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Effect of fibre loading and treatment on porosity and water absorption correlated with tensile behaviour of oil palm empty fruit bunch fibre reinforced composites

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Abstract. The challenge of replacing conventional plastics with biodegradable composite materials has attracted much attention in product design, particularly in the tensile-related areas of application. In this study, fibres extracted from oil palm empty fruit bunch (EFB) were treated and utilized in reinforcing polyester matrix by hand lay-up technique. The effect of fibre loading and combined influence of alkali and silane treatments on porosity and water absorption parameters, and its correlation with the tensile behaviour of composites was analyzed. The results showed that tensile strength decreased whilst modulus of elasticity, water absorption and porosity parameters increased with increasing fibre loading. The composites of treated oil palm EFB fibre exhibited improved values of 2.47 MPa to 3.78 MPa for tensile strength; 1.75 MPa to 2.04 MPa for modulus of elasticity; 3.43% to 1.68% for porosity and 3.51% to 3.12% for water absorption at respective 10 wt.% fibre loadings. A correlation between porosity and water absorption with tensile behavior of composites of oil palm EFB fibre and positive effect of fibre treatment was established, which clearly demonstrate a connection between processing and physical properties with tensile behavior of fibre composites. Accordingly, a further exploitation of economic significance of oil palm EFB fibres composites in areas of low-to-medium tensile strength application is inferred.

Keywords: tensile strength; porosity; water absorption; fruit bunch; composite

1. Introduction

Current issues of use of natural fibres have been acclaimed for the unique role in ecological cycle, their abundance, plentiful supply and relative cheapness matched by the ease and readiness with which these resources can be swiftly replenished. Consequently, these 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; but is of lower specific gravity resulting in higher specific strength and stiffness than glass fibres.

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It is noted that, with the fortunes of our economy and development in our living conditions, people are asking for better living environment with less expensive but functional products. Presently, the quest to replace conventional plastics with biodegradable materials-reinforced composite seems to be speedily gaining greater attention, especially in the area of remedying the limitations of natural fibre materials to exhibit structural and functional stability during storage and use.

The general drawback of high moisture absorption of the natural fibres that result in swelling of the fibres and concerns on the dimensional stability of the natural fibre composites affect the use of natural fibres 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 fibre and 14.6% by wet fibre (Sanadi *et al*. 1985). With increasing moisture content, the torsional stiffness of fibres decreased by about 50% (between 25% and 90% relative humidity at room temperature), including the maximum in fibre tensile strength and tensile modulus found at low moisture contents (Swamy 2003). When relatively dry, fibres show low tensile properties due to a poorer stress distribution within their structure, which effect is not restricted to plant and vegetable fibres, but also occur in synthetic fibres.

The absorption of moisture by the fibres 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 fibre but with some increased costs (Rowell *et al*. 2001).

In order to address some of the drawbacks of use of natural fibres, suitable surface treating reagents are employed to block the hydroxyl groups thus making them more hydrophobic. These surface modifiers often penetrate and deposit into lumens of cell wall of fiber, minimizing the possible extent of moisture ingress. Bledzki and Gassan (1996) reported that surface treatment of natural fibres are more involved, and tend to increase adhesion by promoting the process in which adhesion occurs, such as the effect of chemical treatments for the physical and chemical modification to increase specific adhesion properties.

Oil palm, as one of the most economical and very high potential oil-producing crops, is essentially composed of stem, frond, EFB and pressed-fruit fibre, of which the latter two are the important types of fibrous materials left in the palm oil mill. Issues are abound of generated huge amount of biomass in the form of trunks, fronds and EFB, of which only a small percentage of this is used for dumping at plantation sites or processed to produce fibres for mattress, mulching mat, for which they offer great potentials for exploitation.

Largely, it is noted that the reinforcement by short and discontinuous fibres, like the oil palm EFB impregnated in polymer system cannot be as straight forward since only the polymer matrix is continuous, thus the tensile stresses experienced by fibres must derive from shearing forces transmitted by the resin. This condition enables that clearly, the greater the mean stress carried by the fibres the greater will be the modulus enhancement, as considered of the tensile strengths where a critical fibre length, equal to the shortest length which will allow the stress in the fibre to reach the tensile fracture stress. The length depends upon the ratio of the tensile moduli of the two phases, the strength of the interfacial bond, and the shear strength of the polymer.

