ABRASION AND MECHANICAL PROPERTIES OF KERATINOUS BASED POLYESTER COMPOSITES

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ABSTRACT

In this research, the abrasion, mechanical and water absorption properties of treated and untreated short and randomly dispersed cow hair fiber reinforced polyester composites were studied. This was carried out in order to investigate the influence of chemical treatment on the cow hair fiber and other parameters on the developed composite materials. Polyester resin reinforced with alkaline treated and untreated cow hair fibers was produced by hand lay-up technique in predetermined proportions. Abrasion, mechanical as well as water absorption tests were carried out on the developed composites. The results showed that the composite samples reinforced with untreated cow hair fiber showed better enhancement in all the properties than those reinforced with treated cow hair fiber. Optimum tensile properties were obtained with 15 wt.% while 20 wt.% gave the optimum flexural properties. Samples reinforced with 10-15wt.% untreated cow hair fibers had the highest abrasion resistance, while the sample with 4 wt.% cow hair fiber addition had the highest water absorption resistance for both the treated and untreated composite samples.

KEYWORDS*: Cow hair fiber; unsaturated polyester; composites; mechanical and abrasion properties*

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1.0 INTRODUCTION

Animal hair is considered a waste material in most parts of the world and its accumulation in waste streams causes many environmental problems. According to a report by Growth and Employment in States (GEMS), about 7 million cattle are slaughtered annually in Nigeria and the hair is gotten rid of by burning since a lot of people consume the skins of cows in Nigeria (Ekenma, Anelon, & Ottah, 2015; Akwetey, Eremong, & Donkoh, 2013). Preventing waste of such a material requires both addressing the problems in the current usage and developing its utilization systems at locations where they are missing.

The waste hair is nowadays finding its use in the field of material science. Usage of hair as a reinforcement material is a new trend as it evolves a new method to utilize the material which is available in large quantities and could otherwise be discarded as waste. Hair can be used as a reinforcement material due to its capacity to resist stretching and compression (Velasco et al., 2009). It can be used to produce animal fiber reinforced composite materials which can be applied in the automotive, aerospace and sports equipment industries. Compared to most metals and unreinforced plastics, animal fiber composites may offer a high strength-to-weight ratio, corrosion and termite resistant (Mohini, Asokan, Anusha, Ruhi, & Sonal, 2011). Hair has a high tensile strength which is equal to that of a copper wire with similar diameter (Jain & Kothari, 2012).

Hair is composed of proteins, lipids, water and small amounts of trace elements. All proteins in animal and human bodies are built from permutations of amino acid molecules in a polypeptide string. The polypeptide chains of protein keratin are organized into filaments in hair cells (Shubham, 2013). In the hair structure, lipids are present in Inner Root Sheaths and hair shaft lipids provide sheen to the hair and contribute towards its tensile properties. In terms of raw elements, on an average, hair is composed of 50.65% carbon, 20.85% oxygen, 17.14% nitrogen, 6.36% hydrogen, and 5.0% sulfur. Amino acid present in hair contain cytosine, serine, glutamine, threonine, glycine, leucine, valine and arginine (Popescu & Hocker, 2007).

Natural fiber shows comparatively poor fiber/matrix interactions, water resistance, and relatively lower durability. The weaker interfacial or adhesion bonds between highly hydrophilic natural fibers and hydrophobic, non-polar organophilic polymer matrix, leads to considerable decrease in the properties of the composites and, thus, significantly obstructs their industrial utilization and production. Among the main challenges of natural fibers reinforced composites are their inclination to entanglement and the tendency to form fibers agglomerates during processing due to fiber-fiber interaction. This causes uneven dispersion of the fibers into the matrix, resulting in poor interfacial adhesion between the hydrophobic matrix and the hydrophilic reinforced natural fiber (Fakultat, 2006; Alaneme, Oke, & Omotoyinbo, 2013). However, several approaches and schemes have been established to supplement this deficiency in compatibility, including the introduction of coupling agents and various surface modification techniques (Kalia, Kaith, & Kaur, 2009). Fiber treatment is also considered to modify the fiber surface topology before been used as reinforcement in the matrix (Najafi & Kordkheili, 2011; Oladele & Agbabiaka, 2015a).

