Tribology in Industry

RESEARCH

Effects of Fiber Fraction on the Mechanical and Abrasion Properties of Treated Cow Hair Fiber Reinforced Polyester Composites

I.O. Oladele[a], N.I. Agbeboh[a], S.M. Omokafe[a], O.I. Ibrahim[a]

[a] Department of Metallurgical and Materials Engineering, Federal University of Technology, PMB, 704, Akure, Ondo State, Nigeria.

Corresponding author:

Oladele Isiaka O
Department of Metallurgical and Materials Engineering, Federal University of Technology, PMB, 704, Akure, Ondo State, Nigeria.
Email: iooladele@futa.edu.ng

A B S T R A C T

Fiber reinforced polyester composites were developed by reinforcing polyester resin with Cow hair fibers obtained from the tail of Zebu breed cattle in Nigeria. Composites were fabricated using hand lay-up techniques in which the 10 mm lengths of the NaOH treated fibers were randomly dispersed in a polyester matrix using open molds and allowed to cure at ambient temperature before testing. The tensile, flexural, abrasion and water absorption properties of the cow hair fiber (CHF) reinforced polyester composites were evaluated. Different Fiber reinforced composites showed the greatest enhancement in mechanical (tensile, flexural), abrasion resistance and water absorption properties compared to the unreinforced polyester material. The different fiber fractions which showed the best blend of properties were noted and plausible justifications for such values in each measured property were deduced. Ultimate tensile strength (UTS), abrasion resistance and hydrophobicity *were optimum at 4 wt% CHF content with a value of about 10 MPa (UTS) while Young's Modulus and flexural modulus were 756 and 5179 MPa at 15 wt%, respectively. Flexural strength at peak was best with a value of 35 MPa at 20 wt% CHF content.*

1. INTRODUCTION

Over the past three decades, composite materials have been the dominant emerging materials. The needs for sustainable engineering materials and environmental considerations have given opportunities for rigorous research in the field of natural fibre-reinforced composites. Despite the effectiveness and advantages of natural fibres from plants as reinforcement in the production of composite materials, it has been observed that such fibres have limitation of a high rate of absorption of moisture. In most cases, this weakens the properties of the composites. So, there is need to divert attention into the use of other source of natural fibres such as avian fibres [1]. This has created the need for rapid material development,

which necessitates an improvement over the conventional methods of composite engineering. Composite materials can be developed using various materials, where one material forms the matrix and another forms the reinforcement. The reinforcements may be either in form of particles or fibers. Most, synthetic fiber reinforcements are expensive and toxic, thus leading to the exploration of viable options, the most prominent being natural fibers. Natural and thus biodegradable fibers are safer and more readily available. There has been a proliferation of research into the development of natural fiber reinforced polymeric composites with the aim of replacing the more expensive synthetic fibers with the readily available natural fibers which are hitherto wastes and contribute to environmental pollution due to problems with disposal. The interest in using natural fibers in composite development is no doubt due to their light weight, nonabrasive, combustible, nontoxic, low cost and biodegradable properties. However, poor interfacial adhesion, low melting points and poor resistance to moisture absorption, make the use of natural fiber reinforced composites less attractive. Pretreatments of the fiber can clean and chemically modify the surface, stop the moisture absorption process and increase the surface roughness [2]. The use of these fibers as reinforcements in both thermoplastic and thermoset polymers give the twin benefits of solving disposal problem and cost effectiveness. Prominent among the natural fibers are animal fibers, specifically the hairs of mammals which contain structural proteins notably keratin that form an intricate network of intermediate filaments in the cytoplasm of epithelial cells, which fundamentally provides structural maintenance for cells and tissues. This gives them the ability to withstand various chemical and thermal treatments and an appreciable variety of physical and mechanical stresses without sustaining permanent damage [3-4]. Due to these advantages animal hair has proven to be an adequate reinforcement to thermoset and thermoplastic polymers. Re-examination of animal fibers, particularly, keratin-based fibers for composites development has manifested in quite a remarkable but not exhaustive number of investigations with encouraging results [5]. Dwivedi et al. [4] used human hair fiber to reinforce polypropylene and documented a significant improvement in the mechanical properties of the developed composites; the work

