Investigation of Flexural and Microstructural Properties of Coir Fibre and Wood Dust Reinforced Polyester Composite

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Abstract: - Natural fibre is gradually replacing synthetic fibres for composite production because of their numerous advantages. This leads to the use of coir fibre and wood dust as reinforcement for the production of composite in this research. In this study, an investigation of the effect of the wood dust filler loading on the flexural properties and morphology of the coir fibre reinforced polyester composites was carried out. The flexural strength of the composite materials was determined in accordance with ASTM D790M standard using an INSTRON testing machine while Scanning Electron Microscope (SEM) was also used to observe the morphology. The flexural properties increased with increased filler loadings for up to 31.32 MPa at 7 wt%, above which it 81better compaction between the matrix and the reinforcement materials. From these results, it can be concluded that optimum composition of coir fibre and wood dust filler can be used to develop fibre-reinforced composites with relatively better mechanical properties that are comparable to synthetic composite. Thus, natural fibres can serve as alternative reinforcement materials for the production of composite.

Key Words: —*Polyester, Coir fibre, Wood dust, Flexural properties, Morphology*.

I. INTRODUCTION

Natural fibres such as Pineapple, oil palm and coir fibres are considered as undesirable waste in most cases, and are burnt or left to decompose on landfills. These practices contribute to environmental pollution. Therefore, in order to preserve the environment, economically feasible solutions should be provided to the increasing amount of natural fibre wastes. This can be achieved through the use of natural fibres as recyclable materials, which could be used for different applications, ranging from handicrafts to reinforcement elements for composite materials [1].

Natural fibres could be obtained from animal or plant. Natural fibre is defined as a hair-like or thread like material naturally obtained with high aspect ratio. Plants producing natural fibers can be classified as primary or secondary depending on their utilization. Primary plants are grown to produce fibre majorly such as Jute, hemp, kenaf, and sisal while in secondary plants fibres are obtained as a byproduct or waste and examples of these are Pineapple, oil palm and coir are examples of secondary plants [2]. Some examples of natural fibre which are used in composites are flax, hemp, jute, kenaf, ramie, abaca, coir, cotton, sisal etc [3].

Nowadays, the fibres from the coir fruit crust that are disposed as an unwanted waste, might be seen as a recyclable potential alternative to be used as reinforcement in polymeric matrix composite material [1]. The coir palm tree (*Cocos nucifera*) is a multifibre producing tree because fibres can be extracted from almost all part of the tree, from the leave to the fruit crust [1]. Coir (coir) fruit fibres are extracted from the husk of the fruit. The advantages of coir fibre it is plentiful and it can be obtained all year round, it has a low density, non-toxic, biodegradable, low density and highly economical. It is a renewable resource and CO_2 neutral-material. The fibre also has a high degree of water retention and is rich in micronutrients. [4]

In the past, coir has been considered as a low-quality, low-value product, with its main uses as door foot mats, coir brooms and brushes. Coir coir has outstanding resistance to sea water, and therefore has great value for marine uses (shipping and fisheries) .Coir has highly expanded In the last three decades, for the manufacture of rubberised coir products for automobiles and upholstery and subsequently as woven and knitted

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geotextiles for erosion control and as a base for binding earth on sloping lands [3].

Wood dust is obtained from natural resources and in a large amount from wood industry as a waste. Wood dust popularly known as saw dust is a by-product of wood processing which involves cutting, grinding, drilling, sanding or sawing of wood. Wood dusts are used in some poultries as beddings for birds or discarded as wastes in most cases. The use of sawdust for composite is not very common, but basically it is light, cheap, abundant and it can be added to commodity matrix in certain loading level hence offering one of the best solutions for the utilization of waste wood and cheap product [5].

Over the years, a number of plant material wastes used in composite have been studied. These include wood dusts[5] [6], ramie [7], coir [8] [1], rice husk [9], coir and cotton [10], jute and hemp [11], kenaf [12], typha [13] etc. Using these natural plant material to reinforce composite materials offers several advantages over synthetic reinforcements such as strong and rigid, light weight, environmental friendly, economical, renewable, and abundant resource [9].

Polymer used as a matrix material for these composites are generally classified into two classes, thermoplastic and thermosetting. Thermoplastic materials commonly used as matrices for this purpose are polypropylene, polyethylene, polyvinyl chloride (PVC) while phenolic, epoxy and polyester resins are the most commonly used thermosetting matrices [2].

