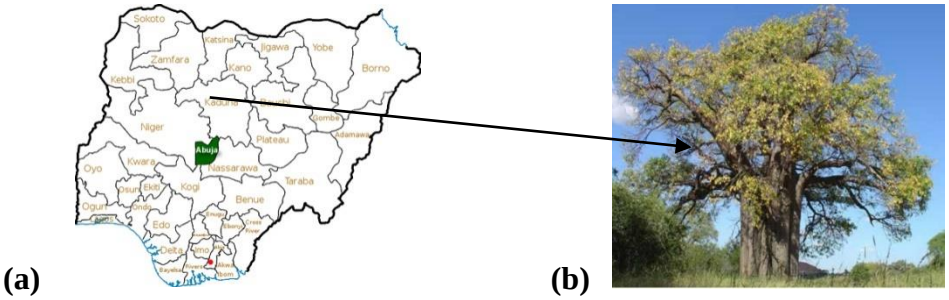

Figure 1: Photo showing (a) location of Baobab tree (b) Baobab tree

The Baobab tree also known as the tree of life is huge with a very large trunk which can grow up to 25 m in height and may live for hundreds of years. The plant is predominantly found in the hot and drier regions of tropical Africa. It has multi-purpose uses and every part of the plant is reported to be useful.

Fibre from the inner bark is strong and widely used for making rope, basket nets, snares, fishing lines and it's even used for weaving. Fibres are also available from disintegrated wood and have been used for packing. Other fibres used for rope are obtained from root bark (Leja, 2020). But fibres from pod have been ignored and its potential use has not been properly explored.

Baobab fibre have been commonly used in Nigeria by local farmers for making several materials such as rope, basket nets, snares, fishing lines and is even used for weaving. Fibres are also available from disintegrated wood and have been used for packing. Baobab fibres, even though available locally, are presently underutilized in Nigeria due to lack of good marketing system and poor processing (Sidibe and Williams, 2022).

Fibres are the most important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Fibres fall short of ideal performance due to several factors. The performance of a fibre composite is judged by its length, shape, orientation, composition and the mechanical properties of the matrix (Nissen *et al*., 1985). This study was carried out to extract and prepare the raw baobab fruit fibre from the pod and analyze and characterize the fibres for their physical,

chemical, mechanical and thermal properties to see if they are viable for engineering applications.

2.0 Methods

Materials used are:Ripe and mature Baobab pods were collected from Baobab trees in Zaria. Sodium hydroxide (NaOH) pellets (98 % purity, analytical grade) and distilled water (100 % purity) were supplied by a vendor. All chemicals were used as received.

2.1 Materials Preparation:

Baobab pods were sliced open mechanically using a knife. The fibres were screened out from the pods by hand, and then washed in a running tap water to remove the remaining pulp on the fibres. Finally, the fibres were allowed to dry for 24 hours. The dried Baobab fibres were subjected to size reduction by grinding using local milling machine.

2.2 Characterization of Baobab Pod Fibres (BPFs):

In order to fully comprehend the behaviour of Baobab pod fibres and to have a good understanding of its properties, different physical, thermal, chemical and mechanical tests were carried out. These include diameter measurement, density measurement, proximate analysis, ultimate analysis, chemical analysis, tensile test, water absorption measurements, Fourier Transform Infra-red (FTIR) analysis, Scanning Electron Microscopy/Energy dispersive X-ray spectroscopy (SEM/EDS), X-ray Diffraction (XRD) analysis and Thermogravimetric Analysis (TGA).

2.3 Length and diameter measurement:

Single fibre measurement was achieved using a ruler. Twelve fibres were chosen at random and their individual lengths were measured and recorded, mean average was then taken. The length obtained was 50 ± 0.2 mm.

The diameter of the Baobab pod fibre was determined using a micrometer screw gauge. Twelve fibres were chosen at random and diameter measurements were obtained for the different fibres after which the mean average was taken. The average diameter obtained was 0.28 ± 0.02 mm.

