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EVALUATION OF MECHANICAL PROPERTIES OF POLYESTER MATRIX REINFORCED WITH BAMBOO FIBRE FOR THE PRODUCTION OF LOW STRENGTH BUILDING PRODUCTS

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ABSTRACT

The development of natural fiber reinforced composite-based products to substitute traditional engineering materials is becoming a trend in engineering application. Despite the inherent advantages of low cost, low density, competitive specific mechanical properties and sustainability, these agricultural wastes seem to have some limitations of susceptibility to microbial and environmental challenges that preclude their use for product standardization and repeatability. In this study, composite panels made by hand lay-up technique from randomly oriented bamboo fibers reinforced polyester matrix were evaluated. The processing parameters included surface treatment of fibres in phenylsilane, manipulation of fibre content and evaluation of ash content in relation to the mechanical properties. The results show that the tensile strength, flexural strength and Izod impact strength, including modulus of elasticity and rigidity values for the samples were similar to those of kenaf and talc fibre composites. The scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis of the samples suggest that the composition of higher ash content in the treated bamboo fibre reinforced polyester composite panels, coupled with the non-significant effect of surface treatment, is indicative of correlation between ash content and mechanical properties of bamboo fibre reinforced polyester composites. It is inferred from the results that surface treatment processes may not necessarily be required for bamboo fibre as reinforcement in composites production for some low-to-medium structural applications. In terms of practical interest, the bamboo fibre composites can be regarded as valid alternatives to replace some conventional fibres as reinforcement in polyester matrix in areas of low strength structural applications. In spite of the relatively low strength exhibition of bamboo fibre composites, they are stronger than kenaf and talc composites and can be considered for the production of low strength building products such as panels and ceilings. The fact that these natural fibre composites are impervious to moisture and still support deformation, represent advantages in comparison with the relatively brittle gypsum board, which deteriorates in contact with water.

Keywords: Bamboo, Polyester, Silane, Tensile, Flexural, Strength, Modulus, Elasticity, Rigidity, Composite, Fracture.

1.0 INTRODUCTION

Most often, new materials are taken as the necessary building blocks for product development and technological breakthroughs in engineering. New researches lead to development of new materials for application in building, construction, auto, aero and domestic/toy industries. Advances in technology and development of new products are mostly limited by the availability of the materials used for fabrication. The use of bamboo fibre as new reinforcement material in the plastic matrix is promising in polymer matrix composite development.

The bamboo tree belongs to a group of woody perennial evergreen plants in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. It is one of the fastest growing woody plants in the world. This is perhaps due to their unique rhizome system and is dependent on local soil and climate conditions. They are of economic and high cultural significance in East Asia and South East Asia where they are used extensively in gardens as building material as well as food source. In Nigeria, they are used for building supports and tooth picks. While wood has a hard centre and becomes weaker toward the outer part, bamboo is hard in its outer, while weak in its inner parts, this leads to a much more stable construction. The more stable fiber structures are most dense where you find the highest stress [1]. Accordingly, the adoption of bamboo fibre in composite application, especially in low strength areas will be most desirable.

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The development and application of Bamboo Fibre Reinforced Polyester Composites (BFRPC) have wide application possibilities, high potential of developing new industries using local crops, wastes and labor, and significant reduction in the demand for tropical hardwoods and plastics used in the industries. In addition, it will provide a useful alternative to the use of glass fibre as reinforcement in polyester composites that are prone to difficult waste disposal and severe negative health effects.

Several researches have shown that natural fibre can be modified for improved properties but properties of natural fibre reinforced composites have not achieved the necessary property values for the production of standardized products of suitable properties, perhaps due to the general drawback of high moisture absorption of the natural fibres that result in swelling of the fibres and concerns on the dimensional stability. In oil palm for example, the moisture update is high (12.5%) at 65% relative humidity and 20%, by dry fibre and 14.6% by wet fibre [2]. These limitations can be minimized through the encapsulation of fibre in the polymer matrix including good fibre- matrix bonding.