II. MATERIALS AND METHODS

A. Materials

Matured brown coir husks (Fig. 3a) extracted from the outer shell of coir palm fruit obtained from Dagbolu coir plantation in Ikirun, Osun state, were used for the present study. The fibre extracts were processed at the Department of Science Laboratory Technology, Federal Polytechnic Offa, Kwara state. Wood dusts made from mahogany tree, were obtained from Ajegunle sawmill in Offa. The unsaturated polyester resin was purchased from local market. Other chemicals that were used are methyl ethyl ketone peroxide in dimethyl (Butanox HBO-50) as catalyst and curing agent, cobalt octanoate as accelerator and acetone as a cleaning agent. Sodium hydroxide solution (NaOH) and distilled water were used for fibre and filler treatment. A wooden mould of dimensions 125 mm x 12.7 mm x 3.2 mm was fabricated at the Kam furnitures, Offa. Other materials/equipment used are sieves, masking tape (mould release agent), scissors, stopwatch, Instron testing machine (INSTRON 3369), and electronic Balance (Scout Pro 400g, 2Hz) model.

B. Methods

Fibre Preparation:

Figure.1(a) shows the coir husks from which the coir fibres were extracted by mechanical process (i.e pounding in mortar to remove the fibres). The husks were pounded to loosen up the fibres and were removed by hand.

Chemical Treatment of Fibres and Fillers:

Production of natural fibre reinforced composites involve bringing together two materials that are incompatible because natural fibres are hydrophilic and the matrix systems may be hydrophobic. Therefore, in order to overcome this incompatibility and enhance the composite system performance, surface treatment of the fibres is done. Surface treatments of the raw natural fibres may include acetylation, biological treatments, bleaching, grafting, mercerization, oxidation, plasma treatment and scouring [14]. Composite materials made with the use of untreated plant fibres frequently exhibit unsatisfactory mechanical properties. NaOH is widely used for treatment of natural fibre by composites. This treatment changes the orientation of highly packed crystalline cellulose and forms an amorphous region by swelling the fibre cell wall. This enables improved reception to penetration by chemicals. Alkali-sensitive hydrogen bonds existing among the fibres are agitated and new hydrogen bonds form between the cellulose molecular chains, increasing the surface roughness. The treatment removes the waxy substances on the fibre surface thereby improving the close contact of the fibre–matrix [4].

The fibre and filler were soaked in NaOH to improve their properties as shown in Fig 1(b). The coir fibre was treated with sodium hydroxide in order to improve interfacial bonding between the matrix and reinforcements and hence, mechanical properties of the composite [15]. The fibres were removed and washed with distilled water and then oven dried at 110ºC as shown in Figure.1(c). The fibres were then reduced to small sizes then sieved through a mesh size of 300 µm. Fibres lengths of 10 mm and less were used for the composites. Treatment of wood dust fillers was done in a 10 % solution of NaOH. The alkali solution was added into the beaker containing wood dust and thoroughly stirred. This was kept for 3 hrs at room temperature with subsequent stirring. The wood dust fillers were then washed thoroughly with distilled water to remove the excess NaOH sticking to the fillers and then dried in an oven at 110ºC for 8 hrs. Figure.1 (d) shows the oven dried wood dust

fillers, which were then sieved through a sieve size of 0.8 mm size as shown in Figure.1(e).

Fig.1. Coir Fibre And Wood Dust Processing, Showing (A) Coir Husk (B) Coir Fibre In 5% Naoh Solution (C) The Oven Dried Fibre (D) The Oven Dried Wood Dust (E) The Sieved Wood Dust.

Mould Preparation:

Mould of dimensions 125 mm x 12.7 mm x 3.2 mm (Figure 2a) was fabricated with hard wood and used to cast the flexural test specimens and other specimen for microscopic examination. The mould was lined with masking tape for easy removal of the cast composite specimen after curing. The dimension of the flexural test specimens is shown in Figure.2b.

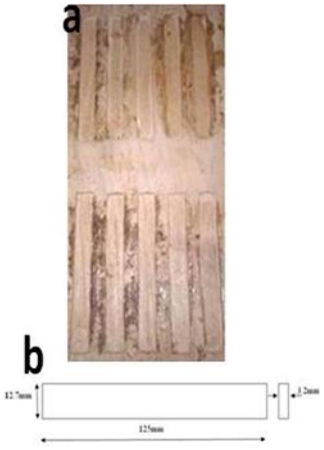

Fig.2. Flexural test and microscope examination specimens (a) Wooden mould (b) Dimensions.

