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EFFECT OF NATURAL PLANT LATEX TREATMENT ON THE MECHANICAL PROPERTIES OF BORASSUS PALM LEAF STALK FIBRE/EPOXY COMPOSITE

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ABSTRACT

Interest is on the increase in the use of ligno-cellulosic fibre as potential replacement of its man-made counterpart for reinforcement in polymeric material because of the growing global environmental and ecological awareness. Borassus palm leaf stalk fibre (BPLSF) was extracted by the combination of water retting and mechanical method. The fibre was pretreated with 6wt% NaOH for an hour, and followed by natural plant latex treatment to modify the fibre surface for enhanced fibre-matrix interfacial interaction. The neat epoxy was reinforced with BPLSF using hand layup method and mechanical properties of the composite were evaluated. It was observed that tensile strength of epoxy (23.69MPa) increased more than double fold (50.48MPa) on addition of 25wt. % latex treated fibre. Flexural strength increased from 49.93MPa for epoxy to 72.35MPa for latex treatment at 25wt% fibre content. Impact strength also increased slightly from 75.00KJ/m^2 for epoxy matrix to 80.25KJ/m^2 at 25wt.% latex treated fibre content addition. Hardness value increased progressively with percentage fibre content to more than double fold at 25wt.% latex treatment with micro Vickers hardness value of 42.77 as compared to 17.50 for unreinforced matrix. It was concluded that latex treatment was efficient in improving interfacial interaction between the BPLSF and epoxy matrix.

1. INTRODUCTION

In the last two decades, growing interest in ligno-cellulosic fibres as polymeric reinforcements since their emergence in the 1940s has been rampant. Researchers in Asia, Europe and other parts of the globe have shown kin interest and unwavering commitment in this research area due the advantages of these fibres over their synthetic counterparts (Bledzki and Gassan, 1999; Ansell and Aziz, 2004; Tserki *et al*., 2006; Abdelmouleh *et al*., 2009; Kabir *et al*., 2012; Rassiah *et al*., 2012; Fakhrul and Islam, 2013; Ramesh *et al*., 2013). The advantages include low density, low cost, high specific strength and stiffness, low emission of toxic fumes when subjected to heat during incineration at the end of life and low hazard manufacturing processes (Pickering *et al*., 2016). Despite the stated advantages, the main disadvantage of ligno-cellulosic fibres in reinforcements of composites that calls for research attention is the poor compatibility between fibre and matrix due to their relatively high hydrophilic nature as a result of hydroxyl (–OH) group present between the macromolecules in the fibre cell walls. The interaction between hydrophilic fibres and hydrophobic matrices causes fibre swelling within in the matrix. This results in weakening the bonding strength at the interface, which leads to dimensional instability, matrix cracking and poor mechanical properties of the composites. The quality of the fibre–matrix interface is significant for the application of ligno-cellulosic fibres as reinforcement for polymers (Faruk *et al.,* 2012). Therefore, ligno-cellulosic fibre modifications are considered in modifying the fibre surface properties to improve their adhesion with different matrices (Faruk *et al.,* 2012). Since, stress is transferred between matrix and fibres across interface, good interfacial bonding is required to achieve optimum reinforcement and composite properties. Success of which is dependent on the efficiency of the modification method which could be either physical or chemical. Amirou *et al.* (2013) modified date palm fibre by using corona discharge treatment (a physical modification method), which results in surface oxidation and reported that for composites containing treated fibres, there was a significant increase in tensile strength and young modulus compared to the composites with untreated fibres. They concluded that the interfacial contact between both components was improved because of a higher mechanical anchorage enhanced as a consequence of the etching effect. Surata *et al.* (2014) showed that tensile strength and modulus as well as flexural strength of rice husk reinforced polyester increased with increase in fibre weight fraction. They also reported that the mechanical properties further improved with alkalization (a chemical modification method) of the fibres due to better interfacial bonding between the fibre and the matrix.

Borassus aethiopum with local names: English: borassus palm, African fan palm; Hausa: giginya; Igbo: ubiri and Yoruba: agbon-eye is an economical important palm tree of the Sahelian and Sudanian zones in Africa (Alabi *et al*., 2016). The stem of *B. aethiopum* delivers a hard wood that is resistant to decay and the damaging effect of sea water and is widely used as timber in construction sites because of its durability and excellent working properties when used for construction purposes and furniture (Sambou et al., 1992).