Barone (2005) and Ahmad (2014) prepared composites taking human hair as the fiber and polymers as the matrix and affirmed that the human hair is an emerging engineering composite fiber. They collectively wrapped up with the conclusion that the tensile and flexural properties decrease when the fiber loading percentage increases; the work of Oladele, Olajide and Ogunbadejo (2015b) also showed an improvement in the flexural properties of cow hair fiber reinforced high density polyethylene composites (Oladele et al., 2015b; Dwivedi, Darbari, & Verma, 2015; Oladele, Omotoyinbo & Ayemidejo, 2014).

Investigations on the mechanical properties of hair and it suitability for production of composites are inadequate. There is lot of scope for new studies on composites development using hair which may result in a new material with better performance leading to effective recycling and utilization of hair for value added engineering application and conversion of waste into wealth. This research tends to consider the use of natural fiber, cow hair fiber, as reinforcement in synthetic polymer, unsaturated polyester. The choice of cow hair was due to its availability in large quantity in Nigeria. Cow meat consumption in Nigeria is very high and the disposal of the hair has been a menace to the society. Now that the research trend is moving towards utilization of natural products and plant has been highly researched, there is a need to also consider waste from animals of in which cow hair happened to be one of such raw materials.

2.0 MATERIALS AND METHOD

2.1 Materials

The materials utilized in this research work are polyester (with catalyst and activator), Cow hair, sodium hydroxide (NaOH) and distilled water with pH value of 5.8. The polyester serves as the matrix phase and cow hair serves as the reinforcing fiber.

2.2 Preparation of Cow Hair Fiber

Cow hair fiber was extracted by scraping the hairs of the tail of White Fulani cows (Zebu breed) procured from a local abattoir at Ijoka Area in Akure, Ondo State, and South-West, Nigeria. The fibers were washed thoroughly to remove dirt and debris after which it was sun dried for 7 days and cut to 10 mm lengths. The 10 mm cow hair fiber were divided into two parts, one part was treated with 0.15 M solution of NaOH at 50°C for 4 hours in a shaker water bath and the other part was used as the untreated fiber. The treated fibers were washed with tap water and rinsed with distilled water in order to ensure neutral status as confirmed by litmus paper test followed by sun drying for 3 days.

Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) was carried out on the samples. The surface morphology was studied with scanning electron microscopy, Model JEOL JSM-6480LV. The samples were thoroughly cleaned, air-dried and coated with 100 Å thick platinum to enhance the conductivity of the composite samples prior the microphotography. Observations were made at 20 kV. The images as well as the spectra were as shown in Plate1.

2.3 Development of composites

The composites were fabricated using an open mold process. The composites were fabricated by hand lay-up technique and the fibers were incorporated in the polyester matrix in predetermined proportions of 2, 4, 6, 8, 10, 15 and 20 wt. %. The composites were removed from the mold after curing and allowed to cure further for 27 days before subjecting them to tests.

2.4 Tensile test

Tensile tests were performed using an Instron Computerized Mechanical Universal Testing Machine, Series 3369 with a Load Cell Capacity of 50 kN in accordance with ASTM D3038M-08 standards. To ensure accuracy and reliability of tensile test results, three repeatability tests were performed for each sample composition (Barone, 2005).

2.5 Flexural test

Three-point bend test was performed on the composites as per ASTM D7264M-07 standard. The test was performed using a Universal testing machine, Instron incorporated USA model; Instron-series 3369 operated at a crosshead speed of 0.3 mm/mm and at a specific strain rate of 10^{-3}/s. Three samples were tested for each representative samples from which the average values for the test samples were used as the illustrative values (Rokbi, Osmania, Imad & Benseddiq, 2011).

