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Exploration of Green Composites of Oil Palm Frond for Low Strength-Moderate Flexure Building Applications

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Abstract:
The exploration of new materials with comparative performance at affordable costs facilitated the outcome of emerging innovative products of green composite materials. In the current work, natural oil palm frond fibres were used in long and random fiber form as reinforcement in polyester matrix to fabricate green composites using the hand layup technique. Some mechanical, physical and processing property tests were conducted to elucidate the utilization potentials of green composites of oil palm frond fibre in the building industry. In overall, the results showed that the tensile strength and impact strength properties decreased with the increase in fibre loading. The modulus of elasticity increased with the increase in fibre loading up to 60wt. % before dropping. The values of both the flexural strength properties and modulus of rigidity increased with the increase in fibre loading. Even though the fibres were used without surface treatment in this work, the result of respective values of 0.07, 4.27% and 2.08 for the mould linear shrinkage, porosity and specific gravity, including a low water absorption uptake of 6.98%, propounds an indication that green composites of oil palm frond could be acceptable in areas of low strength and moderate flexure applications in the building industry**.**

Keywords: oil palm frond, green composites, low strength-moderate flexure properties

Introduction

Numerous kinds of materials are being developed for use in packaging, building and automobile industries. The growth of natural fibre reinforced composite-based products as alternatives to traditional engineering materials has given rise to various processing methods and ways of protecting the natural fibres from microbial attack and moisture ingress. Particularly attractive are the natural renewable resource materials from the oil palm family. These biodegradable materials of chemical, mechanical and environmental characteristics are in plenty at the tropics, and have been in use for many applications.

Of recent, the exploration of new materials has seemingly facilitated the outcome of emerging innovative products of green composite materials. Some of these research efforts are reported to be progressing in the development of new class of fully biodegradable green composites with emphasis on eco-friendliness and sustainability, culminating into the effective utilization of green composites in various applications such as mass-produced consumer products with short life cycles or products intended for one time or short time use before disposal [1].

In general, oil palm tree fruits and allied parts are presently processed for the pharmaceutical and allied industries, but the fronds are regarded as wastes, often generated from pruning the oil palm trees are sometimes used for making ropes, baskets, etc., could be utilized for the production of fibres for industrial cost-efficient utilization, especially for the production of low strength to moderate flexure applications. Ramli and Suffain [2] reported the oil palm industries produce crude palm oil as their main product, in addition to generating a huge amount of biomass in the form of trunks, fronds and empty fruit bunches, of

