Investigation of Mechanical Properties of Polyester Matrix Reinforced with Coconut Palm Frond Fiber for the Production of Low Strength Building Products

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***Abstract*– Composite panels made by hand lay-up technique from randomly oriented coconut palm frond fibers reinforced polyester matrix were investigated. The results show that the highest values of 10.26MPa and 78.98MPa for respective tensile and flexural strength properties were observed at 10% fibre content by weight in the composite, while the highest values of 40.20MPa and 227.89MPa for respective modulus of elasticity and modulus of rigidity properties were observed at 70% fibre content by weight. The highest value of 134.77 J/m impact strength properties was observed at 10% fibre content. These strength properties of coconut palm frond fibre composites are similar to those of coir, kenaf and talc fibre composites and consistent with literature, giving an indication that standardized products can be produced from coconut palm frond fibres. The Scanning Electron Micrographs of fractured surfaces of coconut palm frond fibre composites is an indication that surface treatment of coconut palm frond fibres is desirable. Similarly, the Energy-Dispersive X-ray spectroscopy result of coconut palm frond fibre composites composed of higher ash content than the untreated fibre samples suggests a strong relationship between ash content and fibre treatment on the strength behavior of natural fibre composites. In terms of practical interest, the coconut palm frond fibre composites can be regarded as valid alternatives to replace some conventional fibres as reinforcement in polyester matrix in areas of low strength building products.**

***Keywords*–** Coconut Palm Frond, Tensile, Flexural, Modulus, Elasticity, Rigidity and Composite

I. INTRODUCTION

Natural fibres have unique role in the ecological cycle, and their natural abundance, plentiful supply and relative cheapness are matched by the ease and readiness with which these resources can be swiftly replenished. Such materials can therefore provide a compatible and competent alternative reinforcing material in composite production. Natural fibre imparts lower durability and lower strength compared to glass fibres; however, low specific gravity results in a higher specific strength and stiffness than glass fibres. This is a benefit especially in parts designed for bending stiffness. In addition, the natural fibres offer good thermal and acoustic insulation properties along with ease in processing technique without wearing tool, BISWAS et al (2005).

The main obstacles in the use of natural fibres have been the poor compatibility between the fibres and the matrix that often led to micro-cracking of the composite and degradation of mechanical properties. Various treatments have been used to improve the matrix-fibre adhesion in natural fibre reinforced composites, ROWELL et al., (1997).

Although, the coconut palm fibres from the stem and frond are of less lignin and more cellulose content, they can be put together using synthetic matrix such as polyester resin to produce a composite material. This technology, which is applicable to raw or recycled fibres from plants as reinforcement fillers in composites, produce composites of improved strength, stiffness, reduced heat distortion(with decreased impact resistance) that are suitable for engineering applications, thus reducing the dependence on other alternative materials, MILEWSKI (1992).

The development and application of coconut palm frond fibre reinforced polyester composites 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 construction or engineering 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. In this study, the effects of surface treatment of coconut palm frond for manufacturing fibre-based green composites have been investigated with a view to ascertaining their suitability, including their utilization as viable alternatives to other fibre composites in the production of low strength building products.

II. MATERIALS AND METHODS

A. Materials

The coconut palm frond fibres were obtained from mature-fruited plants that were felled and used within two weeks. The fibre 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.

B. Methods

Extraction of coconut palm frond fibres: The coconut palm frond 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.

Surface treatment of coconut palm frond fibre: The process adopted in this work was the silane treatment preceded by the sodium hydroxide treatment. Known weights of extracted coconut palm frond 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^{o}C and stored in specimen bag ready for use.

Production of test specimen: The test specimen panels of 10-70% coconut palm frond fibre content were produced by hand lay-up process. Curing was assisted by placing the composite in an oven operated at 110^{o}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 coconut palm frond fibre reinforced composite and untreated (as raw) coconut palm frond fibre reinforced composites.

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 coconut palm frond fibre composite and untreated (as raw) coconut palm frond fibre composites with fibre content of 40% of the sample composites were also carried-out on a SEM/Energy-Dispersive X-ray spectroscopy (EDS) using EVO/MA 10 Scanning Electron Microscope.