2.6 Abrasion test

The abrasion resistance test was carried out with Taber Abrasers, Model ISE-AO16. The specimen has an area of 100 mm^2 and a standard thickness of 6.35 mm. A revolution of 1000 rpm for 5 hours was used. Three samples each were tested for each composition from where the average value was taken as the representative values. The initial weight and final weight of the samples were recorded and the formula in Equation (1) was used to determine the effect of abrasion on the material (Oladele, Adewumi, & Bello, 2015a).

$$\textit{Weight loss (g)=Initial weight-Final weight} \tag{1}$$

2.7 Water absorption test

Water absorption test was carried out in accordance with International Organization for Standardization, ISO 175-1981 (E). 250 cm^3 of distilled water media was measured using a measuring cylinder and poured into a clean plastic container. The initial weight of each of the sample was taken using chemical weighing balance; FA2104A Model of high precision ±0.0001 gram accuracy before putting it into distilled water medium used and readings were taken every day for 7 days. The samples were brought out, cleaned with a clean cloth and weighed (Oladele et al., 2015b). The data collected was used to determine the percentage of water absorption using the formula in Equation (2).

$$\% \, Water \ absorption = \frac{Final \ weight - Initial \ weight}{Initial \ weight} \times 100 \tag{2}$$

At set time points, samples were taken out, dried and then reweighed.

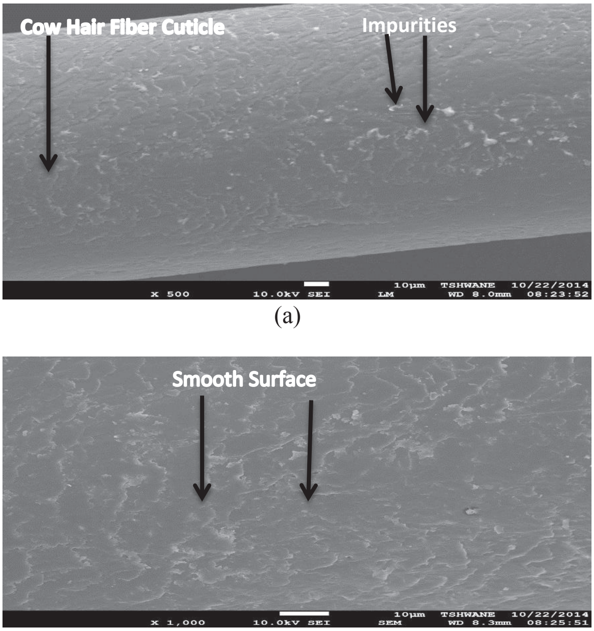
2.8 Scanning electron microscopy (SEM)

The surface morphology of the fractured composite samples was observed using a Phenom ProX Scanning Electron Microscope (SEM) (PhenomWorld, Eindoven Netherlands). This was carried out in accordance with ASTM F1372. The fractured surfaces of the composite samples were mounted on stubs and subjected to SEM observation.

3.0 RESULTS AND DISCUSSION

The SEM and EDS spectra of the fibers were as shown in Figure 1-3. Figure 1 shows the SEM image of the untreated fiber at different magnifications. It can be seen from the image that the surface of the untreated fibers appears smooth. Figure 2 shows the SEM image of the NaOH treated fiber. Rough surfaces with cracks were observed due to the effect of chemical attack on the fiber surface which is expected to aid proper interfacial adhesion between the fiber and the polymer. The cow hair fibers contain keratin and amino acids which are predominantly hydrophobic. They are treated with alkali to reduce the amount of lipids, threonine and serine for good compatibility and proper bonding.