which at present, only a small percentage of this is used for dumping at plantation sites or processed to produce fibres for mattress, mulching and mat.
Abdul Khalil et al. [3] reported that oil palm fronds accounts for 70% of the total oil palm biomass produced in Malaysia, while the empty fruit bunch accounts for 10% and oil palm trunk accounts for only about 5% of the total biomass produced, just as the 89% of the total oil palm biomass produced annually was used as fuel, mulch and fertilizer, yet enough research work have not been concentrated on the more effective use of oil palm frond.
Studies show that oil palm frond fibres are known to elongate substantially when subjected to tensile stress. This leads to a high strain value and high load bearing ability. When compared with other natural plants, oil palm frond fibres are tough, and generally exhibit moderate degrees of elasticity and plasticity [4], additionally, oil palm stem and frond fibres are noted to contain large amount of lignin, with very porous and lacuna-like cross-section with varying diameters, which affect their mechanical properties, such as high ductility, but with lower tensile strength than most other natural plant fibres.
Recent studies indicate that oil palm industries continually attempt to increase the sustainability of palm oil value chain by utilizing all co-products, including the issues of life cycle greenhouse emissions of furniture and bioenergy production from oil palm trunks [5]. The utilization of oil palm frond fibre in composite production for other applications will no doubt compliment the value chain realization goal.
The general drawback with the use of natural fibres in some structural applications was nevertheless, linked to poor fibre-matrix interface and the inability to transfer stress from the matrix to the fibre, which were noted to be as a result of poor compatibility between the fibres and the matrix. These often lead to micro-cracking of the composite and degradation of mechanical properties. Others issues were related to the high moisture absorption of the natural fibres that result in swelling of the fibres and concerns on the dimensional stability of composites of natural fibres as reinforcements in polymer matrix. For example, findings show that moisture update is high (12.5%) at 65% relative humidity and 20%, by dry fibre and 14.6% by wet fibre when natural fibres are used as reinforcements in polymer matrix [6]. Although Rowell et al. [7] reported that effective surface treatment of natural fibres reduces feathering which protects the fibres from breakdown due to oxidation and consequent increased strength of the reinforced composite, the difficulty to entirely eliminate the absorption of moisture without using surface barriers on the composite surface seems to give a relief to a total elimination such surface treatment that often come with additional material and processing costs.
Even with the disadvantage of hydrophilic nature of most natural fibres, Sreekala and Thomas [8] reported that oil palm have proved to be excellent reinforcement in polymers. Other issues included the improved wetting at the fibre-matrix interface, which similarly resulted in improved mechanical properties of composites [9]. Accordingly, increasing the volume of matrix to improve fibre-matrix interface wetting, rather than fibre surface modification, can still achieve improved mechanical properties of natural fibre composites.
Additionally, the works of Rowell et al. [10] gave a promising insight on the use of natural fibres as a viable alternative to inorganic-based reinforcing fibers in commodity fiber-thermoplastic composite application as long as the right processing conditions are used and for applications where higher water absorption may not be desirable, such as in some automobile, building and packaging industrial applications.
Considering the historical background of concern with micro-biological and measure for protection against natural fibre deterioration is the story of man and the sea, for which the Marine transportation and commercial fishing industries used large amounts of cordage under conditions that favor micro-biological deterioration, it does seem therefore that, the protection of fishing nets and marine cordage which was sought by dipping in hot pine tar and tan black liquors, could be regarded as similar to the use of resin matrix for the protection of plant natural fibres in composite production. Since the tars seemed effective because their ingredients were toxic to microbial growth, and the coating of tar around the fibre shield then somewhat from moisture penetration, thereby retarding microbial growth, the use of resin could be taken as performing similar functions.
On the issues of flexural strength properties of composites of oil palm frond fibre decreasing with increasing fibre content, Anyakora et al. [11] reported that untreated fibre composites exhibited virtually no change with increasing fibre content, in addition to the non-correlation coefficient values between the untreated and treated oil palm frond fibre composites.

Interestingly, Abdul Khalil et al. [12] worked on the chemical composition, morphological characteristics, and cell wall structure of Malaysian oil palm fibers and reported that oil palm trunk fiber exhibited the highest content of extractives and lignin, high fiber length, diameter, and cell wall thickness.

The findings of Ahmad et al. [13] on the effect of surface treatment and fibre loading on the mechanical properties of oil palm fibres showed that compressive, tensile and flexural strength properties of concrete improved with the addition of 1% oil palm trunk fibre as crack arrester at low dosage, in addition to improved resistance against NaOH and NaCl attack of the composites. Interestingly, Anyakora [14] reported that there is a correlation between ash content and tensile properties of oil palm frond fibre composites. Anyakora and Abubakre [15] reported that flexural strength properties of composites of treated oil palm frond fiber decreased with increasing fiber content at 10% fiber content to 70% fiber content, unlike the untreated fibre composites, which exhibited virtually no change with increasing fiber content.

Syamani et al. [16] reported that cellulose fibers from oil palm fronds reinforced polylactic acid composite showed that the addition of pulp fibers improved the Young modulus of PLA composite. Similarly, Anyakora [17] reported that fibre content and surface treatment do not lead to improved impact strength properties of oil palm frond composite panels.

Issues of utilization of oil palm trunk for the production of new palm wood material using phenol formaldehyde resin as a matrix are abound. Although the kiln-dried oil palm trunk was impregnated in resin using a high power vacuum pump, without necessarily modifying the surface chemically, and still achieved improved mechanical properties and physical properties [18], it then suggests that the use of green oil palm fibre in composite production can still be adopted in other similar and comparable areas of low strength and moderate flexure application.