Epoxy resins are a class of thermosetting resin materials, characterized by two or more oxirane rings or epoxy groups within their molecular structure. The commonest epoxy resin is the diglycidyl ether of bisphenol A (DGEBA), which is prepared by the reaction of epichlorohydrin (ECD) and bisphenol A (BPA). ECD is prepared from polypropylene (PP) by reacting chlorine with sodium hydroxide. An epoxy formulation must contain a suitable curing agent and some optional ingredients, which are decided after considering the application in which the resin is going to be used. Examples of such ingredients are diluents, fillers or extenders. Diluents are used in an epoxy formulation to reduce the viscosity or to eliminate the need of solvents (Ratna, 2009).

This work attempts to modify the surface of BPLSF with natural plant latex treatment after 6wt% NaOH pretreatment for an hour to improve the interfacial bonding between the fibre and epoxy resin matrix. Mechanical properties of the composites produced were evaluated, results of which was compared to that of untreated reinforced composites reported in earlier work by authors (Alabi *et al*., 2016).

2. MATERIALS AND METHODS

2.1. Materials

The materials and equipment used in this work include: BPLSF extracted from borassus palm leaf stalk obtained from a borassus palm (*borassus aethiopum*) tree in Daurayi, Giwa Local Government, Kaduna State, natural plant latex, water, wooden moulds, syringes, digital weighing balance, oven, spatula, plastic containers, release agent and lubricant, Instron universal testing machine, Charpy impact testing machine, micro Vickers hardness machine, epoxy resin and hardener purchased from Rodco Nigeria Limited, Ojota, Lagos, Nigeria.

2.2. Methods

2.2.1. Fibre Extraction

A combination of water retting and mechanical method was used to extract BPLSFs from the leaf stalks. This was achieved by submerging bundles of leaf stalks in water for 30 days after the thorns at the edges and the bark of the leaf stalk had been shaved. The retted stalk were dried in open air and stored for 7 days to dry. Finally, separation of the fibre was done by breaking process in which the brittle woody portion of the retted stalk were broken by beating and scraping (Mussig, 2010).

2.2.3. Fibre surface modification

Surface pretreatment with NaOH was carried out to clean the fibre surface. The fibres were immersed in 6 wt.% solution of NaOH for an hour at room temperature (25 - 26°C), after which it was washed with distilled water and the effect of NaOH was neutralized in 2 % glacial acetic acid solution (Ansell and Aziz 2004); Thomas *et al.*, 2004). The fibre was oven-dried for 3 hours at 110°C. Thereafter, the NaOH pretreated fibre was given latex coating by dipping into a natural plant latex solution having 10% dry rubber content, dissolved in water according to Sreekala *et. al.* (2002). The fibre was thereafter oven-dried for 3 hours at 110°C.

2.2.4. Production of composite

Wooden moulds were used in the production of the epoxy/BPLSF reinforced composite. The dimensions and shapes of cavities were made according to the size and shape of the sample as per ASTM standards for tensile, flexural, impact and hardness testing. The composite was formed using the hand lay-up method by laying the continuous fibre unidirectionally with fibre loading (0 wt.%, 5 wt.%, 10 wt.%, 15wt.%, 20 wt.% and 25 wt.%). After the composites had hardened, they were removed from the moulds and placed in the oven for 6 hours at 40°C to cure (Sarki, 2012).

2.2.5. Mechanical Test

The study of mechanical properties such as tensile, flexural, impact and hardness behavior of epoxy/BPLSF reinforced composite were conducted according to ASTM standards.

2.2.5.1. Tensile test

Tensile test was carried out using Intron 3369 Universal Testing Machine. Dumbbell standard samples according to ASTM (D638) were prepared, specimen measuring 100.0 × 8.0 × 4.0 mm were positioned in the grips of the testing machine. The grips were tightened firmly to prevent any slippage with gauge length kept at 60 mm. The test was conducted at constant cross head speed of 5mm/min. As the tensile test starts, the specimen elongates; the resistance of the specimen increases, and is detected by a load cell. This load values were recorded on a computerized screen until a rupture of the specimen occurred. Three samples of each composite sample were used for the test and the average results were recorded.

