ISSN 2249-0582 World J of Engineering and Pure and Applied Sci. 2013;3(1):1
Anyakora, 2013. Tensile Behavior of Coir Reinforced Polyester Composite
OPEN ACCESS

Original Article

Basic Science

Correlation Between Fiber Treatment and Ash Content on the Tensile Behavior of Coir Reinforced Polyester Composite

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ABSTRACT [ENGLISH/ANGLAIS]

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 untreated (as raw) and silane-treated coir reinforced with polyester matrix was studied. The processing parameters included surface treatment and manipulation of fiber content and, the evaluation of ash content in relation to the tensile properties. The results obtained indicate that fiber content and surface treatment can lead to improved tensile strength and modulus of rigidity of coir composite panels. The scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis showed presence of higher ash content, which is indicative of positive effect of improved tensile strength of the treated coir reinforced polyester composite panels. Chiefly noted is the higher percentage calcium in the untreated (as raw) coir, which is associated with aiding to neutralize toxic effects of acid on fiber.

Keywords: Coir, composite, tensile strength, modulus of rigidity, fracture, silane

RÉSUMÉ [FRANÇAIS/FRENCH]

Le développement de la fibre naturelle composite renforcé de produits à base de substituer génie des matériaux traditionnels devient une tendance dans les applications d'ingénierie. Malgré les avantages inhérents à faible coût, de faible densité, la concurrence des propriétés mécaniques et de durabilité, ces déchets agricoles semblent avoir certaines limites de sensibilité aux enjeux environnementaux et microbiens qui empêchent leur utilisation pour la standardisation des produits et la répétabilité. Dans cette étude, les panneaux composites fabriqués à la main lay-up technique du non traitée (comme matière première) et traitée au silane de coco renforcé de polyester matrice a été étudiée. Les paramètres de traitement inclus un traitement de surface et la manipulation de la teneur en fibres et, à l'évaluation de la teneur en cendres par rapport aux propriétés de traction. Les résultats obtenus indiquent que la teneur en fibres et en traitement de surface peut conduire à une meilleure résistance à la traction et le module de rigidité des panneaux de fibre de coco composites. La microscopie électronique à balayage (MEB) et la spectroscopie à dispersion d'énergie (EDS) a montré la présence d'un contenu en cendres plus élevée, ce qui est révélateur de l'effet positif de la résistance à la traction améliorée des panneaux de fibre de coco traités polyester composites renforcés. Surtout noter est le plus fort pourcentage de calcium dans le non traitée (aussi brut) de coco, qui est associé à aider à neutraliser les effets toxiques de l'acide sur la fibre

Mots-clés: Coco, composite, résistance à la traction, module de rigidité, de fractures, de silane

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Accepted/Accepté: September, 2012

Citation: Anyakora AN. Correlation Between Fiber Treatment and Ash Content on the Tensile Behavior of Coir Reinforced Polyester Composite. World Journal of Engineering and Pure and Applied Science 2013;3(1):1-6.

INTRODUCTION

The use ofcoconut palm empty fruit bunch (EFB), often called 'coir' for reinforcement of polymeric matrix for structural components has given rise to the exploration of viable alternatives in engineering material selection and application. These renewable materials have been recently used for making ropes for floor covering and automobile cushion because of their chemical, mechanical and environmental characteristics [1].

Although these natural fiber materials have the 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 fiber reinforced polyester composites that are prone to difficult waste disposal and severe negative health effects including the alleviation of environmental problems related to the disposal of most plant wastes [2].

The Coir fiber obtained from the fruit shell (Figure 1) of coconut palm, *Cocos nucifera* - is short, brown, 'spingy', coarse, rough and highly lignified with correspondingly less cellulose that resists strong microbial attack. It is chemically inert, though, in the presence of strong acids, coir fiber is hydrolyzed, and not affected by light concentration of alkaline These properties make them one of the toughest plant fibers available[3,4].

Nevertheless, researches show that coir, like other natural fibers impart lower durability and lower strength compared to glass fibers, while offering low specific gravity which result in higher specific strength and stiffness than glass fibers. This gives the benefit of bending stiffness in addition to good thermal and acoustic insulation properties along with ease in processing technique without wearing tool [5].

