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The Influence of Chemical Treatment on the Mechanical Behaviour of Animal Fibre-Reinforced High Density Polyethylene Composites

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ABSTRACT: *This research work has investigated the influence of chemical treatment on the mechanical behaviour of animal fibre-reinforced high density polyethylene composites. The animal fibres used for this present study were chicken feather and cow hair fibres procured from local poultries and abattoirs. Prior to the development of the composite materials, the animal fibres were washed and dried, cut into 10 mm and divided into two portions; one portion was treated with 0.25 M NaOH maintained at 60 ^{0}C for 1 hour in a water bath, rinsed with distilled water and dried in the oven while the other portion was left untreated. Both portions were then used to reinforce the high density polyethylene polymer at 2, 4, 6, 8 and 10 % fibre loading respectively from which, the flexural and tensile test samples were produced by hot compression moulding. From the test results, it was observed that the chemically treated cow hair and chicken feather fibre reinforced high density polyethylene composites gave the best flexural properties for most fibre loading percentages compared to their untreated animal fibre-reinforced high density polyethylene composites counterparts and the neat high density polyethylene matrix. However, the tensile properties of all the animal fibre-reinforced high density polyethylene composites were not enhanced. Chicken feather and cow hair fibres were chosen for this research work to consider their potential applications as reinforcement for polymeric materials with a view to curtail the environmental pollution they generate by means of their disposal, as they are considered as unusable animal waste.*

Keywords: *Animal fibres, High density polyethylene, Composite, Chemical treatment, Mechanical behaviour*

I. INTRODUCTION

Intensive research in adopting natural fibres as reinforcement in polymeric composites with an objective to take advantage of nature's gift to mankind and contemporaneously reduce the huge expenses pumped into the development of synthetic fibres, has intensely attracted the interests of contemporary materials' scientists and engineers [1]. Natural fibers are integral part of our day to day life and they are appreciably ample all over the earth. They include cotton, coconut fiber, straws of wheat, hemp, sisal, silk, avian fibre, horse hair, alpaca hair, human hair and more. Their availability, renewability, low density, and inexpensiveness as well as satisfactory mechanical properties render them an eye-catching ecological substitute for glass, carbon and man-made fibres that have been conventionally used for the manufacturing of composites [1, 2]. They are subdivided based on their origins, coming from plants, animals, or minerals [3]. The predominant ones exploited, are those of vegetal origins, due to their wide availability and renewability in short time with respect to others [4]. However, this present study concentrates its pivotal point on the animal fibre; specifically fowl feather and cow hair fibres. Research on natural fibre composites has existed since the early 1900's but failed to receive substantial attention until late in the 1980's [5]. In recent times, studies on the use of natural fibres as replacement to synthetic fibres in fibre-reinforced polymeric composites have augmented and unlocked a new channel for supplementary industrial prospects [6]. This has manifested in a rapid growth of interests of researchers in natural fibre reinforced polymeric compositesboth in terms of industrial applications and fundamental research.

A reinforced plastic consists of two main components; a matrix which may be either thermoplastic or thermosetting and reinforcing fillers which usually take the form of fibres but could also be particles [7]. High Density Polyethylene (HDPE) is one of the common thermosetting plastics vastly used for industrial purposes. It was created in the 20th century byCarl Shipp Marvel, an American chemist (by subjecting ethylene to a large amount of pressure), and since then has served great engineering purposes [8]. HDPE is used in a variety of applications and industries where excellent impact resistance, high tensile strength, low moisture absorption, excellent low temperature toughness, relatively high softening temperatures and chemical and corrosion resistance properties are required.Its common applications include making of toys, utensils, bottles, pipes and processing equipment, wire and cable insulation, 3-D printer filaments, snowboard rails and boxes, and corrosion protection for steel pipelines [8-9]. Their ability to be reinforced, even with natural fibres and made into composites further gave them a wider range of applications.

