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Effect of fiber loading and surface treatment on flexural strength of polyester matrix reinforced with oil palm frond fiber wastes

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Abstract

Natural fibers are abundantly available and potentially valuable biomass that is under-exploited. Regardless of many advantages, one shortcoming of use of natural fiber is the deformation after being formed into composite structure which is caused essentially by poor adhesion at the interface with the polymer matrix. In this study, processed oil palm frond fiber was surface - treated with phenylsilane and used in tangled mass and random orientation of varying lengths and diameters in the production of composites by hand lay-up technique with 10% to 70% fiber content in polyester matrix. The 'as natural' (untreated) and treated oil palm frond fiber composites were characterized with emphasis on the effect of fiber content and surface treatment on the flexural strength properties. As expected, the results show that the flexural strength properties of composites of treated oil palm frond fiber decreased with increasing fiber content of 69.65MPa at 10% fiber content to 52.98 MPa at 70% fiber content, unlike the 'as natural' (untreated) counterpart that exhibited virtually no change with increasing fiber content. The flexural modulus of treated oil palm frond fiber reinforced polyester composites increased with increasing fiber content as reported by other researchers. The non-correlation coefficient values between the untreated and treated oil palm frond fiber composites showed the non-stable characteristics of the material similar to most other natural plant fibers. The scanning electron microscopy result showed that the surface-treated oil palm frond fiber systems exhibited gradual but consistent failure pattern indicating improved bonding between the fiber surface and polyester matrix. In principle, the result showed that the prediction of failure behavior of oil palm frond fiber reinforced polyester composite will interest material selection designers especially in the replacement of wooden panels and in areas of less structural application that often find the use of more expensive glass fiber reinforced composites.

Keywords: Oil palm frond; polyester matrix; silane; flexural strength; modulus; fracture; composite

1. Introduction

Most often, new materials are taken as the necessary building blocks for product development and technological breakthroughs in engineering. Advances in technology and development of new products are mostly limited by the availability of the materials used for fabrication. The use of oil palm frond fiber, often regarded as wastes, as new reinforcement material in the plastic matrix is promising in composite development.

The development and application of oil palm(Elaeis guineensis) frond fiber 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 fiber reinforced polyester composites that are prone to difficult waste disposal and severe negative health effects.

Additionally, the development of an agricultural sector of an economy largely depends on value addition to agricultural product. Oil palm frond fibers are presently used for traditional products with low value addition. The failure of natural fiber reinforced polyester composites at low loadings could be as a consequence of the poor fiber - matrix adhesion from poor wetting, necessitating that work in the three distinct areas – fiber system, matrix system and fiber-matrix bonding characteristics becomes expedient.

A study on the effect of fiber loading and surface treatment will no doubt, induce further interest in the use of cheap renewable oil palm frond wastes in composite production. It will also address the issues of prediction of failure patterns and standardized fiber loading parameters as with glass fiber reinforced composites.

Fibers extracted from the oil palm plant consist essentially of the empty fruit bunch and oil palm mesocarp (pressed-fruit) that are highly lignified with moderate cellulose content, and the stem and frond fibers that are of higher cellulose content (Ramli and

Suffain, 2004). Presently, emphasis is placed on the extraction of oil from the fruits, while the fronds, pressed fruit fibers, stems, kernel shells are under-utilized but chiefly treated as wastes that constitute serious environmental problems.

The general drawback of high moisture absorption that result in swelling of these fibers and concerns on the dimensional stability of natural plant fiber composites affect their use as reinforcements in polymer matrix. In oil palm for example, the moisture update is high (12.5%) at 65% relative humidity and 20%, by dry fiber and 14.6% by wet fiber (Sanadi et al., 1985). Findings show that good fiber- matrix bonding decrease the rate and amount of water absorbed by the composite, effective surface treatment of natural plant fibers reduces feathering by encasing the cellulose fibers, it protects the fibers from breakdown due to oxidation and consequent increased strength of the reinforced composite(Bismarck et al., 2001). The strength of a joint depends on both the cohesive strength of the matrix (or fiber) but also on the degree of adhesion to the bonding surface. Adhesion at the fiber-matrix interface occurs within a layer of molecular dimension and the bond strength can be reduced to nothing by surface contaminants which themselves weakly adherent and which prevent contact between fiber and matrix (Rowell et al., 2001).

