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Mechanical impact evaluation of natural fibres with LDPE plastic composites: Waste management in perspective

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ABSTRACT

There is increased enthusiasm towards the use of natural hair fibers for plastic reinforcement due to their toughness and light weight. In this research, low density polyethylene (LDPE) was reinforced using 0.25 M NaOH treated cow tail, human and sheep hair fibers at 2, 4, 6 and 8% concentration respectively prior to injection moulding. The average densities, diameters and lengths of hair fibres were assessed The results obtained from the analysis of reinforced LDPE composites indicated that cow tail hair gave the highest average density and diameter. Sheep hair had the highest length after grinding. The study also analyzed the ultimate tensile strength and modulus, flexural strength and modulus, elongation, impact and hardness test on the polymer and their composites as well as the morphology and statistical analysis of the composite. This study indicated that human hair LDPE composites achieved highest flexural strength, flexural modulus, ultimate tensile strength and tensile modulus at 8% fibre loading whereas elongation at break and hardness were at 4% fibre loading while impact strength was at 2%. The cow tail hair LDPE composite gave the best impact strength at 8% fibre loading and sheep hair at 6%. The SEM results showed no serious manufacturing defects on the composites. The analysis of variance indicated that only the means of the composites' flexural properties were statistically significant. This study shows that short animal hair fibres could be effectively used to reinforced LDPE, and therefore suggest an alternative waste management strategy of these natural fibres that are currently viewed as environmental nuisance in the study area.

1. Introduction

Hair is a proteinous fibre having a strong hierarchical organization of sub-units that form the α-keratin chains via intermediate filaments in the fibres. The exceptional properties of hair such as its unique chemical composition, slow degradation rate, thermal insulation, high tensile strength, elastic recovery and unique interaction with water and oils has led to many diverse uses including its use as reinforcing material in composites [1]. Composites are materials that comprise of strong load carrying material incorporated in weaker material. Reinforcement gives strength and toughness, helping to support structural load [2]. The use of natural fibre of which hair is one of them is receiving much attention from scientists and engineers all over the world, and utilization of natural fibres as reinforcement in polymer composite for producing low cost construction materials, is nowadays being given wide popularity [3,4]. The need to utilize these natural fibres which are majorly considered as a waste in the study area in enhancing the properties of polymer composite is to take advantage of nature's gift to mankind and reduce huge amount of money pushed into the development of synthetic fibres [5]. The use of natural fibre is rapidly dominating the use of synthetic fibre, as natural fibres have many advantages over them, such as easy availability, low density, easy renew-ability, high toughness, non-corrosive in nature, less abrasion to processing equipment, as well as satisfactory mechanical properties make natural fibre reinforcement polymer composites attractive [6–8]. In the automotive industry for instance, density is of paramount importance in the choice of fibre for plastic reinforcement [6]. These render them as an eye-catching substitute for glass, carbon and manmade fibres that have been conventionally used in the preparation of composites [5,8,9].

Preliminary survey in the study area on the use of human hair conducted in various salon indicates that the hair are disposed alongside other municipal wastes [10,11], while others engage in burning them.

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Also animal fibres are burnt by abattoir operators in meat processing, this constitutes serious environmental air pollution, with attendant serious health effects. The current practice in the study area clearly suggests that an improved waste management strategy on the use of natural fibres is imperative to avert the environmental challenges. A study that eliminates the impact of air pollution, global warming from the burning of these natural fibres is therefore critical in achieving a better environment. This study is therefore essential in achieving cleaner environment and would serve as an enhanced waste management strategy.