Fortea-Verdejo *et al*. (2015), in their work, on tensile properties of various plant fibre-reinforced polymers, compared the various renewable engineering polymers and commercially available randomly oriented glass fibre-reinforced polymers and reported that composites containing random short plant fibres possess similar properties to randomly oriented glass fibre reinforced plastics (GFRP) at a lower overall part weight, including the better offer performance of unidirectional plant fibre-reinforced polymers than randomly oriented GFRP, which espouses the potentials for adaptation in applications requiring better mechanical performance, particularly in applications where cost of use of synthetic fibres is less attractive.

Allied studies on composite materials included the works of Azman *et al*. (2010), which inferred that oil palm fibers and commercially available polymers offer some specific properties which could be compared to conventional synthetic fiber composite materials. The finding was buttressed the works of Rozman *et al*. (2005) reported that oil palm EFB consisting of a bunch of fibre materials have been used in the production of potassium fertilizers as well as mulching even as they are of high fibre content, and that a great deal of potential is derived from using oil palm EFB as fillers in thermoplastic composites, which finds useful applications in engineering as well as alleviating environmental problems related to the disposal of oil palm wastes and produce materials, including the offer as a favorable balance of quality, performance and cost.

Additionally, Yusoff *et al*. (2010) worked on Mechanical properties of short random oil palm fibre reinforced epoxy composites using by hand-layup technique and reported that the tensile and flexural properties showed a decreasing trend with increasing fibre loading. The examination of physio-chemical properties of moisture content, lignin, extractives, alpha cellulose, and ash content, fiber dimensions of oil palm EFB fibre for its suitability and potential as raw material in the production of acoustic board production by Anyakora *et al*. (2011) showed that the fiber yields were exceptionally high, with good strength properties at a maximum pulping temperature of 156^{o}C with an average fiber yield of 42.25%. The results also indicated that the burst factor and tear index of oil palm EFB contain 68 % medium fibre.

Yeow and Lik (2015) reported in their work on epoxy empty fruit bunch palm fibre mat composites - the effects of fibre weight fraction on mechanical behaviour that, the EFB loaded specimens showed measurable improvement in mechanical properties as compared to pure epoxy, consequent upon which the composite loaded with 27% EFB fibres achieved the highest increment in the measured tensile strength (14.8%) and Young's modulus (87%), including the increasing fibre content that led to a reduction in elongation at break.

Another noticeable importance of use of EFB of oil palm in composite application was in the works of Chee *et al*. (2010) reported in their study on the processing of various oil palm derived cellulose loading ranging from 0 to 30wt.% into low density polyethylene biocomposites for use as packaging material that, in order to sustain the stable flow of mixture, higher torque value was required of the mixture as the cellulose loading was increased, including , the monotonically decreasing elongation at break and impact strength with the increasing of cellulose loading.

The related works of Arif *et al*. (2009) on the effects of chemical treatment on oil palm empty fruit bunch reinforced high density polyethylene composites showed that chemical treatments were effective in the reduction of water absorption of the composites while the treated fibers with 3% MTS showed highest reduction in water absorption and higher increase in tensile strength and modulus properties when compared to untreated fibers and fibers treated with other types of chemicals.

The behavior of cellulose-based composites is often affected by the hydrophilic character of the fibres, which is related to a low interfacial compatibility with hydrophobic polymeric matrices, as well as with a loss of mechanical properties after moisture uptake. This enables the employment of suitable surface modification of fibres to reduce the hydrophilic character to improve the strength of their adhesion to the matrix as presented by Belgacem and Gandini (2012).