Additionally, 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. Although, it is difficult to entirely eliminate the absorption of moisture without using surface barriers on the composite surface, which is reduced through chemical modification of some of the hydroxyl groups in the fibre but with some increased costs [3].

Generally, the strength of fibre reinforced composite structures depends primarily on the morphology, amount, arrangement and type of fibre in the resin matrix. By changing these parameters, the strength properties can be tailored to meet specific demands. Also noted is the stiffness and strength-to-weight properties that make some composite materials like carbon fibre composites attractive for applications in aerospace and sporting goods, including the extensive application of glass fibre composites in the chemical industries and marine and automobile applications, need be challenged with the development of comparable strong products from bamboo fibre composites in less structural product applications.

The material cost savings arising from the use of relatively low cost bamboo fibre, low density, renewability, biodegradability, high filling levels resulting in high stiffness properties, high specific properties are some of the benefits of use of bamboo fibre-based materials. Also, the non-food agricultural/farm-based economy, low energy consumption is most of the issues that can not be easily ignored in the engineering research and development in the area of Bamboo Fibre Reinforced Polyester Composites (BFRPC). The development of composite products from bamboo fibre materials will address the many needs of alternative to glass fibre for use in low cost housing and low strength structural applications, including the creation of job and wealth from waste while protecting our environment from pollution problems.

2.0 MATERIALS AND METHODS

The bamboo fibres were obtained from five year old mature plants that were felled and used within two weeks. The bamboo extracts were processed at the Pulp and Paper section of Federal Institute for Industrial Research, (FIIRO) Oshodi, Lagos, Nigeria.

The Polymer used was Siropol 7440 un-saturated polyester resin purchased from Dickson Chemicals Ltd, Lagos, Nigeria with specific gravity of 1.04, viscosity of 0.24 Pa.s at 25^{o}C. Other chemicals used were the cobalt in styrene, diglycidylethers and phenylsilane procured from Zayo - Sigma Chemicals Limited, Jos, 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, was adopted in the production of test specimen plates.

Other equipment used were Universal Testing Machine, Instron, Model 3369, Compact Scale/Balance (Model – FEJ, Capacity – 1500g, 1500A) and EVO/MA 10 Scanning Electron Microscope, controlled by JPEG SmartSEM software, of 5 nanometer resolution installed at Shetsco Science and Technology Complex, Gwagwalada, Abuja, Nigeria.

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2.1 Methods

2.1.1 Extraction of Bamboo Fibre

The collected bamboo fibres were extracted by chemico-mechanical process. The process involved the impregnation of sample with "white liquor' and conversion of the softened sample into fibre by mechanical action, followed by thorough washing, screening and drying. The extracted fibres were separated, re-washed and dried in the forced-air circulation type oven. The fibres were subsequently weighed and percentage yield determined. The fibre systems were fluffed and separated into two tangle-mass bulks, one for surface-treated fibre composite while the other for the 'as natural' fibre composite production.

2.1.2 Surface Treatment of Bamboo Fibre

The process adopted in this work was the silane treatment preceded by the sodium hydroxide treatment. Known weights of extracted bamboo fibres were soaked in prepared known volume of 0.5 mol/litre of NaOH for 2 hours. The products were removed and washed with distilled water before air-drying. Subsequent processes included soaking the treated bamboo fibres in 2% phenlysilane solution for 24 hours. Subsequently, the product was removed, dried at 60°C and stored in specimen bag ready for use.

2.1.3 Production of Test Specimen

The test specimen panels of 10-70% bamboo fibre content were produced by hand lay-up process. Curing was assisted by placing the composite in an oven operated at 110°C. The mouldings were removed from the oven after 30 minutes and conditioned. Five (5) test samples each was cut from seven (7) stocks (10-70%) of the surface-treated bamboo reinforced composite and untreated (as raw) bamboo reinforced composites.

2.1.4 Composite Characterization

The strength properties were measured on a Universal Testing Machine of 10KN capacity operated at a crosshead speed of 5 mm/min. Similarly, the fractured surfaces and the elemental analysis of both surface-treated bamboo composite and untreated (as raw) bamboo composites with fibre content of 40% and the of the bamboo reinforced polyester composites were also carried-out on a SEM/Energy-Dispersive X-ray spectroscopy using EVO/MA 10 Scanning Electron Microscope.