LDPE plastic finds application in building material, mat, bags, packaging material etc. It is important in day to day activities of average person in developing countries. The poor quality of the various LDPE products alone results in reduced lifespan of the products, and therefore increased production, and consequently increase in discarded products in the environment. It is opined here that good quality LDPE products with improved mechanical properties will increase the lifespan of composite, and will lead to fewer products in circulation, this ultimately will reduce discarded products and waste generated. This study therefore is beneficial in achieving reduced LDPE plastic waste generation and consequently reduction in plastic wastes in dumpsites, landfills and the entire environment, this is in addition to the attendant benefit of reduced environmental pollution. The need for eco-friendly environmental products in the design of materials have been emphasized to have high performance, durable and reliable [10].

Severa\l researches have investigated on the best use of various natural fibres. For instance Ref. [12], investigated on the application of composite that consists of flax woven epoxy for the interiors of rail, cars, panels of aircraft and sports equipment. Another study evaluated the potential of banana fibre related hybrid composites that would successfully carry greater loads, and serve as substitutes for expensive glass fibre based composites [13]. Bagasse extracted from natural products such as oil palm and sugarcane has been studied, the bagasse was designed to create a thermal insulation board, the study reported higher flexural strength of sugarcane bagesse compared to unreinforced cement panels [14]. Areca fibres is reported to be inexpensive and abundant, a study assessed the mechanical properties of flower pot produced from Areca fibres in combination with other fibres (jute fibre), with glass fabrics, and epoxy resin, the study asserted that deformation is less as a result of the fibre [15]. Despite the abundance of these natural fibres (human, cow and sheep hair) in the study area, and the weak environmental management strategies, to the best of the authors knowledge, there are scarce literature on the management perspective and utilization of these fibres generally and particularly in the study area as explored in this study.

This research hopes to address the environmental challenges created by the aforementioned hairs that is not properly disposed in the abattoirs and salons where they constitute major waste. The objective of this study is to model polymer bio-composite with improved mechanical properties by reinforcement of low density polyethylene with natural fibres of human, cow and sheep to provide the attendant environmental and socio-economic advantages.

2. Materials and methods

2.1. Materials

Natural animal fibres used as reinforcement in this research were sourced from Nigeria; the Hausa-specie sheep hair was procured from Birnin Kebbi; cow tail hair from Awka-Etiti; human hair from a hair salon in Nnewi both in Anambra State. Other materials include low density polyethelene (LDPE), and 99.9%anhydrous sodium hydroxide.

2.2. Preparation of hair fibre samples

Cow tail, human and sheep hair fibre samples were thoroughly washed with distilled water and detergent to remove dirt and blood stain. The fibres were sun dried for 5 days, then ground and sieved using 210 μm to ensure homogeneity. After sieving, short rod-like forms of the hair fibres were obtained with cow tail having the least average length (Fig. 1).

2.3. Chemical treatment of hair fibres

The hair fibres were treated with an aqueous solution of 0.25 M NaOH [5]. This was to enhance the surface topology and elasticity of the fibres for appreciable mechanical bonding between fibres and the polymer, and to improve the fibre functionality within the polymer matrix. Two hundred grams (200.0 g) of each of the hair fibre samples was immersed in the alkali solution for 2 h at room temperature after which the hair fibres were rinsed with excess distilled water several times to wash off any trace of aqueous NaOH on the fibre surface. The treated fibre samples were oven dried at a temperature of 105 °C for 1 h 30 min.

2.4. Determination of hair fibre dimension

The hair fibres were individually placed on the focal point of the profile projector, model DC-3000. The length and diameters of the fibres were recorded. The same process was repeated for the three randomly picked fibre strands of cow tail, human and sheep hairs. The average dimension was calculated for each of them.

2.5. Determination of density of hair fibres

The density of each hair sample was determined according to Ref. [16] standard procedure. 0.5 g of dried hair sample was weighed into100.0 ml of canola oil of density 0.907 g/cm^3. The weight of the sample in oil was taken when the sample has been totally immersed in the fluid. The same procedure was given to other fibers and the density calculated as follows:

$$\rho_a = (\rho_c\ w_a)/\ (w_a - w_c)$$

Where: ρ_a = density of fibre; ρ_c = density of oil; w_a = weight of fibre in air; w_c = weight of fibre in oil.