Aznizam and Norfhairna (2008) worked on the influence of untreated and benzoylated oil palm empty fruit bunch short fiber loading on the mechanical properties of the polyvinyl chloride composite and reported that the tensile and impact strength of untreated and benzoylated oil palm empty fruit bunch composites decreased whereas the tensile modulus increased with increasing fiber loading from 0 to 40 phr. They inferred that the benzoylated oil palm empty fruit bunch was able to improve the tensile properties and impact strength of composites when compared to the untreated fiber.

Similarly, in the review work of Mohanty *et al*. (2012) on Surface modifications of natural fibers and performance of the resulting biocomposites, issues of various surface modifications of natural fibers to improve fiber-matrix adhesion was presented, thus espousing the importance of quality of fiber-matrix interface as vital factor in the determination of final performance of the composite materials.

Additional works of Khalid *et al*. (2008) on effect of compatibilizers on the mechanical and morphological properties of the PP-cellulose derived from oil palm empty fruit bunch fiber and PP-oil palm empty fruit bunch fiber biocomposites showed that the tensile strength of composites improved significantly at 2.0wt% of MAPP concentration, which they inferred was related to the enhanced fibre-matrix adhesion, as a consequence of crosslinking of multifunctional monomer with the hydroxyl groups of cellulose. Also, the importance adhesion between fiber and matrix was presented in works of Jacob *et al*. (2005) on study of advances in characterization of interfaces and fiber surfaces in lignocellulosic fiber-reinforced composites, who inferred that treatment of lignocellulosic fibre surfaces and polymer matrix surface could be modified to obtain a strong interface.

Similarly, Razak and Kalam (2012) studied the effect of oil palm empty fruit bunch size on the mechanical properties and water absorption behaviour of oil palm empty fruit bunch/PPnanoclay/PP hybrid composites and reported that the increase of oil palm empty fruit bunch fibre size increased the water absorption capability of composites mainly due to the hydrophilic nature of oil palm empty fruit bunch fibres. Also, Sreekala *et al*. (2002) worked on water sorption kinetics in oil palm fiber reinforced phenol formaldehyde composites and oil palm/glass hybrid fiber reinforced PF composites and reported that composite with 10wt.% fiber loading exhibited maximum water uptake, with inference that hybridisation of the oil palm fiber with glass considerably decreased the water sorption by the composite.

Fatra *et al*. (2016) studied the effect of alkaline treatment on the properties of oil palm empty fruit bunch fiber-reinforced polypropylene composite and reported that the tensile and flexural strength properties of oil palm empty fruit bunch increased with increase of fiber length and concentration of the oil palm empty fruit bunch ash extract solution. However tensile strength decreased with a longer soaking time. They reported also that the water absorption increased with lower and higher concentrations of oil palm empty fruit bunch ash extract solution and fiber length and with shorter and longer soaking times, including the achievement of highest tensile strength (20.100 MPa) at 5%wt alkaline concentration, while the lowest water absorption (0.324%) was achieved at 10%wt alkaline concentration.

Rozman *et al*. (1998) worked on the mechanical properties of composites consisting of high-density polyethylene and oil palm empty fruit bunch (EFB) fiber and reported among others that, the Modulus of elasticity (MOE) of the EFB-HDPE composites decreased with increasing filler loading. Additionally, their work on scanning electron microscopy showed that the particles embedded in the matrix were in the form of irregular-shaped fiber bundles, and that the tensile failure occurred through extensive fiber bundles pull out and de-bonding.

Another closely related work of Rozman *et al*. (2006) on oil palm empty fruit bunch (EFB)-based composites using different types of thermoplastic as matrices showed that tensile modulus of

PE and PP composites improved upon the addition of fillers, though, tensile strength and elongation at break results for all composites reduced as the filler is incorporation, which they attributed to the poor filler-matrix compatibility and size irregularity, etc. additionally, their result showed that water absorption and thickness swelling increased as the filler loading was increased. Also, Karina *et al*. (2008) worked on the effect of oil palm empty fruit bunch fiber on the physical and mechanical properties of fiber glass reinforced polyester resin and reported among others that, water absorption and thickness swelling ability increased with increasing EFB fiber addition, including that short EFB specimen was able to absorb water.