2.4 Density measurement of BPFs:

The density (ρ) in g/cm^3 of the fibre was obtained using Equation 1:

$$\rho = \frac{m}{v} \quad (1)$$

ρ = density

m = the mass of the ground BPFs measured using the weighing scale

v = the volume of the samples measured

The sample was weighed using a weighing balance, then volume was measured by displacement of the amount of water when sample was inserted in measuring cylinder containing known amount of distilled water at 23 °C. Density was then calculated. The mass of the ground BPFs was measured using the weighing scale; the volume of the samples was measured using a pycnometer.

2.5 Proximate analysis of BPFs:

Proximate analysis is a method of partitioning of the compounds in the fibre. This system consists of the analytical determination of water (moisture) content, ash content, volatile content and fixed carbon content. The methods of the analysis are thus:

2.6 Moisture content:

Each sample of mass 10 g were measured and placed in the porcelain separately. The

porcelain and its content were then dried in an oven at 110 ˚C to a constant weight for 3 hours. The moisture content was calculated using Equation 2.

$$\% \text{ Moisture content} = \frac{(g-x)}{g} \times 100 \quad (2)$$

Where:

g is weight of sample

x is weight of dry matter

(g – x) is loss in weight

2.7 Ash content:

The total ash content equals the weight of the ash divided by the weight of the original sample multiplied by 100 %. The formula is given in equation 3.

$$\% \text{ Ash} = \left(\frac{X}{g}\right) \times 100 \quad (3)$$

Where:

g is weight of sample

x is weight of ash

Volatile matter:

The volatile matter of the fibre is calculated using Equation 4.

$$\% \text{ Volatile matter} = \left(\frac{x-y}{g}\right) \times 100 \quad (4)$$

Where:

x is weight of sample

y is weight of dry matter

g is weight of residue

2.8 Fixed carbon:

The percentage of fixed carbon was determined using Equation 5.

$$\% \text{ fixed carbon} = 100 - (\text{VM} + \text{Ash} + \text{MC}) \quad (5)$$

Where:

VM is Volatile matter

Ash is Ash content

MC is Moisture content

2.9 Elemental analysis of BPFs:

The elemental analysis simply refers to the chemical contents of the fibre; it gives the carbon content, hydrogen content, nitrogen content and oxygen content. The formula used for determining the constituent of the ultimate analysis is according to (Miyashiro and Umumeri, 2020)

2.9.1 Carbon content:

The non-aqueous titration method was used for this analysis. The carbon content was determined using Equation 6.

$$\% \text{ Carbon} = \frac{(B-T) \times M \times 0.003 \times 100 \times 1.33}{g} \quad (6)$$

Where:

B is Blank titre

T is Sample titre

M is Molarity of the acid used

g is weight of sample

2.9.2 Hydrogen content:

The non- aqueous titration method was used for the determination of hydrogen content of the fibre sample. The hydrogen content was determined using Equation 7.

$$\% \text{ Hydrogen} = \frac{wt\ of\ H_2O \times 0.1119 \times 100}{wt\ of\ pellet} \quad (7)$$

2.9.3 Nitrogen content:

The non -aqueous titration method was also used for this analysis. The Nitrogen content was determined using Equation 8.

$$\% \text{ Nitrogen} = \frac{T \times M \times 0.014 \times DF}{g} \times 100 \quad (8)$$

Where:

M is Molarity of the acid used

g is Weight of sample

T is Titre value

DF is Dilution factor diluted

2.9.4 Oxygen content:

The total amount of all substances including ash content subtracted from 100% gives the percentage of Oxygen present in the sample. The Oxygen content was determined using Equation 9.