2.6. Development of composite

The fibre reinforced LDPE composites with animal hair and the control sample were produced using Injection moulding technique. Four hundred grams (400.0 g) of LDPE resin pellets were thoroughly mixed with different percentage concentrations (i.e. 2, 4, 6 and 8) % of hair fibres separately. The mixtures were reweighed before being transferred to injection moulding machine. The composites were developed at an average temperature of 170 °C (160–180 °C) and injected into a disc-shaped mould of dimensions 200 mm × 5 mm, with the help of the torpedo injector, where they were formed into hard plastic materials upon cooling. The LDPE without hair fibre was also injected.

2.7. Testing of the mechanical properties of the composite

2.7.1. Flexural test

The flexural test of the composites samples cut 13 mm × 75 mm was performed using Flexural Testing Machine according to Ref. [17]. The flexural force applied to break the sample was used to determine the sample's flexural strength at break by the machine. The same method was also used to determine the material's flexural modulus which is the ratio of stress to strain in flexural deformation before break.

2.7.2. Tensile test

The method adopted for the analysis of the tensile strength was according to Ref. [18]. The force required to pull the sample apart and how much it stretched before breakings were measured. The same method was used to determine the tensile modulus and elongation at break of the sample.

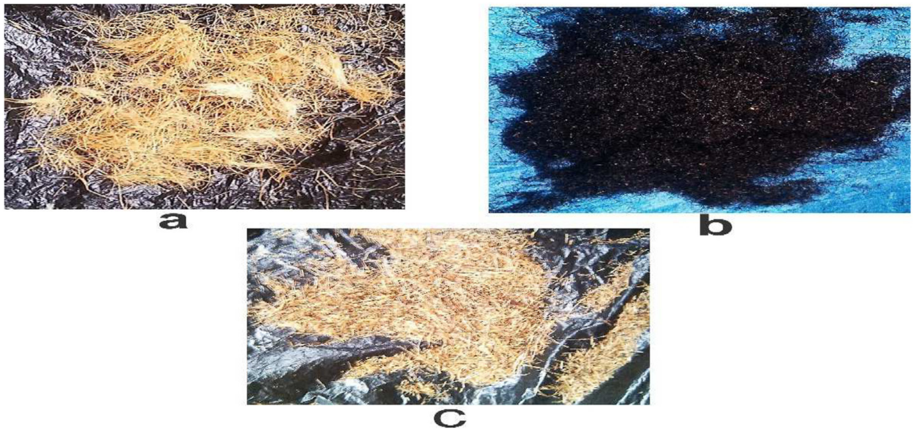


Fig. 1. Samples of ground hair fibres; a. Sheep hair (SH) b. Human hair (HH) c. Cow tail hair (CH).

2.7.3. Impact test

The Charpy impact test machine was used for the analysis according to Ref. [19]. The impact strength (kJ/m^2) was obtained by dividing impact energy by the area (in m^2) of the sample.

2.7.4. Hardness test

The Brinell hardness test was performed according to Ref. [20], using the dynamic hardness tester. The signal, which is equivalent to the absorbed energy, was displayed on the instrument with instant calculations. This was repeated on three different areas of the composite and the average was obtained.

2.7.5. Morphological analysis

The microscopic study of the prepared composites was carried out using scanning electron microscope (SEM).

2.7.6. Statistical analysis of the composites' mechanical properties

Statistical analysis was carried out using ANOVA.

3. Results and discussion

3.1. Hair fiber properties

The hair fibres were treated in order to prepare their surfaces for efficient adhesion to the polymers. The results of the average density, length and diameter of the three hair fibres (CH, HH and SH) show that cow hair has the highest average density and diameter, while the sheep hair gave the least average density and diameter (Table 1). The differences in the average diameters obtained for the hair types can be attributed to the cuticle thickness. The slight reduction observed in the diameters of the hair fibres after treatment may be attributable to the removal of the oils and waxes on the fiber surfaces.

