Environmental Challenges 11 (2023) 100688

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Reinforcement of polypropylene with natural fibers: Mitigation of environmental pollution

R.U. Arinze[a], E. Oramah[a], E.C. Chukwuma[b,d,*], N.H. Okoye[a], A.N. Eboatu[a], P.I. Udeozo[c], P.U. Chris-Okafor[a], M.C. Ekwunife[a]

[a] *Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria*
[b] *Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria*
[c] *Enugu State University of Science and Technology, Enugu*
[d] *Future Africa Institute, University of Pretoria, South Africa*

A R T I C L E I N F O

Keywords:
Animal hair fibers
Polypropylene
Bioomposite
Waste management
Material properties

A B S T R A C T

Recently, natural fibers have gained research attention in reinforcing polymers due to their availability and unique properties in polymer applications. Preliminary studies indicate indiscriminate disposal of human hair (HH) and the burning of cow hair (CH) and sheep hair (SH) by abattoir operators in Nigeria; this has become a source of concern owing to the hazardous nature of these activities to human health and the environment. This study is, therefore, essential and seeks to utilize these waste materials in an environmentally sustainable way, as the hair fibers used in this work are renewable and will enhance the economy of any country if adequately utilized. The composites of Polypropylene (PP), human, sheep, and cow tail hair fibers were prepared at different weight percentage concentrations of 0, 2, 4, 6, and 8 w% using an injection molding machine. Untreated and treated PP composites were analyzed for average diameter, length, and density; the composites were also characterized for ultimate tensile strength, flexural strength, hardness, and impact strength. The average diameter assessment indicates viz: Cow tail hair > Human hair > Sheep hair. The sequence for hair fiber lengths shows that Sheep hair > Human hair > Cow hair, and the order for average density is Cow tail hair > Human hair >Sheep hair. The analysis of the mechanical properties of the reinforced and unreinforced PP composite showed that the Human hair/PP composite gave the best enhancement for ultimate tensile strength and modulus, flexural strength, and modulus at 8% fiber loading. Cow tail hair/PP composite yielded the best elongation at break at 2% fiber loading. Human hair/PP composite showed the best yield for impact strength at 4% fiber loading, while the Cow tail hair composite performed best for the hardness test at 2% fiber loading. The surface scanning electronic microscope (SEM) images showed no significant manufacturing defect on composites except for the air entrapment in the image of cow tail hair. The study also observed that there is no fiber breakage or void observed in the images. SEM images of the PP-composites interface at 8% maximum loading showed reasonably good fiber adhesion to the polymer matrix. This study is recommended for environmental sustainability and to improve material properties for various applications.

Introduction

The development of natural fiber-reinforced composites is taking place at a tremendous rate compared to synthetic fiber-reinforced composites (Kumar et al., 2019). This development is connected to desired characteristics associated with fiber-reinforced plastics, such as being economical, environmentally friendly, biodegradable, lightweight, high strength-to-weight ratio, accessible, having less energy required for processing the products, and having good mechanical properties (Reddy et al., 2018; Rao et al., 2017; Dixit et al., 2017; Faruka et al., 2012; Rao et al., 2017; Rosato and Rosato, 2004; Mueller and Krobjilowski, 2003; Choudhry and Pandey, 2012). Composite materials ensure that the strength of the primary material is enhanced without significantly increasing the weight of the finished product (Senthilnathan et al., 2014). The composite developed has a robust load-carrying material embedded in weaker material. The reinforcement now provides strength and rigidity to help enhance its properties. Though polymer matrix composites have broad applications, the mechanical properties of polymers need to be enhanced for many structural purposes. For example, their strength and stiffness are low compared to ceramics and metals. These problems can be overcome by reinforcing polymers with other materials (Rao et al., 2020). Many researchers have investigated the effect of nat-

* Corresponding author.
E-mail address: ru.arinze@unizik.edu.ng (R.U. Arinze).

https://doi.org/10.1016/j.envc.2023.100688
Received 6 October 2022; Received in revised form 25 January 2023; Accepted 26 January 2023

ural fibers such as sisal, flax, jute, hemp, bamboo, flax, wood, rice husk, coir, banana fiber, kapok, grass, and abaca on the mechanical properties of the developed composites (Reddy et al., 2018; Liu et al., 2019; Balachandar et al., 2019). The bond strength among reinforcing fibers and matrices as the transmission of stress matrices-fiber determines the effectiveness of reinforcement (Nijjar et al., 2022).

