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Effect of silane treatment on the impact strength properties of oil palm (EFB) fiber- reinforced polyester composites

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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, the effect of silane treatment on the impact strength properties of oil palm empty fruit bunch fiber - reinforced polyester composites was evaluated. The oil palm EFB fibers were used in two distinct tangled mass; 'as natural'-untreated and treated forms. Composites of EFB fiber wastes up to 70% by weight in polyester matrix were fabricated by hand lay-up technique and analyzed. As expected, the results show that the composites of oil palm EFB fiber treated with phenylsilane exhibited improved impact strength properties from 10% fiber content to 60% fiber content after which problems of poor wettability set-in. The result s permitted the comparison of the impact strength performance of the 'as natural' and surface-treated oil palm EFB fiber composites, for which an indication is made that oil palm EFB fiber represent a promising alternative to wood fillers and glass fiber in the production of composites for medium impact strength application in engineering.

Keywords: Oil palm; polyester matrix; silane; impact strength; fracture; composite; empty fruit bunch (EFB); HDPE

1. Introduction

With the prosperity of our economy and the improvement of our living conditions, people are asking for better living environment. Various kinds of materials have emerged and are being developed for use in engineering and in various aspects of the economy. The development of fiber reinforced composite-based products to substitute traditional engineering materials is becoming a trend in engineering application.

Particularly attractive are the new materials in which a good part is based on natural renewable resources like the oil palm (Elaeis guineensis) EFB fiber. Oil palm is one of the most economical and very high potential oil-producing crops. Oil palm empty fruit bunch fiber and oil palm mesocarp (pressed-fruit) fiber are two important types of fibrous materials left in the palm oil mill, but they are good potentials for exploitation especially the empty fruit bunch (Fig. 2) which is of highest fiber. Oil palm empty fruit bunch fiber is highly lignified with moderate cellulose content, while the fibers from the stem and frond are of less lignin and more cellulose content. Depending on the mode of processing, oil palm empty fruit bunch fiber is resistant to attack by weak acids and alkaline (Ramli and Suffain, 2004).

These trees (Fig. 1) are in abundance in Nigeria and have been in use for hundreds of years for many applications. Their use is becoming increasingly important because of their chemical, mechanical and environmental characteristics (Katz and Milewski, 1987). However, not much has been carried out to characterize these class of materials with a view to exploring their potentials as engineering materials. 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.

But the general drawback of high moisture absorption that result in swelling of the 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).

Generally, the absorption of moisture by the fibers is minimized in the composite due to encapsulation by the polymer. 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 fiber but with some increased costs (Rowell et al., 2001).

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. 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.

The role of the surface treating reagents therefore is primarily to block the hydroxyl groups on natural fibers thus making them more hydrophobic as these surface modifiers penetrate and deposit into lumens of cell wall of fiber, minimizing the possible extent of moisture ingress (Jang and Yang, 2000). Other role of surface treatment of natural fibers includes the means for stress relaxation in situations of different dimensional changes of matrix and fiber when the composite is deformed.

It is noted that during composite production, the metallic surfaces of the handling chambers often experience wear with time showing that fiber surfaces is responsible. It thus infers that appreciable damage is done to the fiber during the processing, and to withstand destruction, the fibers must be capable of absorbing energy imparted to it during stress application, and releasing this energy upon removal of the stress, without occurrence of failure. Therefore, the oil palm EFB fiber proposed for use as alternative reinforcing material in polyester composites, should be processed such as becoming tough to absorb great amount of energy to resist early fracture as needed in most engineering application(Kempster, 1979).

The development and application of oil palm EFB 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 including the alleviation of environmental problems related to the disposal of palm wastes.

Fig. 1. The oil palm tree.

Fig. 2. The bunch of oil palm fruit.

2. Materials and methods

2.1. Materials and equipment

EFB fibers were obtained from fruited oil palm plants, they were felled and used within two weeks. The EFB 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 of liquid properties: monomer - styrene, acid number(solids) : 14-19, specific gravity : 1.04, flash point range : 23-38^{o}C, viscosity: 0.24 Pa.s at 25^{o}C. from Norpol chemical company, including 1% cobalt in styrene and diglycidylethers procured from dickson chemicals Ltd, Lagos, Nigeria. The 2% phenlysilane silane was procured from Zayo – Sigma Chemicals Ltd.