The diameter result of the human hair fibre (88.3 μm) in this work is comparable to 80.0 **μm** obtained by Ref. [21]. They reported on the effect of chemical treatment in the physicochemical and tensile properties of CH fibre. The average densities 1.32g/cc and 1.34g/cc shown in the studies by Ref. [21&22] respectively compares well with 1.32 g/cm^3 gotten in this research. Sheep hair fibre gave the highest length. This may be as a result of particle size which made it least exposed to the blades of the grinder. The results of the surface morphology of the LDPE composites (Fig. 2) analyzed using Scanning Electron Microscope (SEM) at 8% fiber loading for the hair fibers indicate that there is no significant manufacturing defect on the composites. There are no fibre breakages or voids noticed in the images. The surface SEM images obtained in this research is similar to that of the cow hair fibre reinforced low-density polyethylene composite prepared by (5) using compression method. The only observable difference is that, in the experiment by (5), more pronounced air entrapment were seen from the surface SEM images of the prepared composites, some of which were ruptured. This may be due to the application of more pressure during composite preparation with compression method.

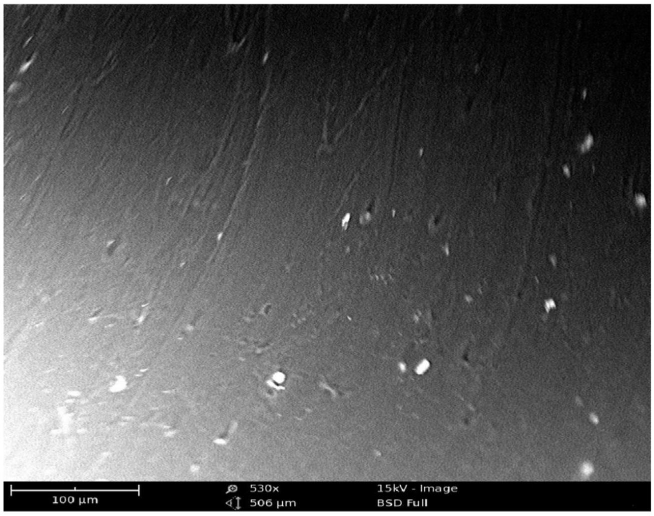
From the results obtained (Fig. 3), the flexural strength of LDPE composites was enhanced by the three hair fibres and all the hair fibres LDPE composites increased in their flexural strength with increase in loading. Fig. 3 reveals that HH composites has the overall best result of the flexural strength 145 MPa from the control value of 40.1 MPa at 8% fibre loading. Sheep hair performed best at 8% fibre loading with value at 57.5 MPa while CH is best (89.0 MPa) at 6% fiber loading. Sheep hair fibre given the least flexural strength may be because it has highest length before and after grinding. The statistical values obtained for F and P, [$F(2, 9) = 142.67$; $P = <0.001$] show that the mean in the data set are significantly different. This implies that the hair fibers have significant effect on the flexural properties. Human hair mean data is the most significant and the only hair fiber that attain the optimal flexural strength at breakage target for automotive applications which is said to be '100 MPa [23].

The consideration of the three hair fibers for flexural modulus in Fig. 4 indicates that HH fibre LDPE composites gave the overall best flexural modulus at 8% fiber loading with increase from a control value of 1.00 GPa–7.50 GPa whereas, the SH gave the least value 1.05 GPa at 6% fiber loading. The statistical analysis shows that the F and P-values are 370.21 and < 0.001 respectively. This difference in the means may be attributed to the contribution of the fibre stiffness to the flexural properties.

