EVALUATION OF COCONUT FIBRE REINFORCED LOW DENSITY POLYETHELENE COMPOSITES

Abstract

Physical, mechanical and dynamic properties of composites produced from coconut fibres using pure water sachet (LDPE) as matrix were evaluated in this study in order to assess its suitability for use as particleboards. The LDPE (waste water sachets) and coconut coir/fibre were collected, shredded and milled into pellets. Five compositions with coconut fibre loading 5, 10, 15, 20, and 25 %, and corresponding LDPE of 95, 90, 85, 80 and 75%. A sixth sample with 100% LDPE was also produced as control. The LDPE samples were heated at 170 ^{o}C for 30 minutes, and each melted solution was loaded with the corresponding coconut fibres and the mixture stirred and poured into a pre-designed metallic mould, pressed and cured in air for 24 hours. The results show that water absorption, swelling thickness and flaking concentration increased with, while the density decreased. The bending strength decreased with fibre loading, while the tensile strength, compressive strength and modulus of elasticity increased with increasing loading to a point before decreasing sharply. The results of dynamic mechanical analysis for the storage and loss modulus shows that as the temperature of the samples was increased these properties reduced except for the damping factor which increased. On the whole, the results showed that the sample with 15 % coconut fibres loading and 85 % LDPE exhibits more desirable properties compared with the others. These results imply that the composites produced from coconut fibres with LDPE as a matrix can be used as particleboards as well as in areas other areas of applications in the automobile industries. This will improve on savings in foreign exchange and mitigate environmental degradation as result of indiscriminate disposal of portable water sachets and coconut fibres.

Keywords: Composites, Coconut fibre, Modulus of elasticity, Low Density Polyethylene, Storage modulus, Loss modulus, Flaked concentration, Particleboard.

I. Introduction

The high cost of conventional construction materials is a major factor affecting housing and industrial systems around the world. This has necessitated research in developing alternative materials which depends directly or indirectly on other source of raw materials. Most matrices used in the production of composites are not environmentally friendly. Development of composites has been, as a result of man's quest for optimum utilization of timber and wood wastes, which earlier were used mainly as fuel (Ganyam, 2010). Composites are made from lignocelluloses fibres combined with a synthetic resin or other suitable bonding system that are combined together under heat and pressure, (Yang *el. al.*, 2003). Reinforcing a polymer matrix with lignocelluloses materials have several advantages such as lower density, high stiffness, less abrasive to equipment, biodegradable and lower cost (Rowell et al., 1996; Jacob *et al.*, 2004). However, the major concern in producing good lignocelluloses–thermoplastics composites, especially in terms of the chemical and physical properties, thereby bringing better compatibility between the constituent materials [26,27].

Also, the health hazards associated with synthetic fibre and some binders such as phenol formaldehyde are of concern to manufacturers of composites. One of the potential natural wastes is the coconut coir fibres, it contains a high lignin ratio and thus low cellulose content, as a result of which it is resilient, strong and highly durable, making this fibre stiffer and tougher (Alma *et al.*, 2001; and Erakhrumen *et al.*, 2008).

Coconut coir/fibre is a fibrous material found between the leathery covering and the shell. The natural color of coir varies from light brown to very dark brown, depending on the variety and maturity of the nut from which it was extracted, and the processing conditions. The fibers are stiff coarse, resilient, pliable and quite resistant to bacterial attack. They have very good water resistance being second only to the black fibers of the sugar palm (*Arenga saccharifer*). Coir has been used to produce a variety of composite products including particleboards and fibre boards. When used as a reinforcing fibre in inorganic-bonded composites, coir is very resistant to alkalinity and variations in moisture, when compared to other lignocelluloses.

Abdullahi and Sara (2015) stated that waste water sachets is a low-density polyethylene heavily characterized by hydrocarbon chains (just as bitumen), resulting to a tough material insolvable at room temperature, but does at high temperature in the presence of aromatic hydrocarbons. Almost every nook and cranny in Nigeria is littered with waste water sachets resulting from large sale volumes of package water popularly called locally "pure water". Millions of these used sachets are thrown indiscriminately on daily basis onto the streets of virtually every city, town, and village in Nigeria (Abba *et al*, 2014).

Researchers have investigated natural fibres such as cassava, palm kernel, sugar cane, and maize stalk etc. (Idris *et al.*, 2021 and Akinyele, 2013). Ajikashile *et al.* (2014) investigated the suitability of rice husk as alternative to wood-based particleboard as composite. Abdullahi and Sara (2015) produced and investigated composites from periwinkle shell ash using low density polyethylene. Samotu *et al*. (2015) used palm kernel shell- iron filings to develop composites for automobile application. All these works came up with different results and benefits.

2.0 MATERIALS AND METHODS

2.1 Preparation of Materials

The Coconut seed with shells collected from Railway and Igbor markets in Makurdi and Aliade in Benue State were properly washed with water to remove dirt, and sun dried for 3 days to remove any moisture content. The fibre was then removed from the shells using a decorticating process. Further preparation and cleaning of the coconut fibre was done using Sodium hydroxide (NaOH) before keeping in a desiccator at room temperature of 32 °C for 24 hours to free the fibres from further moisture. The coconut fibre was then manually cut to a nominal size length of 20 mm. Also, the waste water sachets (LDPE) obtained from dump sites in Makurdi town were properly washed using detergent to remove dirt, label, and contaminants such as abrasives. The LDPE was sundried for 24 hours to remove moisture content. Manual shredding was then carried out, using a pair of scissors, before further grinding to the size of 3 mm using a grinding machine.