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 and Sawoe mechanical workshop, Abuja, as shown in Figs. 3 and 4, was adopted in the production of test specimen plates.

Other equipment used were:

(i) Impact Testing Machine: Amsler - Nominal energy 450J, Maximum Impact velocity - 5.23m/s, continuous adjustable pendulum.

(ii) Compact Scale/Balance : Model – FEJ, Capacity – 1500g, 1500A.

2.2. Methods

2.2.1. Oil palm EFB fiber extraction

The collected oil palm plant EFB 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 oil palm EFB fibers

The process adopted in this work was the silane treatment preceded by the sodium hydroxide treatment.

2.2.3. Production of test specimen

The test specimen panels of 10-70% fiber 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 following the BS

Fig. 3. A two-part mould (cope and drag).

Fig. 4. A-two part mould (assembled).

ISO 1268-3:2000 instructions and guidelines because of the anticipated changes in humidity level in the laboratory. 5 test samples each were cut from 7 stocks (10-70%) of the surface-treated fiber composite and ‘as natural’ fiber composites to dimensions of 200mm x 200mm x 5mm.

2.2.4. Composite characterization

The Izod Impact test was conducted according to BS2782-3: Method 352F:1996. During the test, the notched specimens cut into dimensions of 200mm×200mm×5mm were mounted in-between machine supports and the pendulum was allowed to strike the specimen after swinging from a fixed height. The support displacement of machine was 240mm. Since the machine scale is graduated on 0 to 10 (kg-m), the first hammer was lifted and locked at the top and then gauge adjusted on 10 (kg-m), then The number on the scaled part was then read as presenting the impact strength of the specimens after dropping hammer. This test was repeated 5 times. The results obtained are presented in Tables 1.

2.2.5. The scanning electron microscopy of fractured surfaces

The impact fractured surfaces of both surface-treated fiber composite and ‘as natural’ fiber composites with fiber content of 40% were quantitatively analyzed using EVO/MA 10 scanning electron microscope as shown in figures 6 and 7.

3. Results and discussion

The results of effect of oil palm EFB fiber content and silane treatment on the impact Strength properties of the composite panels is presented in Table 1 and Fig. 5.

Table 1
Effect of percentage fiber on the impact strength properties and correlation of the untreated and treated oil palm EFB fiber – reinforced polyester composites

% Fiber (by wt)		Izod Impact Strength (J/m)
10	Untreated	132.99
	Treated	426.97
20	Untreated	125.15
	Treated	386.21
30	Untreated	118.42
	Treated	326.14
40	Untreated	103.79
	Treated	287.43
50	Untreated	91.56
	Treated	212.98
60	Untreated	83.76
	Treated	176.35
70	Untreated	76.24
	Treated	98.40
Correlation Coefficient		0.990105

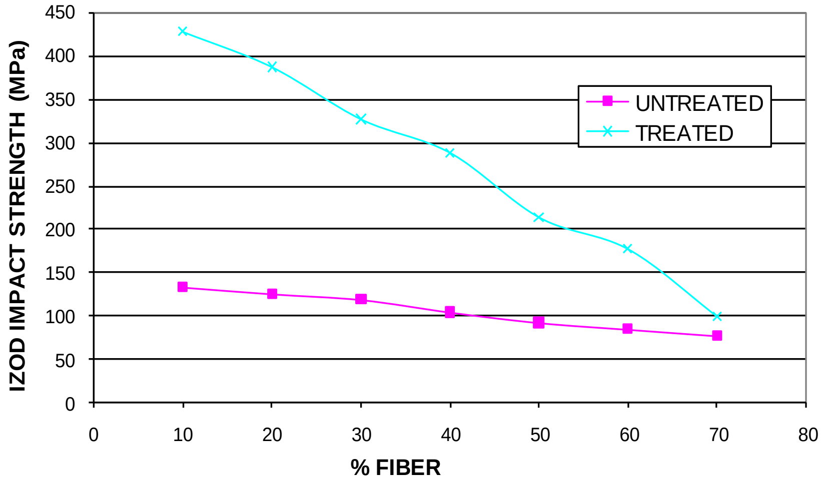

Fig. 5. Comparison of effect of %fiber on the izod impact strength of untreated and treated oil palm EFB fiber - reinforced polyester composite.

