



FABRICATION OF HEAT INSULATION LINING FROM OIL PALM TRUNK FIBRE REINFORCED POLYPROPYLENE COMPOSITE

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Abstract: Fiber of oil palm trunk from selected tree trunks of a plantation in Nigeria was treated with 5% NaOH aqueous solution to improve its surface characteristics, dried, sorted and used to reinforce polypropylene matrix used to form a composite for insulating thermal flask. Loadings of palm trunk fibre were varied as 10%, 20%, 30% and 40% in polypropylene matrix. Raw and treated oil palm trunk fibre samples were subjected to chemical, mechanical and physical analyses to determine composition, density, hardness, impact and tensile strengths in accordance with ASTM D638 standard using standard equipment. Composite samples were subjected to tests such as hardness, density, impact, tensile strength, thermogravimetric and thermal conductivity with equipment that included injection moulding machine, Instron tensile tester, Tinius impact machine, Rockwell hardness tester, Perkin Elmer instrument and Lees disc apparatus accessed at different institutional laboratories. The chemical analysis showed that the treated fibre had cellulose content of 89.14%; hemicellulose of 6.23%; lignin of 3.51% and ash of 1.02% with no heavy metal oxides that could make it toxic for heat insulation of food carrying containers. TGA and DTG result gave initial and final decompositions at 452°C and 514°C respectively which was above the decomposition temperatures of 350°C - 435°C for conventional domestic insulators. Thermal conductivity of samples declined from 0.0035 Wm⁻¹K⁻¹ - 0.0015 Wm⁻¹K⁻¹ for 20 - 40% 10mm thick trunk fibre composite when compared with those of 50mm thick conventional domestic insulators (0.066 Wm⁻¹K⁻¹ of rock wool; 0.036 Wm⁻¹K⁻¹ of glass fibre and 0.03 Wm⁻¹K⁻¹ of polystyrene). Palm trunk fibre reinforced composite had less than 10% heat conductivity of conventional domestic insulators and is therefore suitable alternative. .

Keywords: Oil palm; trunk fibre; polymer composite; thermal insulator lining; thermal conductivity.

1.0 Introduction

Elaeis guineensis fibre is generated from different parts of agricultural trees called oil palm trees for various industrial uses as reinforcements of composites for practical engineering fabrications. Fibre is usually generated from the tree trunk, bunch, fruit mesocarp and fronds for engineering uses. At old age oil palm trees don't really bear much fruit and are felled to give space for new trees. In olden Africa, fallen trunks were sewn into sections and used as rafters for roofing houses. These days, its uses are limited by modernization and availability of cheap alternatives. They are either burnt or dumped to waste away causing nuisance at farm fields. Studies have shown that

they can be used as alternatives to synthetic fillers to reinforce polymer composites. Also, natural fibre is less difficult to degenerate after use and disposal, cheap, readily available; eco-friendly and very close in properties to the synthetic fibres. Ademoh and Adesoji (2015) used fibres of oil palm male fruit bunch stalk to reinforce composite to produce motorcycle crash helmet and found it very suitable. Akaba et al (2018) used palm frond fibre to produce thermal food flask lining. Studies have shown that natural fibres are much more advantageous over synthetics due to low density/cost, non-toxicity, degradability, environmental friendliness, good thermal, and electrical insulation properties (Shehu et al, 2014).

However, their use is limited by factors such as poor wettability, incompatibility and non-mixing with certain polymer binders and high moisture absorption. These shortcomings are easily mitigated by chemical or biological treatment to make them as good as synthetics (Abdul Khalil et al, 2012). Treatment of natural fibre depends on the targeted end use but usually done to make it less hydrophilic for wettability of matrix and improved mechanical properties. The high moisture absorption adversely affects mechanical properties like flexural strength, modulus and fracture toughness which cause high delamination, poor interfacial bond between resin matrix and fibre that lowers the performance. After treatment oil palm trunk fibre can be used in particulate reinforced composites (FRC) to aid the performance temperature, reduce friction, shrinkage, increase wear resistance and stiffness with strength as it shares load with matrix to lower extent than synthetic fibre (Akaba et al, 2019). Oil Palm fibres are effective as reinforcement filler in thermoplastic and thermosetting materials (Khalil et al, 2008). Fibre reinforcement provides more physical than chemical method of changing the materials to suit different engineering use (Warner, 1995). Its flexibility in multiple formulations gives composites the advantages of high corrosion and fire resistance; toughness, mechanical damping; good tensile/fatigue strength and low cost/density over other materials (Tiesong et al, 2008).

Fibre reinforced composites can easily be formulated for multi-applications such as for thermal insulation as proposed in this work. A thermal insulator is a single material, mixed or composite materials that is placed between surfaces to reduce heat flow from one point to another point. Evaluation of its effectiveness is based on such properties as thermal conductivity which depends on physical and chemical structure of the base material. Thermal conductivity measures the flow of heat energy through unit thickness of material at given a temperature gradient and steady state condition that is guided by Fourier's Law. Modes of heat transfer in fibrous insulators are through solid or still air conduction, convection and radiation. The changes in heat conductivity varied with increased insulator filler. Heat convection usually decreases fast with impediment to convective current. Radiation decreases gradually as scattering/emission at higher density (Al-Nasearawi, 2008). Lower heat conductivity gave better insulation.