of Oladele et al. [2] revealed an improvement in the flexural properties of cow hair fiber reinforced high density polyethylene composites [6]. Also, Oladele et al. [7] show improvement on the tensile properties of cow hair fibers reinforced low density polyethylene composites. It has been observed that low fiber weight fractions enhance mechanical and abrasion properties due to its light weight from its low density while Young's modulus and flexural modulus decrease with an increase in fiber amount in the polymer [2,8].

However, unlike vegetable fibres, most animal fibres are biological wastes such as avian feathers and mammalian hairs which are generated across the globe by agro industries in billions tons per year [9]. Most of these animal fibres are keratinous materials; that is, they are potential bio-resources for keratin extraction.

According to Moore et al. [10], the presence of elements such as C, N, O and S (key elements in amino acids) in significant amounts in the bovine hair fibres indicates that, with appropriate methods of extraction, substantial amount of useful keratins can be tapped from these fibers. The Mean spectra values of the principal elements that constitute amino acids in the fibers are in the same range with that of human hair fibers [11].

Hitherto, chicken feathers, animal wools and human hairs have been the major bio-resources exploited for keratin extraction with little attention on bovine hair, hooves and horns [12-13]. The possibility of extracting keratin from cow hair fiber from different breeds were considered by Oladele et al. [11] and it was concluded that a proper utilization of the fiber would be their exploitation for keratinous applications. Recently, Burnett and Boyd received a US patent for inventing novel methods for extracting purified keratin based biomaterials from different mammalian hair and avian feather wastes [14].

This research was carried out to encourage the use of natural fibers from animal origins as a substitute to synthetic fibers for the production of polyester composites. This was necessitated by the brittle fracture associated with thermosetting plastics like polyester and the growing interest in the use of renewable and

ecofriendly materials previously viewed as waste materials. Also, the research was carried out to add value to cow hair and promote its use for engineering applications while attempting to reduce the environmental issues it poses.

This research was aimed at developing treated cow hair fiber reinforced polyester composites and analyzing its abrasion, mechanical and water absorption behavior.

2. MATERIALS AND METHOD

2.1 Materials

The principal materials used were Polyester resin and Cow hair fibers. The cow hair fibers were extracted by scraping the hairs off the tails of Zebu breed, white Fulani cows procured from an abattoir at Ijoka Area in Akure, Ondo State, Nigeria. The cows were on the average of 2 years old. The cows were raised in North-Central Nigeria under free-range system where the temperature across the year varies between 22.55°C ±0.423°C in the wet season and 33.54°C ±0.23°C in the dry season [15]. The cow hair fiber was as shown in Fig. 1.

Fig. 1. Photographic view of Cow Hair Fibre.

The hair density and length for different breed of cows vary in diameter, length, density and other properties as evidently shown in literature. However, these variations are quite minute and not too significant as the hair sizes and properties fall within the same range for most cows around the world [16-17]. The measured average physical properties are given below:

D = 6.4 ±10 μm

L = 10 ±1.6 mm

l = 13 ±2.2 mm

wt. = 27 mg/cm^2

Mass per volume = 48 mg/cm^3

The fibers were thoroughly rinsed with tap water to remove debris and excrement followed by sun drying for 5 days. The dried fibers were cut into 10 mm lengths before been treated with 0.15 M solution of NaOH at 50 °C for 4 hours in a shaker water bath. The fibers were washed with tap water and rinsed with distilled water in order to ensure neutral status as confirmed by litmus paper test and then sun dried for 3 days.

Sodium Hydroxide (NaOH) pellets were obtained from Pascal Scientific Chemicals, Akure, Ondo State while Polyester resin, accelerator and catalysts were procured from Ibadan, Oyo State, Nigeria. The distilled water was obtained from Chemistry Department, Federal University of Technology Akure, Ondo State.