Preparation of the Composites:

The treated coir fibre and wood dust particles were weighed using the electronic balance before mixing with weighed polyester matrix. Mixing of the composite components was thoroughly done manually. The reinforcement components were mixed with the polyester at room temperature and stirred continuously for some minutes until homogenous mixture was observed. 2% by weight of the polyester catalyst (MEKP) was added with syringe and stirred continuously for 3 minutes to cure the composites. 1% by weight of polyester accelerator; cobalt octanoate, was added to speed up the reaction and stirred for 3 minutes. The prepared mixture was poured into the mould and allowed to cure for an hour. Mixing ratio of composites was done based on literatures and past work. Total weight produced for each of the composites mixture is 100 g. Polyester, P, alone was mixed with 2 wt % of MEKP and 1 wt % of accelerator and then allowed to cure. This was done to compare the mechanical properties of the unreinforced polyester with those of the composites. Composite C10 serves as control sample and it is reinforced with 10% coir fibre only as presented in Table.1.

After the composites were produced, they were left in an open air for 24 h for total curing and optimum strength. Figures 3(a&b) show samples of the unreinforced and reinforced polyester matrix composites after curing for 24 h at room temperature. The composites were reduced to the required dimensions prior to mechanical testing after curing.

Table.1. Composition of prepared coir fibre-sawdust-polyester composite

Specimen Designation*	**% of coir fibre (g)**	**% of saw dust (g)**	**% of USP (g)**
P	-	-	100
C10	10	-	90
C10S1	10	1	89
C10S3	10	3	87
C10S5	10	5	85
C10S7	10	7	83
C10S10	10	10	80
C10S12	10	12	78
C10S15	10	15	75

*P- Polyester, C- Coir fibre dust, S- Wood dust, USP- Unsaturated Polyester Resin.

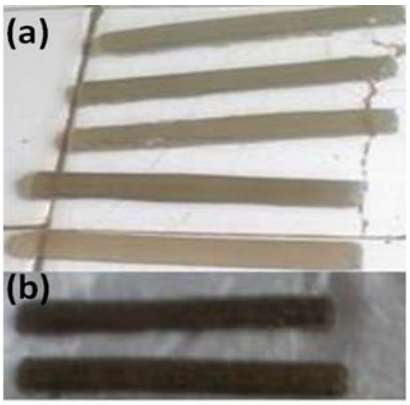

Fig.3. Test specimens showing (a) cured polyester (b) cured composites

Flexural Test:

Flexural strength, also known as the modulus of rupture, bend strength, or fracture strength is defined as the ability of the material to resist deformation under load. The test was carried out at the Department of Materials Science and Engineering laboratory, Kwara State University (KWASU). The maximum load and modulus of the composite materials was determined by subjecting the specimens to load under a three-point bending set in accordance with ASTM D790M standard using an INSTRON testing machine as shown in Figure.4. The machine applied a progressively increasing load on the composite at a constant rate of 20 N/min until it fractured. As the load increases, the load and compressive stress readings were taken. Flexural strength, S, of the test specimen was calculated using the Equation 1[16]:

$$S = 3fl/2bd^2 \quad (1)$$

Where f is the maximum load at the fracture point, l is the distance between the supports, b is the width of the sample and d is the thickness of the sample.

Fig.4. Composite under Flexural Testing Using Instron Machine.

Scanning Electron Microscopy (SEM):

Scanning Electron Microscopy (SEM) analyses were conducted with ASPEX 3020 SEM at Material Science and Engineering Laboratory at KWASU. The morphology of the fractured surface of composites C10, C10S1, C10S7 and C10S12 were analyzed and images were taken.