Human hair can be used as fiber reinforcement because it is strong in tension, as reported by (Khan and Ali, 2018; Nila et al., 2015; Kumar et al., 2015). There is an immense need for a high-performance, yet less expensive natural fiber alternative for thermoplastic reinforcement, especially in the automotive industry (Moritomi et al., 2010). To produce a reinforced plastic, the resin and fiber must be combined efficiently so that the materials developed are strong enough to carry anticipated loads. According to (Hollaway, 1994), the prominent place for load transfer is at the interface. Industries are undergoing an evolution in this field, producing reinforced plastics with enhanced capabilities both process-wise and performance-wise, giving rise to materials that can perform in different environments. Reinforced plastic products, as stated by (Rosato and Rosato, 2004) may contain plastic matric of 10 to 40% by weight or 60% in some cases. On the other hand, (Oladele et al., 2015a) and (Oladele et al., 2014), from their studies, reported that for natural fibers, the resin composition can be up to 98%, especially when using very light but tough reinforcements such as animal hair fibers in thermoplastic composites as in this present study.

The research carried out by (Oladele et al., 2015a) indicated that the composite mechanical strength decreases with an increase in fiber loading. This is attributed to increasing fiber-fiber interaction of fibers within the matrix, poor dispersion of fiber in the matrix and higher void content, and low inter-facial strength resulting in lower efficiency of load transfer with increased fiber loading. This informed the choice in this present study on the weight percentage for fiber loading concentrations of 0, 2, 4, 6, and 8 w%. (Nanda and Satapathy, 2017) examined the mechanical properties of epoxy composites reinforced with 0, 2, 4, 6, and 8 w% human hair proportions, the study observed that the mechanical test performed on the composites gave a notable increase in the compressive strength and a significant increase in the tensile and flexural strengths with increasing fiber loading. Another researcher (Oladele et al., 2014) investigated the mechanical properties of chicken feather and cow hair fiber-reinforced high density polyethylene (HPDE) composite using 1, 2, 3, 4, and 5 w% of both fibers in random order. The result showed that chicken feathers at 1–3 w% fiber loading enhanced the mechanical properties more than cow hair fiber composites. An evaluation of the compressive strength of polypropylene using human hair reinforcement at 3, 5, and 8 wt% was studied by (Nanda and Satapathy, 2017). The result revealed that eight weight percent of human hair produced the best value of compressive strength, (Arinze et al., 2022) also studied the mechanical impact evaluation of natural fibers with low density polyethylene (LDPE) plastic composites at 0, 2, 4, 6, and 8 w% of (human, sheep and cow tail) hair fibers using injection molding method and observed that human hair gave the highest flexural strength, flexural modulus, ultimate tensile strength, and tensile modulus at 8% fiber loading. Considering the broad application of the polypropylene class of plastic, it is essential to utilize it and determine the optimum natural composite that will provide enhanced mechanical properties, hence the core objective of this study.

In many composite systems, the fiber reinforcement is not compatible with the matrix, hence the need to treat the surface of the fibers to optimize compatibility. Surface treatment can introduce compatible chemical groups or modify the original surface. As reported by (Rosato and Rosato, 2004), the interfacial interaction between reinforcement and the matrix is determined by the surface free energy. The surface free energy of the reinforcement must be greater than that of the matrix. It is imperative to modify the surface of the natural fiber to obtain a quality composite with excellent performance. In plastic reinforcement, chemical surface treatment is often applied to the fibers, which fulfill several purposes such as protection against abrasion, enhance adhesion of the matrix, reduction in moisture absorption capacity of the fiber, etc. (Oladele et al., 2015b). Alkali treatment (aqueous Sodium Hydroxide, NaOH or Potassium Hydroxide, KOH) and compatibilizer are the methods used to improve adhesion between natural fiber-polymer matrices. Surface modification generates additional reactive sites on the surface and develops better bonding between natural fiber-polymer composites; the treatment usually removes oil and wax (Srivastava et al., 2018). The major lipid components of animal hair fiber partly removed by the alkali treatment, according to (Lewin, 2002), is a methyl-branched 21-carbon fatty acid; the study also reported that some of the peptide bonding in the keratin network structure is disrupted by alkali with alkali treatment of the fiber surface to produce a rougher fiber surface. The study by (Srivastava et al., 2018) reported that the science behind surface modification is an improvement in adhesion properties between fiber and matrix. This property is essential, especially in producing composite thermoplastic material with fiber. This study, therefore, considered the impact of treated and untreated composite in improving material properties.