Figure 1: This figure shows the husk of coconut palm fruit

MATERIALS AND METHODS

Materials and Equipment

The coir -fibers were obtained from fruited coconut palm plants, which were felled and used within two weeks. The 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°C. Other chemicals used were the cobalt in styrene, diglycidylethers and phenylsilane procured from Zayo – Sigma Chemicals Limited, Jos, Nigeria.

A two-part mold facility (mild steel flat 4mm thick sheet)- of dimensions 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.

Methods

Coir Extraction

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

Surface Treatment of the Extracted Coir

The process adopted in this work was the silane treatment preceded by the sodium hydroxide treatment. Known weights of extracted coir fibers 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 coir fibers in 2% phenlysilane solution for 24 hours. Subsequently, the product was removed, dried at 60°C and stored in specimen bag ready for use.

Production of Test Specimen

The test specimen panels of 10-70% coir (fiber) content were produced by hand lay-up process. Curing was assisted by placing the composite in an oven operated at 110°C. The moldings were removed from the oven after 30 minutes and conditioned following the BS ISO 1268-3:2000 Instructions and Guidelines. Five (5) test samples each was cut from seven (7) stocks (10-70%) of the surface-treated coir reinforced composite and untreated (as raw) coir reinforced composites.

Composite Characterization

Tensile strength properties were measured on a Universal Testing Machine, Instron, machine of 10KN capacity operated at a crosshead speed of 5 mm/min. The tensile fractured surfaces of both surface-treated coir composite and 'as natural' coir composites with fiber content of 40% were quantitatively analyzed using EVO/MA 10 Scanning Electron Microscope. The elemental analysis of the coir reinforced polyester composites was also carried-out on the SEM/Energy-Dispersive X-ray spectroscopy.

RESULTS

The results of tensile strength and modulus of the tested composite panels of surface treated and untreated (as raw) coir are shown in Table 1 and Figures 2 and 3. The microscopy evaluation of tensile fractured surfaces was conducted on SEM to qualitatively observe the nature of failure of the untreated and treated natural coir reinforced polyester composites are presented in Figures 4 and 5. Similarly, the Elemental Analysis giving the elemental compositions in the specimens is shown in Tables 2 and 3.

Table 1: This table shows effect of percentage fiber on the mechanical properties and correlation of the untreated (as raw) and treated coir - reinforced polyester composites.

Fiber (% wt.)		Tensile Strength (MPa)	Tensile Modulus (MPa)
10	Untreated (as raw)	8.16	28.61
	Treated	13.98	36.15
20	Untreated (as raw)	6.56	36.61
	Treated	14.19	50.05
30	Untreated (as raw)	2.88	43.01
	Treated	8.63	64.86
40	Untreated (as raw)	1.56	51.41
	Treated	6.17	72.92
50	Untreated (as raw)	1.48	57.77
	Treated	4.12	81.78
60	Untreated (as raw)	1.32	65.41
	Treated	3.98	89.32
70	Untreated (as raw)	1.11	74.78
	Treated	2.52	93.11
Correlation Coefficient		*0.957313*	*0.976279*

Figure 2: This figure shows effect of % fiber on the tensile strength of untreated and treated coir reinforced polyester composite

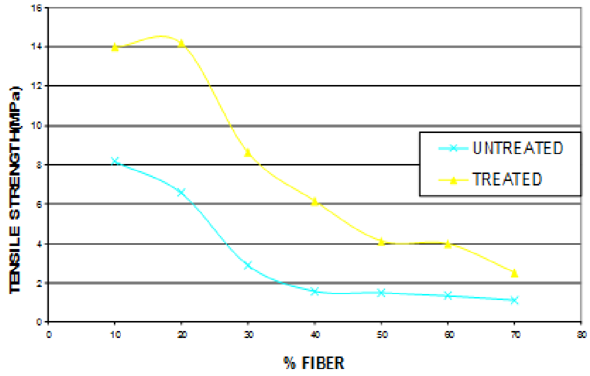


Figure 3: This figure shows effect of % fiber on the tensile modulus of untreated and treated coir – reinforced polyester composite