III. Results And Discussion

A. Flexural Properties of the Composites

The maximum load and modulus of the composite samples of different composition are presented in Table.2. The mean flexural strengths were calculated from the specimen width of 12.7 mm, thickness of 5 mm and the distance between the supports as 100 mm using Equation 1 and the results are given in figure 6. This figure shows the effect of filler loading on the flexural strength of the composites. Composite C10 has a flexural strength of 20.85 MPa which reduced drastically on addition of 1 wt % wood dust, that is, sample C10S1, to 15.40 MPa. The decrease in strength may be due to the non-uniform alignment between fibres and filler particles. There was a gradual increase in strength with increase in filler weight until it peaked at 31.32 MPa for sample with 7 wt % wood dust loading, C10S7. Above 7 wt% filler loading, the flexural strengths started to decline possibly due to the increase of viscosity in the matrix and in turn the increase in porosity and decrease in the wettability of the composites [12]. The presence of fibres or particles increases the effective toughness of a low-toughness matrix by slowing up of cracks in the neighbourhood of the filler [17]. It is possible that there is a good bonding between fibres and particle in composite C10S7 better than other composites. Further addition of wood dust made composites decrease in flexural strength.

Table.2. Flexural strength result (MPa) for the composites.

Composites	**Max. Load (N)**	**Comp. Stress at Max. Load**	**Flexural Strength (MPa)**
P100	114.61	0.076	18.05
C10	132.39	0.888	20.85
C10S1	97.82	0.065	15.40
C10S3	113.91	0.076	17.94
C10S5	118.78	0.079	18.71
C10S7	198.89	0.133	31.32
C10S10	148.33	0.099	23.36

C10S12	137.23	0.091	21.61
C10S15	132.92	0.089	20.93

As the force acts vertically downwards on the specimens, crack propagates and is effectively halted by the fibres. This may be due to the inhibition of the opening of the matrix crack by the fibres. In addition, the strength and stiffness of the fibres are high enough to permit it of being broken by the level of stress concentrated at the tip of the matrix crack. As further crack opening occurs, local shearing force acting at the fibre/matrix interface was sufficiently higher than the strength of the fibres, thereby making the fibres to be debonded. Debonding occurs when there is a significant level of transverse tensile stress concentration ahead of the crack tip, parallel with the crack plane as shown in the work of Cook and Gordon as reported by Harris [17].

Cook and Gordon demonstrated in their work that toughness in fibre reinforced materials is associated with the arrest of cracks made possible by presence of numerous weak interfaces. As these interfaces open, so secondary cracks are initiated at right angles to the primary, thereby dissipating the energy of the original [17]. Debonded fibre extends elastically and further crack opening persists and fracture occurs. The results also showed that the flexural strength was enhanced at higher fibre and filler content. Figure.5. shows a comparison between the graph of tensile and flexural strength results. Results are not similar because the composite produced is not a homogenous material.

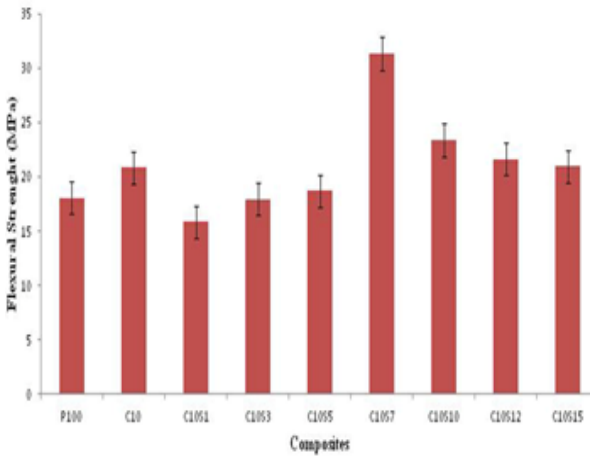

Fig.5. Flexural strength of the composite samples

B. Surface Morphology of the Composites.

Scanning electron microscope (SEM) was used to study the surface morphology of the composites and it revealed the miscibility of the matrix and reinforcements. That is, the results show the homogeneity or otherwise of the composite samples. The fractured surface of the specimens from tensile tests specimens were also observed using SEM. These results are shown in Fig.6. And 7. The hybrid composite is a non-homogeneous material because the stiffness in the direction parallel to the fibres is higher than in the direction perpendicular to the fibres and thus the properties are not independent of the direction. This makes the composite material anisotropic. An anisotropic material is a material property with different properties in all directions [18]. The addition of fillers in the polymer composites has been found to improve the mechanical properties, especially stiffness or moduli of the composites [12]. Fig.6 (a) shows the SEM micrographs of the fractured surface of composite C10. The dark phases are the voids of the fibres pulled out and surrounding the fibres is the polyester phase, which holds the fibres in place. The fibres are the white strands pulled out as a result of the fracture. It is evident from the micrographs that the composite samples were non-uniform and non-homogeneous, as the fibres tend to cluster at a point. In addition, sizes of fibres vary slightly in diameter and length as lengths used where10 mm and below. It is also evident that fibres are not aligned i.e they all exist in the composite in different directions. This is because there was no particular pattern of arrangement of fibres.