Fibrous thermal insulators are made from cellular, granular materials with industrial processes that range from wearing apparel to furnaces/pipes lining

(Shehu et al, 2014). Typical installations are done for cryogenic and moderate temperatures applications. Flexibility and adaptability of the material allows it to fit to common shapes found in the industrial processing equipment and facilities. Its light weight allows its use for temporary insulation and modified for reuse elsewhere without much cost. Since oil palm waste contains fibers with similar physical properties to materials used in fibrous insulators, it is considered possible to make palm trunk fibre into industrial raw material such as filler in composites used for fabricating insulators. Based on these, this work is aimed to use oil palm trunk fibre for composite reinforcement for fabricating heat insulator by characterizing the fibre for polymer matrix reinforcement and performance evaluation of the samples for standard heat insulation tests. The result will be compared with past related works and conventional heat insulators for its suitability and to reduce agro-waste.

2.0 Materials and Methods

2.1 Materials

Research raw material included oil palm trunk fibre which was obtained from trees of Offa plantation located in Kwara State of Nigeria (as in Figure 1); fallen old age after several years of bearing fruits, pure sodium hydroxide for chemical treatment of the palm trunk fibre; distilled water and graded polypropylene for polymer matrix. These chemicals were purchased from industrial chemical and polymer dealers in Kaduna. MFI for polypropylene matrix was 1-2g/10 at 230°C and density 0.9g/cc. Figure 1 shows an oil palm tree plantation and Figure 2 shows the section of the oil palm tree that trunk fibre was obtained.



Figure 1: Typical palm plantation

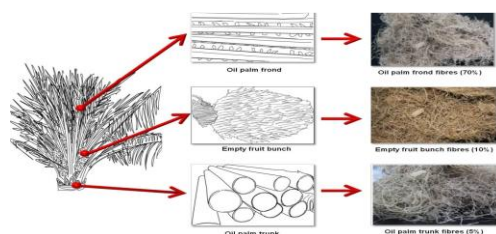


Figure 2: Section sources of fibre in oil palm

Equipment used for the analytical work are; injection molding machine (Model EC1300SX), Perkin Elmer instrument (Model 4000), Lee's disc apparatus at the Engineering Materials Development Institute, Akure; universal tensile testing machine (Instron Model 3360), at Federal University of Technology, Minna. Others are impact machine (Tinius Olsen Model 899) used at Nigerian Defence Academy, Kaduna and hardness testing machine (Rockwell B scale-HRB) used at Ahmadu Bello University, Zaria.

2.2 Method

Fibre surface treatment: Prior to the chemical treatment, the bundles of retted oil palm fibres were scoured in mild detergent solution at room temperature for 2 hours to remove dust and other impurities. Then the fibres were washed in distilled water and dried in air for two days.

Mercerization of fibre in NaOH: Washed and dried palm trunk fibre were reduced to shredded fibres and subjected to natural setting process for a period of 4 weeks in distill water at room temperature to condition it for treatment as done by Ademoh and Adesoji (2015). Retted fibre was then manually cut to average length of 5mm to expose the fibre surface for penetration of NaOH. Mercerization is alkali chemical treatment that subjected natural fibre to interaction with 4% NaOH solution to create strong base to produce great swelling that changed the structure, morphology and the thermo-mechanical properties Bledzki and Gassan (1999). Oil palm trunk fibre was immersed in sodium hydroxide for 1 hour at room temperature. In a study by John et al (2008) 4-5% of concentrated NaOH was considered the most effective for the type of natural fibre treatment and as adopted by Ademoh and Olanipekun (2015) in their related study. After treatment they were washed with distilled water and under tap water to totally remove traces of NaOH. Fibre was sun dried at room temperature (24 hours) to reduce moisture to barest minimum and stored in desiccators to avoid moisture that reduced quality.

2.2.3 Sample production: Varied weight of treated dried and milled particulate palm fibre sieved to size 50 μ , 75 μ , 100 μ (Akaba et al, 2019)

were measured with chemical balance and mixed in fractional ratios in Table 1 to form samples of the polypropylene/trunk fibre composites.

Table 1: Fractional compositional constituents of fibre loading to matrix in the reinforced composite

Specimen Codes	V	W	X	Y	Z
Polypropylene matrix content by fraction (out of 1)	1.00	0.90	0.80	0.70	0.60
Oil Palm trunk fibre content by fraction (out of 1)	0.00	0.10	0.20	0.30	0.40

Polypropylene matrix and palm trunk fibre were mixed based on fractional compositions in table and compounded in injection moulding machine to enable coherent close inter-particle interaction with matrix to homogeneous composite samples. Mixing was done in chamber of machine, preheated to a temperature range of 150-180°C, sucked to die head with pump and transferred to the mould. It was closed with a pressure of 100bar and the composite left for 20minutes to cure. Samples for the mechanical and properties such as tensile, impact and hardness tests were prepared according to ASTM 639 standard.