Although, natural fibre reinforced polymericcomposites have moderately a few disadvantages relative to synthetic fibres such aspoor resistance towards moisture and lack of good interfacial adhesion between the reinforcing fibres and the matrix material, nonetheless, the production of composites reinforced with synthetic fibres and matrices requires a large amount of energy which is only partially recovered with incineration of fibre reinforced composites [5], Thus, the renewed interest in the natural fibres, due to their low density, nonabrasive, nonirritating, combustible, nontoxic, fully biodegradable properties, low energy consumption for production, budget zero CO_2 emissions if burned, low cost, pose no health hazards, main availability and renewability compared to synthetic fibres, has resulted in a remarkable number of applications to bring it at par and even superior to synthetic fibres [1 ,4, 10]. The prominentshortcomings of natural fibres in polymeric composites are the poor compatibility between fibres and matrix interface and the relatively high moisture absorption [3]. Hence, a better understanding of fibre-matrix interface and the ability to transfer stress from the matrix to the fibre is highly essential for developing natural fibre-reinforced polymeric composites [3]. To eliminate these shortcomings associated with natural fibres, chemical treatments are considered the best methods in modifying the fibre surface properties [6]. And this has made the chemical treatment of natural fibres an area of research currently receiving significant attention [5]. A good number of researchers have investigated chemical treatments of natural fibres. The ordinary chemical treatments are alkaline treatment, H_2SO_4 treatment, and acetylated treatment. Alkaline treatment is one of the most effectively used treatments of natural fibres when used as reinforcement in thermoplastics and thermosets [3]. This is because alkaline treatment or mercerization has been successfully used by many researchers.In this study, the sodium hydroxide was chosen because of its low cost and availability. Wang et al (2008), Rokbi et al (2011), and Suardana et al (2011) have also used NaOH to chemically treat natural fibres of vegetal origins used as reinforcement in polymeric composites [11-13].

The animal fibres (chicken feather and cow hair) used in this research are commonly described as waste by-product which are contributing to environmental pollution due to their disposal problems. The two main methods of practically disposing them are burning and burying which both have negative impact on the environment [14]. In Nigeria, aside the meat consumption of cows, prevalently, their skins are used to make shoes, mats and outfits. It is obvious that there is very little research into using cow hair as fibre reinforcement for polymers, this study presents it could be a potential reinforcement for polymeric composites depending on the desired properties. On the other hand, recent studies on the chicken feather waste demonstrated that the waste can be a potential composite reinforcement [15]. Additionally, the development of natural fibre reinforced polymeric composites that are biodegradable promotes the use of environmentally friendly materials and provides alternative way to solve the problems associated with agricultural residues [16]. Thus, this usage of these animal fibres will make a better utilization of them as opposed to the environmental concerns relating to their methods of disposal.

II. MATERIALS AND METHOD

Materials

The sourcing and procurement of all the materials utilized for this research work were done in Nigeria. The high density polyethylene was procured from Euro chemical Ventures Limited, Lagos State while the chicken feather and the cow hair fibres were procured from commercial poultry farms and abattoirs in Akure, Ondo State.

Methods

Reinforcement preparation

Prior to the development of the composites, the animal fibres selected for direct use as fibre reinforcements were washed with distilled water and detergent and sun dried for 1 week to remove any form of impurities such as blood, oil and pigments. They were then cut into 10 mm and divided in to two portions. One portion of the cleaned samples was chemically treated to improve wettability and interfacial bonding strength between the fibres and the HPDE matrix and also to reduce the moisture absorption capacity while the other portion was left untreated. The chemical treatment was performed using 0.25 M NaOH in a water bath maintained at a temperature of 60 ^{0}C for 1 hour. The Fibres were removed from the water bath and rinsed with distilled water several times to remove any NaOH solution sticking to fiber surface and dried in the oven at 60 ^{0}C for 1 hour.