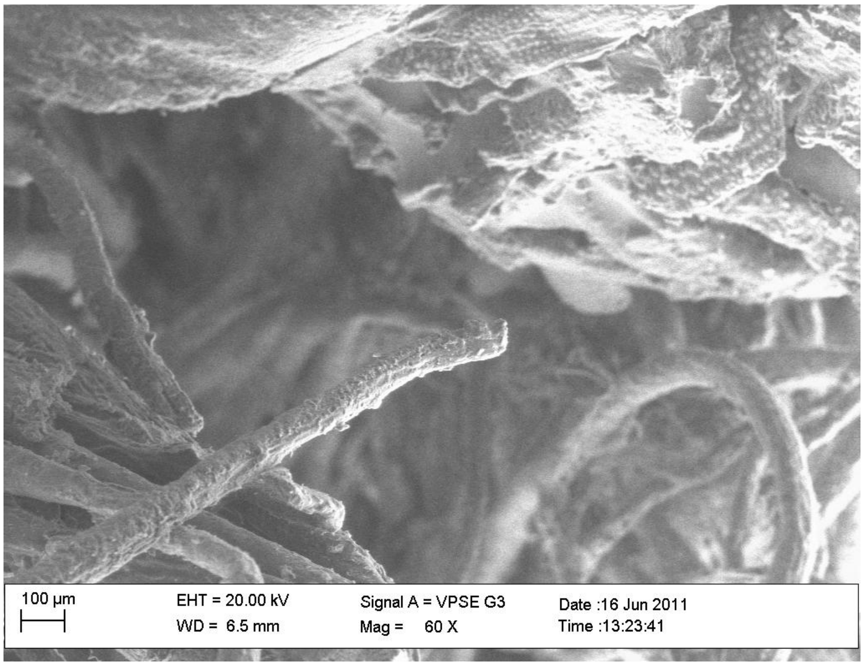

Fig. 6. Impact fractured surface of an untreated oil palm EFB fiber composite showing both fiber pull-out and peeling in large resin area.

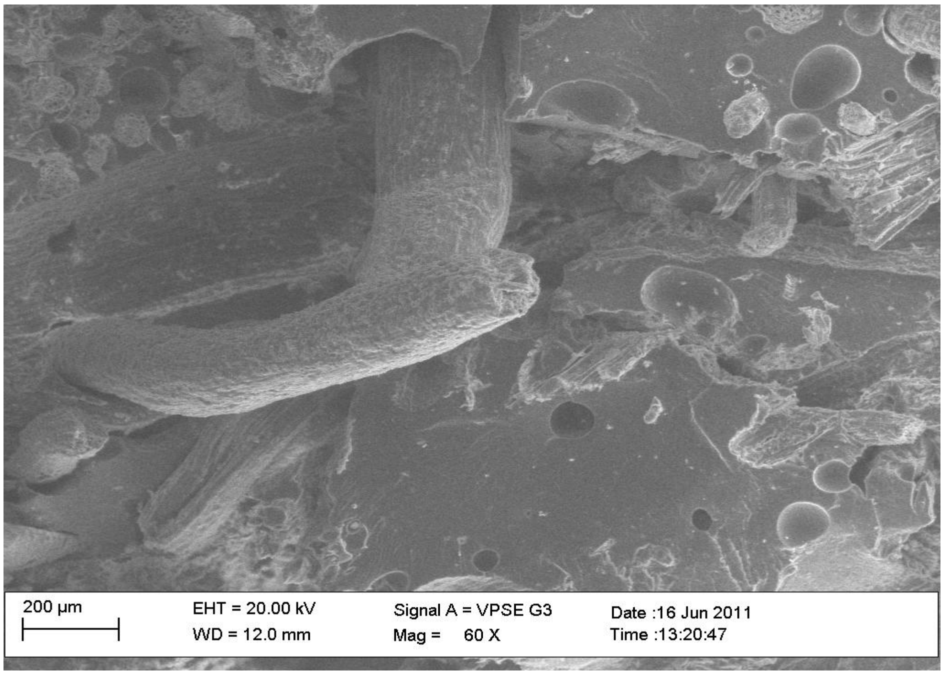

Fig. 7. Impact fractured surface of a treated oil palm EFB fiber composite showing fiber pull-out.