Although new challenges seem to thrive, enormous opportunities exist for eco-friendly green composites; these include the recyclability of the composites that will lead to the cost-effective products, and the remedying of increasing amount of waste materials in the environment.

A cursory look at most researches on oil palm plant showed that emphasis had been on the empty fruit bunch, little effort was made nevertheless, to explore the frond component of the oil palm tree that is often generated more in the environment, but regarded as wastes. From the findings of other researches therefore, it was obvious that surface treatment of oil palm fibres before use as reinforcement in composite structures, entailed additional material and processing costs, which may not be necessary at areas of low mechanical strength property applications. Traditionally, the dipping in hot of pine tar of fishing nets for protection from microbial growth and moisture penetration contributed largely in the quest for alternative use of fibre treatment process in composite utilization, of which the process of embedding oil palm frond fibre in polyester matrix is analogous. It is noted, nevertheless, that the extra-cost relation in the surface treatment of oil palm frond fibre for composite production could be avoided, especially for the low strength to moderate flexure applications in the building industry.

The current efforts are therefore, geared towards exploiting the potentials of mechanical and physical properties of oil palm frond fibre wastes as raw material for the building industry. The quest will no doubt, provide meaningful employment to the local people where oil palm trees are often found, create wealth, and offer solution to environmental problems associated with improper disposal of agricultural wastes, and most importantly, to ensure that these fast depleting non-renewable resources are preserved. Additionally, the findings will justify the exploration of material cost savings arising from the use of relatively low cost oil palm frond fibre to create the non-food agricultural based economy, low energy consumption which cannot be easily ignored in engineering research and development.

2. Materials and Methods

2.1 Materials

Oil palm frond of average diameter of 0.58mm and length of 36.90mm were extracted from mature plants of three to five years, collected from Nigerian Institute for Oil Palm Research (NIFOR) and Umuahia Forestry Department. These plants were collected, with emphasis on trees that have fruited, but felled and used within two weeks. These extracts were processed at the Pulp and Paper section of Federal Institute for Industrial Research, (FIIRO) Oshodi, Lagos, Nigeria into tangled mass.

The Polymer used was Siropol 7440 un-saturated polyester resin (specific gravity of 1.04, viscosity of 0.24 Pa.s at 25^{o}C), 1% cobalt in styrene and Bisphenol-A diglycidylether, procured from Dickson Chemicals Ltd, Lagos, Nigeria.

A two-part mould facility (mild steel flat 4mm thick sheet) - of 150mm x 150mm with active surfaces ground, pre-designed cavity of 5mm depth, with clamping bolts in place, fabricated at the Dantata & Sawoe Mechanical Workshop, Abuja, Nigeria, was adopted in the production of test specimen plates.

Other equipment used were Universal Testing Machine, Instron, Model 3369, Compact Scale (Model – FEJ, Capacity - 1500g, 1500A).

2.2 Method

2.2.1 Extraction of fibre from the plant

The frond fibres of oil palm were processed by chemico-mechanical process which involved the preparation of sample for chemical analysis through impregnation of the sample with White Liquor (563.52g.wt of NaOH + 281.76g.wt of Na_2S measured in 12 liters of water) at 30% sulphidity and Total Active Alkali of 845.28), and later softened by mechanical action. Further washing, screening and drying of resulting fibre, and subsequent determination of fibre yield was carried-out.
The fibres bundles were separated and re-washed before drying in a forced-air circulation type oven operated at 50^{o}C. The fibres were weighed and percentage yield determined. These extracted oil palm frond fibre was subsequently fluffed for 1 minute and put into tangle mass bulk for composite production.

2.2.2 Processing of matrix

The unsaturated polyester resin was mixed with 1% cobalt in styrene and Bisphenol-A diglycidylether at varying volumes to establish the earliest cure times for the various percentage fibre content (10%, 20%, 30%, 40%, 50%, 60% and 70% by weight) in the composite. Subsequently, polyester mix was prepared using 100 ml of unsaturated polyester resin and 1 ml of accelerator plus 1 ml of hardener (which was previously determined to the best curing needed for the fibres). The polyester mix was weighed on calibrated compact scale.