Composite Development

The animal fibre-reinforced HPDE composites and the control samples were produced by hot compression moulding technique. To produce the composites, the matrix and the fibres were mixed together in predetermined proportions as shown in table1. The materials were weighed using an electronic weighing balance and poured into the flexural and tensile test moulds made of steel. The filled moulds were placed inside the compression moulding machine maintained at 160 ^{0}C for 5 minutes. The samples were extracted from the mould when they were still warm and allowed to cure in air. The same compositions were adopted for all the various fibre samples used.

Composition of the animal fibre-reinforced HPDE composites

Table 1: Composition of the animal fibres-reinforced HPDE Composites

Composition	*Wt. %*	*Wt. %*	*Wt. %*	*Wt. %*	*Wt. %*
HPDE	98	96	94	92	90
Fibre	2	4	6	8	10

Mechanical Testing of the Materials

Flexural Test

Flexural test was carried out by using Testometric Universal Testing Machine in accordance with ASTM D790[17]. To carry out the test, the grip for the test was fixed on the machine and the test piece with dimension of 150 x 50 x 3 mm was hooked on the grip and the test commenced. As the specimen is stretched the computer generates the required data and graphs. The Flexural Test was performed at the speed of 100 mm/min.

Tensile Test

In the present study, tensile tests were performed on INSTRON 1195 at a fixed Crosshead speed of 10 mm min-^{1}. Samples were prepared according to ASTM D412 [18]standard and tensile strengths of the conditioned samples were calculated.

III. RESULTS AND DISCUSSION

Flexural Properties

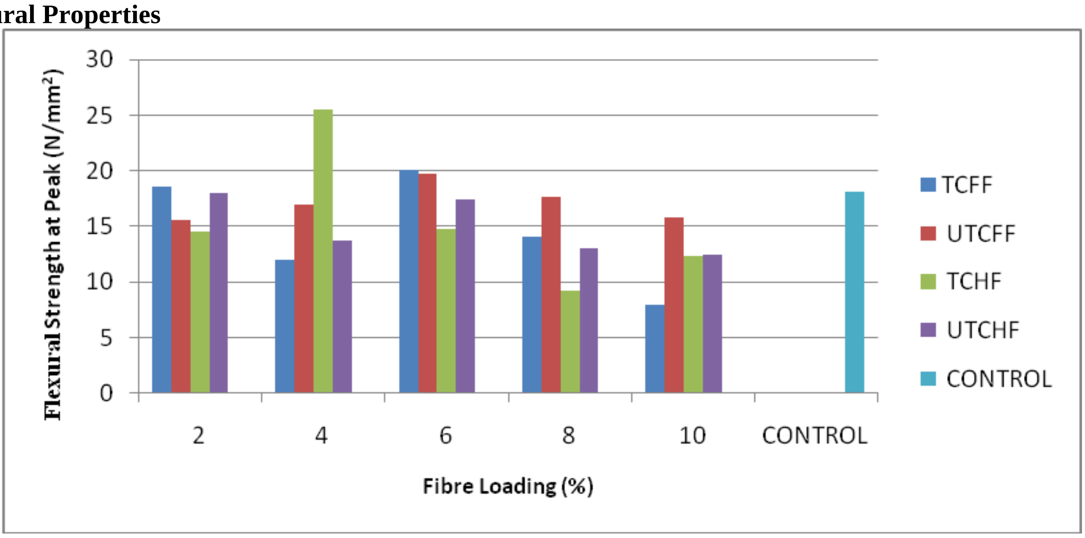

Figure 1: Variation of flexural strength at peak with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