III. RESULTS

The results of some mechanical strength and processing properties including the correlation of treated and untreated (as raw) coconut palm frond fibre reinforced polyester composite panels are shown in Table 1 and Fig. 1 to Fig. 5, while the results of Elemental Analysis (Energy Dispersive Spectroscopy- EDS) are presented in Table 2. Fig. 6 and Fig. 7 show the scanning electron microscopy of fractured surfaces of the composite panels. Some of the mechanical and processing properties of coconut palm frond 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 coconut palm frond fibre - reinforced polyester composites

Fibre (wt. %)	Fibre Identity	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Flexural Strength (MPa)	Modulus of Rigidity (MPa)	Izod Impact strength (J/m)
10	Untreated	5.12	7.68	21.89	38.76	100.97
	Treated	10.26	15.66	78.98	151.77	134.77
20	Untreated	4.93	11.1	18.52	41.65	104.66
	Treated	9.75	18.33	69.33	147.15	128.15
30	Untreated	4.63	15.88	15.16	36.78	98.95
	Treated	6.77	20.21	60.76	172.37	125.02
40	Untreated	3.89	18.17	13.37	44.56	95.07
	Treated	4.62	23.54	54.37	181.22	123.97
50	Untreated	2.13	23.04	10.88	51.41	92.78
	Treated	2.51	29.87	25.31	192.32	118.37
60	Untreated	1.87	29.56	9.15	60.21	89.33
	Treated	2.03	35.66	21.26	214.97	112.98
70	Untreated	1.32	33.72	7.68	73.62	85.67
	Treated	1.44	40.2	17.91	227.89	109.78
Correlation Coefficient		0.95097	0.99185	0.96501	0.9116	0.975156

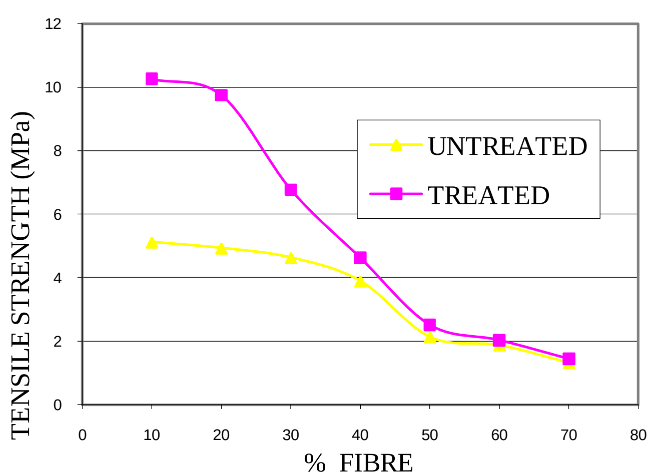

Figure 1: Effect of % fibre on the tensile strength of untreated and treated coconut palm frond fibre- reinforced polyester composite

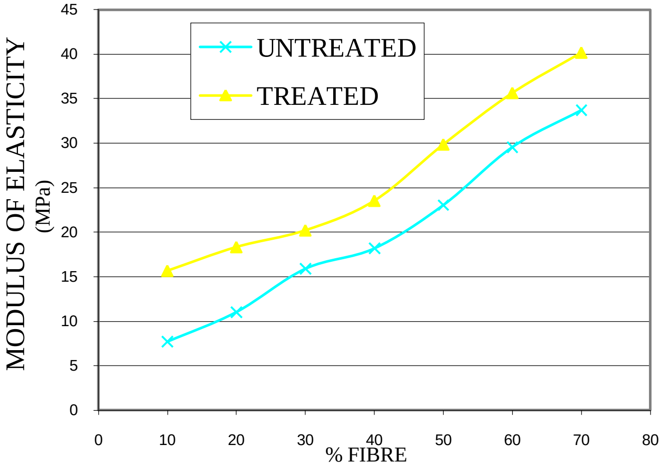

Figure 2: Effect of % fibre on the modulus of elasticity of untreated and treated coconut palm frond fibre reinforced polyester composite.

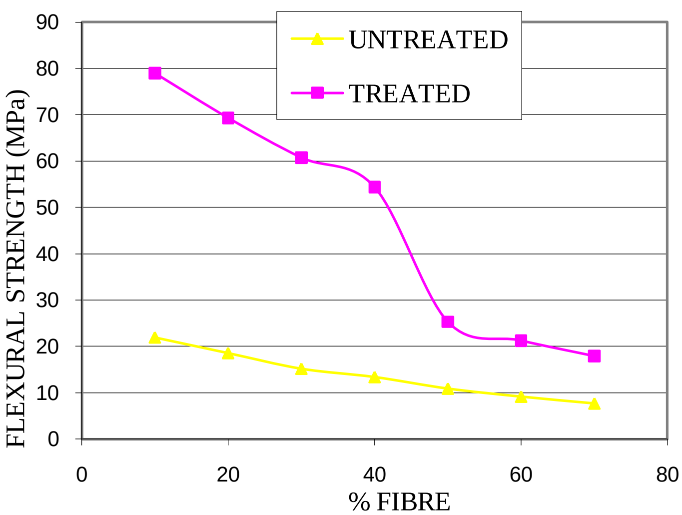

Figure 3: Effect of % fibre on the flexural strength of untreated and treated coconut palm frond fibre - reinforced polyester composite