$$\% \text{ Oxygen} = 100 - (C + H + N + S + \%Ash) \quad (9)$$

2.10 Determination of chemical composition of BPFs:

The determination of chemical composition (cellulose, hemicellulose, and lignin contents) of Baobab pod fibres (BPFs) before and after treatment was achieved by acid digestion using a Fibre Analyzer. The standard acid detergent fibre (ADF), neutral detergent fibre (NDF) and acid detergent lignin (ADL) analysis were carried out using Ankom 200 Method 5, Method 6 and Method 8, respectively. 0.5 g of ground fibres was used for each analysis. The percentages of cellulose, hemicellulose and lignin content were determined from the following Equations 10 – 12.

$$\text{Lignin (\% dry matter)} = \text{ADL} \quad (10)$$

$$\text{Cellulose (\% dry matter)} = \text{ADF} - \text{ADL} \quad (11)$$

$$\text{Hemicellulose (\% dry matter)} = \text{NDF} - \text{ADF} \quad (12)$$

2.11 Tensile strength test:

Tensile properties of raw Baobab pod fibres were determined using a universal testing machine according to the ASTM D3379 standard test for Tensile strength (TS) and young Modulus of Elasticity (MOE) for high-modulus single filament materials. The machine was set at a crosshead speed of 1 mm/min and fibre length of 50 mm, diameter of 19.16 mm, area of 958 mm^2, displacement of 1.69 mm and a force of 776 MPa was used.

2.12 Water absorption of BPFs:

The purpose of this test was to determine the water absorption capacity of dry Baobab pod fibres when immersed in water. ASTM D5229 was used, baobab pod fibres were dried in the in the sun for three days and the weight was determined using a weighing scale, the fibres were then immersed in distilled water at room temperature for 4 h and weighed immediately recorded. The water content of the fibres (in wt. %) was computed using Equation 13.

$$\% \text{ absorption} = \frac{W_2 - W_1}{W_1} \times 100 \quad (13)$$

W_1 = weight of dried Baobab pod fibres

W_2 = weight of Baobab pod fibres immersed in distilled water

2.13 SEM/EDX analysis:

Scanning electron microscopy (SEM) machine model Hitachi S3000N VP was used. Prior to SEM measurements, the samples were coated with a gold layer using an Edwards sputter coater model Pirani 50 I.

2.14 FTIR analysis:

The surface chemistry of Baobab pod natural fibres were investigated by using Fourier Transform Infrared (FTIR). It identifies the different functional groups present in the fibres. Shift in the spectre and the complete

disappearance of some functional groups helps in detecting the changes that happens during chemical treatments. The effect of NaOH treatment on the chemical structure of Baobab pod fibres was analysed using Shidmazu/IRTracer-100. The FTIR spectra with percentage transmittance (%T) versus wavelength (cm^{-1}) were recorded within the scanning range of 650 - 4000 cm^{-1}.

2.15 XRD Analysis:

X-ray diffraction measurement of BPFs was carried out using a PANalytical Empyrean X-ray diffractometer with a C_o target, rotating stage and goniometer in 2θ configuration. The wavelength of C_o radiation is 0.179 nm. The generator was utilized at 40 kV and 45 mA. The intensities were measured from 5° to 110° at 2θ with step size of 0.0167° and a scan speed of 0.015 deg/sec. The radiation used was full spectrum Co ($K\alpha_1$, $K\alpha_2$) with the K_β filtered out with a diffracted side Fe filter. The empirical Equation 14 was used to estimate the degree of crystallinity (crystallinity index, CI) of ground Baobab pod fibres from the XRD results.

$$I_{Cr} = \frac{I_{002} - I_{am}}{I_{002}} \times 100 \qquad (14)$$

Where:

I_{002} is the maximum intensity of the 002 lattice reflection (the highest peak for native cellulose) of the cellulose crystallographic form at $2\theta\ is\ 22.5°$

I_{am} is the intensity of diffraction of the amorphous material at $2\theta\ is\ 18.5°$ (Mwaikambo and Ansell, 1999).