2.2 Methods

The composites were developed using open mold process. The short fibers were randomly dispersed in the polyester matrix in predetermined proportions of 2, 4, 6, 8, 10, 15 and 20wt%. The cow hair fiber (CHF) reinforced polyester composites were fabricated by casting the compounded reactants (resin+fibers) into the tensile, flexural and abrasion test sample molds, removed after curing. The cured samples were then tested.

2.2.1 Tensile strength

The tensile test was performed in compliance with ASTM D638 test standard [18]. The specimen's overall length, gauge length, width and thickness were 115, 33, 10 and 5 ±1 mm, respectively. The tensile test was performed using INSTRON 3382 Floor Model Universal Tester at a fixed crosshead speed of 10 mm/min. The experiment was carried out at room temperature of 22 ±2 °C. Three repeatability tests were conducted for each composition and their mean values were used in this study to ensure accuracy and reliability of test results.

2.2.2 Flexural Test

Three samples of the same composition were tested and the average was obtained and used for subsequent calculations. Three-point bend test was performed on the composites in

accordance with ASTM D790 standard [19]. The length, width and thickness of the specimen were 120, 12.7 and 3.2 mm, respectively. Correspondingly, the test was performed on INSTRON 5980-series Floor Model Universal Tester. The machine was operated at a crosshead speed of 0.3 mm/mm and at a specific strain rate of 10^{-3}/s. The test is stopped when the specimen reaches 5 % deflection or breaks before 5 % deflection. The experiment was carried out at room temperature of 22 ±2 °C.In carrying out the test, the grip for the test was fixed on the machine and the sample was hooked on the grip and the test commenced. As the specimen is stretched the computer generates the required data and graphs. The sets of mould used were as shown in Fig. 2.
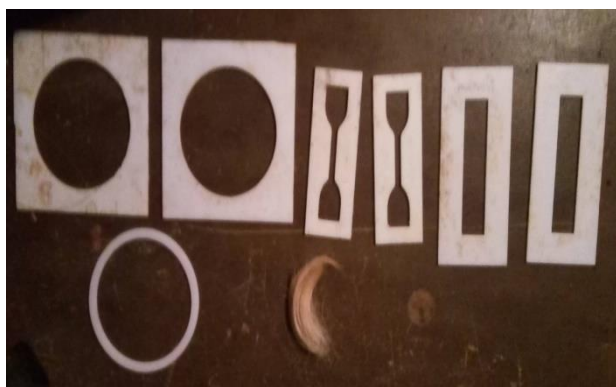

Fig. 2. Photographic view of Mould for the Mechanical Tests.

2.2.3 Scanning Electron Microscopy

The surface morphology of the composite samples was studied using a Phenom ProX Scanning Electron Microscope (SEM) (Phenom-World, Eindoven, Netherlands). The fractured surfaces of the molded samples were mounted on stubs and subjected to SEM analysis as reported by Rout et al. [20].

2.2.4 Water Absorption Test

This was test was conducted in compliance with ASTM D570 test standard [21]. To carry out the test, clean plastic containers were procured into which 250 cm^3 of distilled water was measured. The initial weight of each of the sample was taken using chemical weighing balance; FA2104A Model of high precision ±0.0001 g accuracy before it is dropped inside a beaker of distilled water, readings were taken every day

for seven days (one week). To take each reading, the sample was removed, cleaned with a clean cotton cloth and weighed. The data collected was used to determine the percentage of water absorption using equation 1:

$$\% \ Absorption = \frac{W_t - W_d}{W_d} \ x \ 100 \qquad (1)$$

where: W_t - Weight of test sample at a given immersion time and W_d - Weight of dried test sample.