2.2.3 Preparation of mould facility

A two-part mould system of dimensions 150mm x 150mm, was adopted in the production of test specimen plates.

2.2.4 Production of test specimen

The production of test specimen panels was carried out in compliance with the relevant test standard for reinforced plastics - BS ISO 1268-3:2000 using the method by Anyakora [17]. Recorded weights of fibres were manually placed in the mould facility already prepared while ensuring that no material was lost in the process. Since the fibres are of tangled mass, arrangement of angle did not have a preferred orientation, thus, the composites were considered as randomly oriented.

Using the known 10% to 70% by weight of the green fibres, corresponding 90% to 30% by weight of the matrix system sets were prepared. The polyester resin mix was poured into the mould cavity containing tangled fibre mass fully laid in the cavity cleaned and pre-placed with aluminum foil. The top mould was subsequently placed and clamping bolts fully secured. The mould containing the un-cured composite was placed in an oven operated at 110^{o}C, and removed after 30 minutes, and allowed to cool to room temperature before placing in humidity controlled bag.

2.2.5 Characterization of green composites of oil palm frond fibre

The samples of composites produced with green oil palm frond fibre of 10%, 20%, 30%, 40%, 50%, 60% and 70%, by weight, were employed for mechanical property tests according to the British Standard for the determination of respective mechanical property of fibre reinforced composites.

Tensile strength

The test specimens were cut from stock to dimensions of 50mm x 10mm x 5mm. Using a universal testing machine of 10KN capacity operated at a crosshead speed of 5 mm/min, the determination of tensile strength parameters was conducted following the BS 2782: Part 3, 1977. The tensile modulus was determined using the ratio of tensile stress to the strain of the respective green composites of oil palm frond.

(b) Flexural strength

Composite plates were cut into specimens of dimensions 122 mm x 25 mm x 5 mm thick. Using the Three-Point loading technique in compliance with BS2782 - 10, Method 1005 of 1997 for the determination of flexural properties of green composites of oil palm frond fibre. The flexural modulus was determined by calculation.

(c) Izod impact test

The Impact test analysis was commenced with the notched specimens cut into dimensions of 200 mm × 200 mm × 5 mm for which the support displacement of machine was 240 mm.

2.2.6 Determination of some physical and processing properties of green composites of oil palm frond fibre

(A) Mould linear shrinkage test

This test was carried out as an expression of percent change in dimension of specimen in relation to mould dimensions. The length of mould cavity was measured with the corresponding length of test specimen after it had cooled and mould shrinkage was evaluated.

(B) Porosity test

The boiling point method was used to evaluate the volume of the open pores, into which a liquid can penetrate as a percentage of the total volume.

During the test, three identical test pieces of dimensions 100mm x 150mm x 5mm each, of the samples were prepared. Each of the test pieces of three identical specimens for each type of fibre-matrix sample was placed in an oven operated at 110^oC for 30 minutes; the second test piece was submerged in distilled water for 2 hours and then removed. Their weights were taken after those processes, and applied for the evaluation of apparent porosity of the sample using the expression in Eq. (1).

$$AP\left(\%\right)=\frac{\left(W-D\right)100}{W-A} \qquad (1)$$

Where AP = apparent porosity of the sample, W= weight specimen in air, D = weight of specimen dried in oven at 110^oC and A = weight of specimen submerged in water.

(c) Specific gravity test

Standard test pieces of dimensions of 100 mm x 150 mm x 5 mm were cut with hacksaw, and subsequently weighed, and later immersed in water contained in plastic container. The data collected were used in the evaluation of specific gravity.