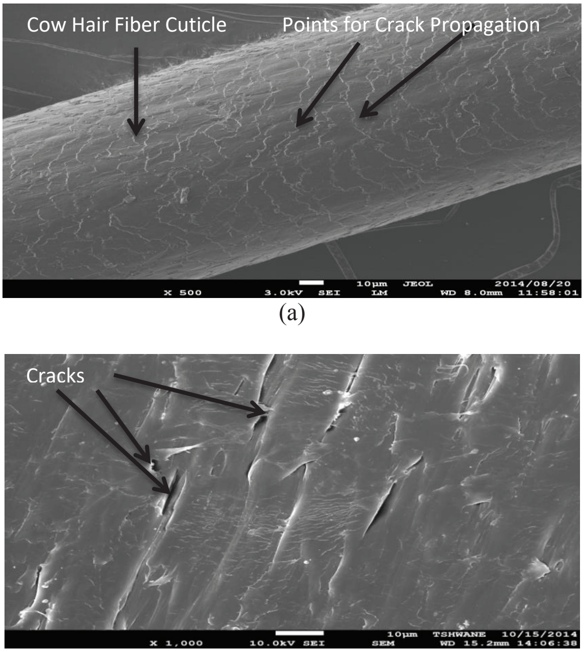
The EDS result in Figure 3 revealed the mass of each of the elements that are present in the untreated cow hair fiber. The values of the major elements were given as follows; 45.39% C, 28.49% O and 21.10% N.



(a)

(b)

Figure 1. SEM imaging of Untreated Cow Hair Fiber with magnifications of (a) x500 and in (b) x1000



(a)

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Figure 2. SEM imaging of treated cow hair fiber with magnifications of (a) x500 and in (b) x1000

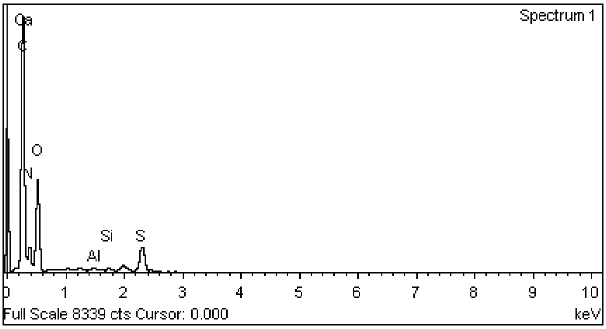


Figure 3. EDS of Untreated Cow Hair Fiber

The stress-strain response of the cow hair fibres is shown in Figure 4. From the result, it was observed that the untreated cow hair fibres showed higher tensile strength than the treated fibres. This may be due to excessive impact of the chemical treatment on the fibre since the treatment ought to aid the enhancement of the tensile strength (Oladele et al., 2015b).

Figure 5 shows the variation of ultimate tensile strength for treated and untreated cow Hair Fiber Reinforced Polyester Composite and the Neat Samples. It can be seen from the result that the neat sample had the least tensile strength with a value of 1.22 MPa when compared with samples reinforced with both treated and untreated cow hair fibers. For the treated cow hair fibre reinforced composites, the ultimate tensile strength reduces with increase in fibre weight content from 4-20 wt. % and the composite sample with 4 wt. % treated cow hair fiber reinforcement had the highest ultimate tensile strength with a value of 10.40 MPa indicating a 917.81% increase in ultimate tensile strength followed by the composite sample with 6 wt. % fiber reinforcement which had ultimate tensile strength value of 9.84 MPa indicating a 861.73% increase.

As shown in Figure 4, however, for the composite samples reinforced with untreated cow hair fibers, the ultimate tensile strength increases as the fiber content increases from 2-15 wt. % and the composite sample with 15 wt. % fiber reinforcement had the highest ultimate tensile strength with a value of 14.50 MPa indicating a 1327.53% enhancement followed by samples with 10 and 8 wt. % fiber reinforcements having ultimate tensile strength values of 12.39 MPa and 11.57 MPa indicating 1116.93% and 1034.44% tensile strength enhancement, respectively. It can therefore be seen that the composite samples reinforced with untreated cow hair fibers had the best enhancement compared to the samples reinforced with treated cow hair fibers. This may be due to the reduction in the strength of the cow hair fiber by the alkaline treatment as shown in Figure 5.