Based on the mass of 2000 g of the commercial particle board, the percentage composition of the coconut fibre loading (CFL) and the LDPE were varied in the proportions shown in Table 1, and the compositional samples were labeled A, B, C, D, and E respectively. Sample F was prepared with a composition of 0:100 for coconut coir:LDPE as control.

Table1. Composition of Coconut fibre loading and LDPE of the produced composite.

Sample code	Coconut fibre (wt %)	LDPE (wt %)

A	5	95
B	10	90
C	15	85
D	20	80
E	25	75
F(control)	0	100

2.2 Production of Composite

A stain less steel pot was placed on an already heated hot plate for fifteen seconds and samples of the shredded waste LDPE were poured into it, and then heated to a temperature of 170 °C to attain a homogeneous mixture. The shredded material was allowed to melt completely inside the heated steel container causing a breakdown of the long plastic polymer chain forming a paste. Stirring was carried out continuously using a long metal stirrer. The respective coconut fibre/coir samples were then added to the paste progressively with continued stirring to achieve homogeneity. The mixture was then poured into the predesigned metallic mould measuring 500 × 500 × 4 mm and covered with a lid, and subjected to a pressure of 5 tons for a dwelling time of 15 minutes to obtain a well compacted composite matrix. Curing carried out in air for 24 hours. This procedure was repeated for the 5 samples. The samples are shown in Figure 1.

Figure 1. Samples of the Coconut fibre/ LDPE composites.

2.3 Physical Tests

2.3.1 Water absorption tests

Water absorption tests were carried out in accordance with D5229M-12 standard. Composite samples of dimensions 30 × 30 × 8 mm were cut and properly cleaned to remove any adhering lubricant and surface moisture before weighing. The weights of the cleaned samples were recorded as initial weight WD_1. The samples were separately immersed in distilled water at room temperature (25 ^{o}C) at time intervals of 1 hour for 72 hours. The water after saturation in the composites samples was noted and the percentage of water absorbed was calculated using equation 1.

$$WA = \frac{WD_2 - WD_1}{WD_1} \times 100 \quad (1)$$

where WD_1 = initial weight before immersion, WD_2 = final weight after immersion, and WA = water absorption expressed as percentage (%).

2.3.2 Thickness swelling test

The thickness swelling tests on the samples were carried out according to BSI 2003. The thickness at the middle of the composites samples were measured using digital vernier caliper (Whitworth, model: metr-150) and recorded as initial thickness. The samples were separately immersed in beakers containing distilled water and allowed to stay for 24 hours after which they were removed, rinsed and re-weighed and result recorded. The thickness swelling (TS) was determined using equation 2.

$$Thickness\ swelling\ (TS) = \frac{T_i - T_0}{T_o} \times 100 \quad (2)$$

Where T_i = the final thickness of the particleboard after immersion, and T_o = the initial thickness of the particleboard before immersion.

2.3.3 Flaking test

Flaking test was carried out to assess the tendency of dust particles to strip off the particleboard. The samples were weighed and recorded as initial weights. A hard iron brush was used to rub against the two surfaces of each of the samples of composites of 100 × 150 mm using fifty strokes of forward and backward movements. The flaked materials from the surfaces of each of the samples were collected and weighed. The flaked composites samples were also weighed and the same procedures were followed for a commercial particleboard. The flaked concentration (F_c) was calculated using equation 3 (Ganyam, 2010).

$$F_c = \frac{W_1 - W_2}{W_1} \times 100 \quad (3)$$

where F_c = flake concentration (%), W_1 = weight of board before brushing, and W_2 = weight of board after brushing.

2.3.4 Density

The Archimedes' volume method was adopted to determine the density. A 5 cm length was obtained from each of the five samples and weighed. A beaker was filled with 500 ml of water and measured as V_1 each of the particleboard samples was separately immersed in the beakers with the aid of thread. The displaced water levels from the beakers for the various samples were recorded. The volume of water displaced (the mass determined while the particleboard is immersed in the water) was measured as V_2. The volume of water displaced by each of the particleboard samples was calculated as (V_2-V_1). The density was then calculated using the using equations 4, taking the density of water to be 1000 kg/m^3 (Ashik *et al*., 2015).

$$Density = \frac{Mass\ of\ particleboard\ sample}{Volume\ of water\ displced\ by\ particleboard\ samples\ (V_2 - V_1)} \quad (4)$$

2.4 Mechanical Tests

2.4.1 Bending test

The bending test was performed using the Universal Testing Machine 100 kN capacity, model No. Cat. Nr. 261 in accordance with ASTM D790 using a 3-point bending fixture utilizing centre loading on a

simple supported beam. A rectangular cross sectional bar resting on two supports was loaded by means of a loading nose midway between the supports with dimensions 100 × 30 × 5 mm. The bending strength was calculated using equation 5. Young's Modulus of elasticity (E) of the bending test was calculated using equation 6.

$$B_{max} = \frac{3FL)}{bt^2} \quad (5)$$

where B_{max} = bending strength (N/mm^2), F = load at rupture (N), L = length between supports (mm), b = width of specimen (80 mm), and t = thickness of specimen (mm).

$$E = \frac{Pl^3}{4bt^3Y} \quad (6)$$

where P = the load (N), l = gauge length (80 mm), b = the width (mm), and Y = deflection.