(d) Water absorption test

The percent increase in weight of each material was evaluated after exposure in water. The exposed test pieces of dimensions 100mm x 100mm x 5 mm were dried and cooled and the initial weights recorded. Three identical specimens for each type of fibre-matrix sample separately were soaked in distilled water at a temperature of 23^oC. They were removed from the soak after 24 hours, weighed and final weight recorded. The percentage water absorbed by the specimens was evaluated using the expression in Eq. (2).

$$W_A\left(\%\right)=\frac{\left(W_2-W_1\right)100}{W_1} \qquad (2)$$

Where W_A = % water absorption, W_1 initial weight of specimen and W_2 = final weight of specimen.

Results and Discussion

3.1 Characterization of green oil palm frond fibres

Table 1 shows the results obtained from an average of three readings from sample tests of green (untreated) oil palm frond.

Table 1: Result of experimental investigation of properties of green (untreated) oil palm frond fibres

Fibre	*Density (g/cm^3)*	*Moisture Content (wt%)*	*Diameter (mm)*	*Length (mm)*	*Stress at Break Point (N/mm^2)*	*Energy at Break Point (N.m)*	*Young's Modulus (N/mm^2)*
Green (untreated) oil palm frond	1.31	27.09	0.58	36.90	0.68	0.38	43.66

From table 1, it is evident that the long fibre lengths oil palm frond exhibited high values of Young's Modulus and high energy at break point. These results show that the adoption of oil palm frond fibre can be very useful in composite production especially in the areas of low-to-medium strength automobile part manufacture subsists, without further surface treatment process.

3.2 Effect of fiber loading on some properties of green composites of oil palm frond fibre

3.2.1 Tensile strength properties

Figures 1 and 2 illustrate the tensile strength behavior and modulus of elasticity (MOE) of green composites of oil palm frond fibre at various fibre loadings as reported in the works of Anyakora [14].

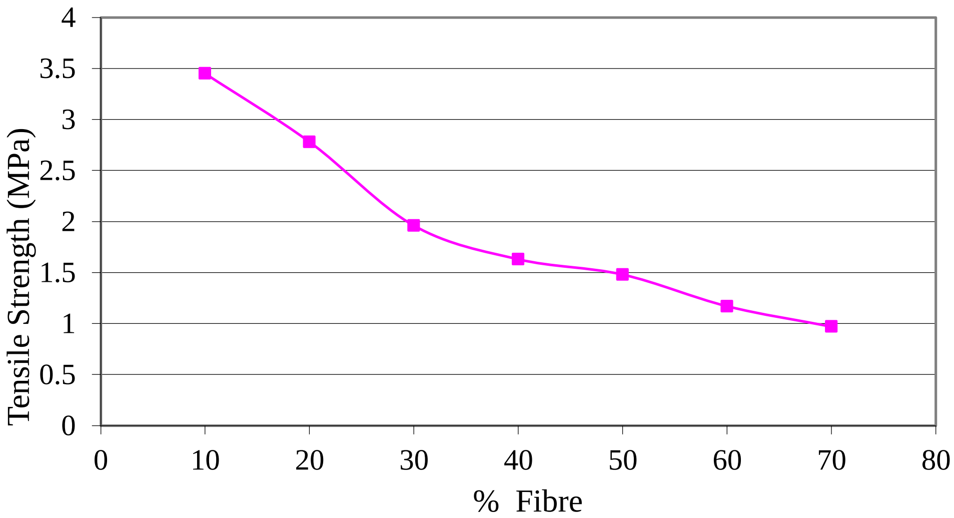

Figure 1: Tensile strength of green composites of oil palm frond fibre at different fibre loading