3.0 RESULTS AND DISCUSSION

3.1 Physical Behaviour of Raw BPFs:

In order to fully comprehend the characteristics of Baobab pod fibres, some important physical characteristics were analyzed. Table 1 summarized the properties that were determined. Average length of the fibre obtained was 50.42 mm which indicates it is a short fibre when compared to that of other plants like, flax fibres which length is of up to 90 cm, ramie fibres with length range of up to 100 cm and sisal fibres with average length of up to 1 meter. Baobab fibres has a very low density of 0.65 g/cm^3 when compared to that of ramie, flax and hemp fibres, all with densities of 1.5 g/cm^3 (Pickring *et al.*, 2016). Figure 2 (a) shows the images of Baobab pod fibres after extraction from the pod. The ground fibres were then sieved as shown in Figure 2 (b), in order to ensure equal distribution of the fibres.

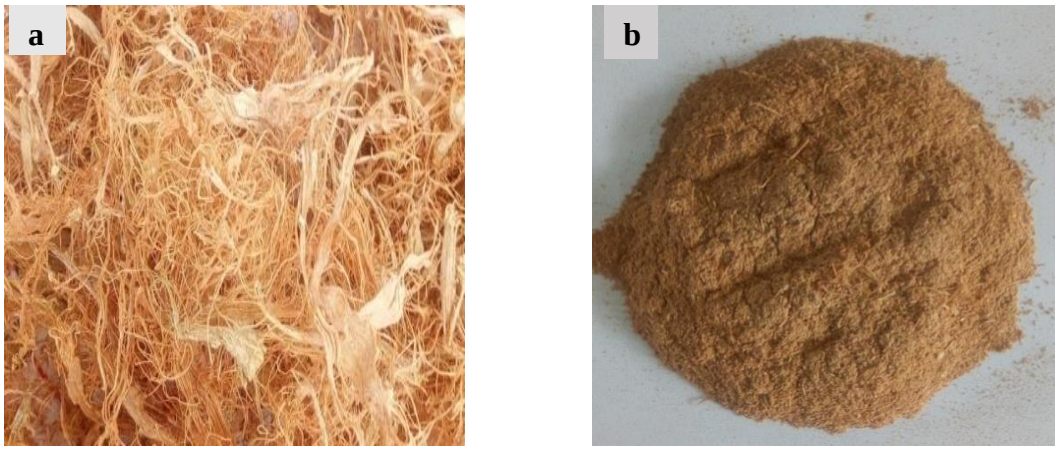

Figure 2: The Images of (a) Raw Baobab Pod fibres (b) Ground Baobab pod fibres

Table 1: Comparison of physical properties of BPFs with other natural fibres

Fibre	Length (mm)	Diameter (mm)	Density (g/cm^3)	Tensile strength (MPa)	Elongation (%)	Reference
BPFs	50.42	0.28	0.65	40.15	1.7	This study
Coir	134	0.86	0.9	13.05	2.1	William *et al.,* 2020
Polyester	600	1.77	1.3	67.8	2.3	Miyashir *et al.,* 2020
Flax	900	1.85	1.5	143	3.4	Mehmet *et al.,* 2019
Raffia	140	1.63	1.5	67.7	2.5	Fadele, 2017
Sisal	1000	-	1.5	379	4.7	Leja, 2020

The mean average for the tensile strength was obtained to be 40.17MPa, variance was obtained to be 0.33 and standard deviation was obtained as 0.57. The fibre exhibited better tensile property when compared to other short fibres of similar length like that obtained for coir at 13.05 MPa.

3.2 Proximate analysis of raw BPFs:

The result for the proximate analysis of raw Baobab pod fibres is shown in Table 2. The moisture content of the fibre has a great effect on performance of the fibres, the higher the moisture content, the more detrimental it is to its performance, it reduces stiffness and flexural strength. Moisture content of 9.4 % for BPFs is considered good as compared to other natural fibres. The proximate analysis of the BPFs reveals that, the fixed carbon 71.9 % which is the major component and the remaining composition is volatile content and ash amounting to about 18.4 %. Amount of ash content have direct correlation with the flexural properties, fixed carbon and volatile matter which indicates the amount of inorganic substituent in the carbon. High ash content is not suitable because adsorption capacity of fibre will be reduced. The low moisture content and low ash content of the BPFs makes it an excellent candidate for polymer reinforcement. Proximate and mineral composition of the pod fibres is presented in Table 2.