3.0 RESULTS AND DISCUSSION

3.1 Results

The results of some mechanical strength properties and correlation of treated and untreated (as raw) bamboo fibre reinforced polyester composite panels are shown in Table 1 and Figures 1 - 5, while the results of Elemental Analysis (Energy Dispersive Spectroscopy- EDS) are presented in Table 2. Figures 6 and 7 show the scanning electron microscopy of fractured surfaces of the composite panels. Some of the mechanical properties of bamboo fibre composite panels of 40wt. % fibre are compared with other natural fibre composite panels are shown in Table 3.

Table 1: Effect of Percentage Fibre on the Mechanical Properties and Correlation Coefficient between the Untreated and Treated Bamboo Fibre – Reinforced Polyester Composites.

Fibre (wt. %)		Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Flexural Strength (MPa)	Modulus of Rigidity (MPa)	Izod Impact Strength (J/m)
10	Untreated	6.39	13.31	39.28	59.39	142.46
	Treated	9.87	15.56	44.56	171.60	144.16
20	Untreated	6.32	16.21	44.64	91.42	154.14
	Treated	9.98	21.88	69.18	200.89	135.89
30	Untreated	6.25	24.41	50.92	121.97	148.96
	Treated	8.97	34.68	80.64	312.39	135.89
40	Untreated	6.11	33.26	53.63	178.77	144.17
	Treated	8.15	43.41	104.96	467.36	130.29
50	Untreated	5.98	40.45	52.74	232.87	128.94
	Treated	7.21	55.37	112.89	512.77	125.63
60	Untreated	5.91	54.89	54.36	297.65	112.42
	Treated	7.02	60.30	121.76	598.32	119.86
70	Untreated	5.89	58.21	59.02	345.74	103.66
	Treated	6.79	69.56	129.66	654.23	101.92
Correlation Coefficient		*0.98838*	*0.981445*	*0.961137*	*0.978538*	*0.905817*

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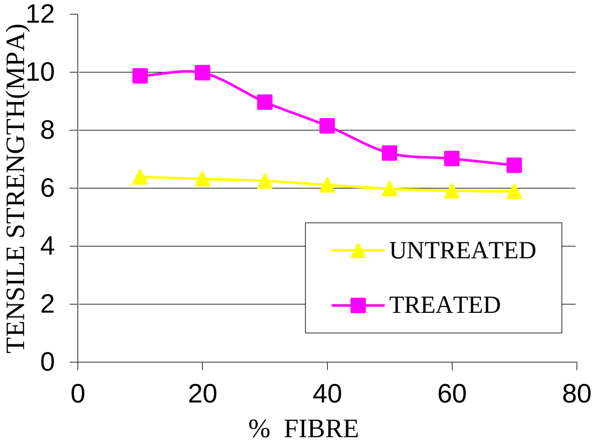

Figure 1: Effect of % Fibre on the Tensile Strength of Untreated and Treated Bamboo Fibre - Reinforced Polyester Composite

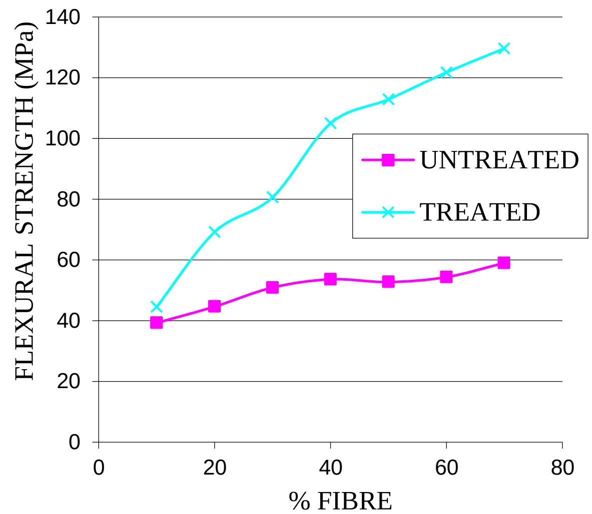

Figure 3 : Effect of %Fibre on the Flexural Strength of Untreated and Treated Bamboo Fibre - Reinforced Polyester Composite