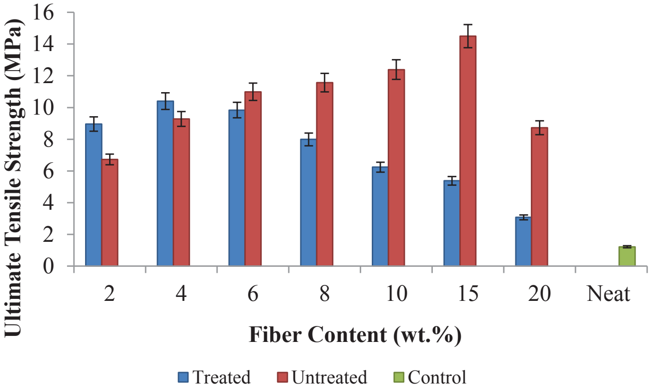


Figure 4. Variation of Ultimate Tensile Strength for Treated and Untreated Cow Hair Fiber Reinforced Polyester Composite and the Neat Samples

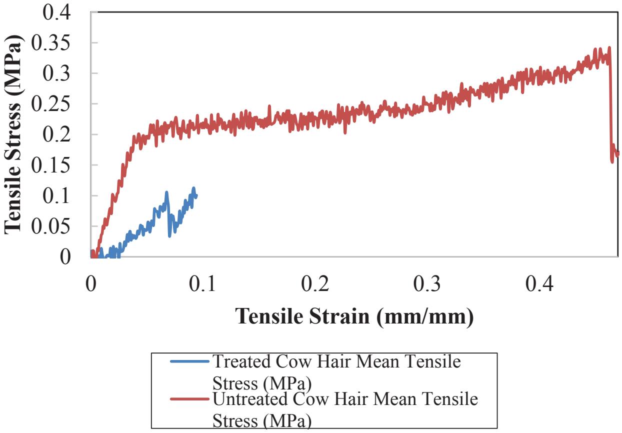


Figure 5. Tensile Stress Strain Curves of Treated and Untreated Cow Hair Fibers

Figure 6 shows the result for tensile modulus of the composite samples. The result shows that the tensile moduli of the reinforced composites is higher than the neat samples in all the developed composites. The composite samples that were reinforced with untreated fibers showed better enhancement in most of the fiber weight fractions than those reinforced with treated fibers. The tensile modulus of the developed composites tends to increase with increase in the fiber reinforcement content from 2-15 wt. %. The composite sample reinforced with 15 wt. % untreated cow hair fiber had the highest tensile modulus with a value of 1418.43 MPa followed by the sample with 10 wt. % untreated cow hair fiber having a modulus values of 890.83 MPa which were better than the control sample having a value of 203.97 MPa. These results show that the tensile modulus was enhanced by over 100% in all the fiber reinforced composites.

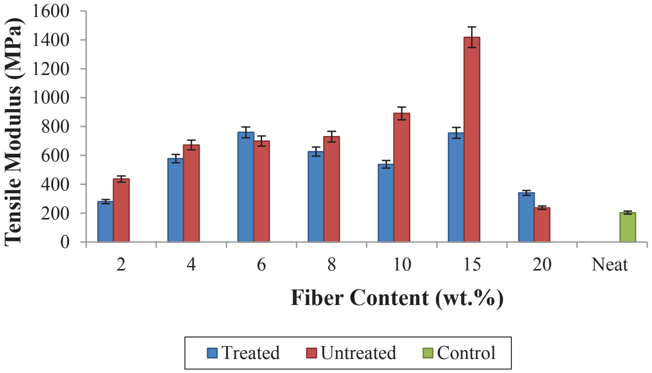


Figure 6. Variation of tensile modulus for the treated and untreated cow hair fiber reinforced polyester composite and the neat samples

From the results presented in Figure 7, it was observed that the flexural strength at peak for the developed composites increases with increase in fiber content. The untreated cow hair fiber reinforced composites showed better enhancement in flexural strength at peak than the treated cow hair fiber reinforced composites in all the composite samples. The sample developed from 20 wt. % untreated cow hair fiber reinforcement was the best with a value of 42.82 MPa followed by the sample reinforced with 15 wt. % untreated cow hair fiber with a value of 39.87 MPa. It was also observed that greater enhancement was observed for the sample containing 10-20 wt. % than for 2-8 wt. % and this suggests that higher fiber content led to increase in flexural strength at peak.