2.3 Physical property tests on fibre

Fibre thickness and length: Physical measurements were made on treated and raw fibre with digital ruler for length and a digital micrometer screw gauge used to measure thickness each of the five fibre representative samples.

Fibre density: Dried treated and raw fibres were weighed and recorded as w. Distil water was poured into a measuring cylinder and an initial volume recorded as V₁, dried fibre was put into the measuring cylinder with distil water with the final volume recorded as V₂ for each of the fibre specimen. Density was computed from Equation 1 as adopted by Abdul Khalil et al (2011).

$$\frac{w}{V_2 - V_1} \times 1000 \text{ kg/cm}^3 \quad (1)$$

2.4 Chemical analysis of trunk fibre

Measured quantity of 20g each of treated and raw fibre were prepared into standard samples and was subjected to chemical analysis to determine active constituents to ascertain characteristics like

chemical composition and toxicity of fibre as those of the polypropylene matrix were already known because the composites may be used to insulate food vessels to prevent poisoning. Quantity of 0.7g ground trunk fibre was initially hydrolysed by boiling in 5ml 72% H₂SO₄ solution for 4 $\frac{1}{2}$ hours. After hydrolyzing the residue was filtered and oven dried at 105°C for 24 hours. It was cooled in desiccators, weighed and recorded as W₁. Dried sample was later transferred to weighed porcelain crucible, placed in a furnace heated at 600°C for 5 hours cooled, reweighed and noted as W₂. Percentage ash content was determined by similar method used by Ademoh and Olosoji (2015). Acid and insoluble lignin was calculated by finding the difference in recorded weights (W₁-W₂). Five (5) ml filtrate obtained from the hydrolysis that contain sugar released from cellulose and hemicellulose was measured, neutralised with 10% NaOH, stirred and diluted to 100ml. Glucose C₁ and reducing sugar C₂ concentrations in filtrate were measured with the glucose peroxidase assay kit and dinitrisalicylic acid (DNS) techniques was performed by determining the rates of absorption of spectrophotometer with solutions derived from procedures below to evaluate C₁ and C₂ as done by Ververis et al (2007); Ademoh and Olosoji (2015) in closely related previous works.

1ml sample filt+2ml reagent A	}	C ₁
1ml gluc stand+2ml reagent B		
1ml sampl filt+1ml DNS+2ml H ₂ O	}	C ₂
1ml glu stand+1ml DNS+2ml H ₂ O		

These were heated up in water bath for 5 minutes; absorbance was measured with spectrophotometer at 540nm. C₁ and C₂ were determined. Percentage composition of cellulose and hemicellulose in initial material was computed by the method of Ververis et al (2007): %weight/weight of cellulose=(0.9/0.96) x C₁ x (V/M) x α x 100; and %weight/weight hemicellulose=(0.88/0.93) x (C₂-C₁) x (V/M) x α x 100; 0.93 is coefficient of molecular weight ratio of the polymer to monomer hexose. 0.962 is the saccharification yield; 0.88 = the molecular weight ratio of the polymer monomer pentose; 0.93 is saccharification yield of xylane to xylose; C₁ is glucose concentration (g/l). C₂ is reducing sugar concentration (g/l); V is total volume of sugar solution (l); M is dry fibre weight (g); and α is the dilution factor (0.05).

2.5 Mechanical tests on new composite

Mechanical property tests were carried out to give information on capability of composite to perform required functions.

Tensile test:-This was conducted on a computerized universal (Instron model 3396) at materials laboratory of EMDI, Akure in accordance with ASTM D 638 standard. Test specimen measuring 10 cm length was clamped into the two jaws of machine with each jaw end covered with 2cm length of it. Tensile strength was studied over 6 cm gauge length. Gauge of test instrument was initially set at zero. Test was conducted at a constant strain rate in order of 10 mm/min, and the tensile stress was applied until failure of sample. Load versus extension curve was drawn.

Impact test:-Izod impact test was adopted here. Notched impact strength of specimens was done with impactometer (Tiniusolsen, USA) according to ASTM-D 256 standard with notch depth of 2.54 mm and notch angle of 45°. Samples were made with specimen notch to the required profile/dimensions and tested according to ASTM D256 standard.

Hardness:-Rockwell hardness tester was used on B scale (HRB) in compliance with ASTM D224 by which samples were prepared according to ASTM standard, by which the base and load bearing surfaces of test piece were made parallel. Three indentations were made with the loads ranging between 98kN and 980kN across the length of each sample and the average hardness value was taken.

2.6 Thermal analyses of new composite

Thermo-gravimetric and differential thermal analyses (TGA and DTA) were conducted on the newly produced thermal insulator composite specimens.