2.2.5.2. Flexural test

Flexural test was performed on specimens measuring 100.0 × 10.0 × 8.0mm according to ASTM D790 using computerized Instron 3369 Universal Testing Machine. Three point bend flexural test method was used with cross-head speed of 5mm/min and span length of 65mm. Samples were positioned on the support span and the load was applied to the centre by the loading nose producing three point bending. The test was stopped at 5% deflection.

2.2.5.3. Impact test

Charpy impact test was conducted on all the composite samples using impact testing machine. A 15J hammer was used for the samples. The test samples were produced according to ASTM 2000 with dimension of 100.0 × 10.0 × 8.0 mm. Before the test samples were mounted on the machine, the pendulum was released to calibrate the machine. The test samples were then gripped horizontally in a vice and the freely swinging pendulum provided the force required to break the bar. The value of the angle through which the pendulum swung before the test sample was broken corresponded with the value of the energy absorbed in breaking the sample and this was read from the calibrated scale of the machine.

2.2.5.4. Hardness test

Micro Vickers hardness test was conducted on the specimens produced according to ASTM C1327. Indentation technique using Vickers diamond pyramid indenter on the micro hardness tester was used. The measurement was done on the surface by applying 0.3 kg load for 15 seconds. Three Vickers hardness readings were taken for each sample and the average recorded.

3. RESULTS AND DISCUSSION

3.1. Tensile strength

Figure 1 presents the tensile strength results of neat epoxy resin, untreated and latex treated fibre reinforced composites. It was observed that neat epoxy matrix exhibited tensile strength of 23.69MPa and that increasing fibre content in all composite formulations resulted in increase in tensile strengths of the composite as compared to the neat epoxy with an exception of 5wt.% latex treated fibre reinforced composite. This can be attributed to good interfacial bonding between epoxy and BPLSF, which agrees with earlier reports (Mishra and Srivastava 2014; Venkatesh *et al.*, 2016) that considerable increase in tensile strength with increase in fibre loading could be attributed to the good interaction between matrix and reinforcement. Latex treated fibre reinforced composite show marked decrease in tensile strengths at 5 and 10 wt.% fibre contents with tensile strengths of 9.79MPa and 24.13MPa as compared to the untreated fibre reinforced composites with tensile strengths of 33.77MPa and 42.71MPa. Latex treated composite only show slight decrease in tensile strengths at 15wt.% fibre content and above as compared to the untreated.

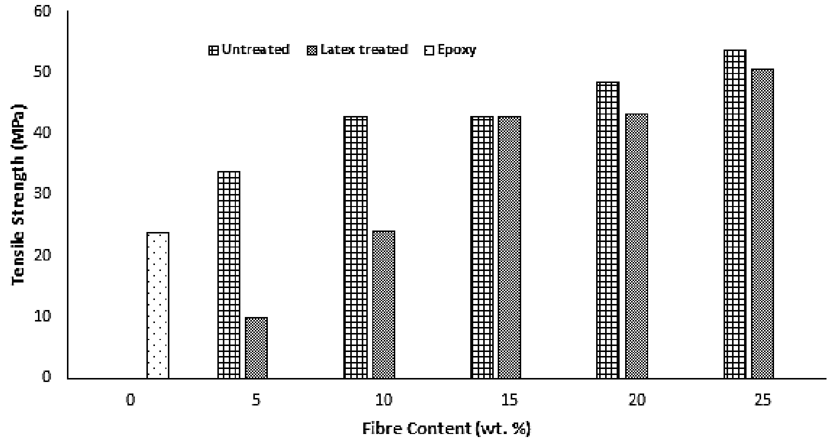

Figure 1: Tensile strength vs. fibre content of composite

Decrease in tensile strengths of latex treated composites may be attributed to the loss of intra-matrix hemicellulose, and cell wall lignin between micro fibrils during NaOH surface pretreatment, thereby destroying the packing in cellulose chains and causing disorder in crystalline pattern. This finding is in line with earlier reports that amiopropyltriethoxysilane (APS) treatment will destroy packing of the cellulose chain and cause disorder in the crystalline pattern (Singha and Rana 2012; Zhu *et al.*, 2013). These findings revealed that effect of surface modifications on ligno-cellulosic fibre strength in composites is an important aspect that requires careful optimization, since the fibre bulk structure may also be altered, especially when the treatment involves extended reaction times or aggressive chemicals. In such cases, as the case in this work, the result may be increased interfacial strength but decreased fibre strength, which can in turn result in composites with decreased mechanical properties (Pickering, 2011).