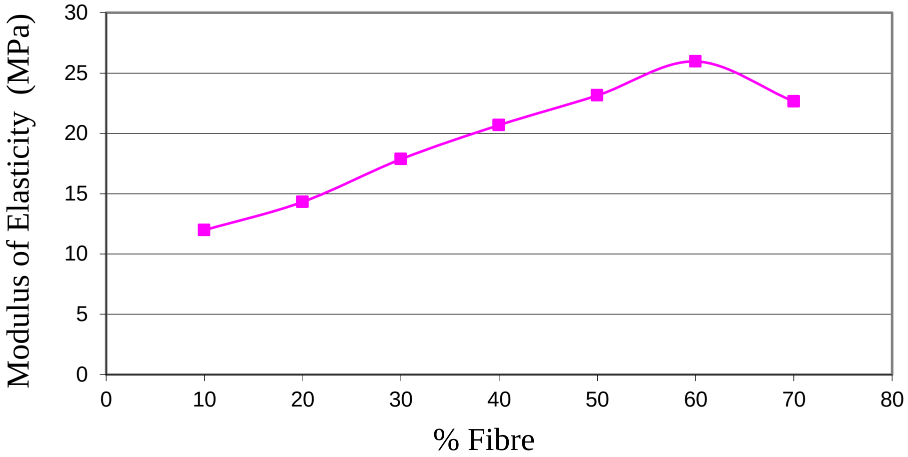

Figure 2: Modulus of elasticity of green composites of oil palm frond fibre at different fibre loading

From figure 1, it can be observed that the tensile strength properties of green composite oil palm decreased with increasing fibre loading. Similarly, the MOE increased with increased fibre loading till 60wt. % fibre content before dropping. As expected, the low tensile properties could be attributed to the random orientation of the oil palm fbres, and to the poor interfacial interaction arising from poor compatibility between the polar natural fibres and non-polar matrix, which resulted in reduction of effective stress transfer from matrix to reinforcing fibres.

3.2.2 Flexural strength properties

Figures 3 and 4 illustrate the flexural strength behavior and modulus of rigidity (MOR) of green composites of oil palm frond fibre at various fibre loadings, as reported by Anyakora et al. [12].

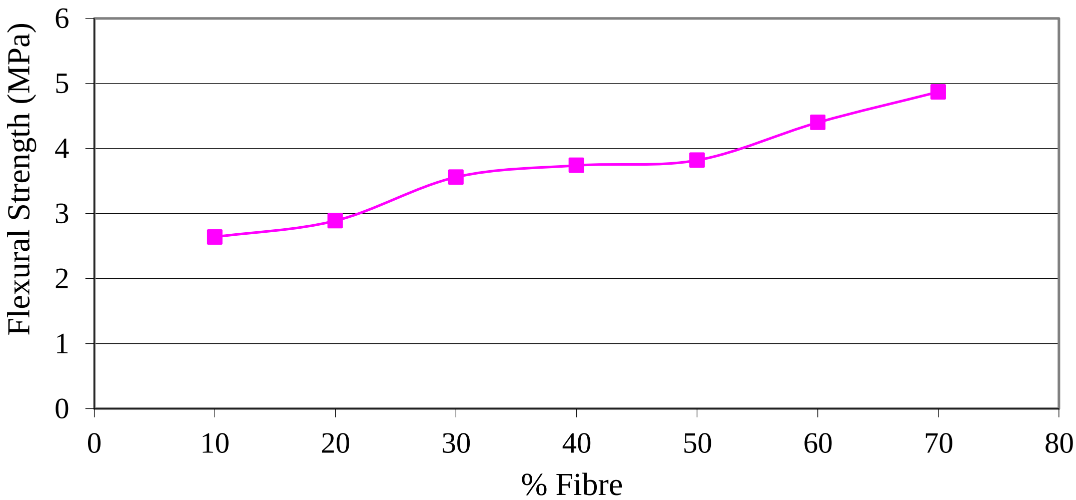

Figure 3: Flexural strength of green composites of oil palm frond fibre at different fibre loading