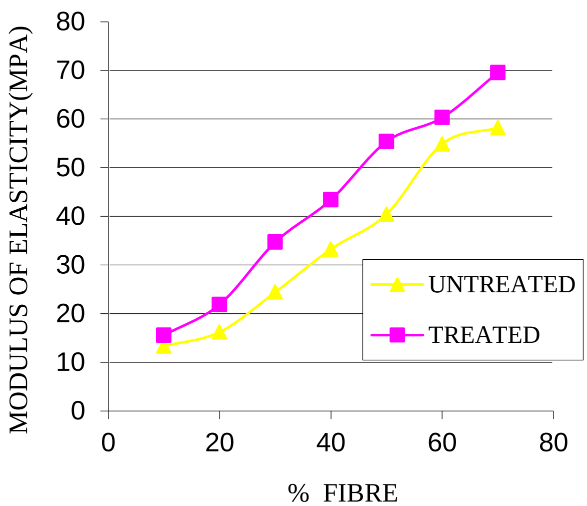

Figure 2: Effect of % Fibre on the Modulus of Elasticity of Untreated and Treated Bamboo Fibre - Reinforced Polyester Composite

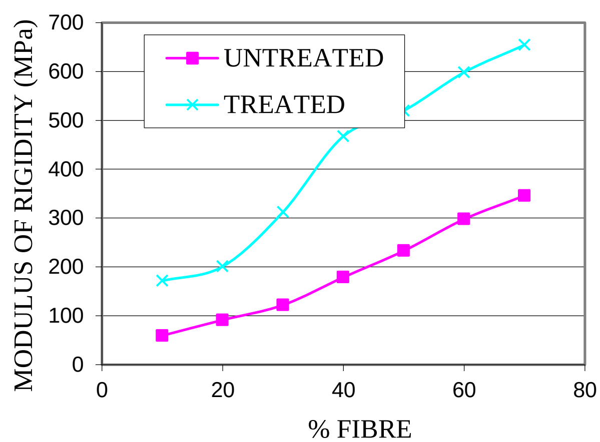

Figure 4: Effect of %Fibre on the Modulus of Rigidity of Untreated and Treated Bamboo Fibre - Reinforced Polyester Composite

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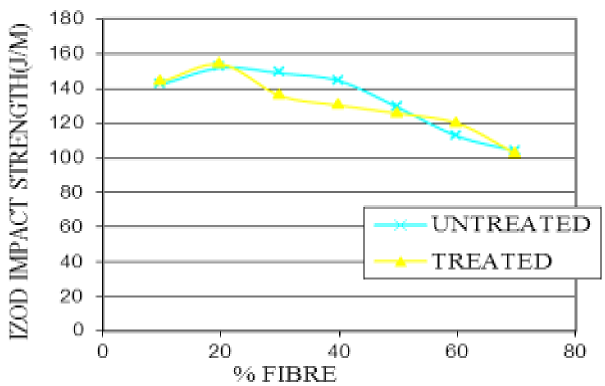

Figure 5 : Effect of %Fibre on the Izod Impact Strength of Untreated and Treated Bamboo Fibre - Reinforced Polyester Composite

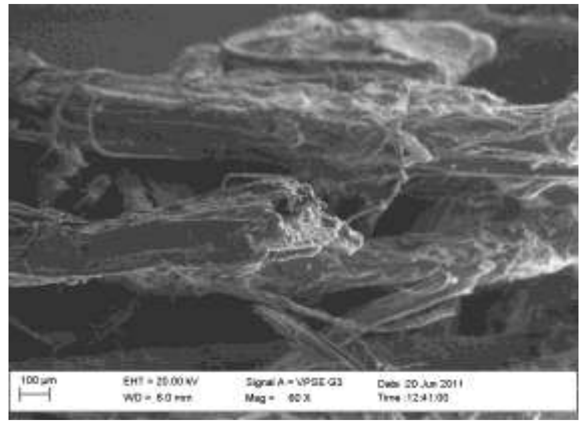

Figure 6: Fracture surface of an untreated bamboo fibre composite showing fibre peeling and large resin 'crazing'.