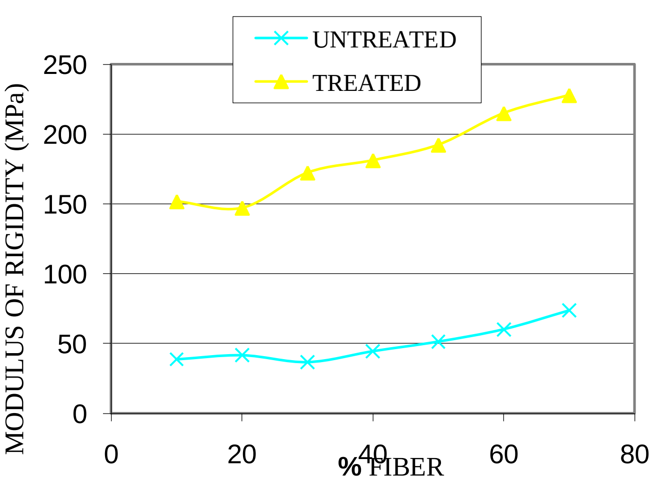

Figure 4: Effect of % fibre on the modulus of rigidity of untreated and treated coconut palm frond fibre - reinforced polyester composite

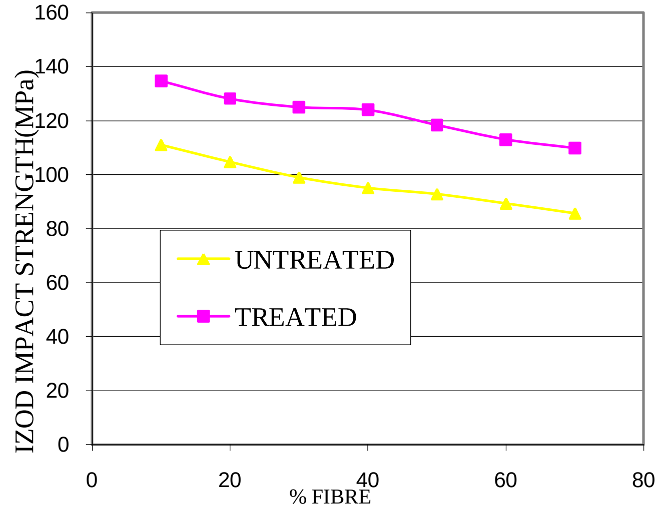

Figure 5: Effect of % fibre on the impact strength of untreated and treated coconut palm frond fibre - reinforced polyester composite

Table 2: Result of elemental analysis (Energy Dispersive Spectroscopy- EDS) of coconut palm frond fibre reinforced polyester composites

	Composition of Element (%wt.) in the Composite												
Specimen	**C**	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Fe**	**Co**	**Zn**
Untreated coconut palm frond fibre composite	47.67	42.75	-	-	2.63	0.84	-	-	0.15	0.16	0.18	0.55	0.34	4.73
Treated coconut palm frond fibre composite	56.59	30.37	1.38	-	10.13	0.61	-	-	-	-	0.12	-	0.26	0.55

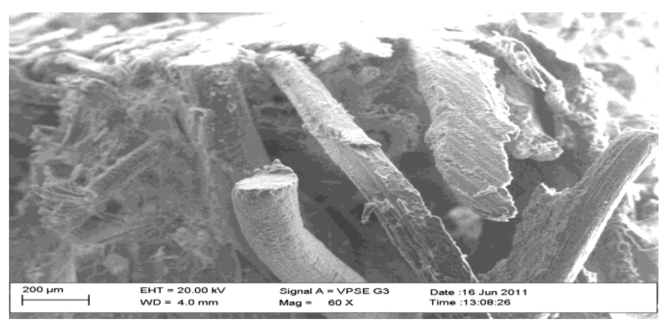

Figure 6: Fracture surface of an untreated coconut palm frond fibre composite showing fibre pull-out and large resin 'crazing'