3.2. Tensile modulus

Figure 2 shows the tensile modulus of neat epoxy resin, untreated and latex treated fibre reinforced composites.

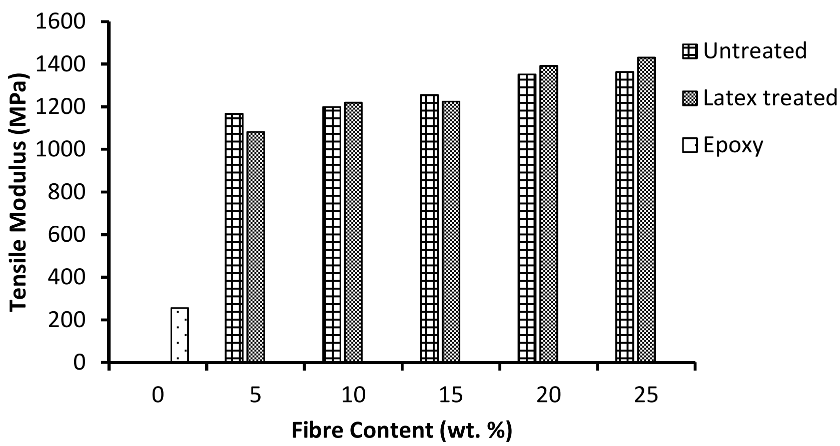

Figure 2: Tensile modulus vs. fibre content of composite

It was observed that the tensile moduli increase generally with increasing wt.% of fibre content of composite as compared to the neat epoxy matrix. This could be attributed to good fibre-matrix adhesion that results in high degree of stress transfer from matrix to fibre during loading (Heitor *et al.*, 2010). Tensile moduli values of 1166.68MPa and 1256.81MPa for the untreated fibre reinforced composites at 5 wt.% and 15 wt.% were slightly higher than those for the modified fibre reinforced composites exhibiting tensile modulus of 1082.38MPa and 1224.92MPa respectively. Latex treated fibre reinforced composites exhibited tensile moduli values of 1220.01MPa, 1391.41MPa and 1431.72MPa at 10, 20 and 25 wt. % fibre contents respectively. Nayak and Mishra (2013), Shanmugam and Thiruchitrambalam (2013) obtained similar results and reported that tensile modulus increased up to 66% in modified fibre reinforced composites as compared to the neat matrix.

3.3. Flexural strength

Figure 3 presents the flexural strengths of neat epoxy resin and all composites formulations. It was observed that neat epoxy resin exhibited flexural strength of 49.93MPa. Flexural strengths of composites at 5 and 10wt.% fibre contents decreased as compared to the neat epoxy matrix. It can be seen that increase in wt.% fibre content of all composites resulted in increased flexural strengths. This agrees with earlier findings of steady increase in flexural strength with increase filler content, as a result of increasing degree of molecular orientation (Khalid *et al.*, 2008).