Similarly, Ahmed *et al*. (2010) worked on *t*he physical and mechanical properties of oil palm empty fruit bunch reinforced polypropylene matrix composites and reported that tensile and flexural modulus significantly increased with fiber loading while tensile and flexural strength were found to decreased beyond 25% by weight fiber loading. Additionally, the composites absorbed less water compared to raw and urea treated oxidized oil palm empty fruit bunch fibers reinforced PP composites, which they attributed to the positive effect of effect of chemical treatment the resulted in better fiber/matrix interactions.

It is obvious that most researches concentrated on the effect of surface treatment and fibre loading on the mechanical properties of oil palm EFB fibre composites. Other areas of research work that attracted much work were the water absorption effects, whilst limited mention was made of level of porosity implications on oil palm EFB fibre composites. Additionally, the diverse relationship between the various processing and physical properties and mechanical properties received limited attention, which this work is aimed at espousing. It is intended that the attained knowledge and data of effect of one property on another will aid in controlling such parameter as would enable the tailoring of some other properties in correlation, such as controlling the levels of porosity and water absorption in composites to achieve certain tensile property values, for increased utilization of oil palm EFB fibre in composite application.

2. Materials and methods

2.1 Materials

2.1.1 Matrix

A commercially blended polyester resin (Siropol 7440) with specific gravity - 1.04, viscosity - 0.24 Pa.s at 25°C. Other ancillary products used were the cobalt in styrene and Bisphenol-A diglycidylether. 2% Phenyltrimethoxysilane - $[(CH_3O)_3SiC_6H_5]$; Molecular Weight-198.3; Specific gravity at 25°C - 1.06; assay-98%, produced by Sigma-Aldrich, and purchased from Zayo Nigeria limited, Jos, Nigeria, including 98% Methanol and 0.5 mol of NaOH were adopted in the work.

2.1.2 Fibre

The oil palm empty fruit bunch (EFB) fibres were obtained from empty husks of mature and fruited plants with known age, and used within two weeks of felling. These extracts were processed and characterized at the Pulp and Paper section of Federal Institute for Industrial Research, Oshodi, Lagos, Nigeria into tangled mass of average diameter of 0.45 mm, average length of 0.81 mm, moisture content of 23.63wt.% and density of 1.49 g/cm^3.

2.1.3 Equipment

Other equipment used were Universal Testing Machine (Instron, Model 3369), Compact Scale

(Model – FEJ, Capacity – 1500 g, 1500A), a-two-part mould facility and carbolite muffle furnace.

2.2 Methods

2.2.1 Fibre extraction

The EFB fibres of oil palm were processed by chemico-mechanical process with precaution to reduce severe damage of fibres under the following procedures:

(a) Preparation of sample for chemical analysis.
(b) Impregnation of the sample with White Liquor.
(c) Conversion of the softened sample into fibre by mechanical action.
(d) Washing, screening and drying of resulting fibre.
(e) Determination of fibre yield.

After a thorough cleaning process, 3 kg of air-dry chips (35 mm × 0.5 mm) of the sample was loaded into the digester. The sample was covered with 'white-Liquor' (563.52 g.wt of NaOH + 281.76 g.wt of Na_2S measured in 12 liters of water) at 30% sulphidity and Total Active Alkali (T.A.A.) of 845.28. The lid of the digester was firmly bolted to prevent leakage. The digester was switched-on and the number of rotation as 6.0.

The digester was subsequently switched-off and discharged of its content after 2 ½ hours. The resulting sample was subjected to thorough washing with adequate water. When it was observed that the colour change had remained constant, the sample was transferred to the revolving roll stone for further processing, i.e., mild mechanical action to effect necessary thrust on the sample by way of rolling over the sample slowly to break-off the weakened lignin bond without damaging the fibres. At this point, the fiber became frayed that they were easily torn apart by hand.

The fibres bundles were separated and re-washed before drying in a forced-air circulation type oven operated at 50°C. The fibres were weighed and percentage yield determined. These extracted oil palm EFB fibre was subsequently fluffed for 1 minute and separated into two tangle mass bulks, one for surface-treated fibre composite and the other for untreated fibre composite production.