2.6.1 Thermo-gravimetric analysis:-TGA tests were conducted on the Perkin Elmer (Instrument: Model 4000 UK at EMDI, Akure) thermal analysis was done at a heating rate of 10°C/min under nitrogen atmosphere at flow rate of 20 ml/min. Each specimen was heated at 10°C/min in oven in nitrogen atmosphere for about 30 minutes. Changes in temperature of the composite were measured during heating and respective variations in weight were recorded and plotted against temperature changes in sample to generate TGA graph as computed with equation 2. Percentage changes in sample mass were obtained as:

$$\omega_s \% = \frac{m_n - m_o}{m} \times 100\% \quad 2.$$

Where: $\omega_s\%$ = change in mass; m_o = old mass; m_n = new mass (g); m = sample mass before the test.

Thermal conductivity:-The analysis was done with Lee's disc apparatus on specimens of 40mm diameter and 10mm thickness. A brass disc (B) was hung from the stand with the help of 3 strings. On the brass disc (B) was placed a sample disc (S). A metallic disc (M) was placed on top of sample disc (S) and on metallic disc, a heating chamber (H) with facility for in/out passage of steam was created. Two holes were made in the brass disc (B) and metallic disc (M) for insertion of thermometers to read temperature. Prior to the test, the brass disc was weighed on digital balance. Specimen thickness was measured with micrometer screw gauge, and diameter was measured with Vernier caliper. Heater (H) was started by sending steam through heat chamber of apparatus. Temperatures T_1 and T_2 were read at regular intervals of 5 minutes until steady state was attained by when the supply of steam was cut off; upper metallic disc (M) and sample disc (S) were removed. Steam was again passed to above steady state temperature T_2 . Heating chamber was thereafter to allow cooling of the brass disc. Temperatures were read after every 30 seconds until the steady state temperature T_2 . A graph placing cooling time as abscissa and temperature of brass disc as ordinate was developed with a tangent drawn at steady state temperature T_2 ; slope of which gave rate of cooling (T_t) at steady state temperature T_2 . The values of $(\delta T/\delta t)_{T_2}$ was the gradient or slope of temperature time graph at steady state and temperature differential (T_1-T_2) was noted and found from raw result graph as Equation 3:

$$(\delta T/\delta t)_{T_2} = 4.105 \times 10^{-3} \text{ } ^\circ\text{C/s}; \quad (3)$$

For $(T_1-T_2) = 337\text{K}$

Calculation of heat conductivity was on the fact that it measured rate at which heat flowed within body for given temperature change. Thus, rate of heat conducted through sample was given by Equation 4

$$Q = KA. (T_2-T_1)/L \quad (4);$$

Where: L was sample thickness; A was its cross-sectional area; K was thermal conductivity; Q was rate of heat transfer; (T_1-T_2) was the temperature difference.

The rate of heat loss by brass disc (B) surrounding under steady state was given by Equation 5.

$$Q = mc (\delta T/\delta t)_{T_2} \quad (5)$$

Where, m was the mass of brass disc (B); c was the specific heat of brass disc (B) and $(\delta T/\delta t)$ was the rate of cooling at T_2 . A comparison of Equations (4) and (5) gave rise to Equation 6 as follows

$$K = mc (\delta T/\delta t)_{T_2}/A (T_1- T_2)/ L \quad (6)$$

$(\delta T/\delta t)_{T_2}$ and (T_1-T_2) were determined with Lee's disc apparatus through given input value of mass of brass disc (B), specific heat of brass disc, thickness and cross-sectional area of sample. Values obtained from the raw experimental result in temperature against time graph as done by computations according to Equation 7:

$$\delta T/\delta t_{T_2} = 4.105 \times 10^{-3} \text{ } ^\circ\text{C/s}; T_2-T_1=33. \quad (7).$$

Based on the computation of the thermal analysis results the following computations were carried out to determine the thermal properties of the composites.

Sample thickness, $x = 10\text{mm} = 0.01\text{m}$; Sample diameter, $d = 40\text{mm} = 0.04\text{m}$;

Cross-sectional area of the sample,

$A = \pi r^2 = \pi d^2/4$; constant variables from above equations being Mass of brass (B) $M = 0.097\text{kg}$; Sample cross-sectional area = $1.2568 \times 10^{-3} \text{ m}^2$;

Sample thickness = 0.01m ;

Specific heat of brass disc = 0.38KJ/Kg .

Based on thermal conductivity test data, by reference to Equation 1, the Fourier's equation of heat transfer and from Equations 3, 4, 5 were used to evaluate thermal conductivity, using such relevant parameters as sample thickness, diameter, cross-sectional area and mass of brass the thermal conductivity graph was plotted with Equation 8.

$$K = mc (\delta T/\delta t)_{T_2} L/A (T_2- T_1); \quad (8)$$

Where k =thermal conductivity of sample.

The computed results based on table 6 are presented in section 3.7.2.

3.0 Results and Discussion

3.1 Physical properties of trunk fibre

The density and thickness of the raw and treated trunk Fibre was measured for consistency of weight to ensure property stability and the wettability with matrix as shown in Table 2 which shows that the density and thickness of fibre reduced due to treatment with NaOH.