2.2.5 Abrasion Test

The wear test was conducted in compliance with Taber Wear test standard D4060 [22].The abrasion resistance test was carried out with Taber abrasers, Model ISE AO16. Each specimen was a flat and round disc of approximately 100 mm^2 and a standard thickness of approximately 6.35 mm. It was affixed to the turntable platform and rotated at 1000 rpm for 5 hours. Abrasion resistance was measured using the weight difference before and after abrasion (weight loss technique). Care was taken to remove loose particles adhering to specimens during testing, especially prior to weighing. This procedure was carried out for all the various samples to determine the effect of abrasion on the material using equation 2:

$$L = A - B \qquad (2)$$

where: L - Weight Loss; A - Weight of test sample before abrasion in grammes and B - Weight of test sample after abrasion in grammes.

3. RESULTS AND DISCUSSION

Tests were performed on three samples from each weight percent of the composites developed and the average of the results obtained after the tests were taken. This was used as representative of the respective response for each of the developed composites.

3.1 Tensile Properties

The charts in Figs. 3-4 showed the ultimate tensile strengths and moduli of the developed composites and the control sample.
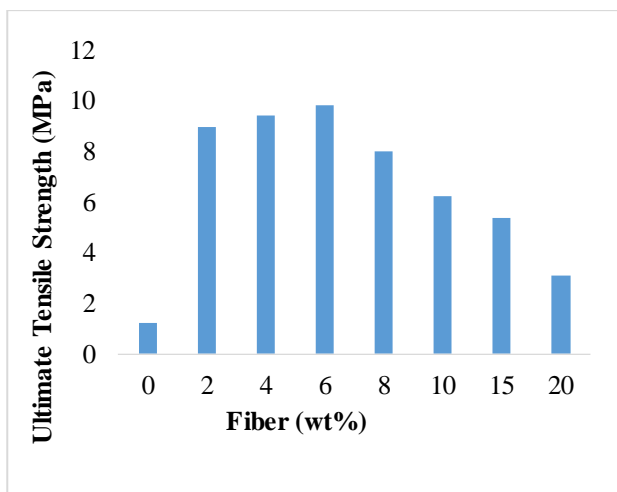
Fig. 3. Variation of UTS for Treated Cow Hair Fiber Reinforced Polyester Composites and the Control Sample.
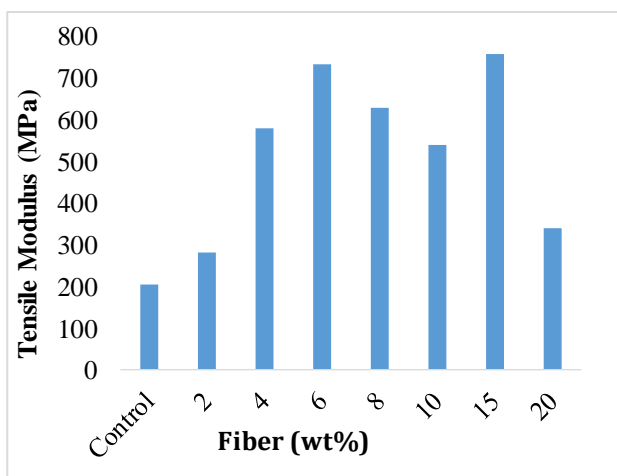

Fig. 4. Tensile Moduli for Cow Hair Reinforced Polyester Composites and the Control Sample.

The plots in Fig. 3 showed that all the fiber fractions enhanced the tensile strength of the composites compared with control sample. The fiber fractions with optimum enhancement fall within the range of 2-8 wt% from where it was observed that 4 wt% gave the best result with a value of 10.40 MPa and this value thus implies optimum fiber-polyester ratio that gave the outstanding UTS.

The enhancement of the 2-8 wt% reinforced composites may be attributed to good fiber-matrix interaction at the interface due to the influence of chemical treatment on the fiber surface. Surface modification with chemical treatment eliminates the need for coupling agents, thus, reducing the cost of production as well as environmental pollution emanating from the use of synthetic materials. The fiber fractions seemed to be strong enough to aid load bearing without greatly

compromising matrix plasticity. The good interfacial adhesion between the fiber and the matrix allow easy transfer of load from the matrix to the fiber effectively, by this means, improving the strength of the developed composite materials, particularly within the range stated above.