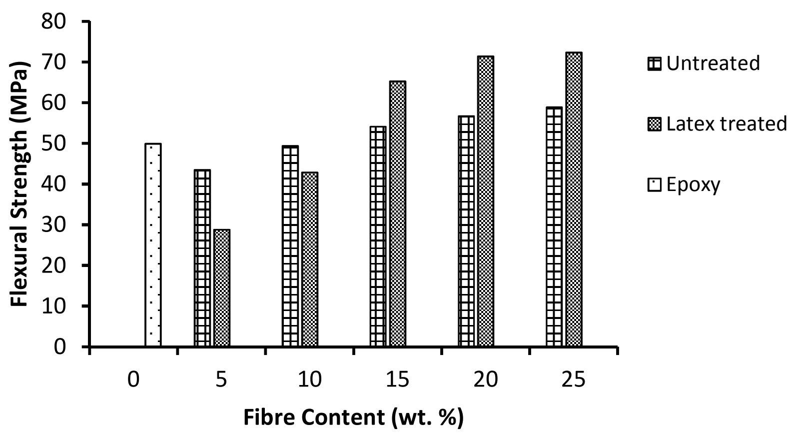

Figure 3: Flexural strength vs. fibre content of composite

It was also observed that untreated fibre reinforced composites from 15wt.% fibre content exhibited the least values of flexural strengths ranging from 54.15MPa at 15 wt% and 58.91MPa at 25wt.% as compared to the latex treated fibre reinforced composites with flexural strengths ranging from 65.23MPa at 15wt.% to 72.35MPa at 25wt% fibre contents. This implies that latex treatment has a considerable positive influence on the flexural strengths of the composites.

3.4. Flexural modulus

The flexural moduli of the matrix and composites are shown in Figure 4. It was observed that flexural modulus increase generally with increasing wt.% fibre content. Latex treated fibre reinforced composites with flexural moduli ranging from 1195.03MPa at 5wt.% to 1598.04MPa at 25wt.% exhibited the highest flexural modulus as compared to that of the untreated fibre reinforced composites with flexural moduli ranging from 807.40MPa at 5wt.% to 1574.81MPa at 25wt.%. In their review of mechanical properties of kenaf fibre reinforced polymer composites Jawaid *et al.* (2015) stated that researchers reported that flexural properties of kenaf/PP composites was enhanced by modification of kenaf fibre using zein coating (a coupling agent).

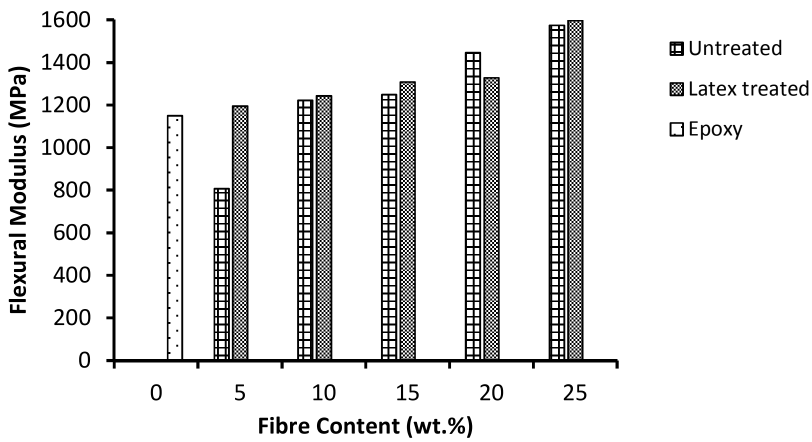

Figure 4: Flexural modulus vs. fibre content of composites

3.5. Impact strength

Figure 5 shows the results of impact strengths for neat epoxy and all formulated composites. Neat epoxy resin exhibited impact strength of 75.00KJ/m^2. Impact strength increased generally with increasing wt. % fibre content. Though, comparing the impact strengths of the composite with that of the neat epoxy resin, there was a decrease up to 20wt% fibre addition, then an increase at 25wt% addition. This agrees with the findings of Pickering *et al.* (2016) who reported that impact strength of epoxy resin was seen to reduce with addition of fibre up to 25wt% fibre, but then increase to give overall improvement in impact strength. Impact strengths decreased generally with latex treatment as compared to untreated fibre reinforced composites.