Table 2: Physical properties of oil palm trunk fibres

Fibre property	Nature of palm trunk fibre	
	Raw fibre	Treated
Fibre diam (mm)	0.22 - 0.45	0.13- 0.21
Dens ($\times 10^{-3}\text{kg/cm}^3$)	4.45	1.23
Length (mm)	0.8 – 1.4	0.55–1.32

Changes were observed in the measured physical characteristics of fibre after the NaOH treatment caused by mercerization that subjected natural fibre to react with concentrated aqueous solution of NaOH. According to Bledzki and Gassan (1999) this caused changes in structure of fibre like morphology, physical, thermal and mechanical properties giving stronger fibre to matrix bond.

Furthermore, it reduced fibre weight by removing the unwanted ash, moisture and impurities. This raised strength and flexural rigidity as the adjoining fibres stabilized molecular orientation/surface modification. NaOH treatment lowered lignin, hemicellulose, wax and oil on fibre surface that reduce reactivity with matrix for firmer composite (Reza et al 2013).

3.2 Mechanical properties of the fibre

The raw and treated fibres were tested for elongation to break and tensile strength. Young's modulus was then computed to determine mechanical bearing strength of fibre laid in matrix as shown in Table 3.

Table 3: Mechanical properties of oil palm trunk fibre

Nature of trunk fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)
Raw fibre	67.23	19.30	11.24	2.23
Treated fibre	89.14	6.23	3.51	1.02

Mechanical properties of treated fibres improved over the raw fibre due to the adduced benefits stated above that alkali treatment raised wettability and promoted closer contact between fibre and matrix to increase bond strength with physical and mechanical properties. This is usually the general trend with natural fibres (Ademoh and Adesoji, 2015). Tensile strength of treated fibre went up by

6-11%; Young's modulus increased by 60-210%. The elongation at break point got reduced by 20-70% over those of the raw palm trunk fibre. Removal of contaminants by NaOH treatment caused closer fibre to matrix bonds that enabled easy transmission of fibre-to-fibre stress for increased strength

3.3 Chemical composition of the fibre

Table 4 presents the chemical constituents of treated and raw palm trunk fibre. The main constituents are hemicelluloses, ash, cellulose and lignin.

Table 4: Chemical analysis of treated and raw oil palm trunk fibre

Fibre property	Nature of palm fibre	
	Raw fibre	Treated fibre
Tensile strength (MPa)	173.48 - 546.65	201.18 - 614.26
Young's Modulus (GPa)	5.633 - 7.457	9.841 - 42.131
Elongation at break (%)	8.87 - 31.16	6.18 - 24.32

In Table 4 cellulose content increased by 33%; hemicellulose reduced by 54%; the ash content decreased by 68% and lignin decreased by about 69% due to treatment of the trunk fibre in the NaOH solution. Mercerization raised cellulose content; it improved strength, lowered hydrophilic nature and imparted better surface wetting ability of the fibres. The enhancements occurred because increased cellulose was accompanied by depressed hemicellulose, lignin and ash contents of treated fibre. In the result, none of chemical constituents are heavy metal oxides; contain any toxic ions and cations or radioactive substances when compared with those of Ademoh and Adesoji (2015) that did XRF analysis on oil palm fibres. Therefore, this group of natural fibres is suitable for reinforcing polymer composites for fabrication of food bearing vessels without risk of poisoning. It therefore enhances versatility of its use.

3.4 Physical and mechanical properties of the polypropylene polymer matrix

The physical and mechanical properties of graded polypropylene vary according to grades. Values of the grade of commercial plain polypropylene used as matrix for this composite are contained in Table 5. Properties usually vary as per manufacturer and storage longevity. The properties (including physical, thermal and mechanical) of polypropylene matrix for the composite formulation in Table 5 were within ranges obtained in a related study by Akaba et al (2019). The values were used as control

data to check effects of the fibre loading on newly formulated insulator composites.

Table 5: Physical and mechanical properties of polypropylene polymer matrix

Property	Graded P/propylene
Tensile strength (MPa)	25 – 40
Impact strength (Jm ⁻¹)	20 - 100
Hardness (HRB- No)	80 - 100
Density (Kg/m ³)	900 - 910
Thermal Conductivity (Wm ⁻¹ K ⁻¹)	0.11 – 0.23

3.5 Mechanical properties of new palm trunk reinforced insulator composite

3.5.1 Impact strength

Figure 5 presents the impact strength test result of composites loaded with 0% to 40% oil palm fibre with 100%, 90%, 80%, 70% and 60% polypropylene matrix respectively. Results at 0% loadings were the same as shown for the polypropylene matrix in table 5. Previous works showed that above 40% fibre loading properties dropped rapidly (Akaba et al, 2019).