2.4.2 Tensile test

The tensile strength of the composites was measured using Monsanto Tensometer Type 'W' with S/No. 9875 in accordance with the ASTM D638 procedure. The dimension of the samples were 100 × 10 × 5 mm with a gauge length of 40 mm. This test was conducted by gripping each end of the reduced section of the sample and slowly pulling it until catastrophic failure occurred and the load at which failure occurred in tension was recorded, and divided by the area of the sample to obtain tensile strength as indicated in equation 7.

$$Tensile\ strength = \frac{Applied\ load}{Area\ of\ sample} \quad (7)$$

2.4.3 Compression test

Avery Denison testing machine was used to determine the compressive strength of the produced composites. The rate of loading of this machine was 10 - 3000 kN min^{-1}. The samples were subjected to a loading rate of 136 kN min^{-1} with loading capacity of up to 500 kN applied until failure occurred in compression. The failure load was divided by the area of the sample to obtain compressive strength as indicated in equation 8.

$$Compression\ strength = \frac{Applied\ load}{Area\ of\ sample} \quad (8)$$

2.4.4 Modulus of elasticity

Modulus of elasticity was used to measure the stiffness of the composites and was determined using the results obtained in the tensile test and computed using equation 9.

$$Modulus\ of\ elasticity\ or\ Young's = \frac{Stress}{Strain} \quad (9)$$

2.5 Thermo-mechanical Tests

Dynamic Mechanical Analysis (DMA) was carried out to determine the thermo-mechanical behavior of the composite material with the aim of manufacturing fibre board with high mechanical performance. This was conducted using Dynamic Mechanical Analyser (DMA) Model No. 242E. The DMA was conducted on the five samples using specimens of dimensions 60 × 12 × 5 mm and that of a commercial particleboard, for comparison. The specimens were inserted in to the combustion chamber of the machine one after another and ran in a dual cantilever bending mode which was subjected to sinusoidal stress at specific temperatures and frequencies (30°C and 180°C, and loading of frequencies of 2, 5, and 10 Hz at a dynamic amplitude of 60 μm). Its glass transition and/or other material relaxation characteristics

associated with the identified decreases in the storage modulus, and a peak in its loss modulus and loss factor were observed.

3.0 RESULTS AND DICUSSIONS

3.1 Physical Properties

The results of the physical properties are in Figure 2 (a-d). The result of water absorption against percentage fibre loading of the composites is presented in Figure 2(a). It was observed that water absorption increased with percentage coconut fibre loading. Sample A (5 % coconut fibre and 95 % LDPE) had the least water absorption of 0.67 % while Sample E (25 % coconut fibre and 75 % LDPE) had the highest of 4.09 %. In between these loading percentages, some disparities were observed. These could be attributed to the mechanisms of moisture absorption as a result of diffusion of water molecules inside the micro gaps between polymer chains, the capillary transport of water molecules into the gaps and flaws at the interface between fibres and polymers due to incomplete wettability (Samuel *et al*., 2012), and the transportation of water molecules by micro cracks in the matrix formed during the compounding process. The characteristics of the coconut coir being a lignocelluloses material that readily absorbs water into cell walls through the formation of hydrogen bonds between its OH groups, and the hydrogen from water could also be responsible (Mahzan *et al*., 2012). The effect of water absorption is important in case the material developed is to be used in contact with water on application. The samples with lower water absorption capacity have better promise for use even in areas where there is presence of moisture (Tewari *et al*., 2012).

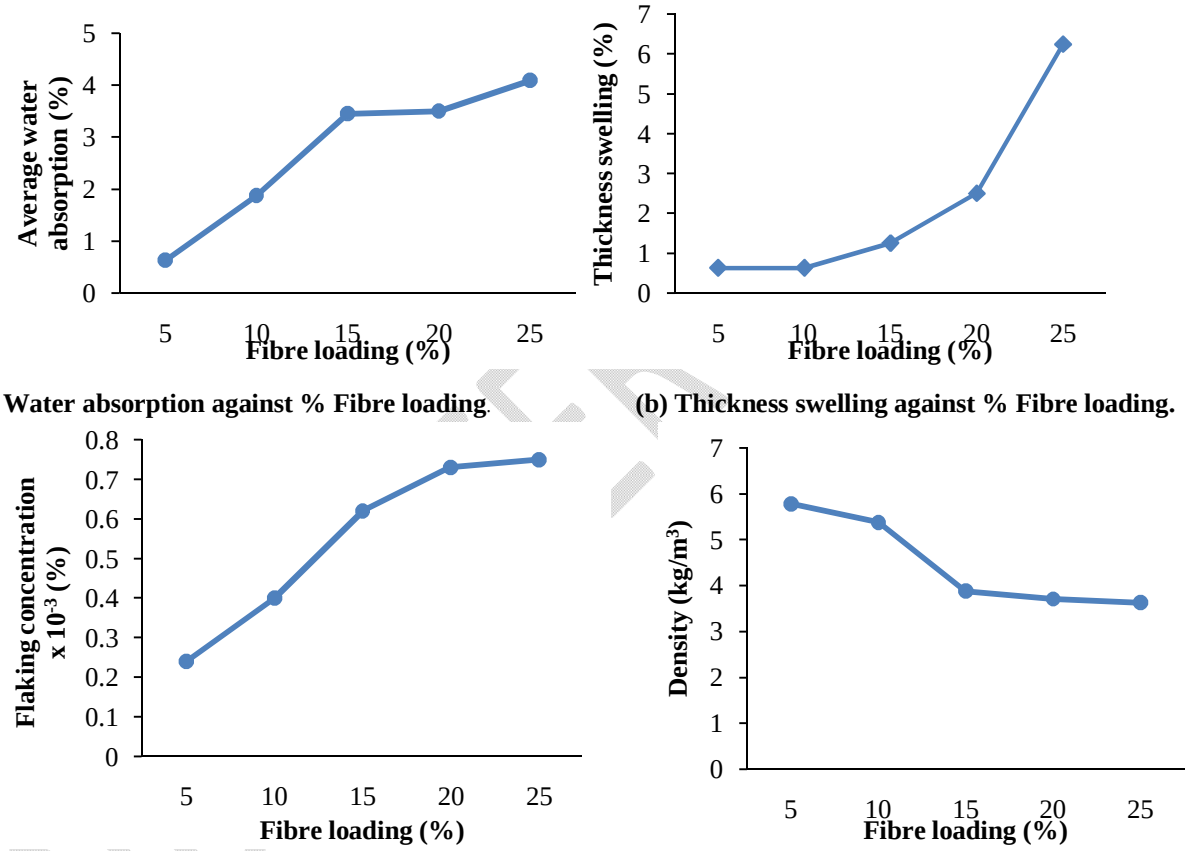
Figure 2(b) shows the swelling thickness against percentage fibre loading of the composites. It was observed that the thickness swelling (T.S.) increased with increasing coconut fibre loading in the matrix. Sample E (25 % coconut fibre and 75 % LDPE) had the highest T.S of 6.8 %. Nemli and Aydin (2007) using EN standard had recommended that T. S. of composites are better at < 8 %. Also, Narendar and Dasan (2012) using IS: 3087 suggested that the minimum T.S. of composites are better at < 10 %. The minimal percentage of the T.S. could be due to water repellent nature of the LDPE in the produced composites. The implication of these S.T results is that they are suitable for interior and exterior decorations such as particleboards.