The animal hair fibers used in this work are human hair, sheep hair, and cow tail fibers. The hair consists of cuticles, a cortex, and a medulla as the innermost layer. The hair fibers are proteinous with a keratin chain. Keratins are proteins consisting of long chains (polymers) of amino acids. Hair contains a large amount of sulfur because the amino acid cysteine is a significant component of the keratin proteins in the hair fiber. The sulfur in the cysteine molecules in adjacent keratin proteins connect in disulfide chemical bonds. The disulfide chemical bond connecting with keratins is the main factor responsible for the durability and resistance of hair fiber to degradation under environmental stress, as reported by (Ansari et al., 2020). The research by (Lewin, 2002) stated that several mechanical properties, such as impact strength and hardness, are directly related to hair diameter. The study observed that sheep hair has the least cuticle thickness of 1–3 cell layers, followed by human hair with 5–10 cell layers, and finally, cow hair which is 30–40. The study also reported that the only significant difference among the amino acid compositions of different animal fibers is in their cysteine and cysteic acid content. The average cysteine content of human and sheep hair cuticle are 17.8% and 13.1%, while that of cow hair is 12.31% (Block and Lewis, 1938). When animal fibers are successfully impregnated into resin to make composites, it offers a much more effective solution to environmental pollution issues. Hence, there is a need to develop measures that adequately improve the environment and, in addition, provide good quality plastic material for various applications such as laboratory equipment, automobile components, chemical tanks, packaging, etc. To the author's knowledge, no studies have considered the composites used in this study in the region. The utilization of the abundant natural fibers in the study area is critical because of the variation in properties of fibers due to environmental factors and nutrient availability to the animals.

Animal fibers such as chicken feathers, human hair, horse hair, goat hair etc. are readily available in the study area and are considered a waste by-product. Their disposal methods and slow degradability create many environmental problems (Kumar et al., 2019; Arinze et al., 2022; Ansari et al., 2020; Verma et al., 2016), they are equally found in municipal waste streams causing ecological issues (Arinze et al., 2022; Sharma et al., 2021). Presently, human hair composites are used in construction, automobiles and molding furniture, agriculture, medicine, engineering industries, etc. (Lewin, 2002; Lewin, 2002; Uzun et al., 2011). Ordinary unreinforced plastics lack strength and stiffness, and some have very poor impact resistance and creep. However, mechanical properties are increased and consequences of physical aging are minimized by fiber reinforcement. Reinforced plastics usually have fibers oriented in several different directions, especially with short fiber forms (Gupta, 2014). Currently, the need for high-quality plastics products in the automotive industry has gained enormous attention due to the lightweight thermoplastics which make for more fuel-efficient vehicles. Research carried out by (Gupta, 2009) reported that an estimation of every 10% reduction in vehicle weight results in a 5–7% reduction in fuel usage. The researchers went further to report that PP ranked first from the list of top 13 high-performance plastic used for automotive parts with approximately end use of 32%, especially for car bumpers, chemical tanks, cable, insulation, carpet, etc. Therefore, there is an increasing interest in utilizing natural fibers, like animal hair, by both developed and developing countries like Nigeria, as alternatives for plastic reinforcement (Rosato and Rosato, 2004; Prakash and Christu, 2016). The literature research showed that the composite formations are performed using the compression molding method because of ease of use and inconveniences associated with long fiber forms. This method goes with the disadvantages of high operating temperature and pressure, which directly affect the properties of the reinforced composites (Rao et al., 2017). One of the novelties of this current research, apart from the previous mention ones, is an attempt to employ reduced hair fibers. This method uses an injection molding technique at a lower temperature which does not affect the properties of the produced composites. This research aim is to employ different hair fibers (cow tail hair, sheep hair, and human hair) to reinforce polypropylene to form composites and to ascertain the improvement in mechanical properties.

Materials and method

Experimental procedure

The materials used in this study were animal hair fibers which include: human hair, sheep hair, cow tail hair, and polypropylene homopolymer. The Hausa specie sheep hair was obtained from Birnin Kebbi in Kebbi State whereas, human hair was obtained from a local salon at Nnewi in Anambra State, cow tail hair from an abattoir located Awka-Etiti in Anambra State, Polypropylene plastic obtained from plastic industry. Canola oil, distilled water, and 99.9% anhydrous sodium hydroxide were also used.