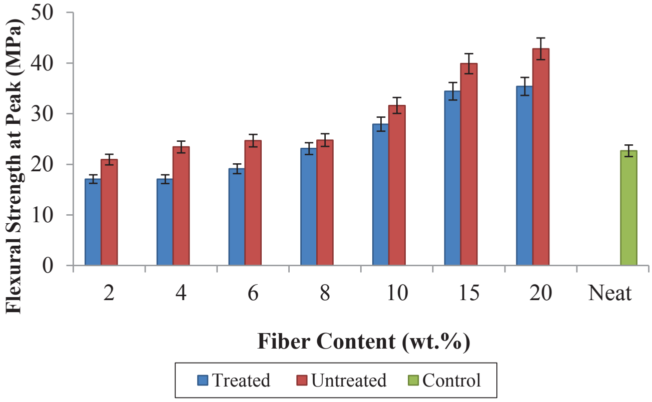


Figure 7. Variation of Flexural Strength at Peak for the Treated and Untreated Cow Hair Fiber Reinforced Polyester Composite and the Neat Samples

Figure 8 shows the result of flexural modulus for the developed composites. It was observed that most of the developed composites possess better flexural modulus than the neat sample which justifies the use of these fibers as reinforcement material. Composite sample reinforced with 20 wt. % untreated cow hair fiber had the highest flexural modulus with a value of 7090.29 MPa followed by the sample with 15 wt. % treated cow hair fiber with a value of 5178.84 MPa. The flexural modulus of the composites increases as the fiber content increases and this implies that the stiffness of the cow hair fibers enhances the overall stiffness of the reinforced composites.

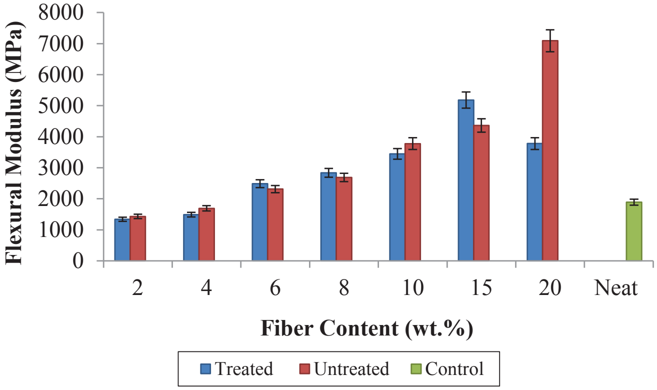


Figure 8. Variation of Flexural Modulus for Treated and Untreated Cow Hair Fiber Reinforced Polyester Composite and the Neat Samples

Figure 9 shows the variation of abrasion resistance of the developed composites and the neat that serves as the control sample. It was evident from the result that the additions of cow hair fiber to the polyester in both treated and untreated conditions have reduced the susceptibility of the matrix to abrasion. The result showed that the untreated fiber reinforced composites performed better than the treated fiber reinforced composites. This may be due to the presence of strong natural polymer structure that characterized the cow hair in the composition. Sample reinforced with 10 and 15 wt. % untreated cow hair fibers with values of 0.05 and 0.08 g weight loss, respectively had the highest abrasion resistance. The control sample without reinforcement had the least abrasion resistance with a value of 2.83 g weight loss. This therefore, indicates that the reinforcements improved the abrasion resistance of the developed composites by impacting the matrix with the potential to resist abrasion.

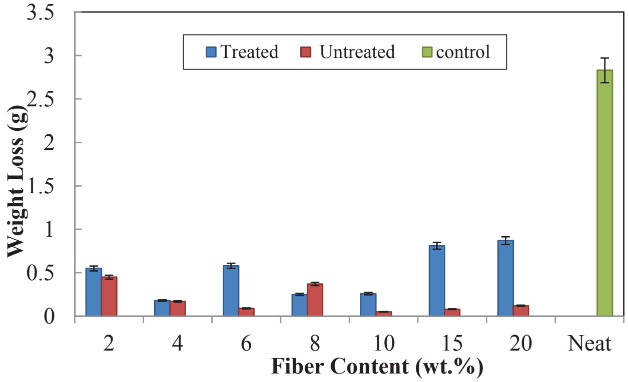


Figure 9. Abrasion Resistance Responses for Treated and Untreated Cow Hair Fiber Reinforced Composite and the Neat Samples

As a result of the growing environmental awareness (increased pollution and increasing demand for biodegradable materials), manufacturers, researchers and scientists are keen to study environmental friendly materials (Oladele & Agbabiaka, 2015b). This new material can be applied in automobile and electronic industries where light weight, strong and good abrasive resistance as well as environmental friendly materials are need.