Table 2: Proximate analysis of Baobab Pod Fibre

Description	Moisture (%)	Ash (%)	Volatile Content (%)	Fixed Carbon (%)
Raw BPFs	9.4	8.3	9.1	71.9

3.3 Ultimate analysis of BPFs:

The value of elemental carbon was consistent with that of the fixed carbon in the proximate analysis. Table 3 summarizes the results for the ultimate analysis, it can be seen that the sample consist predominantly of carbon greater than 60 % which indicates a good percentage of cellulose present in the fibre.

Table 3: Ultimate analysis of Baobab Pod Fibre

Description	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)
Raw BPFs	63.6	0.51	16.3	19.6

Table 4 presents a comparison of the elemental composition of Baobab fibres with some natural fibres.

Table 4: Comparison of elemental composition of BPFs with other Natural fibres

Fibres	C	H	N	O	Moisture	Ash	Volatile	Reference
BPFs	64	0.5	16	20	9.4	8.3	9.1	This study
Raffia	78.2	2.1	8.4	11.6	7.3	2.4	6.4	Fadele, 2017
Rice husk	82	1.2	13	4.4	9.1	32	23	Rohan *et al*., 2020
Marshmallow	70.2	-	3.4	8.2	-	-	-	Mehmet *et al*., 2019
Aloe Vera	23	9	45	5.6	32	-	57	Ruso *et al*., 2021
Corn husk	67	2,1	8.8	4.2	5,7	25	34	Kambli *et al.*, 2017

3.4 Chemical Composition of Baobab Pod Fibres:

The chemical composition of natural fibres constitutes mainly of cellulose, hemicellulose, lignin and other impurities. The high percentage in cellulose increases the tendency of proper adhesion between natural fibres and the reinforcing material. Raw Baobab pod fibres have 53.2 % of cellulose which is higher than that of other short fibres like Bamboo fibres, Coir fibres, flax and corn husk as indicated in Table 5.

Table 5: Comparison of chemical properties of BPFs with other NFs

Fibres	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Waxes (%)	Reference
Baobab	53.2	15.7	26.1	3.7	1.3	This study
jackfruit	20.08	24.4	1.85	52.18	-	Anteneh *et al*., 2021
Coir	53.6	22.5	2.6	15.3	-	Adesina *et al*,2019
Corn husk	43.4	23.8	21.1	-	1.1	Kambli., 2017
Raffia	50.1	11.7	22.3	15.8	6.1	Fadele, 2017
Flax	33.4	22.3	21.5	16.9	-	Zhu and Schamauda, 2021

3.5 FTIR Analysis of Baobab Pod Fibres

The absorbance peaks of interest are clearly marked in the FTIR spectra in Figure 3. The peak at 891 cm-^{1} correspond to ν(C−H) stretching, which indicates the presence of hemi-cellulose for raw untreated fibres. The untreated fibre spectra also exhibit weak absorption peak at 1378 cm^{-1}, which indicates the presence of lignin and is attributed to ν(C=C) stretching (Mwaikambo and Ansel., 2002).