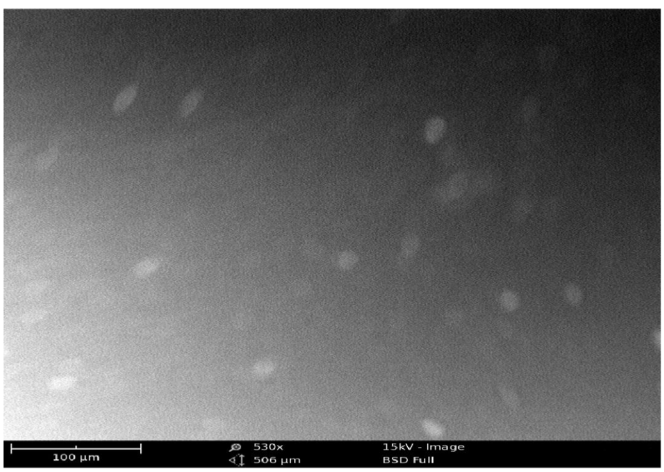
In Fig. 5, it was observed that, except for the SH fibre which decreased from 6.60 N/mm^2 (control) to 5.49Nmm^2 at 6% loading, the ultimate tensile strength of virgin LDPE was enhanced by all the hair fibres. The least enhancement (104%) of the polymer's ultimate tensile strength was produced by SH at 6% fibre loading whereas, the highest (178%) was given by HH at 8% fiber loading from the control value of 6.60 N/mm^2. In the statistical analysis, the F and P-values of the data set analysis of variance are 0.56 and 0.589 respectively. This disclosed that the tensile

Table 1
The properties of human hair, cow tail hair and sheep hair fibres.

Hair fibre type	Average density (g/cm^3)	Average length (mm)	Average diameter before treatment (μm)	Average diameter after treatment (μm)
Human hair	1.32	6.29	95.1	88.3
Cow tail hair	1.34	4.12	173.1	169.9
Sheep hair	1.30	7.53	49.6	36.8



SEM image of Sheep hair LDPE composite



SEM image of Cow hair LDPE composite

SEM image of Human hair LDPE composite

Fig. 2. SEM images of sheep hair, cow tail hair and human hair fibres reinforce LDPE composites.

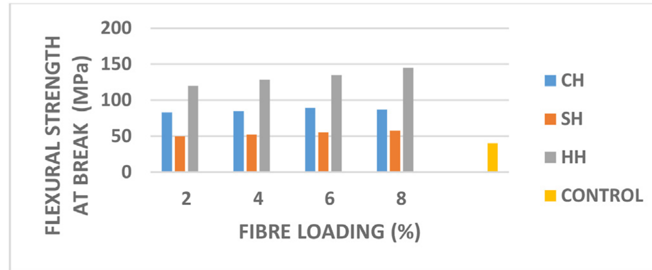


Fig. 3. The flexural strength at break with percentage fibre loading for reinforced and unreinforced LDPE composites.

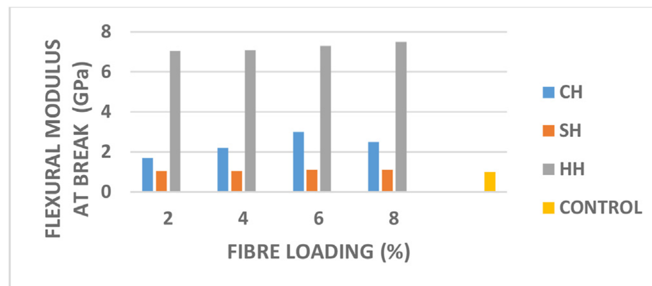


Fig. 4. The flexural modulus at break with percentage fibre loading for reinforces and unreinforced LDPE composites.