Fig. 1. The oil palm tree.

Fig. 2. Tangled mass fiber of oil palm frond.

2. Materials and methods

2.1. Materials and equipment

The oil palm frond fiber wastes were obtained from fruited oil palm plants, the were felled and used within two weeks. The frond fiber 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 25oC. 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 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 as shown in figure 3.

Fig. 3. A-two part mould (assembled) fabricated at danata and sawoe workshop, Abuja.

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.

2.2. Methods

2.2.1. Oil palm frond fiber extraction

The collected oil palm frond 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 fibers were separated, re-washed and dried in the forced-air circulation type oven. The fibers were subsequently weighed and percentage yield determined. The fiber systems 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.

2.2.2. Surface treatment of the extracted fiber

The process adopted in this work was the silane treatment preceded by the sodium hydroxide treatment. Known Weights of extracted oil palm frond fiber systems 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 fiber systems 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% coir fiber content were produced by hand lay-up process. Curing was assisted by placing the composite in an oven operated at 110oC. The mouldings were removed from the oven after 30 minutes and conditioned . Five test samples each were cut from seven stocks (10-70%) of the surface-treated coir reinforced composite and 'as natural' coir reinforced composites.

2.2.5. Composite characterization

The three-point loading technique of flexural strength test, complying with BS 2782-10:Method 1008B:1996 Instructions and Guidelines was carried-out on a Universal Testing Machine, Instron, Model 3369. The fractured surfaces of both surface-treated coir composite and 'as natural' oil palm frond composites with fiber content of 40% were quantitatively analyzed using EVO/MA 10 Scanning Electron Microscope. The elemental analysis of the oil palm frond reinforced polyester composites was also carried-out on the SEM/Energy-Dispersive X-ray spectroscopy.

3. Results

The results of flexural strength and modulus of the tested composite panels of surface treated and 'as natural' oil palm frond are shown in Table 1 and Figures 4 and 5. The microscopy evaluation of fractured surfaces was conducted on SEM to qualitatively observe the nature of failure of the 'as natural' (untreated) and treated oil palm frond reinforced polyester composites are presented in Figures 6 and 7.

Table 1
Effect of percentage fiber on the mechanical properties and correlation of the untreated and treated oil palm frond fiber – reinforced polyester composites

% Fiber (by wt)		Flexural Strength (MPa)	Modulus (MPa)
10	Untreated	2.64	20.10
	Treated	69.65	98.22
20	Untreated	2.89	21.12
	Treated	66.87	132.34
30	Untreated	3.56	32.15
	Treated	62.83	179.54
40	Untreated	3.74	38.18
	Treated	60.31	201.03
50	Untreated	3.82	40.23
	Treated	58.67	245.45
60	Untreated	4.40	44.25
	Treated	55.35	298.67
70	Untreated	4.87	47.28
	Treated	52.98	335.76
Correlation Coefficient		-0.990504	0.963412