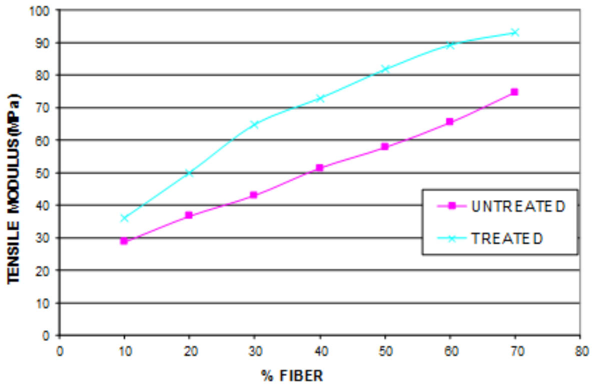


Figure 4: This figure shows SEM micrograph of tensile-fractured surface of 40%fiber/60% matrix of untreated coir composite showing fiber pull-out, peeling and large resin 'crazing".

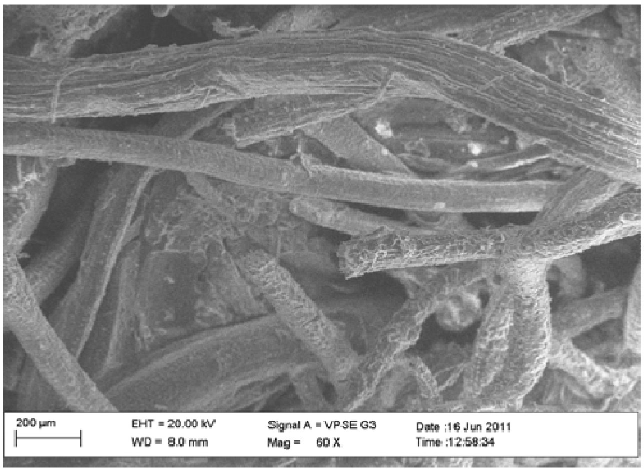
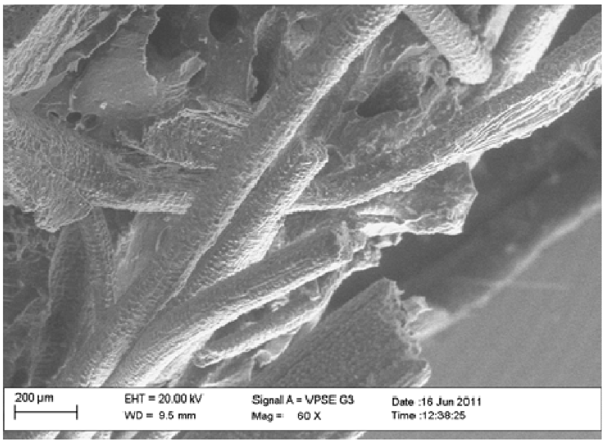


Figure 5: This figure shows SEM micrograph of tensile-fractured surface of 40%fiber/60% matrix of treated coir composite showing gradual fiber failure.



DISCUSSION

From Figures 2 and 3, it can be observed that the tensile strength properties of coir reinforced polyester composites decreased sharply with increasing fiber content while the tensile modulus increased with increasing fiber content consistent with literature [6]. This behavior is common to both synthetic and natural plant short fiber reinforced composites which is indicative of high matrix content needed for effective fiber-matrix bonding.

It is evident that the tensile strength properties of untreated coir reinforced polyester composites exhibited dramatic drop from 8.16MPa at 10% fiber content to 1.11MPa at 70% fiber content, while the treated coir reinforced polyester composites dropped from 13.98MPa at 10% to 2.52MPa at 70% fiber content. Similarly, the 66% average increment between the tensile strength properties of untreated and treated coir reinforced polyester composites is an indication that surface treatment played a major role in the bonding characteristics of the composites. Thus, it could be inferred that the stability and consistent behavior of treated coir in polyester matrix may be applied in the production of standardized products in engineering.

Table 2: This table shows results of elemental analysis (energy dispersive spectroscopy- eds) of untreated coir reinforced polyester composites.