Treatment of fibers and analysis

The hair fiber samples were thoroughly washed to remove impurities and air-dried for five days. The hair fibers were carefully ground to obtain short fibers and sieved with 210 µm mesh. Short rod-like fibers were gotten after sieving and were used to prepare the composites, the fibers are shown in Plate 1:

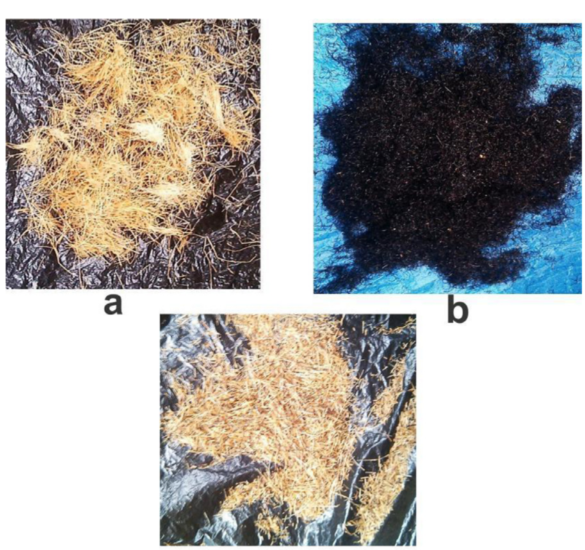


Plate 1. Ground; a. Sheep hair (SH) b. Human hair (HH) c. Cow tail hair (CH).

Each hair fiber of 200.0 g was immersed in 0.25 M NaOH (Moritomi et al., 2010) alkali solution for 2 hrs at room temperature. The hair fibers were removed and rinsed severally. The treated samples were oven dried at 105 °C for 90mins.

Determination of hair fiber dimension

The diameter and length of the randomly picked hair fibers strands were determined using rotational profile projector (model: DC-3000). The average dimension of each was recorded.

Determination of density of hair fiber

The standard method adopted was according to (Ahmad, 2014). The density of the hair fiber was obtained by transferring weighed 0.5 g of the hair fiber into a flask containing 100 ml of canola oil of density 0.907 g/cm^3. The weight of the sample in oil was taken when the sample was totally immersed in the fluid. This was repeated three times for each hair fiber. Eq. (1) was applied in the weight calculation.

$$\rho_a = (\rho_c w_a)/(w_a - w_c)(g/cm^3) \quad (1)$$

Where : ρ_a = *density of fiber* ρ_c = *density of oil*
w_a = *weight of fiber in air* w_c = *weight of fiber in oil*

Formulation of composite

The sample was prepared by thoroughly mixing of 400 g of polypropylene with different weight percentage concentrations (2, 4, 6, and 8 w%) of each hair fiber with a mixing spoon. The mixtures were re-weighed with Labtech electronic weighing balance (BL-7501) before being transferred to the Mingkee injection molding machine (model: MK-602). The composites were developed at an average temperature of 170 °C (160 °C –180 °C) and injected into a disk-shaped mold of dimension 200 mm x 5 mm with the help of a torpedo injector where the composites were allowed to solidified upon cooling. The untreated PP sample was also subjected to the same process (injection molding).

Determination of tensile properties

The method of (Barone, 2005) was employed in carrying out the analysis. A cutter size of 17 mm x 60 mm x 5 mm was used and the cut samples were pulled apart 10 mm per minute by the testing machine. The force required to pull the sample apart and how much it stretched before breaking were measured and used to calculate the ultimate tensile strength by the machine. The strain rate was constant until the sample failed. The stress-strain curve was generated spontaneously as the test was carried out. Young modulus is the ratio of stress to elastic strain in tension. This method was also used to determine tensile modulus and elongation at the break of the samples.

Determination of flexural properties

This technique was performed according to (Gerard, 2014). A sample with dimensions 13 mm x 75 mm x 5 mm was placed on two supports and a load was applied at the center until it yielded. The flexural force applied to break the sample was used to determine the flexural strength of the sample by the machine. The same procedure was also employed to determine the sample flexural modulus which is the ratio of stress to strain in flexural deformation before the break.