Figure1 above represents the effect of the animal fibres (chicken feather fibre and cow hair fibre) reinforcements on the flexural strength at peak for high density polyethylene (HDPE) composites and the control sample (unreinforced HPDE) from where it was observed that the flexural strength decreases as the fibre loading percentage increases. Although at 2, 6, and 8 % fibre loading, the chemically treated chicken feather fibre (TCFF) gave values higher than that of the treated cow hair fibre (TCHF). However, the TCHF at 4 % fibre loading gave the highest value in comparison with all the other samples. The TCHF-reinforced HPDE at 4 % fibre loading has a flexural strength of 25.46 N/mm^2 which is 81.31 % better than the untreated cow hair fibre (UTCHF) with a value of 13.74 N/mm^2 at the same fibre loading and 40.45 % better than the control sample with a value of 18.13 N/mm^2. Oladele et al (2014) used untreated chicken feather fibre (UTCFF) and untreated cow hair fibre (UTCHF) to reinforce HPDE and it was found out that the flexural strength of the UTCFF was better than that of the UTCHF for each fibre loading. However, the results of this research have revealed that the effect of chemical treatment at 4 % fibre loading on the UTCHF enhanced the flexural strength of the TCHF-reinforced HPDE composite better than that of the TCFF, UTCFF, UTCHF and the control sample. This improvement in flexural strength can be attributed to improved interfacial adhesion between the matrix and the fibre which in turn allows a more efficient transfer of stress between the fibre and the matrix. The overall performance of any fibre-reinforced polymer composite depends extensively on the fibre-matrix interface which is a function of the surface topography of the fibre and the chemical compatibility of fibre surface and resin properties [2]. The decrease in flexural strength with increase in fibre loading has been reported by some researchers[2,15,19,20]. They attributed this phenomenon to increase in fibre-fibre interaction, random orientation of short fibres within the matrix, poor dispersion of fibre in the matrix and more over higher void content (which might be due to the presence of moisture in trace amount) and low interfacial strength resulting in a lower efficiency of load transfer with increase fibre loading.

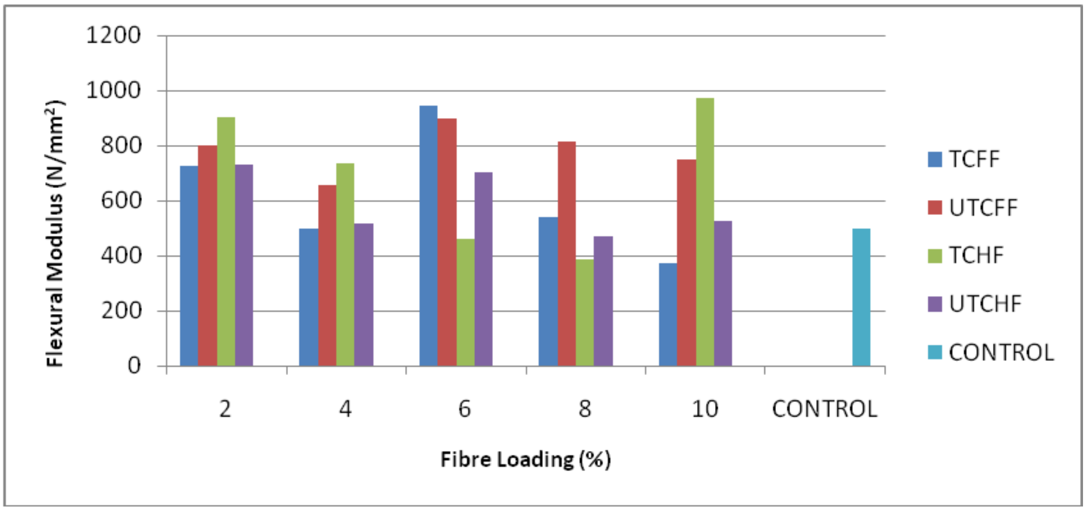

Figure 2: Variation of flexural modulus with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

Figure 2 above represents the effect of animal fibres on the flexural modulus for the samples. From the test results, it was observed that the chemical treatment enhanced the flexural modulus of the cow hair fibre at 2, 4, and 10 % fibre loading respectively. The TCHF reinforcement at 10% fibre loading gave the best result with a value of 972.10 N/mm^2 which is 84.44 % better than the UTCHF with a value of 527.06 N/mm^2 at the same fibre loading and 95.14 % better than the control sample with a value of 498.15 N/mm^2. The results showed that the untreated chicken feather fibre (UTCFF) reinforced composites possess better flexural modulus in all the fibre loading used than the control material. However, the effect of the chemical treatment on the chicken feather fibre (CFF) only increased the flexural modulus at 6 % fibre loading. The TCFF reinforcement has a flexural modulus of 942.80 N/mm^2 at 6 % fibre loading which is 4.87 % better than the UTCFF with a value of 899.00 N/mm^2 at the same fibre loading and 89.26 % better than the control sample.