Table 2: Result of Elemental Analysis (Energy Dispersive Spectroscopy- EDS) of bamboo fibre reinforced polyester composites.

Specimen	Composition of Element (%wt.) in Composite													
	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Co	Zn
Untreated Bamboo Fibre composite	50.12	40.64	0.51	0.15	0.79	1.61	-	0.15	0.19	0.31	1.21	3.68	0.64	-
Treated Bamboo Fibre composite	52.49	26.17	0.38	0.14	18.18	0.67	0.09	0.13	0.27	0.09	0.38	0.77	0.24	-

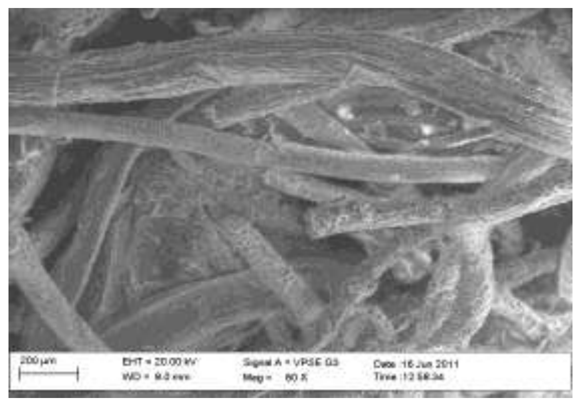

Figure 7: Fractured surface of a treated bamboo culm fibre composite showing fibre damage and little resin crack area.

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Table 3: Comparison of Some Mechanical and Physical Properties of Treated Bamboo Fiber Reinforced Polyester Composites with other Natural Fiber Reinforced Polyester.

Property	Unit	Treated Bamboo	*Treated Kenaf	*Talc
Fiber (wt. %)	-	40	40	40
Tensile Strength	MPa	8.15	3.65	35
Modulus of Elasticity	MPa	43.41	24.83	4
Flexural Strength	MPa	104.96	6.98	63
Modulus of Rigidity	MPa	467.36	73.08	438
Izod Impact Strength (notched)	J/m	130.29	204.32	320
Mould Linear Shrinkage	mm/ mm	0.04	0.07	0.015
Porosity	%	3.18	N/A	N/A
Specific Gravity	-	1.15	1.07	1.27
Water Absorption (24 hrs. in water) 23^{0}C	%	4.08	4.05	1.2

*Source: [4, 5, 6, 7].

3.2 Discussion

3.2.1 Mechanical Properties (Tensile Strength and Flexural Strength)

From literature [8], it is noted that the primarily effect of fibre reinforcement on the mechanical properties of natural plant fibre composites include increased tensile modulus, increased tensile strength with good bonding at high fibre concentrations, decreased elongation at failure, etc. This is line with the modulus of elasticity and modulus of rigidity of bamboo fiber reinforced polyester composite recorded in Table 1 and Figures 2- 4. It is observed from Figure 1 that, while the values decreased, no significant increase was recorded with increasing fiber content in the tensile strength of respective treated and untreated bamboo fiber composites. The sudden drop in tensile strength properties with increasing fiber content suggests poor matrix wettability.

Bamboo fibres with respect to other natural plant fibres generally show a higher degree of elasticity and lower plastic range [9, 10], thus, a major effect of surface treatment and fibre content can not be anticipated as evident with the high correlation values between the untreated and treated bamboo fiber composites. However, these observations should be treated with caution since an opposite trend was noted with the flexural strength, and coupled with the fact that the hand lay-up process of production of the composites may not have achieved a uniform and homogeneous spread of the matrix.