Figure 4 shows the tensile moduli that signify the stiffness of the developed composites when they are subjected to tensile loads. All the developed composites had higher tensile moduli or stiffness than the unreinforced polyester that act as the control when subjected to the same experimental conditions. The moduli were highly enhanced within 4-15 wt% fiber reinforcement with optimum value at 15 wt%. As noted by Pickering et al. [23] the seeming drop in the tensile modulus showed by the 8-10 wt% fiber reinforced composites may be due to factors such as fiber agglomeration. Fiber agglomeration does occur occasionally as a result of experimental imperfection that reduces fiber dispersion. Since good fiber dispersion has been known to promote good interfacial bonding and reduce voids by ensuring that fibers are fully surrounded by the matrix, fiber agglomeration tends to encourage these defects. From the results, the 15 wt% fiber reinforced composite sample had the highest tensile modulus of 756.16 MPa compared to the control sample which had 203.97 MPa.

3.2 Flexural Properties

The results presented in Fig. 5 shows that flexural strength at peak for the developed composites increases with increase in the fiber fractions.
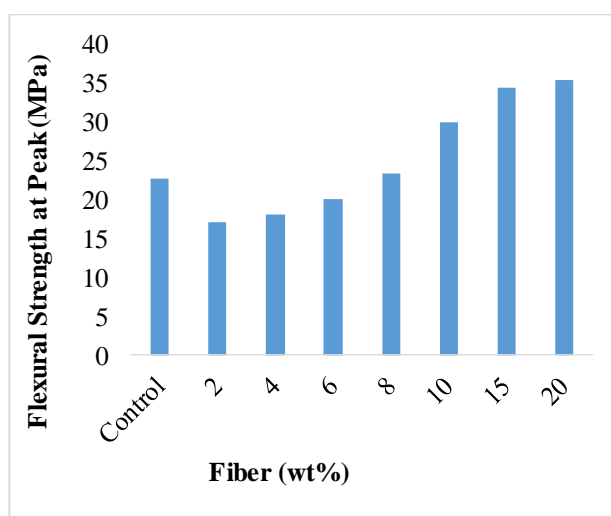

Fig. 5. Flexural Strength at Peak for Treated Cow Hair Fiber Reinforced Composites and the Control Sample.

The composite samples with 20 wt% treated CHF reinforcement had the highest flexural strength value of 35.37 MPa, followed by the 15 wt% treated CHF composite with a value of 34.43 MPa. The control sample had a flexural strength value of 22.67 MPa. This is of course due to the increased load bearers in the composite as fiber fraction increases. The results showed that there are two sections based on the fiber fraction where it was evident that, the flexural strength were not improved within 2-8 wt% reinforced composites while better enhancement were observed within 10-20 wt%.
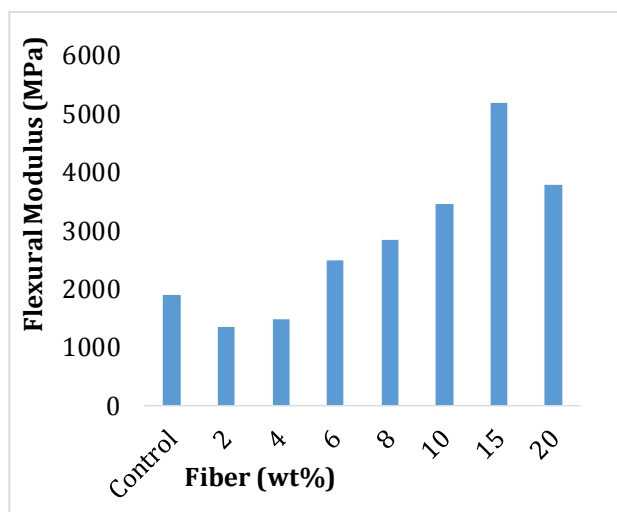

Fig. 6. Flexural Modulus for CHF Reinforced Polyester Composites and the Control Sample.