The result of flaking concentration against percentage fibre loading of the composites is presented in Figure 2(c). The flaking concentration increased with increasing coconut fibre loading in the matrix with LDPE. The maximum flaking concentration of 0.78×10^{-3} (%) was attained from sample E (25 % coconut fibre and 75 % LDPE). Narendar and Dasan (2012) used IS: 3087 and recommended that flaking concentration is better at $< 0.7 \times 10^{-3}$ (%). The reason for the much better flake concentration could be that fibres of coconut were well bonded in the matrix of the LDPE. This implies that the composites cannot easily peel off under indentation when used as particleboards.

The result of density against percentage fibre loading of the produced composites is presented in Figure 2(d). The result shows a remarkable decrease in the density with increasing percentage coconut fibre loading from 5 - 25% of 5.78 – 3.57 g/cm^3. The decrease in density can be related to the fact that the fibres are light in weight but occupy substantial amount of space. The least density of the composites is better than the value of 3.9 g/cm^3 reported by Abdullahi and Sara (2015). The presence of porosity/voids could also be the possible cause of the decrease in density probably due to insufficient pressure applied during the production process (Nitin and Singh, 2013).

3.2 Mechanical Properties

The results of the mechanical properties are in Figure 3 (a-d). The result of the bending test carried out on the composites is shown in Figure 3(a). It was observed that the bending strength decreased with increasing coconut fibre loading. Sample E (25 % coconut fibre and 75 % LDPE) had the least bending strength of 4.47 MPa while Sample A (5 % coconut fibre and 95 % LDPE) had the highest value of 15.03 MPa. The reason for the low bending properties of the samples with high percentage coconut loading may be due to the weak fibre -to- fibre interactions, voids, and poor dispersions of the fibre in the matrix as reported by Das and Biswas (2016). Also, this trend is due to incremental population of the fibre defects. At higher bending strengths the composites exhibit resistance to deformation under load.



(a) Water absorption against % Fibre loading.

(b) Thickness swelling against % Fibre loading.

(c) Flaking concentration against % Fibre loading.

(d) Density against % Fibre loading.

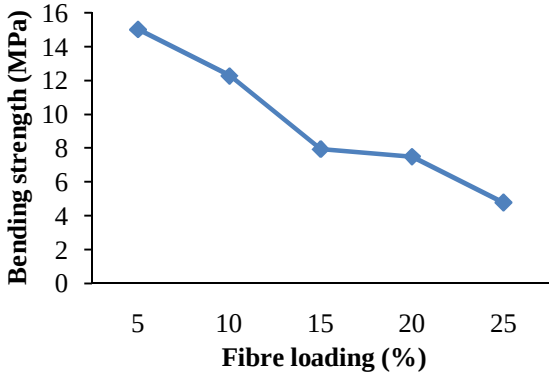
Fig. 2(a-d): Physical Properties of the Composites

The results of the tensile test carried out on the composites is shown in Figure 3(b). It was observed that there was an increase in the tensile strength with increasing coconut fibre loading from 5-15 % (9.6- 11.02 MPa). There was a sharp decrease from 20 - 25 % coconut fibre loading. This trend is in consonance with the findings of Das and Biswas (2016) that improved adhesion of the fibre to the matrix could hinder the continuous increase in the tensile strength. Also, Ismail *et al*. (2014) stated that during tensile loading, partial separation of micro-spaces are created that obstruct stress propagation between the fibre and the matrix. As the fibre loading increased, the degree of obstruction increased which decreased the strength of

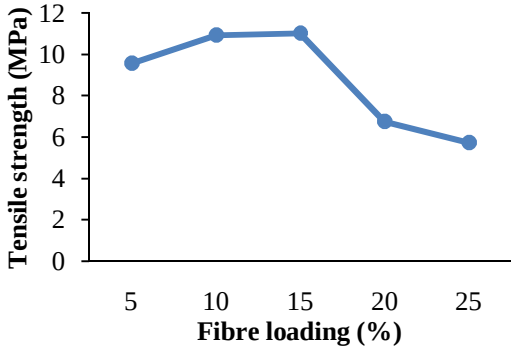
the composite. The highest tensile strength of 11.01 MPa was observed at 15 % coconut fibre loading. This could likely be due to the fact that there was better fibre distribution in the matrix LDPE as the bonds between fibres and the matrix often dictate whether the fibre will improve the property of the composite by transferring an applied load (Rozman *et al*., 2001).