Determination of impact strength

The Charpy impact testing machine was used as stipulated by (Bo‘garde and Shinde, 2014). The sample size of dimensions 50 mm in length and 10 mm in width was cut to have a V-notch with an angle of 45° and depth of 200 mm was clamped vertically with the notch facing the striker. The striker swung downwards impacting the sample at the bottom and locking the energy scale set at a maximum level of 300 J. at the point of impact, the velocity of the striker was 5.23 m/s. The impact energy which reduced the swinging of the pendulum before fracture was read from the scale. The impact strength was calculated as:

$$Impact\ strength = impact\ energy/sample\ area\left(KJ/m^2\right) \quad (2)$$

Determination of Brinell hardness

The dynamic hardness tester procedure was adopted as described by (Tudu, 2009). Carbide-tipped shuttle with definite kinetic energy was impacted on the sample and part of this energy absorbed by the sample was a function of the hardness of the sample. The signal which is equivalent to the absorbed energy was displayed on the instrument and was calculated instantly. This was repeated on three different areas of the composite and the average value was obtained. Each average value was multiplied with a conversion factor (0.7496) to give Brinell hardness..

Microscopic analysis

Phenom Scanning Electron Microscope (ProX) instrument was employed for the microscopic study of the prepared composites.

Statistical analysis of the composites mechanical properties

The statistical analysis of the composites' mechanical property results were obtained using Minitab statistical tool using one way analysis of variance (ANOVA).

Results and discussion

The result from the study is described below. The hair fibers treated with 0.25 M NaOH enhanced the morphology and elasticity of the PP composites for appreciable mechanical bonding between fibers and polymer and improved the fiber functionality within the polymer matrix. The result of the average diameter of the hair fibers in Fig. 1 shows that cow tail has the highest diameter for the treated and untreated hair fibers, and sheep hair is the least. It is also observed that the diameters of the treated hair fibers were lower than the untreated, this could be attributed to the fact that the chemical treatment of the hair fibers removed the oils and wax on the hair surfaces..

The data on the length of the hair is shown in Fig. 2. The sheep hair has the highest length, followed by human hair and then the cow tail hair.

The Fig. 3 shows the average density of the three hair fibers. Cow tail hair has the highest density while the sheep hair has the least density. The sequence for average density is cow tail hair > human hair > sheep hair.

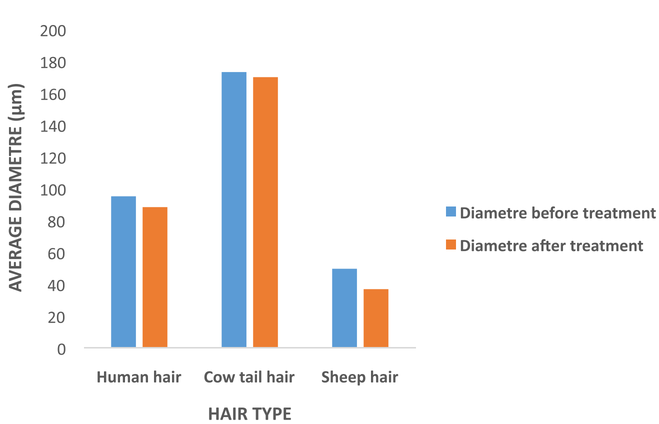


Fig. 1. The variation of the average diameter of untreated and treated human hair, cow tail hair and sheep hair fibers.

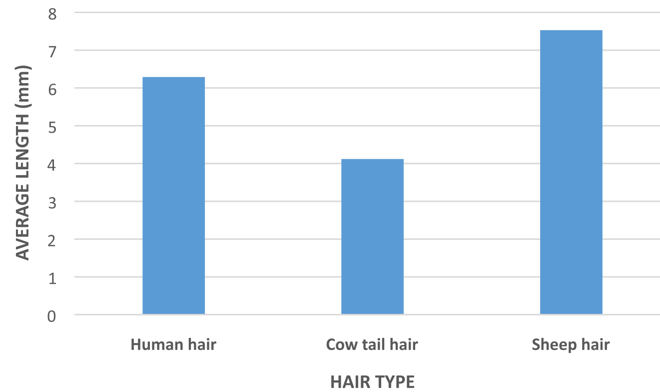


Fig. 2. The variation of the average length of human hair, cow tail hair and sheep hair fibers.

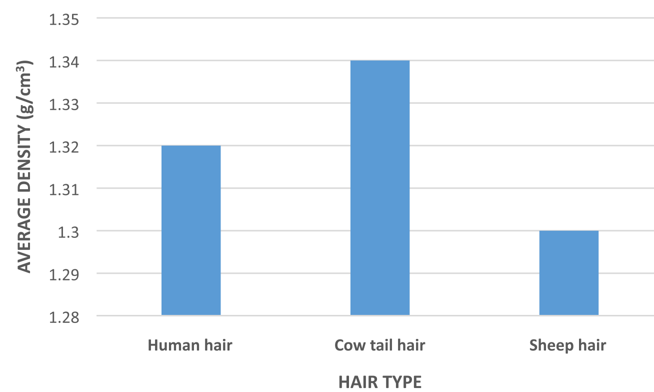


Fig. 3. The variation of the average density of human hair, cow tail hair and sheep hair fibers.