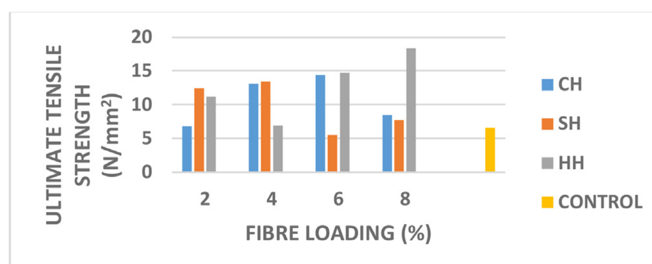


Fig. 5. The ultimate tensile strength with percentage fibre loading for reinforces and unreinforced LDPE composites.

strength was as a result of fibre-matrix synergy other than just the fiber strength. Though the tensile strength of LDPE was somewhat enhanced by the hair fibers, but it failed to reach the optimal target for semi-structural automotive applications which according to Ref. [23] is set at 75 MPa.

It was observed in Fig. 6 that the tensile modulus of the virgin polymer was greatly improved with human hair fiber providing the best enhancement with an upshot of 288% (995.49 N/mm^2) from the control value of 256.84 N/mm^2 at 8% fiber loading. The statistical analysis shows no significant difference in the mean of the data set giving the F and P values of 0.85 and 0.457 respectively. The drop in the tensile modulus of cow tail and sheep fibres after 6 and 4% fibre loading may be attributrd to poor dispersion of fibre in polymer matrix at higher loading. This is in accordance with the result reported by Ref. [24&25]. Nevertheless, the hair fibre LDPE composite could not achieve the optimal value of tensile modulus for semistructural applications, which according to Ref. [23] is set at 5.5 GPa.

In Fig. 7, the results of elongation at break for animal fibre reinforced LDPE composites and control sample showed that the elongation at break of human hair fibre was the highest of the three hair fibres at 4% fibre loading (i.e. 868% increase) from control 3.111 mm–30.142 mm. Cow tail hair and SH produced elongations at break that are respectively 511% (19.006 mm) and 668% (23.888 mm) better than the control value

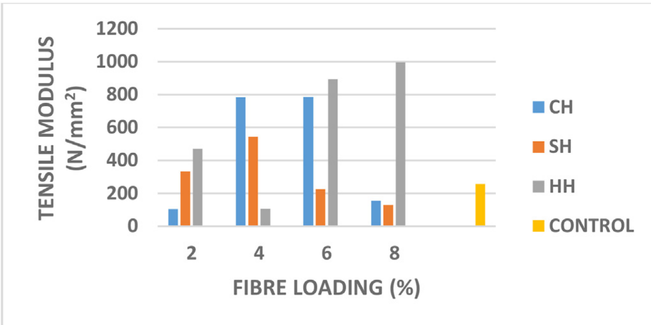


Fig. 6. The tensile modulus with percentage fibre loading for reinforces and unreinforced LDPE composites.

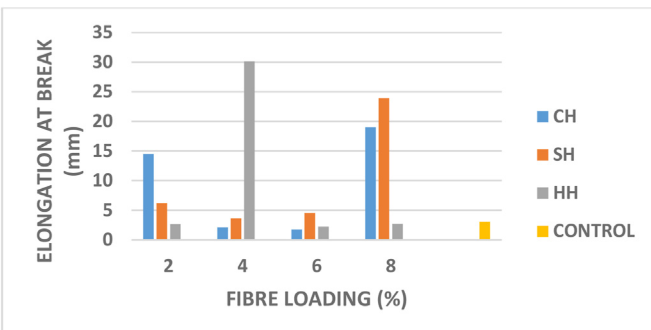


Fig. 7. The elongation at break with percentage fibre loading for reinforced and unreinforced LDPE composites.

of 3.111 mm; both at 8% fibre loading. The elongation at break of HH composites can be seen to be lower than that of the virgin polymer at 2, 4 and 6% fibre loading. Cow tail hair showed the same behaviour at 4 and 6% fibre loading. The statistical analysis shows that there is an outlier for SH and HH fibre composites. The $P = 1.000$, reveals that for a significant level of 0.05, the means of the data set are all equal. This indicates that the elongation at break results obtained is due to fibre-matrix synergy and not due to the intrinsic property of the hair fibres. The increased elongation produced by the different composites is due to the increased adhesion, and even distribution of the hair fibres within the polymer.