2.2.2 Surface treatment of the extracted fibre

Measured weights of 10%, 20%, 30%, 40%, 50% 60% and 70% of extracted oil palm EFB 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 further silane treatment according to the following steps - preparation of 2% Phenyltrimethoxysilane solution; dripping of the EFB fibres for 24 hours; sifting; air-drying, before storing in specimen bag ready for use.

2.2.3 Production of test specimen

The production of test specimen panels was carried out in compliance with the relevant test standard for reinforced plastics - BS ISO 1268-3:2000 as follows:

(a) Measured weights of untreated and treated oil palm EFB fibre bulks were weighed on a calibrated compact scale.
(b) Polyester mix was prepared using 100 ml of unsaturated polyester resin and 1 ml of accelerator plus 1 ml of hardener (which was previously determined to the best curing needed for the fibres). The polyester mix was subsequently weighed. Two sets of matrix

systems were prepared; one set each, for treated fibre and other, for untreated fibre composite preparation. Using known 10wt.% to 70wt.% of the treated and untreated fibres, corresponding 90wt.% to 30wt.% of the matrix system sets was prepared.

(c) Following a sequence, the mould cavity was pre-placed with aluminum foil before pouring-in the tangled mass fibre in random orientation. The polyester matrix mix was subsequently poured into the mould. The top mould was placed and clamping bolts fully secured before placing in an oven operated at 110°C.

(d) After 30 minutes in the oven, the composite was removed and allowed to cool to room temperature and placed in humidity controlled bag.

(e) The sample tests were conditioned following the BS ISO 1268- 3:2000 instructions and guidelines.

(f) Using hacksaw, the test samples specimens were cut from stock to dimensions of 50mm x 10 mm × 5 mm in beams of symmetrical laminates.

During the production of composite specimen plates, the hydrolysis behavior was not considered and thus no data relative to the corresponding behavior of the effect of catalyst and accelerator in the cross-linked networks was collected for any possible prediction. Thus the results were deduced in terms of hydrolytic effect on the curing data provided by the reagent manufacturers, which was presumably restricted to the scope of study.

2.2.4 Composite characterization

2.2.4.1 Tensile strength test

The Universal Testing Machine was used in the determination of tensile strength parameters of both untreated and treated oil palm EFB fibre composites by elongating the specimen and measuring the load carried by the specimen. The tests were conducted on three identical specimens for each type of fibre-matrix sample and average result was obtained. The moduli of elasticity (MOE) were determined using the ratio of tensile stress to the strain of the respective fibre composites.

2.2.4.2 Porosity test

The boiling point method was used to evaluate the volume of the open pores, into which a liquid can penetrate as a percentage of the total volume.

During the test, three identical test pieces of dimensions 100 mm × 150 mm × 5 mm each, of the samples were prepared. Each of the test pieces of three identical specimens for each type of fibre-matrix sample was placed in an oven operated at 110°C for 30 minutes; the second test piece was submerged in distilled water for 2 hours and then removed. Their weights were taken after those processes, and applied for the evaluation of apparent porosity of the sample using the expression in Eq. (1), (BS EN 993-1:1995).

$$AP(\%) = \frac{(W-D)100}{W-A} \tag{1}$$

Where AP = apparent porosity of the sample, W = weight specimen in air, D = weight of specimen dried in oven at 110°C and A = weight of specimen submerged in water.

2.2.4.3 Water absorption test

The percent increase in weight of each material was evaluated after exposure in water. The exposed test pieces of dimensions 100 mm × 100 mm × 5 mm were dried and cooled and the initial weights recorded. Three identical specimens for each type of fibre-matrix sample separately were soaked in distilled water at a temperature of 23°C. They were removed from the soak after 24 hours, weighed and final weight recorded. The percentage water absorbed by the specimens was evaluated using the expression in Eq. (2), (BS EN 2378:1994).

$$W_A(\%) = \frac{(W_2 - W_1)100}{W_1} \tag{2}$$

Where W_A = % water absorption, W_1 initial weight of specimen and W_2 = final weight of specimen.