3.2.2 Impact Strength Properties

Figure 5 showed that the Impact strength property values decreased with increasing fibre content in both treated and treated bamboo fiber composites. Generally, the toughness property of fibres improves with surface treatment especially with the notched samples necessitating that the fibres bridged the cracks while increasing the resistance of the propagation of the crack and further limiting fibre pull-out [11]. The less-significant effect of fibre surface treatment on the impact strength properties of the bamboo fibre composite suggests that its outstanding property, compared to other natural fibres, is consistent with the literature, thus may not be desirable to surface- treat bamboo fibre for reinforcement in areas not requiring high impact properties.

Generally, bamboo fibre elongates more than other fibres by virtue of their structure [12]. The relationship between load and extension enables a quantitative work measurement as delineated by the diagram. It will be noted from the general form of the plant fibre load-elongation curve, that when the load is first applied, plastic flow compacts the fibre. The load take-up is regarded as a two phase operation consisting of rapid instantaneous stretch, followed by slower and lower stretch called creep, until equilibrium between load and elongation is attained. These behaviors seem different when the natural plant fibres are embedded in a bonding matrix to form a composite, which may be responsible for the literal contradictory behavior of bamboo fibre in the matrix in this work.

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3.3 Physical and Processing Properties

Since the modulus of materials increases with bond energy, a fibre with mixed covalent/secondary bonding, (characteristic of many reinforcing fibres) enables that modulus can be increased by orienting the covalent bonds along the fibre axis. Additionally, a small diameter is important in providing a fibre with much needed flexibility, thus, as the diameter of a fibre decreases, its elastic modulus, strength, elongation to break and flexibility all increase [13]. This explains the fact that the strongest materials on earth are fibres. The adoption of randomly distributed bamboo fibres in the composite production seems to compensate for the inter-lay between parallel and crossed fibre arrangement.

From Table 3, it is evident that bamboo fibre composite exhibited similar physical and processing values with other comparable natural plant fibre composites. The relationship between the mould linear shrinkage, porosity and water absorption and the strength properties of composites of treated kenaf and talc may be traced to the chemical structure of the fibres, in which the many hydroxyl groups are available for interaction with water molecules by hydrogen bonding in the cellulose. This is in contrast to glass fibres where water adsorption is important only at the surface, cellulosic fibres interact with water not only at the surface, but also in the bulk. The quantity of sorbed water depends on the relative humidity of the confined atmosphere with which the fibre is in equilibrium, thus bamboo fibre can be adopted as alternative reinforcement in areas requiring low-to-medium strength application, than the m expensive glass fibres.

There is a general trend of improved impact strength of treated natural fibre over untreated natural fibre composites indicating that surface treatment has direct effect on the impact behavior of natural fibre used as reinforcement.

This result suggests that bamboo culm fibre system can compete favourably with glass fibre in some areas of less tensile property application, which suggests why bamboo is often employed, even without surface treatment, in building trusses.

3.3.1 Specific Gravity

Considering the result of tests in Table 3, it is observed that the specific gravity of composite of bamboo fibre is outstanding and compete favorably with those of treated kenaf and talc composites. This gives an indication that the composites can be competitively adopted as good alternatives for low density application. Again, since materials are bought in terms of weight and pieces, and that articles are sold by the number, more pieces can be made with bamboo 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 plastic market.

3.3.2 Mould Linear Shrinkage

Since mould linear shrinkage is expressed as a percentage of change in dimensions of the specimen, it is noted that the relationship between the bamboo fibre composite and other fibre composite, showed lower shrinkage value compared to talc composites. This infers the more stable behavior of talc fibres, which is related to the fact that fibre morphology plays a dominant role in the properties of composites. This further enables that fibre surface modification is necessary in the achievement of low mould shrinkage.

Additionally, the low mould shrinkage property of bamboo fibre composite has a direct correlation with the hydrophilic characteristics of natural fibres which is traced to the fiber morphology, as improved upon by surface treatment process. The results show that the lower linear shrinkage values of bamboo fibre, which have high cellulose content, are stable for the production of composites requiring better structural stability.