Figure 3(c) presents the results of the compression strength carried out on the composites. It was observed that as the percentage coconut fibre loading increased, the compressive strength increased as well. At 25 % coconut fibre and 75 % LDPE, the highest compression strength of 18.16 MPa was obtained. The implication of this result is that LDPE require higher compression strength to fracture when in use.

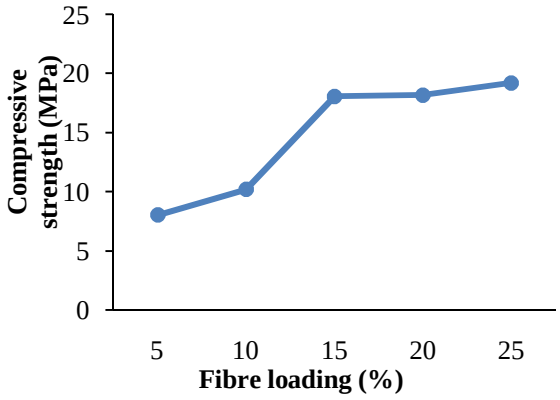
Figure 3(d) presents the results of modulus of elasticity of the produced composites. It was observed that the modulus of elasticity increased with the percentage addition of coconut fibre loading. Sample C (15 % coconut fibre and 85 % LDPE) had the highest modulus of elasticity of 442.45 MPa. The increase in modulus elasticity with increasing fibre loading is due to the inherent stiffness of the fibre which may positively contribute to the overall stiffness of the composites. This implies that the composites are stiff, as young modulus measures the stiffness of solid materials, since high young's modulus materials are considered rigid.



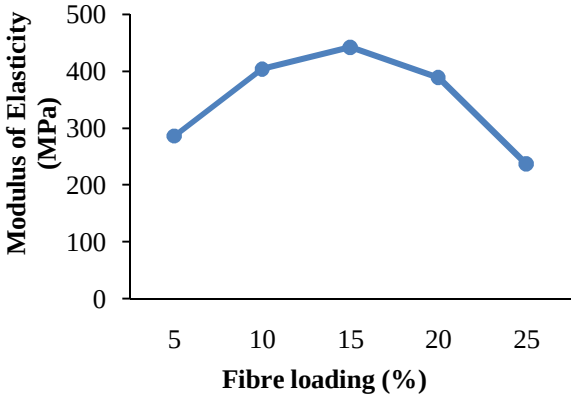
(a) Bending strength against % Fibre loading.



(b) Tensile strength against % Fibre loading.



Compressive strength against % Fibre loading.



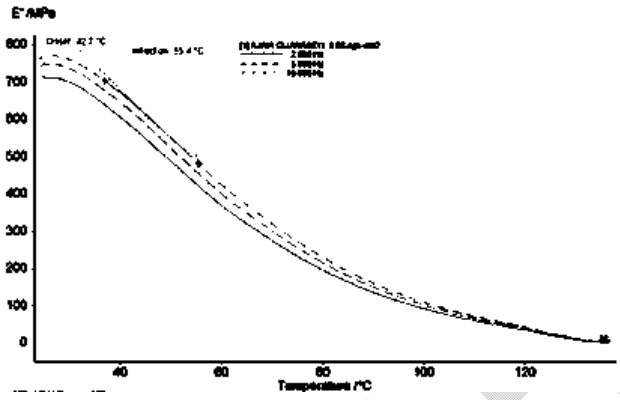
(d) Density against % Fibre loading.

(c)

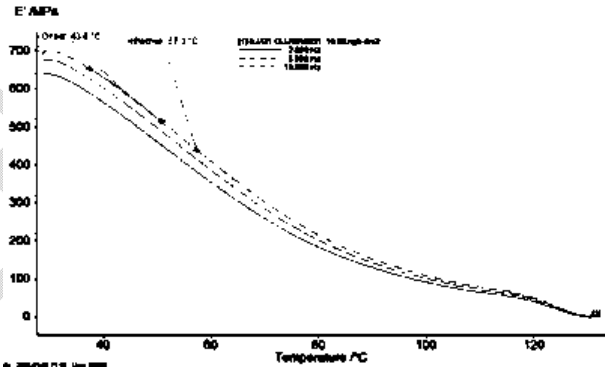
Figure 3(a-d): Mechanical properties of the Composites

3.3 Thermo mechanical properties

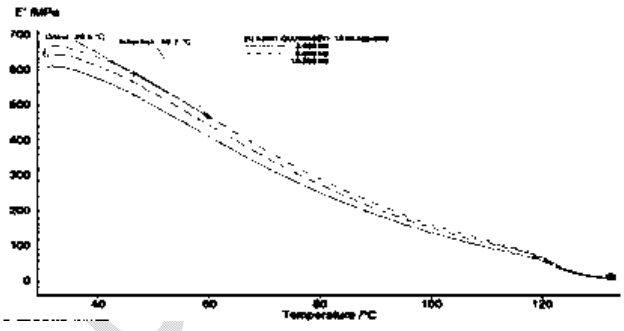
The results of thermo-mechanical properties are shown in Figures 4(a-f) to 6(a-f). Figure 4(a- e) show the variation of storage modulus (E') of the composites against temperature. Figure 3(f) shows the results for the variation of storage modulus at 100 % (control). The Samples were oscillated at varied frequencies of 2.0, 5.0, and 10.0 Hz under functional temperature. For all samples, the results show similar trends revealing that storage modulus (E') decrease with increase in temperature. This could be because of the loss in stiffness of the fibre (Gupta and Strvastava, 2016). Also, it was observed that as the oscillation frequency increased, the storage modulus also increased. This agrees with the submission of Ekhalas (2013) that the dynamic elastic characteristics are material specific depending on the frequency and the measuring condition, showing that frequency has a considerable impact on the dynamic modulus especially at high temperatures as high frequencies give high values. The peak storage modulus for Figure 4(d) Sample D gave the highest value of 859.93 MPa at a frequency of 10 Hz which was also higher than that of the control (100 % LDPE matrix, (Sample F)) which has 578 MPa. The probable reason is that the addition of fibre increased and supported mechanical constraints with recoverable viscoelastic deformation and the stiffness substantially increased with the incorporation of coconut fibre.