Figure 6 shows the flexural modulus of the developed composites as well as the control sample. Similar to the response in Fig. 4, most of the developed composites showed better flexural modulus response compared to the unreinforced sample. With the exception of 2-4 wt% treated fiber reinforced composites that show lower flexural moduli, other fiber fractions gave improved moduli. This may be due to the uniform load distribution within the fibers as the amount of the fiber to bear the load increases. This might also be the reason for the comparable observation in the results obtained in Fig. 5. The 15 wt% composite showed highest flexural modulus with a value of 5178.84 MPa, next was the 20 wt% treated CHF reinforced composite with a value of 3779.73 MPa. The control (unreinforced polyester) sample had 1891.28 MPa. These results showed well dispersed fibers, with more fibers interacting with the matrix properly, hence, enhancing the fiber-matrix interfacial adhesion that leads to direct increase

in flexural modulus which might not occur with low fiber weight fractions.

In all, flexural moduli tend to increase as the fiber content increases. As a result, higher weight fractions are favorable for the development of cow hair fiber reinforced polyester composites to obtain good flexural strength and stiffness.

3.3 Water Absorption Property

The results obtained on conducting water absorption tests for the treated cow hair fiber reinforced composites are as shown in Fig. 7.
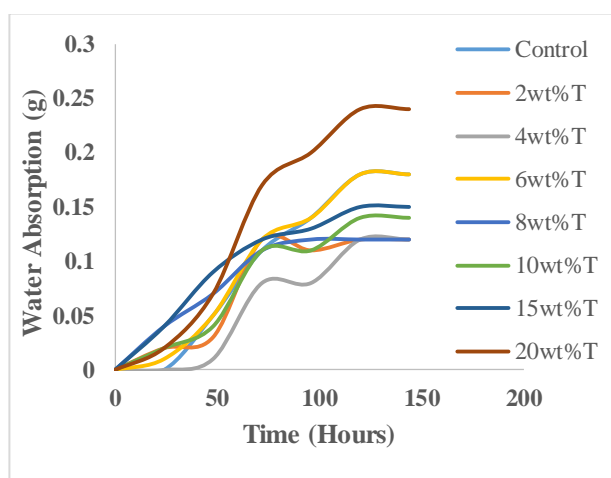

Fig. 7. Water Absorption Test Results for Treated Composites and the Control Sample.

Natural Fibers have been known to be highly hydrophilic, thus, more fibers will imply greater moisture absorption. This is confirmed in the increased moisture absorption as fiber fraction increases in Fig. 7. The lower moisture absorption values initially shown within the 0 to about 40 hours' time range can be attributed to the enhanced hydrophobicity that chemical treatment induces in natural fibers. This also results in good fiber – matrix adhesion and the resultant fiber – matrix interface impedes water ingress. As shown in Fig. 7 the interface mainly accounts for the initial low moisture absorption values recorded. However, this interface breaks down with prolonged attack by water molecules and this result in the spike in moisture absorption values shown beyond the 40 hours immersion time.

More fibers imply higher absorption capacity and this is most pronounced in the 20 wt% composite

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which showed the highest moisture absorption of 0.24 g. All the composites showed limiting absorption capacity after about 120 hours.

The 4 wt% cow hair fiber reinforced composite had highest water absorption resistance (hydrophobicity).This may be attributed to the lower absorption that is consequent of the smaller combined absorption capacity of the individual fibres.

However, the smaller fiber fraction and consequent better dispersion would enable better enveloping of the fibres by the matrix, thus greatly reducing the rate of water ingress into the fibres, thereby improving the absorption resistance. Conversely, as previously explained, 20 wt% treated CHF reinforced composite had the least water absorption resistance and is most hydrophilic of all the composite samples.