3.3.3 Water Absorption

Studies [13], show that water absorption in natural fibre reinforced composites could lead to a decrease in some properties. Thus, when selecting a natural fibre composite for an application, the effect of water absorption need to be considered. It is noted generally that difficulty exists in an attempt to entirely eliminate the absorption of moisture in composites without using expensive surface barriers on the composite surface. Water absorption in natural fibre-based composites can lead to a build-up in the cell wall and also in the fibre-matrix inter-phase region, which could result in fibre swelling, and concerns on the dimension stability cannot be ignored.

The percentage increases in weight of a material after exposure to water under specified conditions often influence the mechanical properties. Although the type of material, additives, temperature and length of exposure can also affect the amount of water absorbed. From the result in Table 3, it is observed that bamboo fibre composites exhibited higher percentage water absorption than talc and kenaf composites which may also be related to the type and morphology of fibre in the composites.

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It could be inferred also, that surface treatment of fibres improved the surface affinity between the fibre and matrix that achieved less moisture ingress, thus, affinity to water absorption may be controlled through surface modification. The fact that bamboo fibre reinforced composites are impervious to humidity and still support deformation, represent advantages in comparison with kenaf and talc composites and the relatively brittle gypsum board, which deteriorates in contact with water.

3.3.4 Porosity

Generally, a strong adhesion at the fibre-matrix interface is needed for an effective transfer of stress and load distribution throughout the interface. The lack of interfacial interactions leads to internal strains, porosity [14]. Residence of voids and porosity in materials often encourage stress initiation which is a function of resistance to several factors such as toughness behavior. The size of this porosity, and in some case, their positions in the material show the trend with which the pattern of failure may be experienced, such as whether the failure will be gradual, instantaneous, etc. The presence of void also aid in predicting what may be the pattern of crack propagation necessary for design applications.

From the results in Table 3, and SEM results in Figures 6 and 7, it is shown that the composites of bamboo fibre exhibited the low porosity level. The effect would have been better appreciated if the comparable values of porosity of Talc and Kenaf composites are available. In determining the correlation coefficient, only the tensile, flexural and Izod impact strength properties of untreated and treated bamboo fibre composites systems with percentage fibre (by weight) from 10 to 70 were used. These results showed cases of positive correlations between the untreated and treated natural fibres inferring that there may not be a need to surface-treat bamboo fibre for application in some areas not requiring high strength properties.

3.4 Scanning Electron Microscopy (SEM) of Fractured Surfaces and Energy Dispersive Spectroscopy (EDS) Elemental Analysis

From Table 2 of EDS results, it is evident that the treated bamboo fibre composite composed of higher ash content than the untreated bamboo fibre composite. When considered with the fracture behavior of results of SEM in Figures 6 and 7, it is noted that the untreated bamboo fibre composite showed fibre peeling with large resin 'crazing' while the treated bamboo culm fibre composite showed little fibre damage with little resin crack area. These types of failure mechanism need be treated with caution as more definite evaluation is suggested for the achievement of more standardized and repeatable products.

The geometrical shape for the reinforcing phase in a structural composite is a fibre. The chance of having a large flaw in a given length of fibre decreases as the cross sectional area decreases, thus the combination of characteristic with the need for a significant surface area for load transfer from the matrix to the reinforcing phase gives an apparent advantage of use of long, slender fibers, thus, a small diameter is an advantage. From the scanned electron microscopy, it is evident that the fibre surfaces were covered with protrusions and small voids in both untreated and treated bamboo fibre reinforced composites. The low porosity value of the treated bamboo fibre composite suggests that the fibre-matrix improved bonding was as a result of surface treatment where the fibre surfaces contained the pits, which in principle facilitated resin impregnation and achieved improved bonding.

There is a general observation of fibre peeling and resin 'craze' with the untreated fibre composites which suggests poor fibre-resin bonding. Under loading, the resin absorbed the load which, when transferred to the embedded fibres started peeling, causing the resin to go through early and crazy failure. This is different from the treated fibre composites where fibre damage showed that transfer of load was gradual till the interface failed before the fibre failure, thus explaining the incompatibility of the interfacial region due to hydrophilicity of natural fibres. This necessitates that natural fibre surfaces be treated to block the hydroxyl groups to make them more hydrophobic and consequent improved mechanical properties.