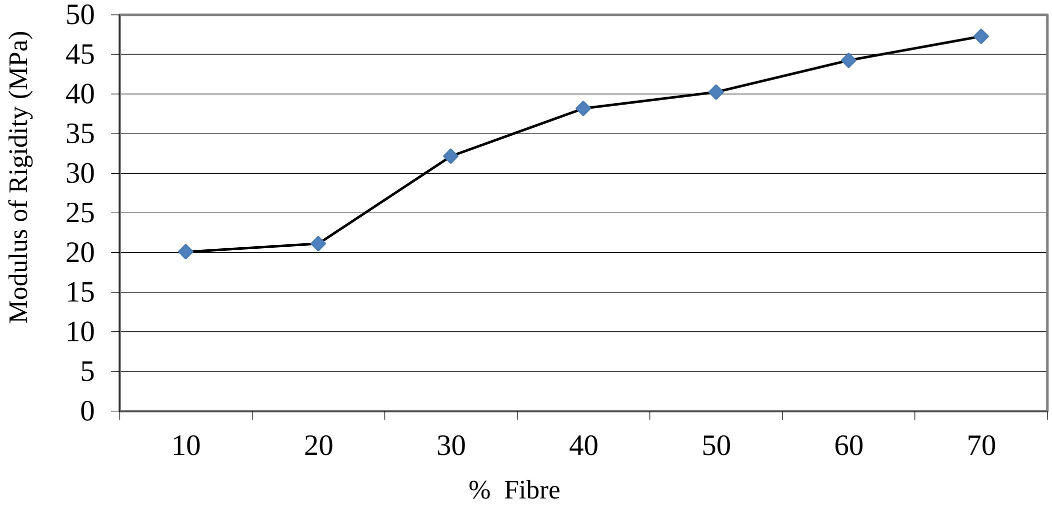

Figure 4: Modulus of rigidity of green composites of oil palm frond fibre at different fibre loading

From figures 3 and 4, it can be observed that the values of both the flexural strength properties and MOR of green composite oil palm increased with increased fibre loading. The improved value of MOR is indicative of the capability to withstand high stress before failure. These results will no doubt, satisfy the needs at areas of application proposed in the automobile, building and packaging industries, where low strength and low cost variance values may be desirable.

3.2.3 Izod Impact strength properties

Figure 5 illustrates the Izod (notched) Impact strength properties of green composites of oil palm frond fibre at different fibre loading, as reported by Anyakora [17].

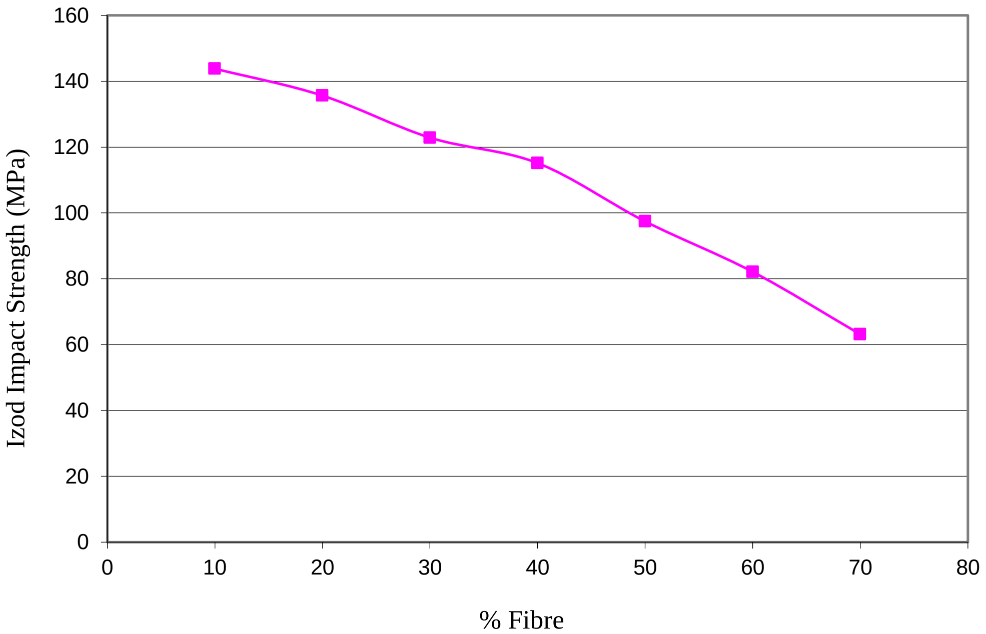

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Figure 5: Izod Impact strength of green composite of oil palm frond fibre at different fibre loadings

From figure 5, it can be observed that the values of Izod Impact strength properties of green composite oil palm frond decreased with increased fibre loading. Under the test conditions, it was observed that the impact properties of loss energy and damping index decreased with increasing fiber content. The impact behavior of composites of green composite oil palm frond is nevertheless, noted to be with observed in both natural and synthetic fibres as reinforcements in composite production, as reported by Sreekala et al. [5].