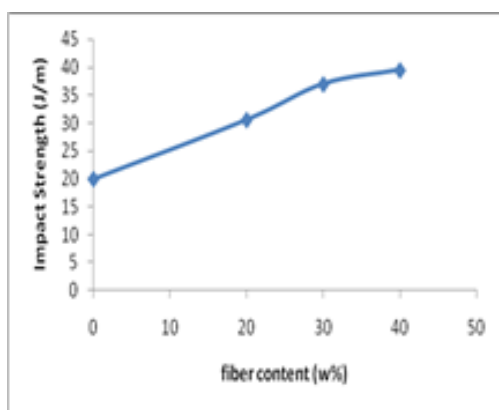


Figure.3: Impact strength of oil palm trunk fibre reinforced polypropylene thermal composite.

In Figure 3, trunk fibers as reinforcement in polypropylene matrix affected impact properties of composite. It showed that 20-30% fibre caused gradual increase in impact resistance. At 0% fibre loading, the impact strength was the same as that of the polypropylene matrix as in Table 5. Increasing the trunk fiber-mass proportion to 40% resulted in a significant increase in impact strength up to the highest value. Impact resistance of the composites was affected considerably by the fiber used as reinforcement. Chai et al (2009) showed that increased untreated softwood fiber reinforcement in polypropylene caused a reduction of impact strength while adding treated fibers improved adhesion between fiber/matrix causing considerable increase in impact resistance (Plackeet et al 2003). There was increase in impact resistance as fiber

increased from 20% to 40% in the composites as higher content of particles promoted better fiber/matrix interaction and stronger bond. At 40% fiber loading peak was attained, impact dropped and wasn't included above it (Maryam, 2011).

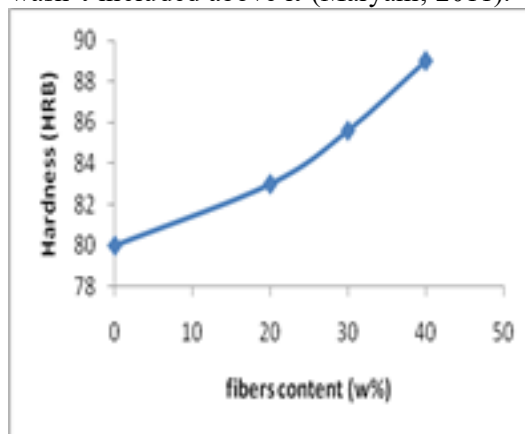


Figure 4: Hardness (HRB) of oil palm trunk fibre reinforced polypropylene thermal composite

3.6.2 Hardness

Figure 4 showed the hardness property of the oil palm reinforce polymer composite. In the figure, highest hardness occurred at 40% fibre loading. This showed that the composite was most rigid at this fibre loading and hence its ability to withstand abrasion when used in lagging vessels. A similar reason was deduced to explain increased impact strength above can be used to explain this trend.

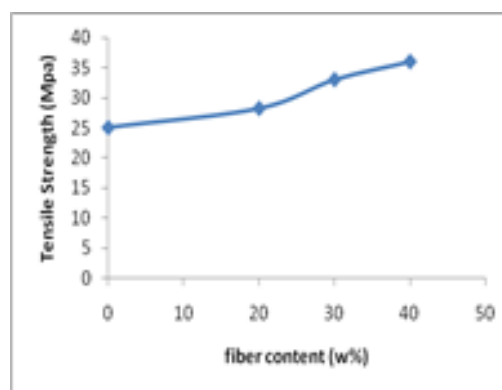


Figure 5: Tensile strength of oil palm trunk reinforced polypropylene composite.

3.6.3 Tensile strength

Strength of composites with varied trunk fibre is as presented in figure 5. Strength increased significantly as palm trunk fiber loading increased from 20% to 40% and thereafter dropped. The fiber modification done with chemical treatment gave better interfacial surfaces for close adhesion of trunk fibers to polymer matrix for higher bond strength. Higher strength (at 40% fiber loading) showed the ability of fiber to absorb stress transferred from polymer matrix. In the work of

Tijani et al (2019) it was shown the loading palm frond fibres beyond 40% peak in composites to 50% caused higher filler and matrix interaction but that this higher loading created more voids and cracks that rendered composites weaker. Therefore, according to literature, loading was limited to 40% trunk fibre as experienced from the initial experiments. Composites with higher fiber contents were not reported as literature had already confirmed the disruption and degradation that it causes during processing because of inter-fibre friction which was observed during the preliminary experiments of this work. Moreover, higher inter fibre friction was also known to raise temperatures of composite which if it went above 200°C would have affected the thermal stability of the natural palm trunk fibre reinforced composite as it could cause burning of fibre and weakening of bond strength.

3.7 Thermal property analysis

3.7.1 TGA and DTG analysis

Figure 6 shows three thermo-gravimetric analysis (TGA) plots of three items that included palm trunk fibre, polypropylene matrix and palm fibre reinforced insulator composite. Thermal degradation of each of them three items occurred in a 2-step process. It was observed that trunk fiber composite degraded at first temperature of 452°C (peak). Polypropylene matrix started losing its stability at 435°C which is below the decomposition temperature of trunk fiber. On the other hand, thermal degradation of the trunk fiber composites occurred in a 2-step process. It exhibited initial mass loss at about 407°C to 515°C. The second thermal degradation step was mostly related to pure polypropylene degradation that overlapped with cellulose and lignin content in trunk fiber.