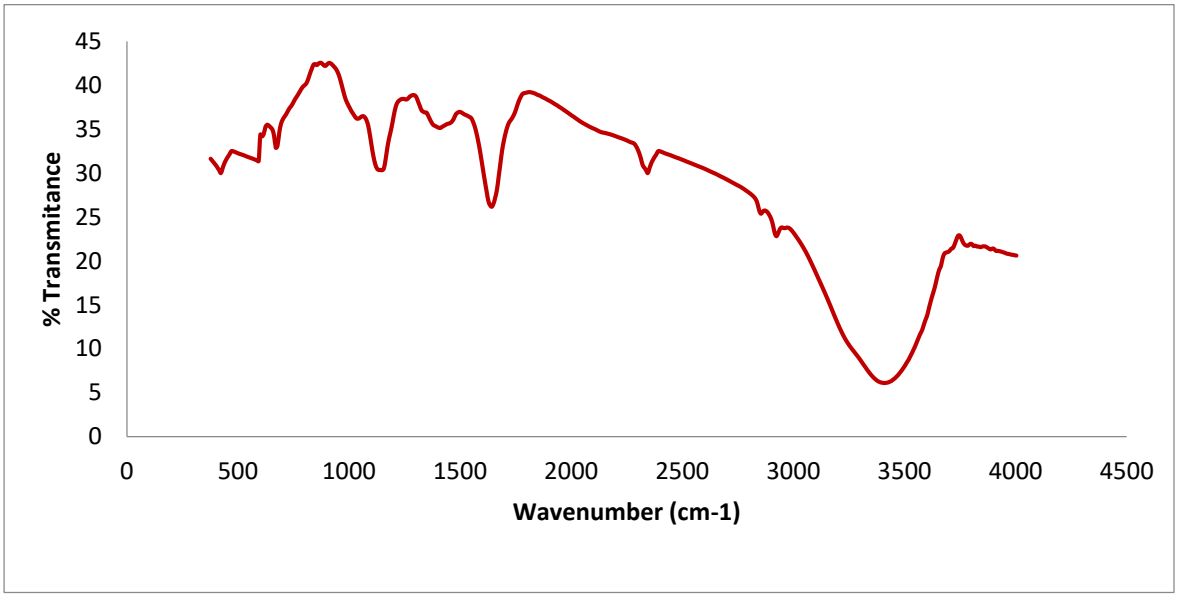

Fig. 3: FTIR Spectra of Baobab Pod Fibres

3.6 Scanning Electron Microscopy (SEM) Analysis

In this study, a simple way to examine Baobab pod fibres by conventional scanning electron microscopy (SEM) was investigated. The SEM indicates three distinct regions: an inner region (lumen), a middle region (cortex) and an outer surface (epidermis). Between the outer surface and the inner core, there are radial pathways, which probably serve as conduits for water/moisture exchange between the core of the fibre and the environment. The cross-sectional

structure of BPF is similar to the reported structure of several natural fibres like, Rafia (Fadele, 2017), coir fibres and sisal fibre. The surface morphology of the raw Baobab Fibre and microfibrils cellulose consisted of an amorphous phase of lignin and hemicelluloses covering the cellulose microfibrils as shown in Figure 4.