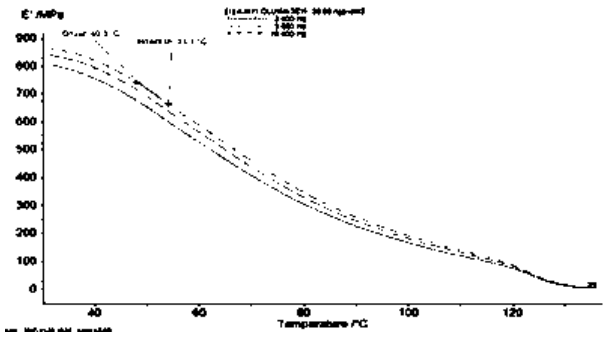
(a) Sample A (5% Coconut coir: 95% LDPE)



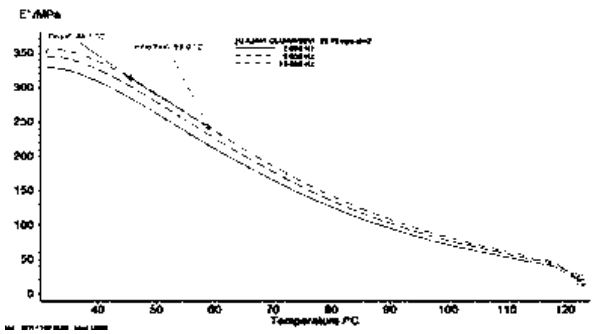
(b) Sample B (10% Coconut coir: 90% LDPE)



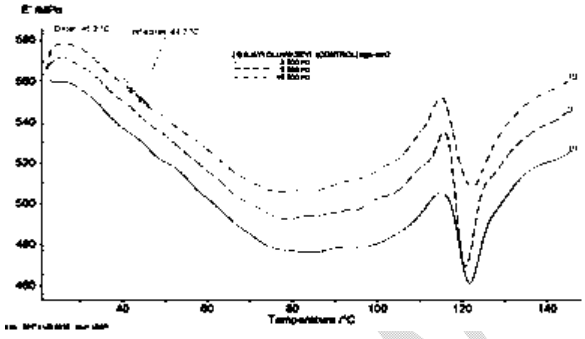
(c) Sample C (15% Coconut coir: 85% LDPE)



(d) Sample D (20% Coconut coir: 80% LDPE)



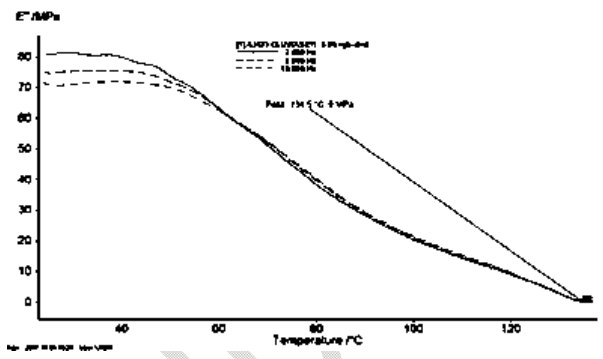
(e) Sample E (25% Coconut coir: 75% LDPE)



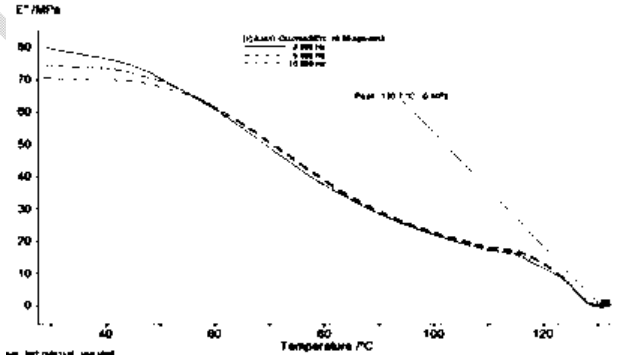
(f) Sample F (100 % LDPE)