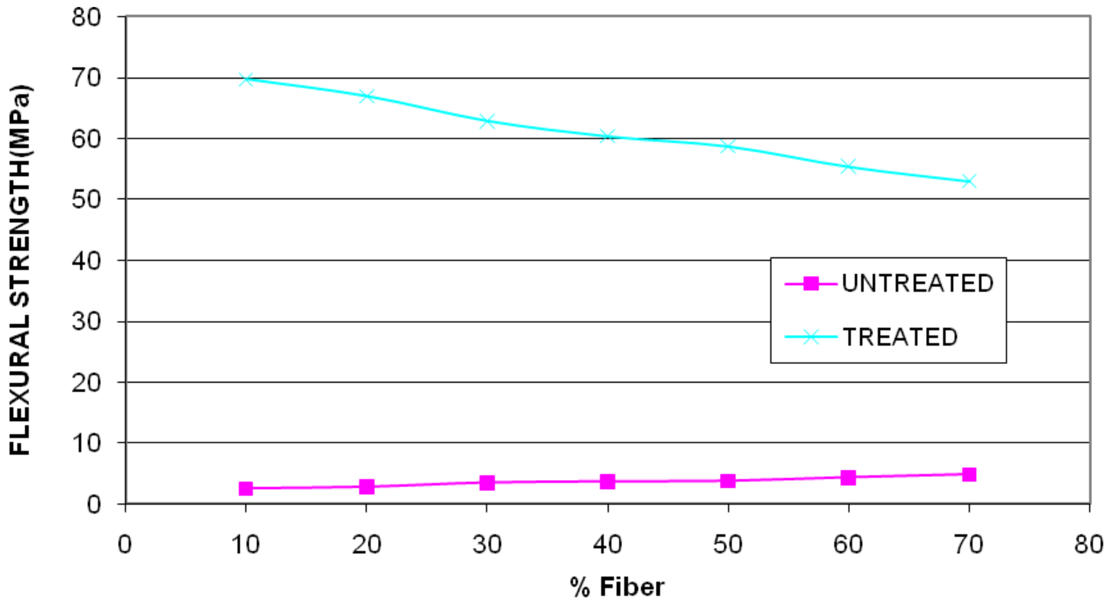

Fig. 4. Comparison of effect of % fiber on the flexural strength of 'as natural' (untreated) and treated oil palm frond fiber – Reinforced polyester composite.

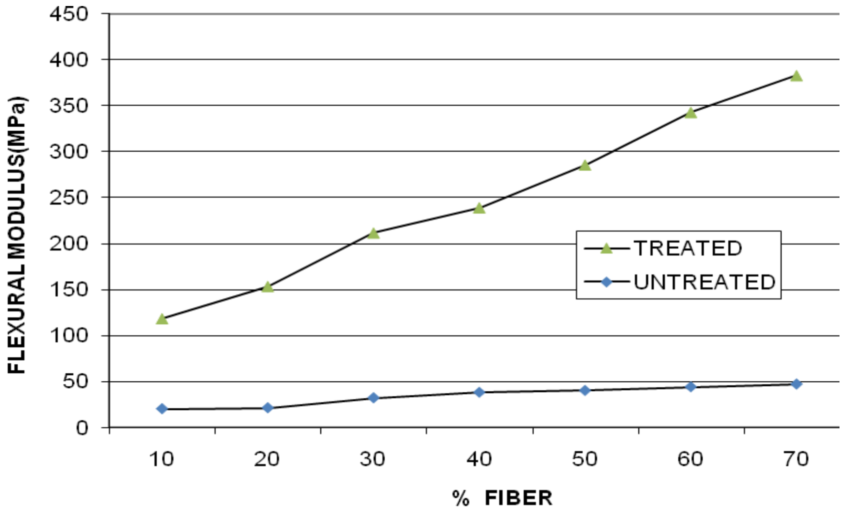

Fig. 5.Comparison of effect of % fibre on the flexural modulus of 'as natural' (untreated) and treated oil palm frond fiber – reinforced composite.

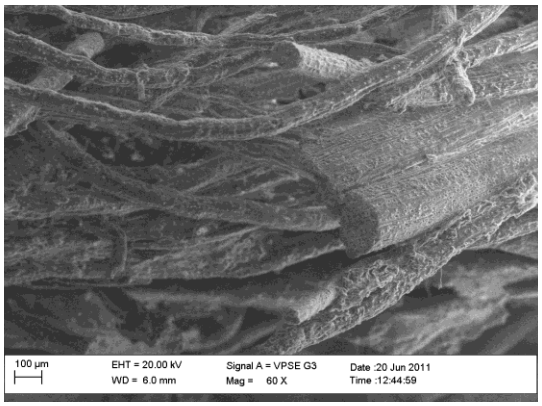

Fig. 6. Fractured surface of 'as natural' (untreated) oil palm frond fiber composite showing fiber peeling from the resin area.