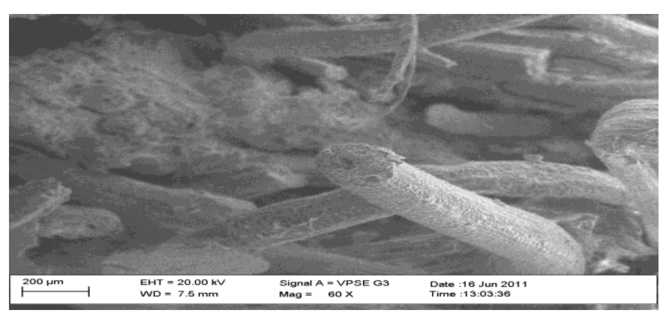

Figure 7: Fracture surface of treated coconut palm frond fibre composite showing fibre damage and little resin crack

Table 3: Comparison of some mechanical and physical properties of treated coconut palm frond fiber reinforced polyester composites with other treated natural fiber reinforced polyester

Property	Unit	Test method	Coconut palm frond	* Coir	* Kenaf
Fiber (wt %)	-	-	40	40	40
Tensile strength	MPa	BS2782-10: Method 1003:1977	4.62	8.15	3.65
Modulus of elasticity	MPa	BS2782-10: Method 1003:1977	23.54	43.41	24.83
Flexural strength	MPa	BS2782-10: Method 1005: 1997	54.37	104.96	56.98
Modulus of rigidity	MPa	BS2782-10: Method 1005: 1997	181.22	467.36	173.08
Izod impact strength (notched)	J/m	BS2782-3: Method 352F:1996	123.97	130.29	204.32
Mould linear shrinkage	mm/mm	BS2782: Part 6: Method 640A:1979	0.05	0.04	0.07
Porosity	%	BS2782-9:Method 920C:1977	4.08	3.18	N/A
Specific Gravity	-	BS2782-6:Method 620A:1991	1.43	1.15	1.07
Water absorption (24 hrs. in water) 23^0C	%	BS EN ISO 62:1999	6.14	4.08	4.05

***Source**: BISMARK et al (2001); JOHNSON (1979); NIELSEN (1994); ROWELL (2001); ANYAKORA (2011)

IV. DISCUSSION

A. Mechanical Properties

From literature, KOLATTUKUDY and CUTIN (1990), it is noted that the primarily effect of fibre reinforcement on the mechanical properties of natural plant fibre composites include increased tensile strength with good bonding at high fibre concentrations, etc. From Figures 1 - 4, it is observed that, while the tensile and flexural strength property values decreased, the modulus properties recorded significant increase with increasing fiber content. The sudden drop in tensile and flexural strength properties after 20% fibre content suggests poor matrix wettability.

Similarly, it is also observed that surface treatment of fibre had an effect on the tensile and flexural strength properties of coconut palm frond fibre composites. This trend shows the very unstable characteristic of the coconut palm frond fibre which is in line with the literature, ROWELL (2001) that the high moisture contents of coconut palm frond gives it some poor characteristics. It also suggests that wettability and poor fibre strength characteristics is responsible for this behavior, and thus may not be desirable to use coconut palm frond fibre in areas requiring medium tensile property application. As expected, the behavior of increasing modulus of rigidity with increasing fibre content with coconut palm frond fibre at the highest value of 40.20MPa at 70% fibre content shows the inherent advantage of the material at loading.

The results shown in Figure 5 indicate that the surface treated coconut palm frond fibre composites exhibited high impact strength property value of 134.77 J/m at 10% fibre content in composite which is 33% higher than the untreated coconut palm frond fibre composites. There is a general trend of drop in the impact strength of treated coconut palm frond fibre composites over the untreated fibre composites at increasing fibre content, thus giving an indication that surface treatment has direct effect on the impact behavior of fibre used as reinforcement, which is observed with both natural and synthetic fibres for reinforcements in composite production, SREEKALA (1997).

Generally, the toughness property of fibres improve 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. The low effect of fibre surface treatment on the impact strength properties of coconut palm frond fibre composite suggests that adoption of expensive extra application of surface treatment on the fibres may only be considered in the areas of outstanding property requirement, which is consistent with the literature, thus, it may not be desirable to surface treat coconut palm frond fibre for reinforcement in areas of low impact properties.

B. Physical and Processing Properties

Specific gravity

From Table 3, it is observed that the specific gravity of 1.43g/cm^3 for treated the coconut palm frond fibre composite compete favorably with those of treated coir, kenaf and talc composites. Thus is an indication that the composites of the coconut palm frond fibre reinforced composites can be competitively accepted 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 coconut palm frond fibre 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.