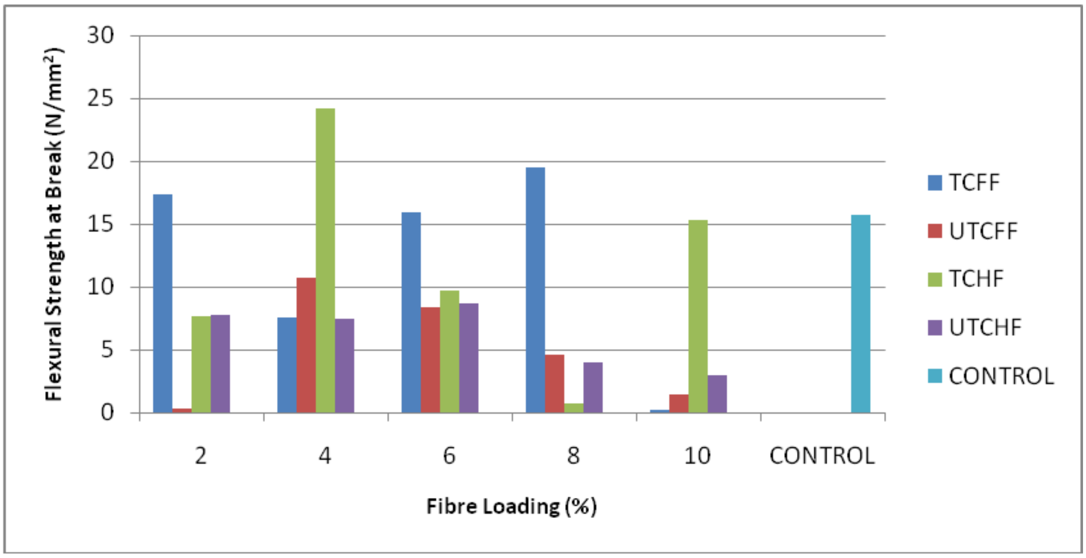

Figure 3: Variation of flexural strength at break with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

Figure 3 above represents the effect of the animal fibres on the flexural strength at break for the samples, from where it was observed, that the TCHF reinforcement at 4 % fibre loading gave the best result with a value of 24.20 N/mm^2 which is 226.04 % better than the UTCHF reinforcement with a value of 7.42 N/mm^2 at the same fibre loading and 53.68 % better than the control sample with a value of 15.75 N/mm^2. The chemical treatment was observed to have improved the flexural strength at break of the cow hair fibre reinforcement as well as that of the chicken feather fibre at variousfibres loading. The results followed a similar pattern as was observed in Figure 2.