3.2.4 Some physical properties of green composites of oil palm frond fibre

Table 2: Result of some physical properties of green composites of oil palm frond fibre

Property	*Unit*	*Test Method*	*Test Result*
Mould Linear Shrinkage	mm/mm	BS2782: Part 6: Method 640A:1979	0.07
Porosity	%	BS2782-9:Method 920C:1977	4.27
Specific Gravity	-	BS2782-6: Method 620A:1991	2.08
Water Absorption (24 hrs in water) 23^{o}C	%	BS EN ISO 62:1999	6.98

3.2.5 Mould linear shrinkage

From the results in table 2, it shows that green composites of oil palm frond fibre recorded 7% shrinkage. The relatively high shrinkage value is suggested to be related to the fibre morphology, similarly exhibited by other natural fibres.

3.2.6 Porosity

From the results in table 2, it is shown that the green composites of oil palm frond exhibited the moderate porosity level of 4.27%, which could be related to the recorded high tensile modulus. The random alignment of long fibre lengths may have invariably contributed to the result. Since, the residence of voids and porosity in materials encourage stress initiation, as a function of resistance to several factors such as toughness behavior, it is noted that the proposed areas of application of green composites of oil palm shall not be of high stress exposure.

3.2.7 Specific gravity

Considering the result of tests in table 2, it is observed that the specific gravity of green composites of oil palm frond in the range of 2.08g/cm^3 is relatively outstanding. This indicates that green composites of oil palm frond can be competitively accepted as good alternatives for low density application. Again, considering that materials are bought in terms of weight and pieces, and that articles are sold by the number, more pieces can be made with oil palm frond fibres as compared to the same weight of mineral fibres, which could result in significant material cost savings in the high volume and low cost commodity market, needed in automobile and allied industries.

3.2.8 Water absorption (24 hrs in water) 23^{o}C

The results in table 2 show that the green composites of oil palm frond fibre exhibited low percentage water absorption of 6.98%. Considering the fact that green composites of oil palm frond fibre are impervious to humidity and still support deformation, it represent advantages in comparison with the relatively brittle gypsum board, which deteriorates in contact with water.

Conclusion

Although the oil palm frond fibres used in this work was not surface-treated, yet exhibited improved properties, it suggests that the green composites of oil palm frond could be acceptable in areas of low strength, and moderate flexure applications in the building industry where low cost and high volume production of components are desirable based on the following corroborated results;

- The tensile strength properties of green composite oil palm decreased with increasing fibre loading.
- The MOE increased with increased fibre loading till 60% fibre content before dropping.
- The values of both the flexural strength properties and MOR of green composite oil palm increased with increased fibre loading.
- The values of Izod impact strength properties of green composite oil palm decreased with increased fibre loading.
- The values of mould linear shrinkage, porosity, specific gravity and water absorption properties showed moderate values at 40% fibre loading.

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4. Conclusion

The results showed that:

a. The tensile strength properties of composite green oil palm decreased with increasing fibre loading.
b. The MOE increased with increased fibre loading till 60% fibre content before dropping.
c. The values of both the flexural strength properties and MOR of composite green oil palm increased with increased fibre loading.
d. The values of Izod Impact strength properties of composite green oil palm decreased with increased fibre loading.
e. The values of mould linear shrinkage, porosity, specific gravity and water absorption properties showed moderate values at 40% fibre loading.

It is noted that, though the oil palm frond fibres used in this exploration were not surface-treated, yet exhibited improved properties, it suggests that the composites could be acceptable in areas of low strength, and moderate flexure applications, in the automobile, building and packaging industries where low cost and high volume production of components are desirable.

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