Fig. 8 indicates that CH reinforced LDPE produced the overall best impact strength result with a 100% (16 kJ/m^2) increase at 8% fibre loading from the control value of 8 kJ/m^2. From the results, it was observed that the impact on strength of LDPE was generally enhanced by the three animal hair fibres. The CH fibre gave a progressive enhancement of the impact strength of its composites with increasing fibre content. The impact strengths of the composites are commendable when compared with the 2 kJ/m^2 target set for notched Charpy impact strength of materials for automobile purposes according to Ref. [23]. Cow tail hair which is the shortest of all the three, proved to be most evenly distributed in the polymer matrix through a steady enhancement of the impact strength with increasing fibre loading.

Fig. 9 showed that the Brinell hardness of the polymer was generally enhanced by the animal hair fibres. The best feat was achieved by human hair at 433.5HB with a 41% increase on the hardness of VLDPE (308.3HB) at 4% fibre loading. In the statistical analysis, the F and P values were found to be 0.83 and 0.466 respectively. The dynamic increase in the hardness of the composites is an indication that at lower fibre loading, there was better interfacial bond between the hair fibres and the matrix and less fibre-fibre interaction.

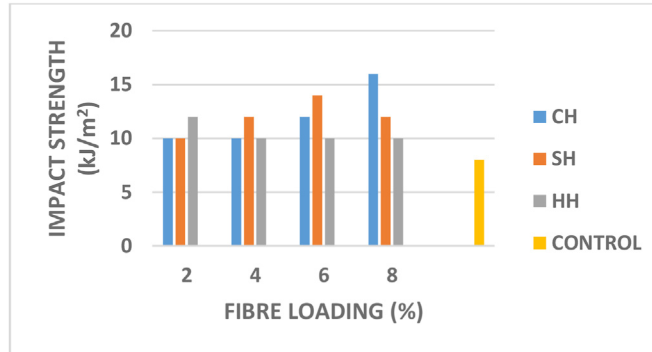


Fig. 8. The impact strength with percentage fibre loading for reinforced and unreinforced LDPE composites.

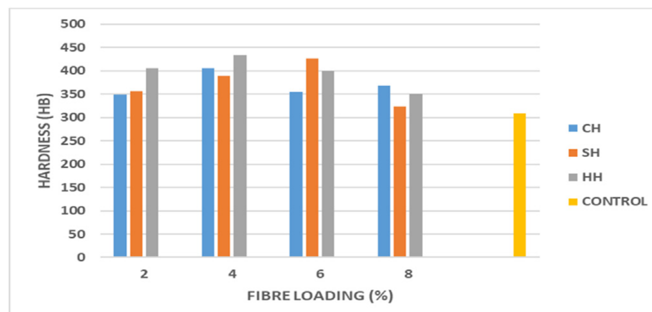


Fig. 9. The Brinell hardness with percentage fibre loading for reinforced and unreinforced LDPE composites.

4. Conclusion

This study examined the utilization of natural polymer to enhance the mechanical strength of LDPE. Deduction from the experiment indicates that human hair contributed most to the mechanical properties of LDPE composites, though, cow tail hair possessed the best impact strength. Sheep hair fibre generally gave the least enhancement of the polymers' mechanical strength. SEM images showed reduced manufacturing defects on the composites. The analysis of variance indicated that only the means of the composites' flexural properties were statistically significant. The animal hair fibres used in this study, which are less dense and more environmentally friendly can be considered for thermoplastic reinforcement, for some automotive applications, and equally serve as a mean of proper waste management of natural polymers in the region.

Author contributions

All authors contributed to the study conception and design. Material preparation, investigation and data collection were performed by ARU, OE, CCE, ONH, and CPU. The first draft of the manuscript was written by ARU and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Code availability

This does not apply to this manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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