3. Results and discussion

3.1 Tensile strength

Fig. 1 shows the tensile property values of oil palm EFB fibre reinforced polyester composites at different fibre loading. It can be observed that the tensile strength of untreated oil palm EFB fibre reinforced polyester composites decreased from 2.47 MPa to 0.13 MPa at 10 wt.% and 70wt.% fibre loadings respectively. Similarly, the tensile strength values of treated oil palm EFB fibre composites decreased at a uniform trend from 3.87 MPa to 1.28 MPa at 10wt.% and 70wt.% fibre loadings respectively. The noticeable effect of fibre treatment was confirmed with the differential in value of 3.78 MPa of treated fibre to 2.47 MPa of - untreated fibre composites at 10wt.% fibre loading. The decrease in tensile strength with increasing fibre loading could be attributed to the formation of agglomerates and random orientation of fibre which caused stress concentration, and in turn generated formation of crack on the fibre-matrix interface. These results corroborated the findings of other researchers (Aznizam and Norfhairna 2008, Rozman *et al*. 2006, Yusoff *et al*. 2010).

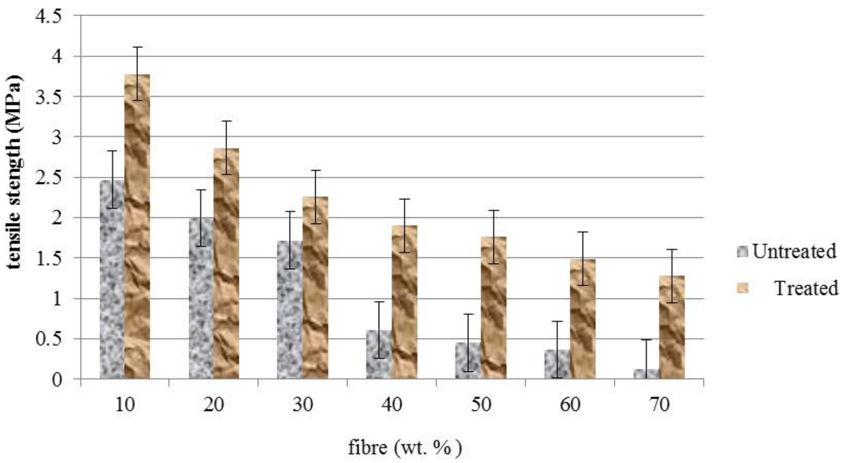

Fig. 1 Tensile strength of oil palm EFB reinforced polyest reinforced composites at different fibre loading

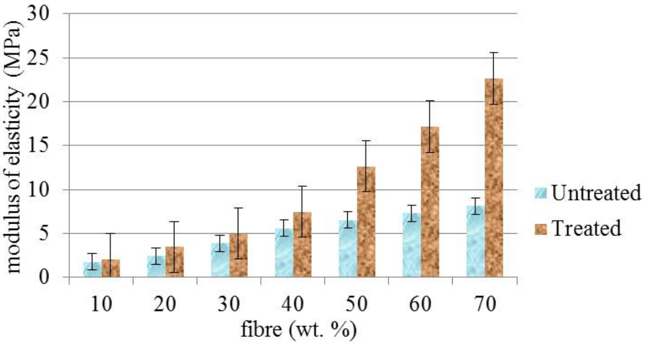

Fig. 2 Modulus of elasticity of oil palm EFB reinforced polyester reinforced composites at different fibre loading

3.2 Modulus of elasticity

Fig. 2 shows the modulus of elasticity values of oil palm EFB fibre reinforced polyester composites at different fibre loading. It is observed that the value of increment in MOE was prominent with the treated fibre composites of 2.04 MPa at 10wt.% and 22.65 MPa at 70wt.% fibre loading, as compared to 1.75 MPa and 8.11 MPa at 10wt.% and 70wt.% fibre loading respectively. The remarkable effect of fibre treatment on the MOE was similarly considered uniform as with the tensile strength, which was noticeable in the values of 1.75 MPa to 2.04 MPa, and 8.11 MPa to 22.65 MPa at 10 wt.% and 70 wt.% fibre loadings respectively. The noticeable variations in MOE values at 30wt.% fibre loading could be explained by some 'generalized' factors associated with the structure of most natural fibres, test method and technique and conditions of specimen preparation.