Figure.6 (b). shows the SEM micrograph of the fractured surface of C10S1. Composites produced are hybrid of discontinuous fibre and particulate composite except the control C10 which is of a single reinforcement. It can be seen from the graph that better compaction is achieved as compared to C10. This can be attributed to the incorporation of wood dust. It can be seen that the fibres are detached from the polyester matrix surface due to poor interfacial bonding, with some voids formed on the matrix surface due to fibre pull out. These analyses are in agreement with the results of Harish *et al.*, where they developed and compared the mechanical properties of a coir/epoxy composite with that of glass fibre/epoxy. Their SEM results show that there was better matrix-fibre bonding in the GFRP specimens than the coir/epoxy because the glass fibres were stronger than the coir fibres [19].

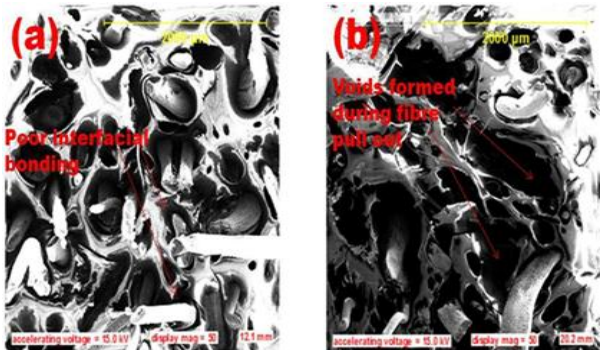

Figure.6. SEM Micrographs of Composites, Showing (A) C10 and (B) C10S1.

Fig.7 (a). shows the SEM micrograph of the fractured surface of C10S7. It can be seen from the graph that better compaction between phases is achieved as voids of fibre pull out are smaller, compared with composites C10 and C10S1. This can be attributed to the presence of large amount of wood dust particles strengthen the interface of resin matrix and filler materials with the coir fibres. It can also be deduced that the wood dust has a good absorbent property because of its hydrophilic nature. The wood dust is well absorbed in the polyester phase making the composite stiffer and stronger. It can be deduced that, the more the wood dust the better the compaction which brings about better stiffness, strength and flexibility. However, above 12 wt % addition of wood dust, the increase in the wood dust may result in poor adhesion and bonding of the matrix and reinforcements. This is observed in composite C10S15, which displayed low strength and stiffness after compaction. All the hybrid composites developed are heterogeneous materials because they have non-uniform pattern of reinforcement arrangements. Figure.7. (b) shows the SEM micrographs of the fractured surface of C10S12. It can be seen in Fig.7(b) shows that fibres have cracked at different levels, which indicate that during fibre pull some certain amount of energy have been absorbed [19].

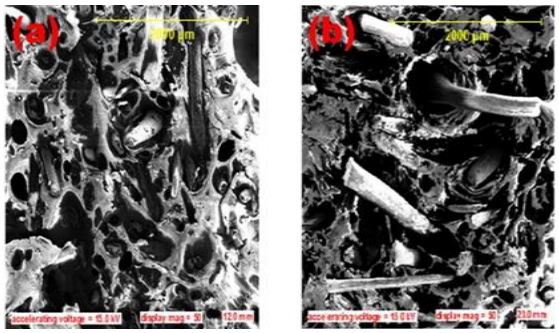

Fig.7. SEM Micrographs of Composites, showing (a) C10S7 and (b) C10S12

IV. CONCLUSIONS

The following conclusions can be drawn from the results of this research:

- Coir fibre and mahogany wood dust reinforced polyester hybrid composite were successfully produced by casting method.
- The addition of fillers (wood dust) in the polymer composites has been found to improve the mechanical properties of the composites
- The flexural strengths of the composite increases with increasing percentage of the wood dust particles and decreases above 7 wt % of wood dust.
- The better strengthening effect of the wood dust can be attributed to the better interfacial bond between the reinforcements and polyester matrix as revealed from the SEM studies.
- The composite produced can find its applications in low strength building materials (e.g ceilings, doors, kitchen slabs, etc), car parts (e.g bumpers, dashboards, car bodies etc), etc.

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