Water absorption

Studies show that water absorption in natural fibre reinforced composites could lead to a decrease in some properties, Rowell *et al (*1997). 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. From the results in Table 3, it is obvious from the higher value of 6.14% water absorption by the coconut palm frond fibre composites than those of coir, kenaf and talc, that this has direct effect on the mould shrinkage value, which is related to the dominance of the type and morphology of fibre in the composite. Inference is made to the fact that, although the results show the coconut palm frond fibre composite are impervious to humidity and still support deformation, represent advantages in comparison with the relatively brittle gypsum board, which deteriorates in contact with water.

Mould linear shrinkage

Since mould linear shrinkage is expressed as a percentage of change in dimensions of the specimen, it became necessary that the relationship was investigated between the coconut palm frond fibre composites and other fibre composites. From the results in Table 3, it shows that coconut palm frond fibre composites recorded 5% shrinkage value as compared to the shrinkage values of 7% for treated kenaf and 4% for coir composites. When compared with that of 1½ % for talc fibre composites, it shows that the more stable behavior of talc fibres, which is related to the fibre morphology plays a dominant role in the properties of composites, thus, coconut palm frond fibre surface modification is suggested for application in areas of low shrinkage requirement for the production of composites of better structural stability.

Porosity

Generally, a strong adhesion at the fibre-matrix interface is needed for an effective transfer of stress and load distribution throughout the interface. 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, BLEDZKI (1996).

From the results in Table 3, it is shown that the composites of coconut palm frond fibre reinforced polyester composites exhibited the high porosity level of 4.08% as compared to 3.18% for coir reinforced polyester composites. This result is surprising, considering the morphology and short length characteristic of coir, even with the low specific gravity that entailed the use of higher resin content needed for better matrix-fibre bonding. Thus, the short fibre lengths of coir require higher matrix alignment, which may have invariably contributed to this result as compared with the higher porosity values of long fibres of coconut palm frond fibres.

Correlation coefficient of some mechanical properties of untreated and treated coconut palm frond fibre reinforced polyester composites

The correlation coefficient of the mechanical properties of coconut palm frond fibre reinforced composites ranged from 0.911586 to 0.991849 as shown in Table 1. These results showed a case of positive correlation between the untreated and treated natural fibres inferring that there may not be a need to surface-treat the coconut palm frond fibre for application in some areas not requiring high strength properties. The low correlation of tensile strength properties compared to the flexural strength properties of composites of untreated and treated coconut palm frond fibre suggests that some other form of surface treatment may be necessary for certain applications, or be attributed to human and experimental errors during analysis.

Morphological analysis of fractured surfaces and elemental analysis (Energy Dispersive Spectroscopy) of coconut palm frond fibre reinforced polyester composites

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, SCHAFFER et al (1999).

From the scanned electron microscopy (SEM), it is observed that the fibre surfaces were covered with protrusions and small voids in both untreated and treated fibre reinforced composites. The little resin crack and non-major fibre damage recorded with the treated fibre composites suggests that the fibre-matrix bonding improvement was as a result of surface treatment where the fibre surfaces contained the pits, which in principle facilitated resin impregnation and achieved improved bonding.

The general observation of fibre peeling and resin 'craze' with the untreated fibre composites 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 the fibres.

From Table 2 showing an EDS spectrum performed at a micro region of the fibre-matrix surface, the spectrum 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 is achieved, for 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 ash content is associated with the protrusions in treated fibre composites as opposed to the peeling of fibres in the untreated fibre composites. The result also show that coconut palm frond fibre reinforced polyester composites contain higher percentage content of some elements of sodium aluminum and zinc, including silicon, calcium and cobalt at varying quantities. This composition may be ascribed to the improved mechanical properties and resilience of treated coconut palm frond fibre composites. The result of lower ash content in treated coconut palm frond fibre reinforced polyester composites indicates high correlation between ash content and some mechanical properties of the composites.

V. CONCLUSION

The results derived from the evaluation of properties of polyester resin reinforced with coconut palm frond fibres show that comparable properties can be achieved from such fibres, because their properties are similar to those of coir, kenaf and talc composites. Accordingly, these fibres can be suitably employed in the production of low strength building products such as ceilings and partitions.

In terms of practical interest, the coconut palm frond fibre composites can be regarded as valid alternatives to replace some conventional fibres as reinforcement in polyester matrix. The fact that coconut palm frond 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.

ACKNOWLEDGEMENT

The following are acknowledged for their useful assistance in many different ways in this work; National Institute for Pharmaceutical Research and Development, Idu, Abuja; Federal University of Technology, Minna, Niger State, Nigeria; Shetsco Science and Technology Complex, Gwagwalada, Abuja, Nigeria and Federal Institute for Industrial Research, Oshodi, Lagos, Nigeria.

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