Figure 4(a-f): Storage modulus against temperature of the Composites

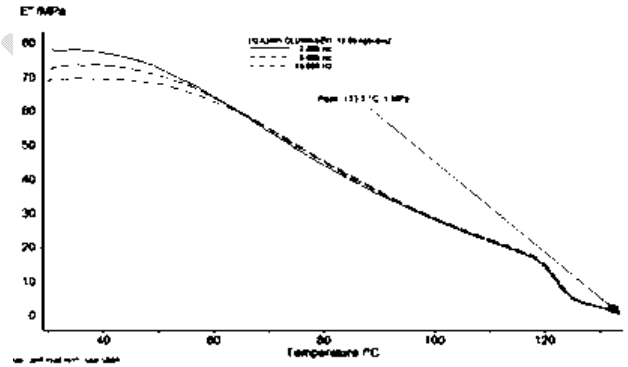
Figures 5(a-e) shows the variation of storage modulus (*E''*) of the composites against temperature, and Figure 5(f) shows the trend for the control with 100% LDPE. This is the amount of energy dissipated in form of heat by a material during one cycle of sinusoidal load. For all samples, the results show similar trends, revealing that *E''* decreases with increase in temperature. The loss modulus was observed to decrease with the addition of percentage coconut fibre loading (5 - 25 %). The glass transition temperature (T_g) known as the peak temperature, was found to increase with increasing temperatures. For Figure 5(f) for the control (100% LDPE), the maximum loss modulus was 180.187 MPa at a frequency of 2.0 Hz. For Sample A, Figure 4(a) indicated higher loss modulus for the composites as compared to the control (100% LDPE matrix).

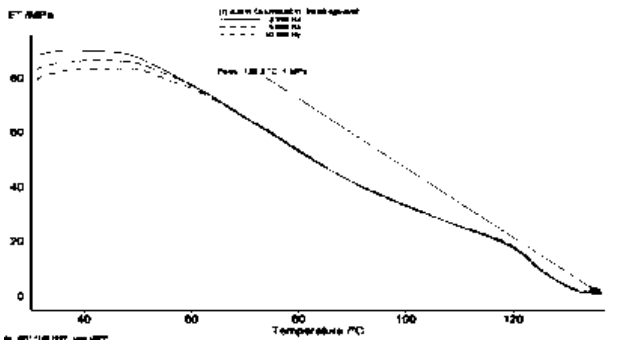


a) Sample A (5% Coconut Coir: 95% LDPE)

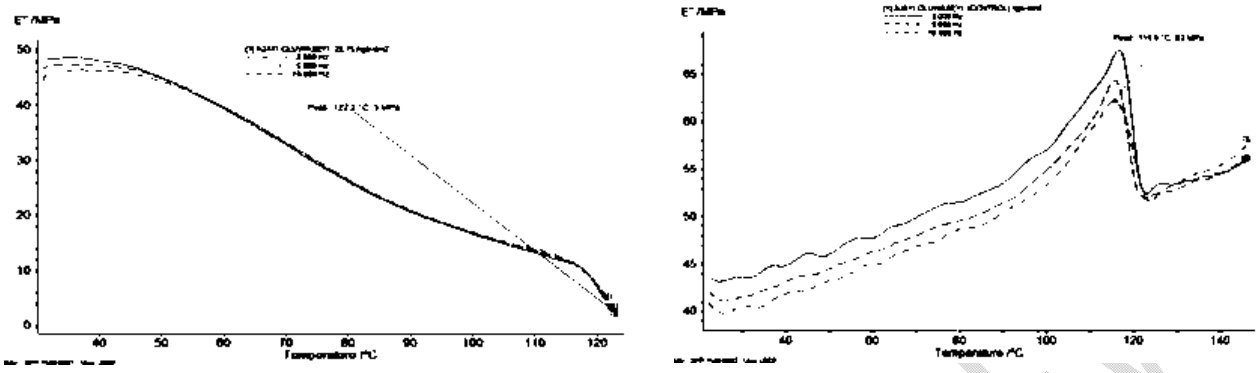


b) Sample B (10% Coconut Coir: 90% LDPE)





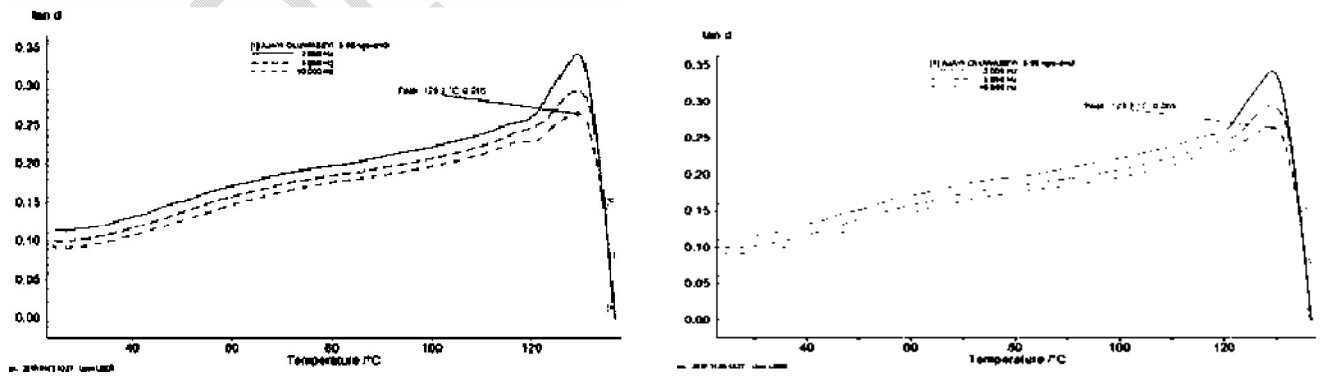
c) Sample C (15% Coconut coir: 85% LDPE) **d) Sample D (20% Coconut coir: 80% LDPE)**