Chiefly noted was the uniform tensile behavior of both treated and untreated oil palm empty fruit bunch fibre reinforced polyester composites, which indicates stability with the short length EFB fibre system, suggesting suitability in composite utilization. It is noted nevertheless, that beyond 40% fibre content in the composite, wettability defects of poor bonding set in, requiring that the matrix continuous phase characteristic holds.

The improved tensile strength properties of treated oil palm EFB fibre composites above the untreated fibre composites may be attributed to a stiffer molecular structure of the silane treatment that provided rough surfaces on the fibres, which resulted in the increased reactive sites. This enabled resin to fill the pores and achieve better bonding between the fibre and the matrix that resulted in an increase in the efficiency of stress transfer from the matrix to the fibre. These results are consistent with the findings of other researchers (Aznizam and Norfhairna 2008, Rozman *et al*. 1998).

3.3 Porosity

Fig. 3 shows the porosity values of oil palm EFB fibre reinforced polyester composites at different fibre loading. It can be observed that increasing the fibre content tended to uniformly increase the percentage porosity in the untreated oil palm EFB fibre reinforced polyester composites increased from 3.43% to 7.16% at 10wt.% and 70wt.% fibre loadings respectively, while the values of treated oil palm EFB fibre composites similarly increased uniformly from 1.68%

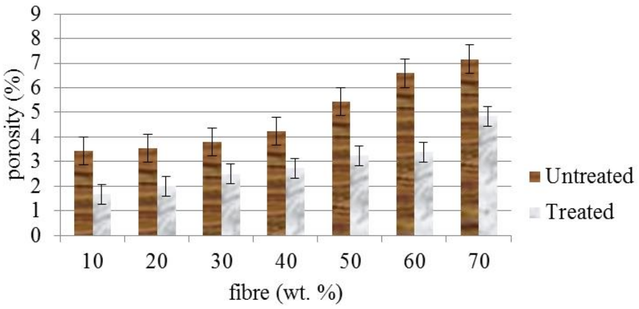

Fig. 3 Porosity of oil palm EFB reinforced polyester reinforced composites at different fibre loading

to 4.85% at 10wt.% and 70wt.% fibre loadings respectively. The observed difference in porosity levels between the treated and untreated fibre composites confirmed the positive effect of fibre treatment necessary to achieve reduced porosity, which generally affects the mechanical behaviour of the fibre composites.

It is noted that 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 often leads to internal strains, porosity as reported by other researchers (Bledzki and Gassan 1996, Fatra *et al*. 2016, Rowell *et al*. 2001).

Residence of voids and porosity in materials often encourage stress initiation. The percentage of porosity in the material shows the trend with which the pattern of failure may be experienced, such as whether the failure will be gradual, instantaneous, etc. The low porosity percentages exhibited by the composites of oil palm EFB as can be related to the MOE values, showed that the morphological characteristics of short EFB fibre is stable. The higher matrix alignment, combined with surface treatment affected the tensile behavior of the composites of oil palm EFB composites.

3.4 Water absorption

Fig. 4 shows the water absorption values of oil palm EFB fibre reinforced polyester composites at different fibre loading. It was observed that the percentage water absorption level of untreated oil palm EFB fibre reinforced polyester composites increased with increasing fibre loading from

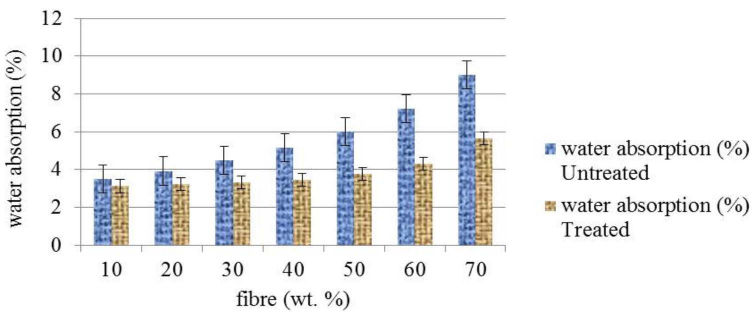

Fig. 4 Water absorption of oil palm EFB reinforced polyester reinforced composites at different fibre loading