Generally, fracture in polymer-matrix composites usually begins with cracking of the fibre component of the composite. The manner in which this initial fracture progresses determines the toughness of the composite. When a fracture occurs in an isolated fibre at any point along its length, the stresses carried by the fibre in the vicinity of the crack must be transferred to the surrounding matrix and other fibres, so much so that, if the surrounding matrix and fibres are able to withstand the stresses, the fracture will stabilize at that location, but will begin at other locations if the deformation is continued. This process will continue until the damage is so widely spread that the stress originally carried by the fractured fibres can no longer be carried by the un-cracked matrix, at which point, ultimate fracture of the composite occurs [12].

From the morphological observation in Figures 6 and 7, it is shown that the treated bamboo fibre composite had better resin homogeneity of uniformly distributed matrix than the untreated bamboo fibre composite. This has a relationship with the void distribution of which the material toughness was evident in the impact strength values of treated bamboo fibre composites.

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This observation may also be related to the morphology of bamboo fibre including the technique used for the composite production.

Similarly, the morphology of fractured treated bamboo fibre composite suggests that the composite failed by a combination of fibre fracture and fibre pull-out indicating that fibre fracture was a major mechanism in the strength of the composite. The results of the fracture also show that the reinforcing fibres were damaged during stress loading as shown on the SEM results, suggesting that the mechanism of fracture is dependent on the fibre type, fibre strength and void content of the sample.

Table 2 shows an EDS composition of the bamboo fibre composite. This reveals that the composite is essentially composed of carbon, oxygen and ash in different proportions. From the result, it is observed that surface treatment process involving the alkali and silane resulted in the prominent improvement in carbon content, reduction of oxygen content in the composites. The reduction in oxygen content in the treated fibre composites suggests that the objective of fibre treatment process of reducing the hydroxyl group of natural fibre was achieved, which achieved better fiber-matrix bonding. The improvement in the carbon content in the treated fibre composites has effect on the strength properties based on the shock absorption effect of carbon presence in materials.

The improvement in carbon content and reduction in oxygen, along with high ash content is associated with the protrusions in treated fibre composites as opposed to the peeling of fibres in the untreated fibre composites. Also shown was the fact that bamboo fibre reinforced polyester composites contain some elements of magnesium, phosphorus and sulphur, etc., which may be ascribed to their outstanding tensile property and resilience. The result of higher ash content in treated fibre reinforced polyester composites indicates a correlation between ash content and some mechanical properties of the bamboo fibre-reinforced polyester composite.

4.0 CONCLUSIONS AND RECOMMENDATION

4.1 Conclusions

From the results, it is deduced as follows:

- That bamboo fibre exhibited outstanding mechanical properties and thus can be adopted in many composite applications where cost or lower weight is of greater importance than high strength.
- Bamboo fibres do not need expensive fibre surface treatment processes for use in some low-to-medium structural load applications.
- The high ash content of treated bamboo fibre and loading has significant effect on the mechanical properties of composites.
- That, the bamboo fibre, a non-wood resources exhibited outstanding properties in the production of value-added composite panels in the conditions tested.
- That such environmentally friendly product will also provide an alternative way to convert under-utilized or otherwise waste into useful materials for building, auto and allied industries.

In terms of practical interest, the bamboo fibre composites can be regarded as valid alternatives to replace some conventional fibres as reinforcement in polyester matrix. These composites are flexible and could be used in areas of low strength structural applications. In spite of the relatively comparable mechanical property values, they are stronger than kenaf and talc composites and can be considered for panels or ceilings. The fact that these natural fibre composites are impervious to moisture and still support deformation, represent advantages in comparison with other similar panels like brittle gypsum board, which deteriorates in contact with water.

4.2 Recommendation

From the conditions under which the tests were carried-out, it is recommended that bamboo fibre be used for the production of high quality composites for application in low structural building areas such as ceilings panels using more improved processing technique such as resin Injection moulding in place of hand lay-up technique with curing limited to a heat controlled environment of 200^{o}C.

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