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C K	133.31	0.9506	53.46	0.72	61.78
O K	54.38	0.5091	40.72	0.74	35.33
Na K	1.49	0.8032	0.71	0.09	0.43
Al K	5.91	0.8446	2.67	0.10	1.37
Si K	3.89	0.8827	1.68	0.09	0.83
Ca K	1.96	0.9733	0.77	0.08	0.27
Totals			100.00		

Standard:

C	CaCO3	1-Jun-2011	12:00	AM
O	SiO2	1-Jun-2011	12:00	AM
Na	Albite	1-Jun-2011	12:00	AM
Al	Al2O3	1-Jun-2011	12:00	AM
Si	SiO2	1-Jun-2011	12:00	AM
Ca	Wollastonite	1-Jun-2011	12:00	AM

Table 3: This table shows results of elemental analysis (Energy Dispersive Spectroscopy- EDS) of treated coir reinforced polyester composites

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C K	228.12	1.0535	54.62	0.45	62.53
O K	84.40	0.5163	41.24	0.46	35.44
Na K	4.90	0.7877	1.57	0.08	0.94
Al K	0.41	0.8245	0.13	0.03	0.06
Si K	5.99	0.9000	1.68	0.05	0.82
Ca K	0.77	0.9755	0.20	0.03	0.07
Co K	1.73	0.7629	0.57	0.08	0.13
Totals			100.00		

Standard:

C	CaCO3	1-Jun-2011	12:00	AM
O	SiO2	1-Jun-2011	12:00	AM
Na	Albite	1-Jun-2011	12:00	AM
Al	Al2O3	1-Jun-2011	12:00	AM
Si	SiO2	1-Jun-2011	12:00	AM
Ca	Wollastonite	1-Jun-2011	12:00	AM
Co	Co	1-Jun-2011	12:00	AM

Processing option: All elements analyzed (Normalised) Number of iterations = 6

The tensile modulus of the composites of treated coir reinforced polyester composites showed improvement of 28.61MPa for the untreated coir at 10% fiber content to 74.78MPa at 70% fiber content. This is similar to the improvement of the treated fiber counterpart of 36.15MPa at 10% to 93.11MPa at 70% fiber content. The result of behavior of the coir reinforced polyester composite supports the literature that tensile modulus depends much on the fiber content of reinforced plastics [7].
The high correlation coefficient values of 0.957313 for the tensile strength and 0.976279 for the tensile modulus properties of the untreated and treated coir reinforced composites suggests that some form of surface treatment may be necessary to stabilize the properties for use in areas low-to-medium application [6].
From the scanned electron microscopy (SEM), it is evident that the fiber surfaces were covered with protrusions and small voids in both untreated and treated coir reinforced composites. The result of improved tensile properties between the untreated and treated coir and polyester matrix suggests that the fiber-matrix improved bonding was as a result of surface treatment where the fiber surfaces contained the 'pittings', which in principle facilitated resin impregnation and achieved improved bonding.
There is a general observation of fiber peeling and resin 'craze' with the untreated coir composites which suggests poor fiber-resin bonding. This is different from the treated coir composites where fiber damage showed that transfer of load was gradual till the interface failed before the fiber failure, thus explaining the incompatibility of the interfacial region due to hydrophilicity of natural fiber systems.
The SEM results in figures 54 and 5shows that the short fiber composites of coir exhibited resin 'crazy' failure for both the untreated and treated coir composites. The short lengths of the fibers enabled that the continuous phase (matrix) was carrying the imposed load, and failed as if no reinforcement was incorporated. This is a common phenomenon with all short fiber systems including glass fiber composites, suggesting that the use of short fiber systems has very promising application.
Tables 2 and 3 show the Energy-dispersive X-ray spectroscopy (EDS) spectrum performed on the coir composite. From the spectrum results of the quantitative analysis, it is observed that the treated fiber of coir reinforced composites composed of higher percentages of essential metals and non-metals of carbon, oxygen, sodium, silicon, and less aluminum and calcium than the untreated coir. The presence of low ash content in untreated coir, especially the higher percentage calcium that is associated with aiding to neutralize toxic effects of acid on fiber, is suggestive of lack of corresponding protrusions for effective matrix embedment.

CONCLUSION

From the results, it can be concluded that;

- The tensile strength properties of coir reinforced polyester composites decreased sharply with increasing fiber content while the tensile modulus increased with increasing fiber content.
- The treated coir reinforced polyester composites exhibited higher ash content and lower calcium content than the untreated coir composites.

Thus, indicating a relationship between fiber morphology, elemental composition and tensile strength behavior of coir reinforced polyester composites.

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ACKNOWLEDGEMENT / SOURCE OF SUPPORT

Nil.

CONFLICT OF INTEREST

No conflict of interests was declared by authors.