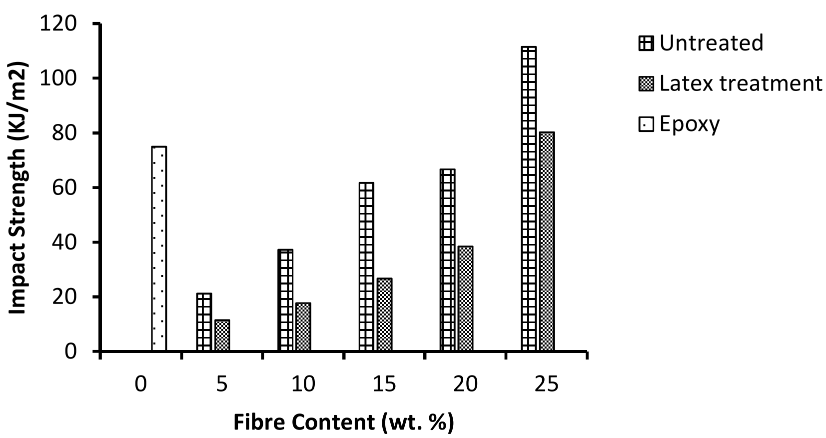

Figure 5: Impact strength vs. fibre content of composites

As for the reinforced composites, the untreated samples exhibited higher impact strength than the treated samples. This may be attributed to reduction in fibre toughness base on the effect of surface modification on fibre make-up. This result is contrary to that of Haque *et al.* (2015) that reported that impact strength of 40% fibre volume treated sisal/polyester composite showed ten times increase in impact strength with respect to neat polyester composite.

3.6. Hardness test

Hardness values of neat epoxy resin and all composite formulations are shown in Figure 6. Neat epoxy resin matrix with 17.5 Micro Vickers hardness (MVH) value exhibited the least hardness value. Micro Vickers hardness values of the composites increase progressively with increase in wt.% fibre content ranging from 20.23 to 30.27MVH for untreated composite at 5 wt.% to 25wt.%, and 26.77 to 42.77MVH at 5 wt.% to 25wt.%MVH for latex treated fibre reinforced composites respectively. This agrees with the findings of Shehu (2015) who reported that there is a general increase in hardness values with percentage increase in filler content. This could be attributed to a more compact or rigid structure on the surface of the composite that led to generation of greater resistance to penetration and consequently, higher hardness values are obtained for the composites with increasing fibre loading. It was also observed that fibre modification improved hardness values of composites which could be argued in terms of a more rigid and compact fibre structure due to removal of NaOH soluble fractions such as moisture content, waxy layers, hemicellulose and lignin during fibre pretreatment with alkali solution before latex treatment.

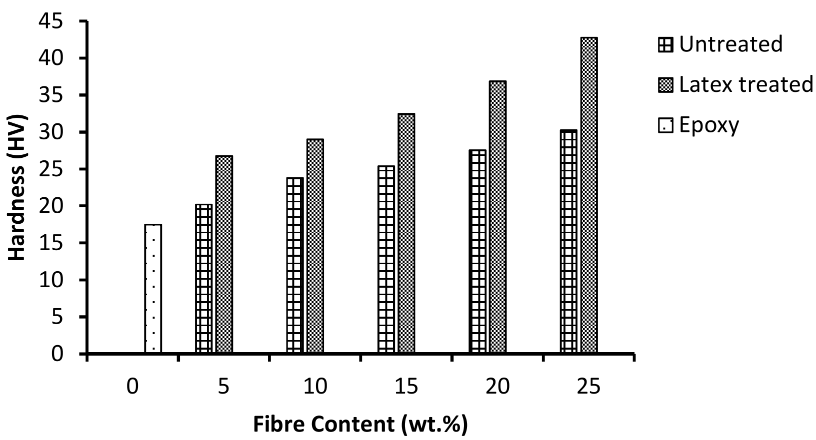

Figure 6: Hardness value vs. fibre content

4. CONCLUSION

The following conclusions can be drawn from this study.

1. The tensile, flexural and impact strengths increase generally with percentage increase in fibre content.
2. Tensile strength of epoxy (23.69MPa) increased more than double fold (50.48MPa) on addition of 25wt. % latex treated fibre.
3. Flexural strength increased from 49.93MPa for epoxy to 72.35MPa for latex treatment at 25wt% fibre content.
4. Impact strength also increased from 75.00 kJ/m^2 for epoxy matrix to 80.25 kJ/m^2 at 25wt. % latex treated fibre content addition.

5. Tensile and flexural moduli increased with percentage fibre content in the same order as the corresponding strengths.
6. Hardness value increased progressively with percentage fibre content to more than double fold at 25wt.% latex treatment with micro Vickers hardness value of 42.77 as compared to 17.50 for unreinforced matrix.
7. The enhancement of mechanical properties of latex treated fibre reinforced composites indicate the efficiency of latex treatment in improving interfacial interaction between the BPLSF and epoxy matrix. Therefore in could be concluded that based on the results obtained in this study, the objective of the study has been met:

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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