Figure 10 shows that the water absorbed by the composites increases with increase in fiber weight fraction. It was also observed that the water absorbed by the composites increases with increase in immersion time and attains equilibrium after 120 hours. At this stage, the composites have attained saturation point and can no longer absorb water. This is in accordance with Alaneme et al. (2013).

From the result, it was discovered that in both treated and untreated composite samples, 4 wt. % cow hair fiber reinforced composite samples had the highest water absorption resistance while the sample with 20 wt. % untreated fiber reinforcement had the least water absorption resistance. This implies that samples developed with low fiber weight fractions were more resistant to water absorption than samples of higher weight fractions. This could be as a result of the fact that animal fibers are more hydrophilic than polyester and would therefore absorb more water in less time than the surrounding polyester matrix.

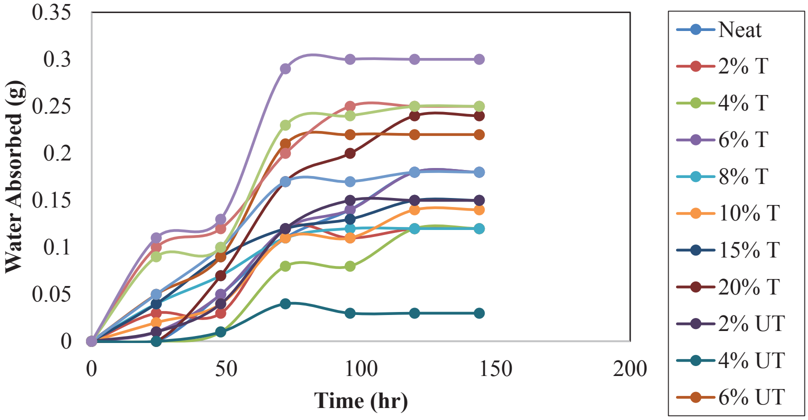
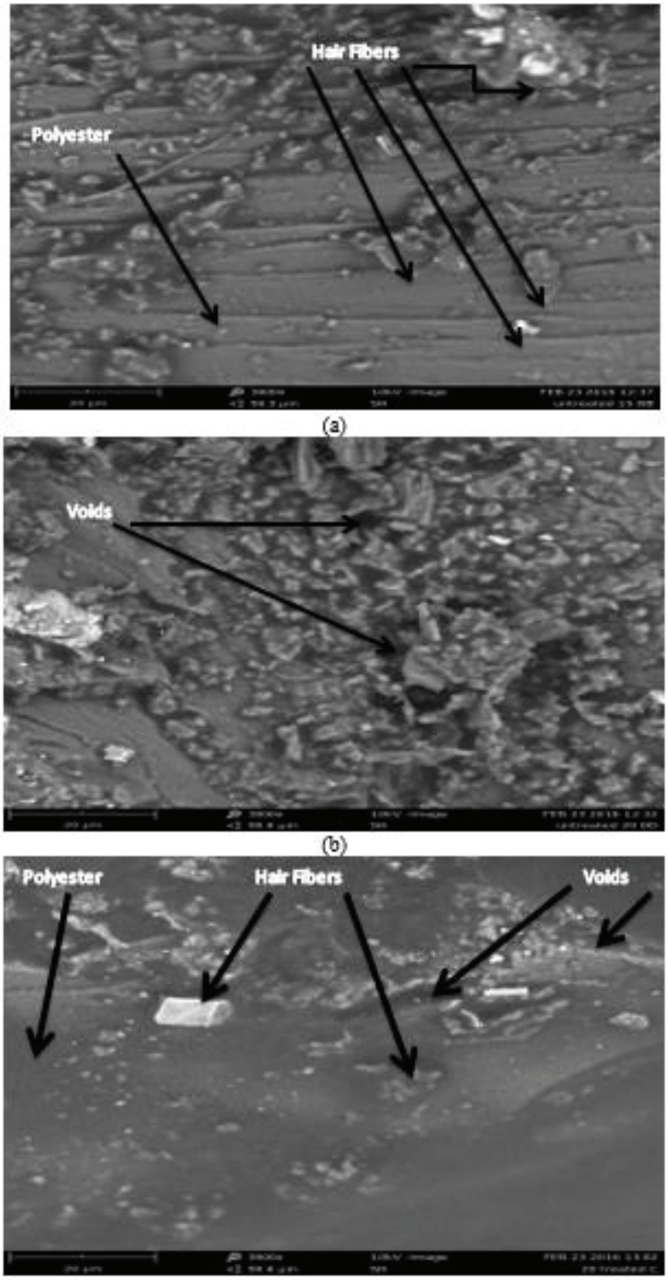