3.51% to 9.02% at 10wt.% and 70wt.% loadings respectively. Similarly the values of treated oil palm EFB fibre composites increased from 3.12% to 5.66% at 10wt.% and 70wt.% fibre loadings respectively. There was a uniform trend in water absorption percentage values in both the treated and untreated fibre composites, which was due to the hydrophilic characteristics of oil palm EFB that facilitated the easy presence of water up-take (Rowell *et al*. 2001).

Expectation was high for a large water absorption value between the treated and untreated fibre composites as reported by other researchers (Ahmed *et al*. 2010, Arif *et al*. 2009, Karina *et al*. 2008, Razak and Kalam 2012, Rozman *et al*. 2006), as noted with the untreated fibre composites. This gave an indication of improved compatibility between matrix and treated fibre, where the combined alkali and silane treatments provided the micro-voids for entrapment of matrix. The observed water absorption percentage values achieved with the untreated fibre at 40wt.% was similar to the value at 70wt.% of the treated fibre composites, which gave an insight on the positive effect of treatment on the properties of fibre composites. Since difficulty exists in an attempt to entirely eliminate the absorption of moisture in composites without using expensive surface barriers on the composite surface, it is inferred that wettability was more desirable than fibre treatment for low water absorption expectation beyond optimal fibre loading of 40wt.%.The findings of other researcher (Bledzki and Gassan 1996, Fatra *et al*. 2016, Rowell *et al*. 2001, Swamy 2003) corroborated the results.

In general, water absorption in natural fibre-based composites often lead to built-up in the cell wall and in the fibre-matrix inter-phase region, which result in fibre swelling. Thus, concerns on dimensional stability cannot be ignored in the selection of a natural fibre composite for an application, of which the effects of water absorption need to be fully considered.

Since the type of material, additives, temperature and length of exposure can indeed affect the amount of water absorbed under specified conditions in any composite structure, it then suggests that, the mechanical properties, especially the tensile behavior, can be predicated on most physio-chemical and processing parameters in composite production. Additionally, since oil palm EFB fibre reinforced composites are impervious to humidity and still supports deformation, the improved mechanical properties of oil palm EFB composites represents advantages in comparison with the relatively brittle gypsum board, which deteriorates in contact with water.

A cursory look at the percentage values of porosity and water absorption parameters as related to the tensile strength and MOE values of oil palm EFB fibre reinforced polyester composites, infers that silane treatment provided rough surfaces on the fibres, which resulted in the increased reactive sites that enabled resin to fill the pores and achieve better bonding between the fibre and the matrix. Additionally, the high values of porosity and water absorption resulted in lower tensile behavior, thus espousing a strong correlation between processing and physical properties with tensile behavior of composites.

4. Conclusions

Present work demonstrated the positive effect of fibre treatment and correlation between porosity and water absorption parameters with tensile behavior of oil palm EFB fibre reinforced polyester composites based on the following inferences;

- The tensile strength properties of untreated and treated oil palm empty fruit bunch fibre reinforced polyester composites decreased with increasing fibre content.
- The MOE of untreated and treated oil palm empty fruit bunch fibre reinforced polyester

composites increased with increasing fibre content.

- The percentage porosity and water absorption parameters of untreated and treated oil palm empty fruit bunch fibre reinforced polyester composites increased with increasing fibre content.
- The combined effect of alkali and silane treatments was evident on the improved tensile behavior of treated oil palm EFB fibre composites.
- The high percentage values of porosity and water absorption contributed to the reduced tensile behavior of composites.

In essence therefore, these findings will aid in exploring varied ways of reducing or, at best eliminate levels of porosity and water absorption while choosing the type of fibre treatment process and suitable manufacturing technique for the achievement of improved tensile property of fibre reinforced composites.

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