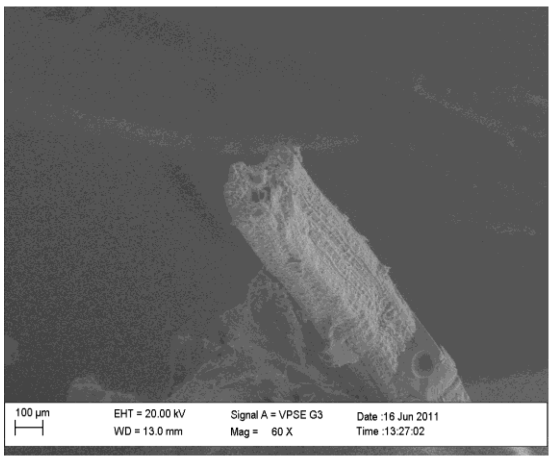

Fig. 7. Fracture surface of a treated oil palm frond fiber composite showing fiber damage.

4. Discussion of results

There is a general trend of improved flexural strength properties with the treated fiber composites as shown in figure 4, with the highest value of 69.65MPa at 10% fiber content and least value of 52.98MPa at 70% fiber content in the composite. It is observed that at 10% fiber content, the surface treatment process caused an increment of 2538.26% of the flexural strength property. Similarly, an increment of 987.89% was recorded between the 'as natural' and treated oil palm frond composite at 70% fiber content, showing that flexural strength values increased in the 'as natural' fiber but decreased in the treated oil palm fiber composites. It is generally noted that flexural strength properties of most materials improve with increasing fiber content which is different with the result of oil palm frond composites. This may be ascribed to the unstable characteristics of the part of plant structure that is impervious to high moisture content. Following the results recorded, it may not be desirable to employ surface treatment process where cost is considered optimum.

As expected (Bledzki, 1996), the treated oil palm frond fiber composites showed the behavior of increasing flexural modulus with increasing fiber content. The 'near' non-effect of fiber content on the flexural modulus with the 'as natural' oil palm frond fiber composites further shows the unstable characteristic of the frond part of oil palm plant. It is observed that flexural modulus increased with increasing fiber content in the composite, which gave the high correlation coefficient value between the 'as natural' and treated oil palm frond fiber composites, thus supporting the literature.

From the SEM result in figure 6, it is evident that poor bonding in the 'as natural' (untreated) oil palm frond fiber and the matrix caused the peeling effect in the matrix area. The frond fibers tend to pull-out unlike in Figure 7 of the treated oil palm frond fiber composite where the observed fracture surface exhibited gradual failure pattern, indicating that the bonding between the treated fiber and the matrix was improved. This characteristic is suggestive of presence of sites for matrix penetration provided by the surface treatment process. The morphology of fractured treated oil palm frond fiber composites showed that the composites failed by a combination of fiber fracture and fiber pull-out indicating that fiber fracture was a major mechanism in the strength of the composite. The results of the fracture also shows that the reinforcing fibers were damaged during stress loading suggesting that the mechanism of fracture is dependent on the fiber content, fiber characteristics and bonding parameters.

As noted by Rowel et al in 1997, there are three main factors affecting the modulus of a fiber reinforced composite; fiber modulus, fiber loading and fiber aspect ratio. Since these three factors were kept relatively constant, it can be inferred that the presence of silane led to a significant improvement in the fiber-matrix interfacial bonding. The improvement obviously resulted in an increase in the efficiency of stress transfer from the matrix to the fiber.

5. Conclusion

From the results, it is concluded that:

Increasing fiber content caused the decreasing flexural strength of treated oil palm fiber composites, but had 'almost' no effect on the 'as natural' (untreated) oil palm frond fiber systems.

Increasing fiber content caused the increasing flexural modulus of treated oil palm fiber composites, but had 'almost' no effect on the 'as natural' (untreated) oil palm frond fiber systems.

Failure characteristics of treated oil palm frond fiber composites may be adopted for the prediction of behavior of the products.

Surface treatment of oil palm frond fiber systems is desirable in areas of high flexural modulus application, and where cost is less desirable.

6. Recommendation

From the results, it could be seen that oil palm frond fibers, often regarded as wastes can be converted into useful end at areas of flexural property application, thus it is recommended, from practical interest that, oil palm frond fiber may be regarded as valid alternatives to replace some conventional fiber systems as reinforcement in polyester matrix. In spite of their relatively low flexural strength, the composites of oil palm frond fiber are stronger than gypsum board and can be considered for panels or ceilings. The fact that these natural plant fiber 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.

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