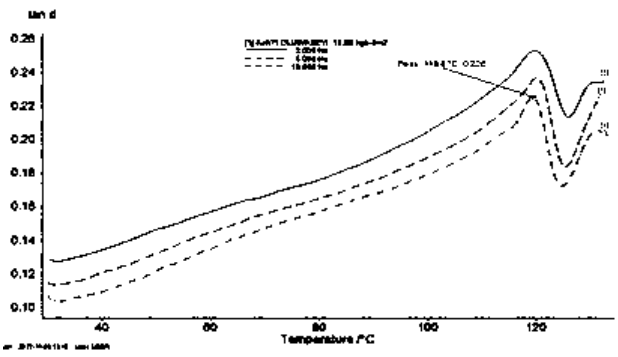
e) Sample E (25% Coconut coir: 75% LDPE) **f) Sample F (100 % LDPE)**

Figure 5(a-f): loss modulus against temperature of Samples

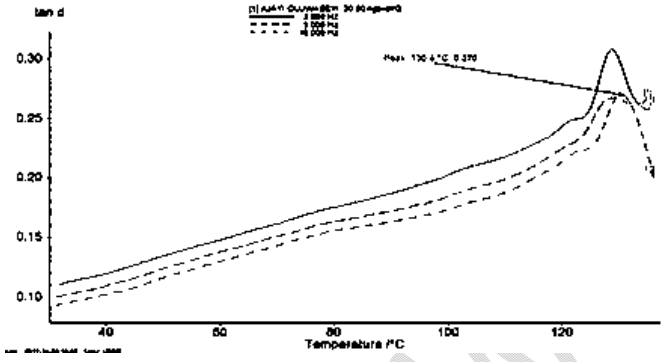
Figures 5(a-e) show the variation of damping factor (tan δ) of the composites against temperature indicating the damping parameters on the material. Figure 6(f) shows the trends for the control with 100% LDPE as a function of temperature at frequencies of 2.0, 5.0, and 10.0 Hz. This measures how the material can reject energy being tangent of the phase angle, and this indicates how good a material will be at absorbing energy. Hence, the higher the value of tan δ, the better the damping properties of the material. For all samples the results show similar trends, revealing that the damping factor increased with increasing temperature, attaining a maximum level in the transitional region and decreasing in rubbery region. The temperatures corresponds to the peak (on the curve) representing the glass transitional temperature of the composites, with the higher damping peak in the composites implying that once deformation is induced, the material will not recover to its original shape. The damping factor was below the glass transition temperature (T_g) because at this stage chain segments are in frozen states and as the temperature increases the chain segments become more mobile which results in increased damping factor. The samples with lower values will exhibit good load capacity and strong adhesion between fibres and matrix as reported by Pothan *et al*. (2010).



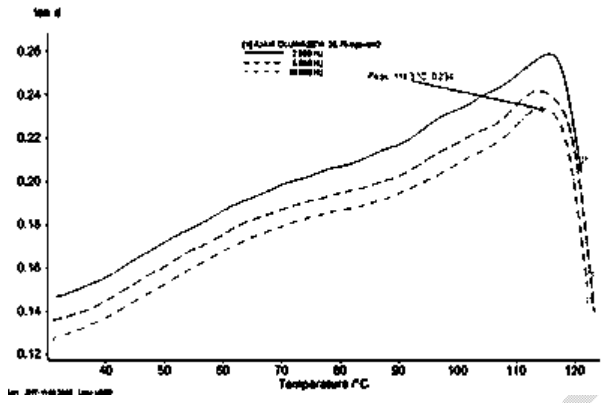
a) Sample A (5% Coconut coir: 95% LDPE) **b) Sample B (10% Coconut coir: 90% LDPE)**



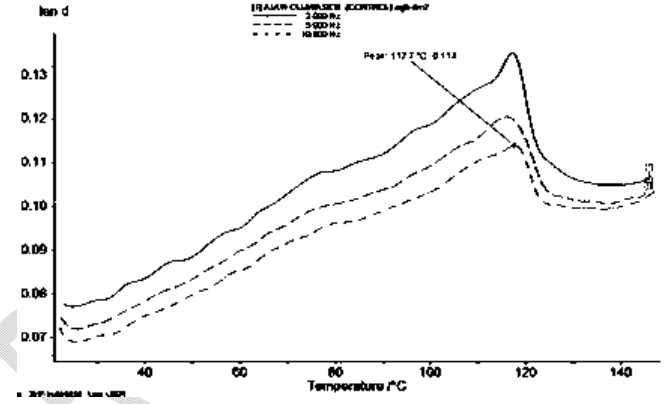
c) Sample C (15% Coconut coir: 85% LDPE)



d) Sample D (20% Coconut coir: 80% LDPE)



e) Sample E (25% Coconut coir: 75% LDPE)



f) Sample F (100 % LDPE)

Figure 6(a-f): Damping factor (tan δ) against temperature of the produced composite

4.0 CONCLUSION AND RECOMMENDATIONS

Based on the results obtained from this study, the best compositional mixture in terms of the desired properties is sample C (15 % coconut fibre and 85 % LDPE). It can be concluded that composites can be produced from recycled LDPE in various proportions. Also,

i. The composites have good physical properties (water absorption, swelling thickness, flaking concentration, and density and can be used as particleboards.

ii. The mechanical properties such as Bending strength, Tensile strength, Modulus of elasticity and compression strength of the composites produced were found to be satisfactory as these properties were in agreement with other composites produced from other natural fibres reported in literature.

iii. The thermo-mechanical/dynamic properties of the produced composites were enhanced and found to depend on volume fraction of the fibre. Addition of coconut fibre lowers tan δ (damping) peak and shifting the glass transition temperature T_g towards the positive thus indicating good fibre-matrix adhesion. The storage modulus, loss modulus and damping peaks were observed to be affected by frequency.

From the results and analysis we can conveniently recommend that composites produced from the coconut fibre and LDPE (pure water sachets) be used for particle boards and light top surfaces.

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