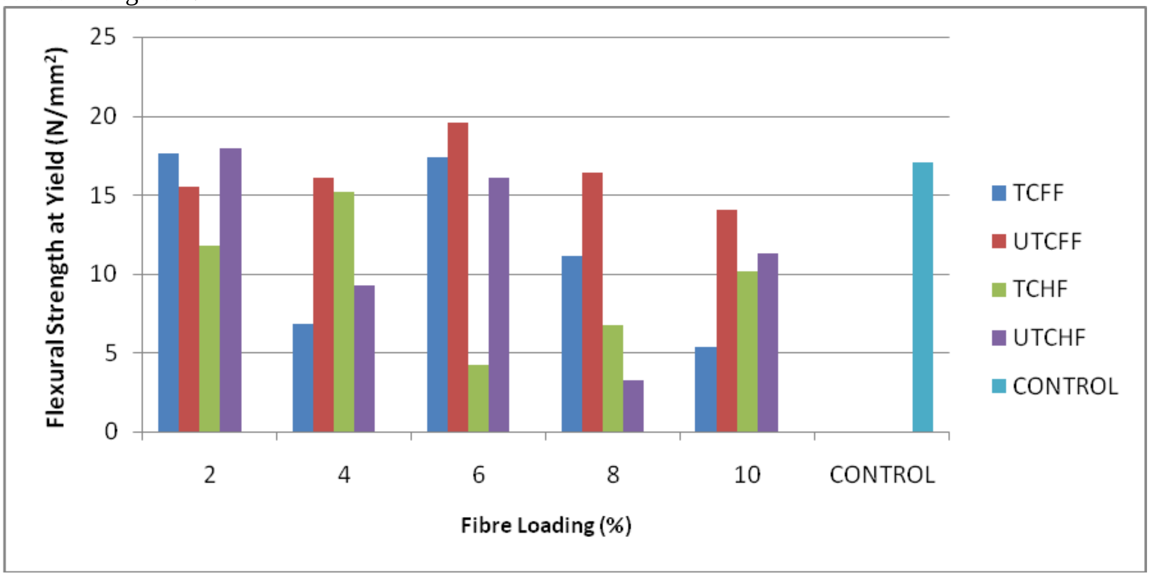

Figure 4: Variation of flexural strength at yield with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

Figure 4 above revealed the variation of flexural strength at yield for the samples. The results showed that the UTCFF reinforcement at 6 % fibre loading gave the best result with a value of 19.60 N/mm^2 which is 12.86 % better than the TCFF reinforcement with a value of 17.36 N/mm^2 at the same fibre loading and 15.16 % better than the control sample with a value of 17.02 N/mm^2. From the test results, it was observed that the chemical treatment only improved the property of the chicken feather fibre reinforcement at 2 and 6 % fibre loading respectively compared to the control sample.

Tensile Properties

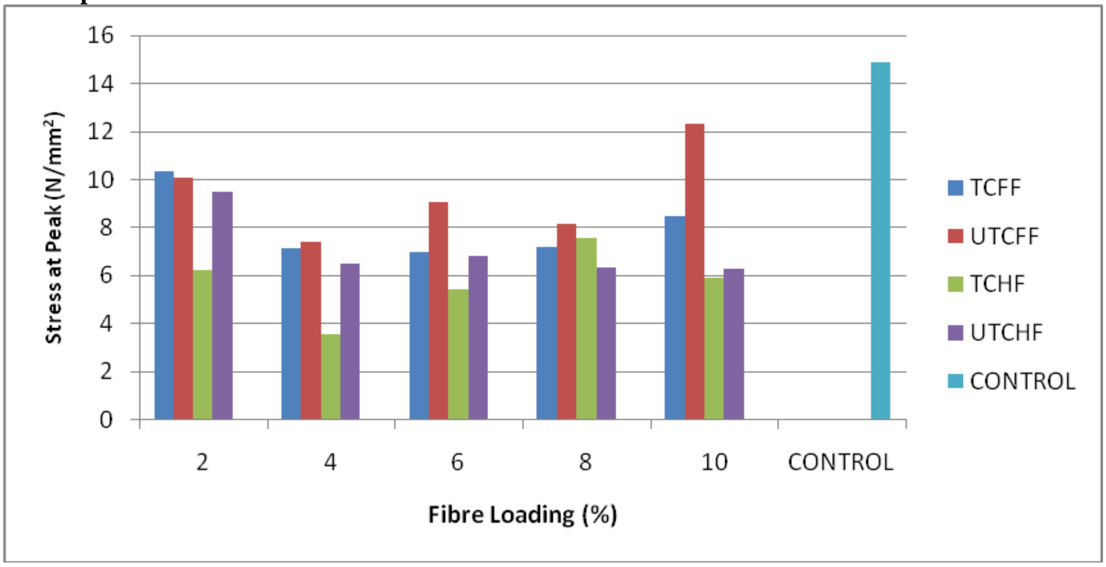

Figure 5: Variation of stress at peak with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