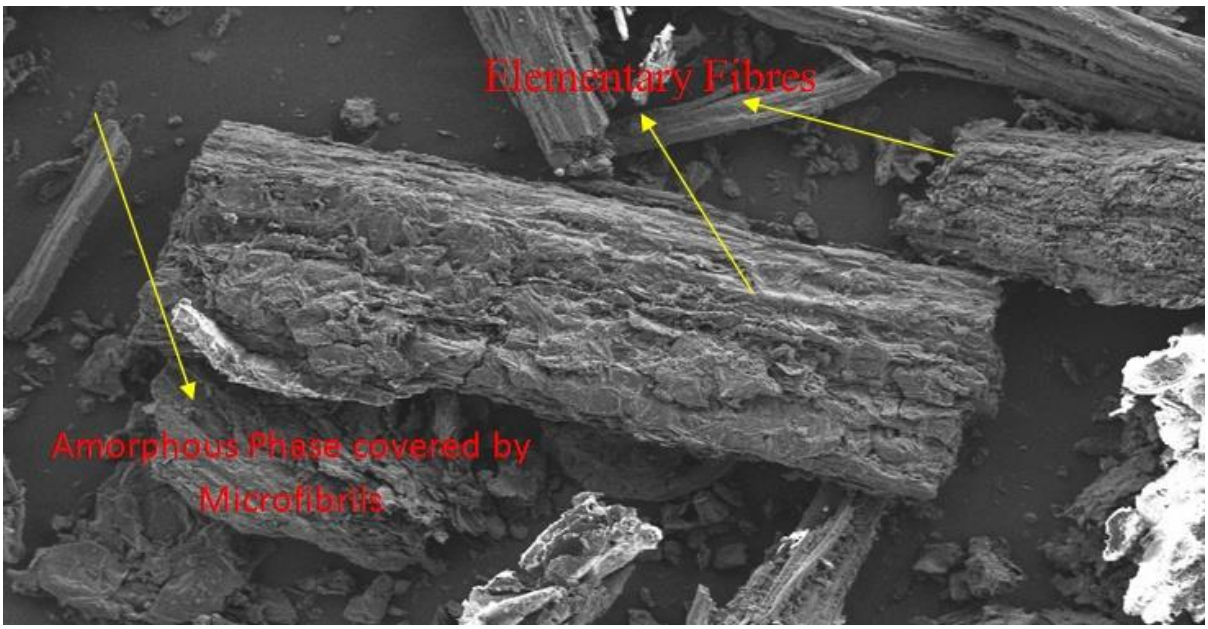

Fig. 4: SEM Spectrum for Raw Baobab pod fibres

3.7 XRD Analysis of Baobab Pod Fibres

The XRD of raw Baobab pod fibres showed in Figure 5, indicate peaks which are peculiar to natural fibres.

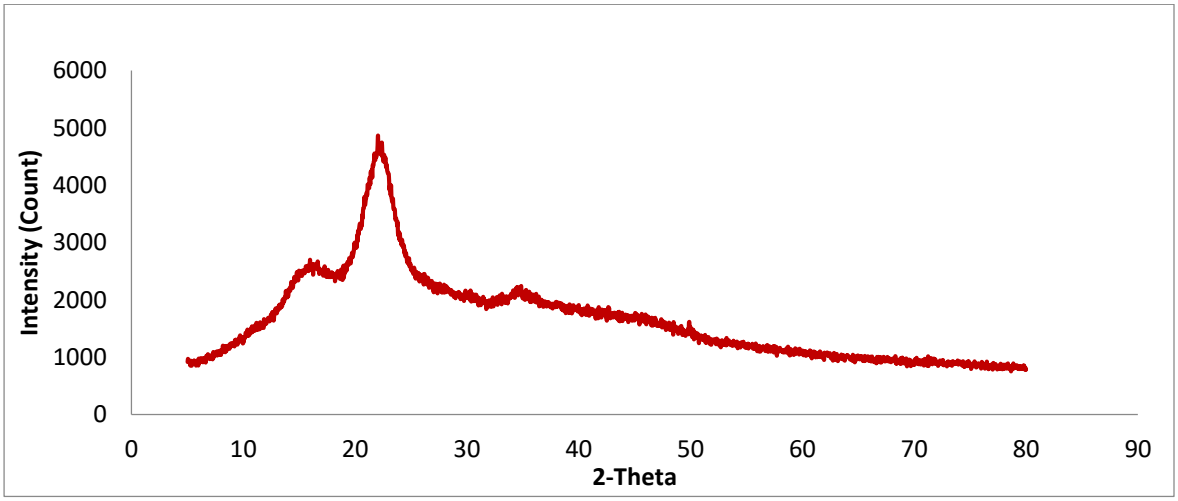

Fig. 5: XRD Patterns of Baobab pod fibres

Investigation of the crystalline structure of the fibre was done using X-ray Diffraction Analysis. The XRD patterns of the samples were recorded in the diffraction angle range 5.000° to 79.9850°. The sharp and strong diffraction peaks in the XRD patterns of the fibre confirm the high crystalline nature of the fibre.