The 2nd step degradation act demonstrated that the thermal degradation temperature of polypropylene was higher than that of trunk fibre. This showed that the presence of trunk fibre as reinforcement increased heat resistance and thermal stability of the polymer matrix. Peak degradation/range temperature of trunk reinforced composite are obtained from DTG curve in Figure 7.

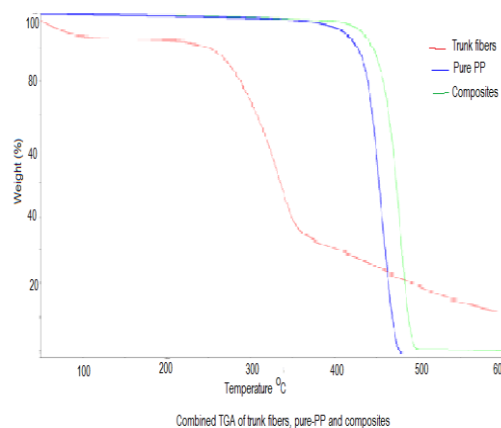


Figure 6: Combined TGA of trunk fiber reinforced composite

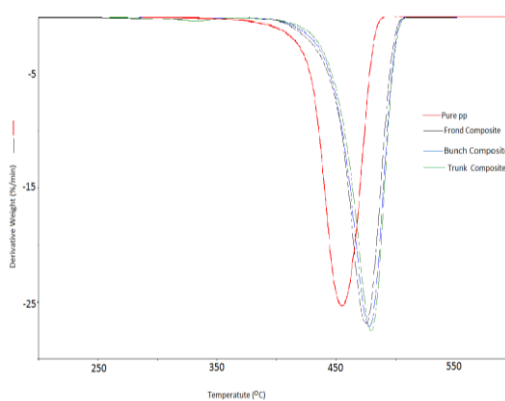


Figure 7: DTG of trunk fibre reinforced composite

It showed that the composite content was totally lost at peak degradation temperature. Thermo-gravimetric analysis (TGA) of the raw trunk fibre polypropylene resin and composite were studied as function of percentage weight loss against increasing temperature. Oil palm trunk fiber initially de-polymerized and dehydrated between temperature of 230-191°C followed by cleavage of C-H, C-C and C-O bonds as initial decomposition temperature (IDT) and the final decomposition temperature (FDT) for oil palm fibers and have been found to be between range of 250°C and 400°C by Singha et al (2008).

Polypropylene had initial decomposition 435°C; final decomposition temperature of 490°C. In Figure 8 bio-composites with trunk fibre reinforcement initial and final decomposition temperatures were 452°C and 514°C respectively. The differential thermal analysis of the composites was observed that in addition to exothermic peaks there were also endothermic peaks in different temperatures when compared to parent polymer matrix. Comparing the magnitude and location of peaks of the DTA/DTG curves, it is evident that there were changes in thermal behaviour of oil palm

trunk fibre composite as it had an effect on the degradation process. Thus, it showed it was thermally more stable than polymeric polypropylene resin matrix.

This is similar to the observation with the frond fibre reinforced polymer composite (Beydokhti et al., 2006). This was due to surface area availability for adequate fibre and matrix interaction (Singha et al., 2008). Basically, for a composite to be an effective load bearing system reinforced fibre and matrix must cooperate. These depend on presence of interfacial strength which in turn depends on the fibre surface topology. The interface acted as binder and transferred load between the matrix and reinforcing fibre as its major role.

The interfacial area played a major role in polymer composite material because each fibre formed individual interface with matrix. Cellulose is the major component in natural fibres contain strong hydroxyl groups in its structure which tend to form hydrogen bonds with the macromolecule with the hydroxyl groups of the polymer matrix. Therefore, different degrees of reinforcement bond effects are achieved by palm trunk fiber to polypropylene heat-resistant composites. During the process of fabrication, some sections of the palm trunk fiber acted as the load carriers by transmitting stress from polymer matrix to the reinforcement fibre. These gave composite good mechanical strength and thermal properties

3.7.2 Thermal conductivity

Table 6 shows weight percentage contents of the palm trunk fibre in each composite sample, temperature and the time used as parameters for computations of thermal conductivity of each specimen as treated by the equations in section 2.2 to generate Equation 8. Table 6 was used to calculate thermal conductivity (K) of trunk fibre reinforced composite at 20% fibre loading for instance. It was repeated for the other fibre loadings as illustrated in Equation 9.

$$(\delta T / \delta t)_{T_2} = 4.105 \times 10^{-3} \text{ } ^\circ\text{C/s} \quad (9).$$

From the experimental result curve of the temperature against time, $(T_2 - T_1) = 337\text{k}$. These constant variables are inserted into equation 4 above to determine K for 20% fibre loaded insulator composite as:

$$K_{20} = (0.097 * 0.338 * 4.105 * 10^{-3} * X(0.01)) / (1.2568 * X 10^{-3} * 335).$$

Values of K_{30} and K_{40} were computed with same procedures accordingly and plotted in a graph for the composites as shown in Figure 10.