The tensile strength at peak results of the control sample (unreinforced HPDE) and the animal fibre-reinforced HPDE composites are presented in Figure 5. These results showed that the tensile strength at peak of the control sample was highest with a value of 14.89 N/mm^2. The 10 % UTCFF reinforcement gave the best results of the animal fibre reinforcements witha value of 12.32 $N/mm^{2.}$ However, from the results, it was observed that the UTCFF reinforcement at 4-10 % fibre loading gave the best results in comparison with all the other animal fibre-reinforced HPDE composites except at 2 % where the TCFF gave the best result. This decrease in tensile strength exhibited by the animal fibre-reinforced HPDE composites as revealed by these results is similar to what was reported by Uzun et al (2011) when they used chicken feather quill and fibre to reinforce vinylester and polyester and also Reddy et al (2014) when they used Emu feather fibre to reinforce epoxy and polyester[19-20]. The effect of the chemical treatment on the animal fibres reinforcement was only positive for the chicken feather fibre at 2% fibre loading.

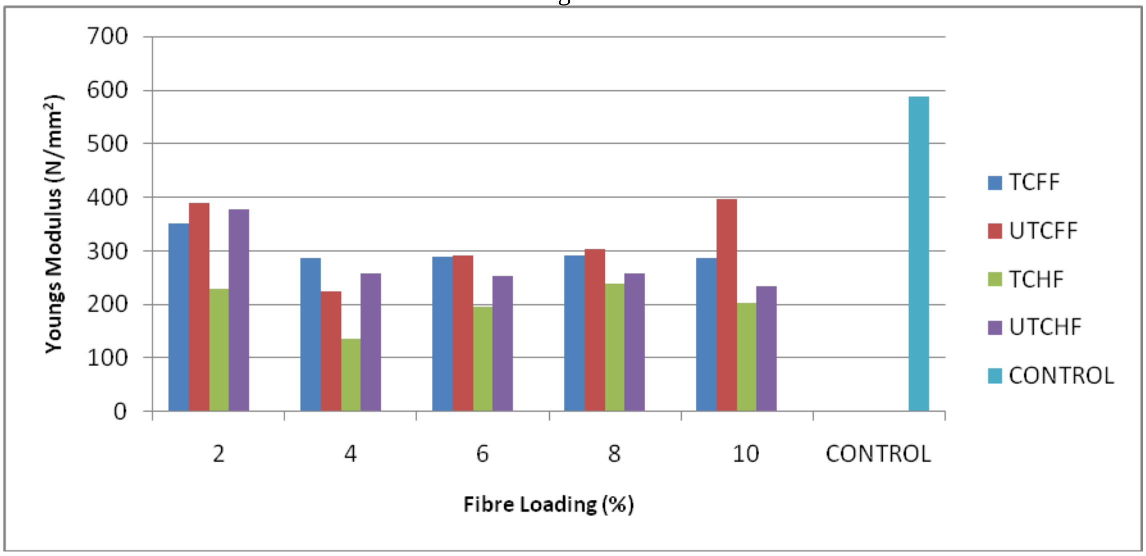

Figure 6: Variation of Young's Modulus with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

The Young's moduli of the control sample and that of the animal fibre-reinforced HPDE composites are presented in Figure 6. These results showed a similar occurrence as was observed in Figure 5 above. From the results, the control sample has the highest value of 588 N/mm^2 Young's modulus. This was followed by 10 % UTCFF reinforced composite with a value of 397.58 N/mm^2. It was observed that the chicken feather fibre has better modulus than the cow hair fibre samples in all samples. For the cow hair fibre reinforcement, the chemically treated samples have lower values than that of the untreated samples. However, the chemical treatment was able to improve the property of the chicken feather fibre reinforcement at 4 % fibre loading in comparison with the UTCFF reinforcement at the same fibre loading. The 2 % fibre loading gave the best performance in terms of weight fraction used with the exception of TCHF. However, the best result was given by the UTCFF at 10% fibre loading.