Figure 10. Water Absorption Behavior of the Treated and Untreated Composite and the Neat Samples

The SEM micrographs shown in Figure 11 displays the fractured surfaces of the developed composites with best mechanical properties from untreated and treated composite samples reinforced with 15 and 20 wt.% cow hair fibers. The micrographs showed that the fibers were homogenously distributed within the matrix. The white phases represent the cow hair fibers while the dark phases represent the unsaturated polyester matrix. Improved enhancements were not achieved for the chemically treated fiber reinforced polyester composites which may be due to the treatment being too harsh for the fibers. Low surface adhesion between the fiber and the matrix that aids fiber pull out as shown in Plate 4 (c) contrary to what was observed for the untreated fiber reinforced samples with rough surfaces as shown in Plate 4 (a-b). The existence of rough and interlocking surfaces promotes strong interfacial adhesion between the reinforcement and the matrix and is responsible for the good abrasion and mechanical properties obtained for these compositions as shown in Plate 4 (a-b). In addition, good impregnation and uniform dispersion of the reinforcement is essential to enable optimum transfer of load between both phases to give good abrasion and mechanical properties. Enhancement of properties was observed for abrasion, tensile and flexural properties compared to the neat polyester matrix as a result of adequate fiber distribution in the matrix and the good surface adhesion between the cow hair fibers and the unsaturated polyester matrix.



(a)

(b)

(c)

Figure 11. SEM images showing (a) untreated fiber reinforced sample (15 wt. %); (b) untreated fiber reinforced sample (20 wt. %) and in (c) treated fiber reinforced sample (20 wt. %).

4.0 CONCLUSION

The work was carried out to unfold the potentials of using animal waste as reinforcement source for synthetic polymer as well as encourage the use of biodegradable materials for engineering applications. From the research, the following conclusions have been made:

- Composites with good abrasion and mechanical properties can be developed with both treated and untreated cow hair fibers. However, composite samples reinforced with untreated cow hair fiber showed better enhancement in all the properties than those reinforced with treated cow hair fiber which may be due to the reduction in the strength of the fiber by the alkaline treatment.
- For the composite samples reinforced with untreated cow hair fibers, the ultimate tensile strength increases as the fiber content increases from 2-15 wt. % and the composite sample with 15 wt. % fiber reinforcement had the highest ultimate tensile strength while for the treated cow hair fiber, the ultimate tensile strength reduces with increase in fiber weight content from 4-20 wt. % and the composite sample with 4 wt. % treated cow hair fiber reinforcement had the highest ultimate tensile strength while the flexural properties where noticed to increase with increase in fiber content for both treated and untreated fibers.
- Optimum abrasion and mechanical characteristics were obtained with the addition of the cow hair fiber at higher content within 10-20 wt. %.
- The amount of water absorbed by the composites increases with the increase in the weight percent of the reinforcement phase.

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