Table 6: Temperature and time for computing thermal conductivities of oil palm trunk fibre composites

Trunk fibre loading	Values					
Time (Min)	5	10	15	20	25	30
T($^{\circ}$ C) for 20% fibre	33.8	31.0	30.5	28.9	25.7	28.0
T($^{\circ}$ C) for 30% fibre	36.3	34.0	32.8	30.5	30.0	30.0
T($^{\circ}$ C) for 40% fibre	39.8	37.9	36.9	35.8	34.6	33.2

Figure 8 shows that use of trunk fiber to reinforce polypropylene matrix lowered the thermal conductivity of composites.

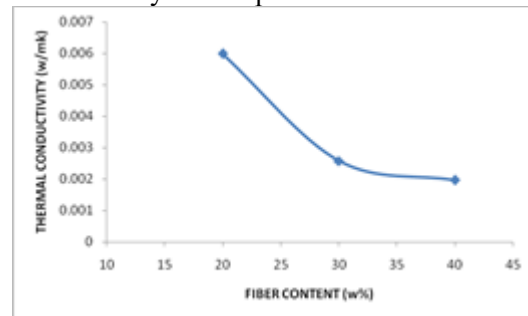


Figure 8: Thermal conductivity of trunk fibre reinforced composite.

Rapid decline in composites conductivity was observed at the fibre loading of 20 to 30% due to the presence of trunk fibre whose atoms became more compacted to close the voids in material for heat penetration through conduction. The steady decline in conductivity continued to peak load of 40% trunk fibre. This is a very desirable property of the composite as it indicated ability to hold and conserve heat energy. In comparison with established past works and conductivities of conventional insulators thermal conductivities of the newly formulated polypropylene insulator composites reinforced with fibre loading varying from 10 - 40% in Figure 10 were compared to Table 7 (Ashrae, 2001).

Table 7: Thermal conductivities of some conventional insulation materials

Material	Thermal conductivity (Wm ⁻¹ K ⁻¹)	Density (kgm ⁻³)
Rock Wool	0.016-0.026(50mm thick)	9.6-32
Glass Fiber	0.036	64-140
Polystyrene	0.03	29-56

It is observed that thermal conductivity of trunk composite at 40% fiber loading was lower than those of the conventional materials. Thus, it showed capability of being used as replacement for synthetics in Table 7. When compared with results of studies done by Akaba et al (2018[2019]) on use of oil palm fronds and fruit bunch stalk fibres as

reinforcements in insulator polymer composites with same thickness of 10 mm, palm fibre reinforced composite displayed lower conductivity. Conventional insulators in Table 7 were 50 mm thick and expected to have lower conductivities because according to Al-Nasearawi (2008), thick materials usually give better thermal insulation. Invariably by increasing thickness of the palm trunk fibre reinforced composite to 50mm could have drastically reduced its thermal conductivity much further thereby making them much more suitable cheaper and safer than the conventional materials.

4.0 CONCLUSION.

The study used oil palm trunk fiber with average length of 5mm for reinforcement of commercially graded polypropylene matrix for its suitability for fabricating domestic thermal insulation use. Samples were tested for mechanical properties that included toughness, hardness and tensile strength increased proportionately with fibre load of 10% - 40%. NaOH treated trunk fibre gave better composite than untreated fibre due to eliminations of ash, cellulose and other contaminants that promoted closer fibre to fibre contact that enhanced bond and fibre to fibre transfer of stress within matrix. Average increases in these properties were 10 to 20% over frond and palm fruit bunch stalk fibre composites of Akaba et al (2018 & 2019). These were comparable and even better than conventional thermal insulators and are therefore suitable. Thermal properties like TGA and DTG showed degradation temperature of the trunk fibre composites increased with fiber load of 10 - 40% with initial/final decomposition temperatures at 452°C and 514°C respectively. These were above the values obtained by Akaba et al (2018 & 2019). They are marginally above those of the conventional domestic insulator by 12%. Thermal conductivity dropped from 0.006 to 0.0015 Wm⁻¹K⁻¹ at 10 to 40% fibre loading of 10 mm thick which was lower than that of 50 mm thick rock wool (0.016 Wm⁻¹K⁻¹) and those of Akaba et al (2018 & 2019) for palm frond and male fruit bunch stalk fibre reinforced polymer insulator composites. Therefore, polypropylene reinforced by palm trunk fibre composite would be suitable for alternative domestic insulator based on better results obtained from physical, mechanical and thermal analysis determined above. It is recommended for further investigation for engineering applications for fabrication of insulator panels/boards, furniture, air craft and automotive components manufacture due to the lightweight advantage.

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