3.8 TGA Analysis of Baobab Pod Fibre

Thermal analysis of the Baobab pod fibres are carried out to further comprehend the thermal properties. The results are presented in Figure 6. It showed that the thermal behaviour exhibited by the fibre is in line with those that are used in the production of polymeric composites. The curve for the fibre shows an endemic peak within the range of 110 ˚C to 140 ˚C, this can be attributed to evaporation of water. Exothermic peaks were observed at higher temperatures, which can be attributed to decomposition of hemicellulose and cellulose (Martins *et al.*, 2008).

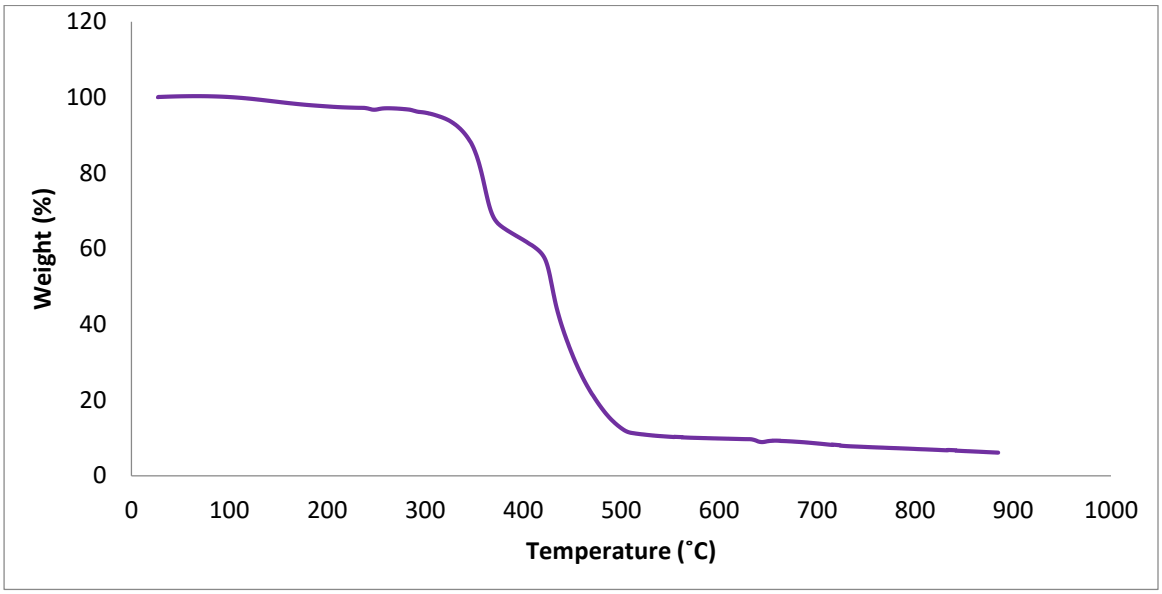

Fig. 6: TGA of Baobab Pod fibres

4.0 CONCLUSION AND RECOMMENDATIONS

The research serves as means of obtaining data on raw Baobab pod fibres which is very rear, the physical, mechanical and thermal properties related to the raw Baobab were investigated to ascertain its economic viability for use in engineering applications. The results shows that fibres obtain from Baobab pod shows excellent properties when compared to other short fibres, it's found to have high cellulose content of 53.2 %, good moisture content of 8.4 %, good tensile strength and excellent morphology.

These properties make it a good candidate for engineering applications; it excellent features shows that it can be used in polymer reinforcement. Reinforced composite materials produced from the fibre can be an alternative material for petroleum based

synthetic polymers because of its low density, good tensile strength, renewability and biodegradability. More so, alternative use of Baobab pod fibres will also leads to development in the field of agriculture as it can bring more income to the farmers and will also help in the field of solid waste management and control.

Based on the findings of this research, it can be concluded that, Baobab pod fibres have excellent potential to be used in various engineering applications ranging from reinforced composites which has lot of significance in automotive industries, chemical industries and construction industries.

It is recommended that consideration be given to producing cellulose nanocrystals from the fibres and reinforcing them with polymer matrix for manufacture of composites for engineering applications.

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