3.4 Abrasion Property

Abrasion tests were conducted on the cow hair fiber reinforced polyester composites and the unreinforced samples.
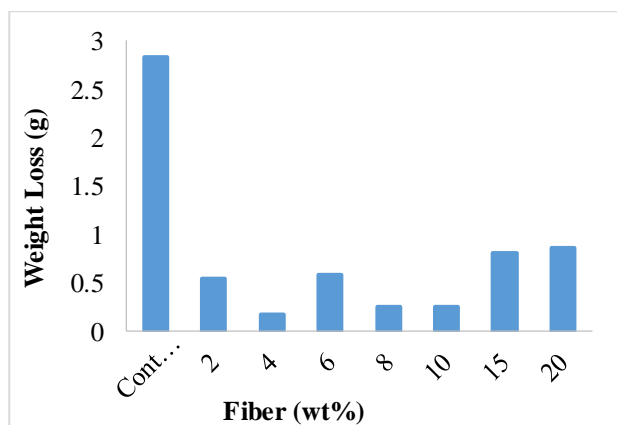
The result of the test was as shown in Fig. 8.

Fig. 8. Variation of Abrasion Responses for Treated Cow Hair Fiber Reinforced Composites and the Control Sample.

The weight loss values of the composites and control produced upon being subjected to abrasion during wear test are presented Fig.6. Wear is the progressive loss of material due to relative motion between a surface and the contacting substance or substances [24]. Wear resistance is the ability of a material to resist the gradual wearing away caused by abrasion and

friction. Since these materials are usually subjected to wear challenges from the environment, there is need to understand the behavior of these materials and how they will respond to this encounter in service. As shown in Fig. 8, samples reinforced with NaOH treated cow hair fiber aid enhancements in all the fiber contents used compared to the control sample. To study the abrasion properties of the materials, sample with the highest mass loss is usually the sample with least wear or abrasion resistance while sample with the least mass loss is usually the sample with the highest wear or abrasion resistance. It was observed that from the result that, fiber reinforced composites show very high wear resistance compared to the control, particularly, from 2 to 10 wt%. This may be due to the presence of fiber as reinforcements in appropriate proportions within the composites (optimum range). The control sample loss the highest mass of about 2.8 g compared to composite sample with highest abrasion resistance of 0.2 g obtained from 4 wt% fiber reinforcement. Treated cow hair fiber can, therefore, be used as natural fiber to improve the abrasion resistance of polyester matrix composites.

3.5 Scanning Electron Microscope (SEM)

The SEM image of the treated cow hair fiber reinforced composite sample was as shown in Fig. 9. The image reflects the significant volume fraction of the fibers even with homogenous dispersion in the matrix.

Fig. 9. SEM Image of the Fractured Treated Cow Hair Fiber Reinforced Composite.

The cow hair fibers contain keratin and amino acids which are predominantly hydrophobic. Alkali treatment helped to reduce the amount of lipids, threonine and serine, thus improving wettability and bonding within the cow hair fibers (white part) and the polyester matrix (dark part) as shown in the image.

Good fiber impregnation and uniform dispersion is essential for effective load transfer between both phases and composite mechanical properties. These were achieved in this result and the reason for the good enhancement of both tensile and flexural properties that was obtained from the composites compared to the neat polyester matrix.

4. CONCLUSION

The outcome of the research showed that the reinforcements aided the enhancement of the properties examined with respect to the mechanical, tribological and physical properties. Ultimate tensile strength, abrasion resistance and hydrophobicity were optimum at 4 wt% CHF content with a value of about 10 Mpa (UTS) while Young's Modulus and flexural modulus were 756 and 5179 MPa at 15 wt%, respectively. Flexural strength at peak was best with a value of 35 MPa at 20 wt% CHF content.

Fiber content was noticed to have great influence on the ensuing properties in addition to the fiber as reinforcement. This was revealed from the results where 4 and 15 wt% gave most of the optimal results.

The developed composites can be used for the interior parts of automobile due to the demand for increase amount of renewable materials in automobile parts.

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