4. Discussion of results

From the results in figure 5, it is shown that the impact strength properties of oil palm EFB fiber reinforced polyester composite decreased with increasing fiber content. The surface treated EFB fiber composites exhibited an outstanding impact strength property value of 426.97J/m at 10% fiber content in composite, an increase of 221% value of the ‘as natural’ untreated EFB fiber composites. This improvement was consistent till at about 50% fiber content when the effect of silane treatment started to drop to a difference of2.3 % at 70% fiber content. At higher fiber content, when wettability defects set-in, the energy absorbed by the fibers started to drop leading to very significant drop in impact strength of the oil palm EFB fiber reinforced composites.

This behavior is consistent with literature for the use of natural and synthetic fibers as reinforcement (Sreekala et al., 1997 and Rozman et al., 2001) which showed that the impact strength of various EFB reinforced polymer composites showed a decreasing trend as the filler loading increased, for which in the EFB-HDPE showed significant impact strength than other systems, which is attributed to the ability of HDPE matrix undergoing plastic deformation in the form of crazing and shear yielding during the crack propagation.

The high impact strength property of the short oil palm empty fruit fiber composites shows that they can be applied as an alternative fiber to glass fiber in most medium impact strength application, and most importantly, can be used in areas of similar application with natural coconut palm EFB fibers that are resilient with highly durable behavior that makes them suitable for most automobile application (Goulart et al., 2000).

The correlation coefficient of 0.990105 of impact strength properties of the 'as natural' –untreated and treated oil palm EFB fiber reinforced polyester composites suggests that some form of surface treatment may be necessary in areas of impact strength applications needing oil palm EFB fiber. This is necessary as it will be desirable to use the treatment in removing the problem of formation of effective bond at the interface of polar hydroxyl group of natural oil palm EFB and the non-polar matrix which is worsened by the presence of ester compounds in oil, which often affect the efficiency of silane treatment(Rozman et al., 2001).

4.1. The scanning electron microscopy of fractured surfaces of oil palm EFB reinforced polyester composites

Generally, the toughness property of fibers improve with surface treatment especially with the notched samples necessitating that the fibers bridged the cracks while increasing the resistance of the propagation of the crack and further limiting fiber pull-out. The significant effect of fiber surface treatment on the impact strength properties of the oil palm EFB reinforced polyester composite is consistent with the literature(Zhang, 2001; Singh, et al., 1994).

Schaeffer et al., noted in1999, that fracture in polymer-matrix composites usually begins with cracking of the fiber 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 fiber at any point along its length, the stresses carried by the fiber in the vicinity of the crack must be transferred to the surrounding matrix and other fibers, so much so that, if the surrounding matrix and fibers 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 fibers can no longer be carried by the un-cracked matrix, at which point, ultimate fracture of the composite occurs.

From the scanned electron microscopy(SEM) observation, it is evident that the short fiber surfaces of oil palm EFB were covered with protrusions and small voids in both sets of reinforced composites. There is a general observation of fiber pulling-out of matrix with the both sets of composites which suggests poor fiber-resin bonding. Under loading, the resin at point of load application absorbed the load which, when transferred to the embedded short discontinuous fibers started peeling, causing the resin to go through early failure.

Although, the SEM microscopy showed ales fiber pull-out with gradual fiber damage in the surface-treated oil palm EFB fiber reinforced polyester composites, this is an indication that transfer of load from the matrix to the reinforcing fibers was gradual till the interface failed before the fiber failure, thus achieving the importance of natural fiber surfaces treatment necessary to block the hydroxyl groups to make them more hydrophobic.

5. Conclusion

From the results, it is shown that the values of impact strength properties of oil palm EFB composites are outstanding which could be improved with suitable fiber surface treatment. The exhibition of dimensional stability is evidence of effect of surface treatment, for which the relatively high dispersion and variance with changing fiber content may be taken is a consequence of the intrinsic variability found on natural plant fibers that ranges from their non-uniform cross-section that often preclude property prediction in application.

In terms of practical interest, the oil palm EFB fiber composites may be regarded as valid alternative to replace some conventional fiber systems as reinforcement in polyester matrix especially in areas of medium-to-low impact strength property requirement. Due to their higher impact strength properties, these composite materials may be suitably applied in areas where gypsum board and wooden panels and ceilings are in present use. The fact that these oil palm EFB 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.

Further work

Further research is suggested in the area study of molecular interacts between oil palm EFB fibers and polymer matrix. This will aid in predicting the behavior of products of oil palm EFB polymer reinforced composites.

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