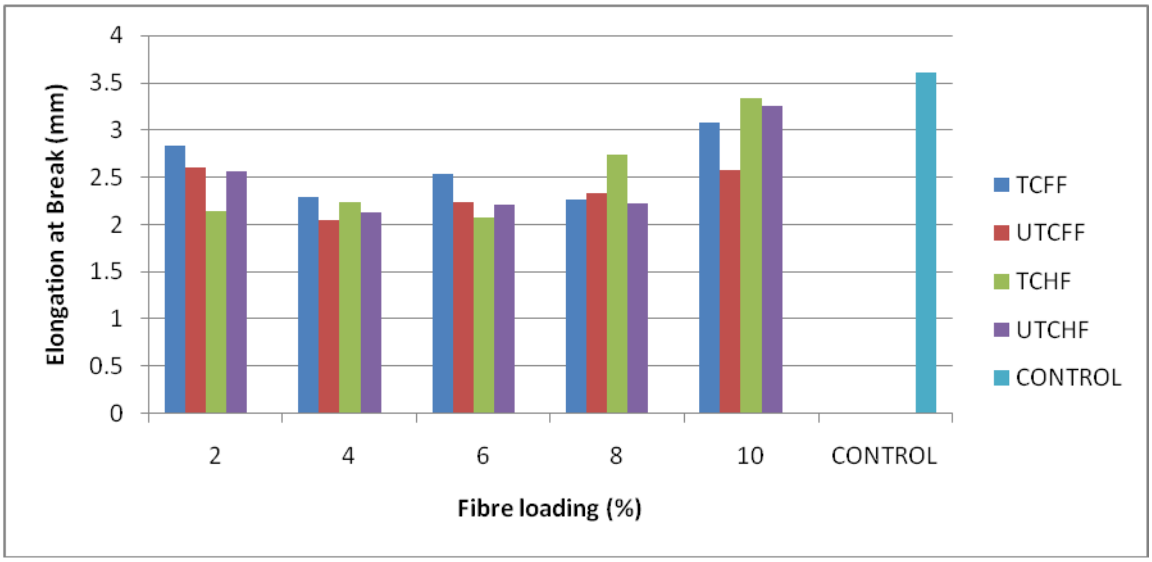

Figure 7: Variation of elongation at break with fibre loading for the animal fibre-reinforced HPDE composites and the control sample

The results for the elongation at break for the animal fibre-reinforced HPDE composites and the control sample are presented in Figure 7. The results of the test also showed that the control sample gave the best result with a value of 3.61 mm. The TCHF reinforcement at 10 % fibre loading gave the best result among the animal fibre-reinforced composites with a value of 3.33 mm which is just 8.31 % lower than the control sample. This performance confirms the reason for the best flexural properties results obtained from TCHF reinforced HDPE in Figures 1-3. The results revealed that the effect of the chemical treatment on the cow hair fiber was more effective at higher fibre loading while the chemically treated chicken feather fibre gave the best results at 2 % and 10 % fibre loading respectively. The 10 % fibre loading gave the best performance in terms of weight fraction used with the exception of UTCFF.

IV. CONCLUSION

The influence of chemical treatment on the mechanical behaviour of animal fibre-reinforced high density polyethylene composites have been investigated where the followings findings were established that;

- Both chicken feather and cow hair fibres can be used to reinforce high density polyethylene in order to enhance the flexural properties of the matrix. This was the case because the addition of these animal fibres to the matrix was able to improve the flexural response of the developed composite materials.
- Chemical treatment can be used to improve the surface condition of the fibres for improve interfacial bonding strength between the animal fibres and the matrix material. This was revealed from the outcome of the results where chemically treated animal fibre reinforced high density polyethylene composites gave the best performance in the flexural properties and elongation at break under tensile properties in comparison with the untreated animal fibre reinforced high density polyethylene composites.
- The work justifies the economic consumption of these otherwise waste materials that are detrimental as environmental pollution agent.

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