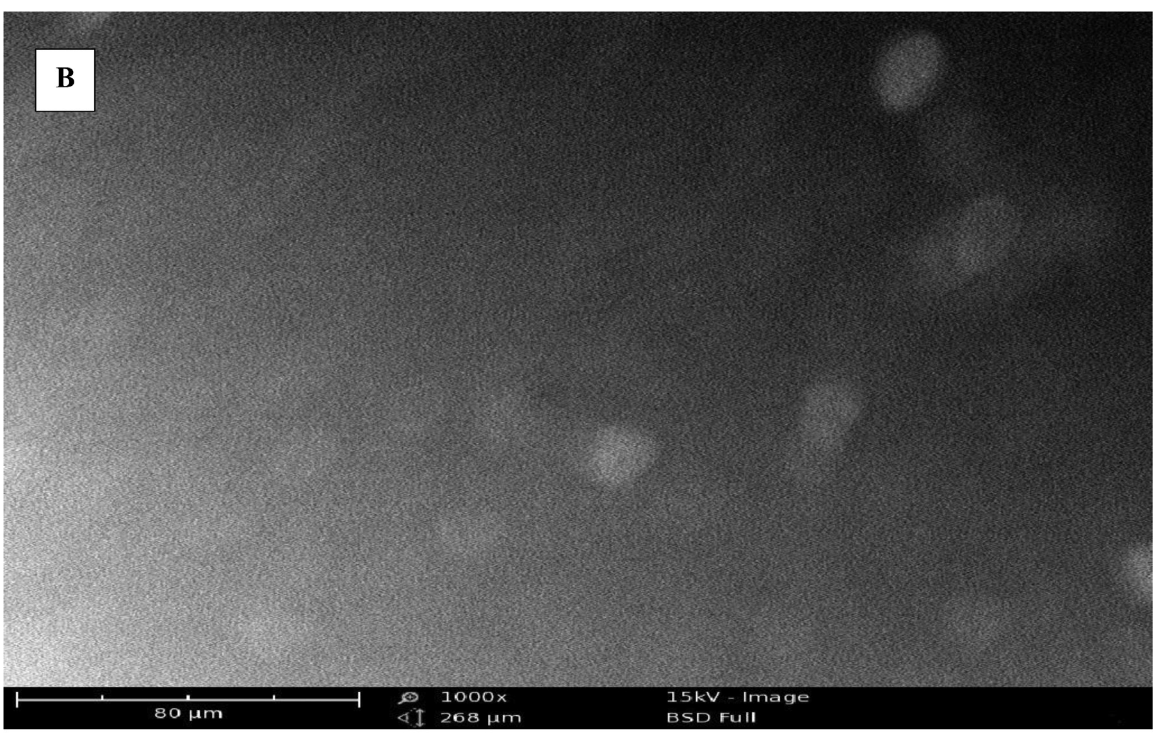
In Fig. 4, the SEM images A, B, and C are that of human hair, sheep, and cow tail hair at 6% fiber loading with the reinforced PP composites. The surface SEM images showed that there is no significant manufacturing defect on composites except for the air entrapment in cow tail hair fiber. There is no fiber breakage or void observed in the images.

Figure 5 shows the PP composites at 8% fiber loading of human hair (d), sheep hair (e), and cow tail hair (f) respectively. Looking at the SEM images of human, sheep, and cow tail hair fibers, show the extent of interaction that was involved when these fibers were used in forming PP composites. Human hair gave the best interaction than other fibers used. Polymer interface play a very important role in determining the quality of composites. The images seem to show good adhesion of fiber to the matrix. The image (f) of the hair fiber can also be said to be multi-directionally arranged in the polymer matrix.

Figure 6 represents the ultimate tensile strength of PP hair fiber composite at varying percentages of the fibers loading. It is seen that the ultimate tensile strength of the polymer was enhanced from the control value of 6.38 N/mm^2 by the three hair fibers at all the fiber loadings. The sequence for the enhancement is human hair 334% at 8% > cow tail hair 118% at 6% > sheep hair 66% at 2%. The statistical analysis shows that there is no outlier in each of the data sets. At $\alpha = 0.05$ significant level, the test revealed that the means of the data set are not significantly different, given the F and P values of 1.74 and 0.230 respectively.

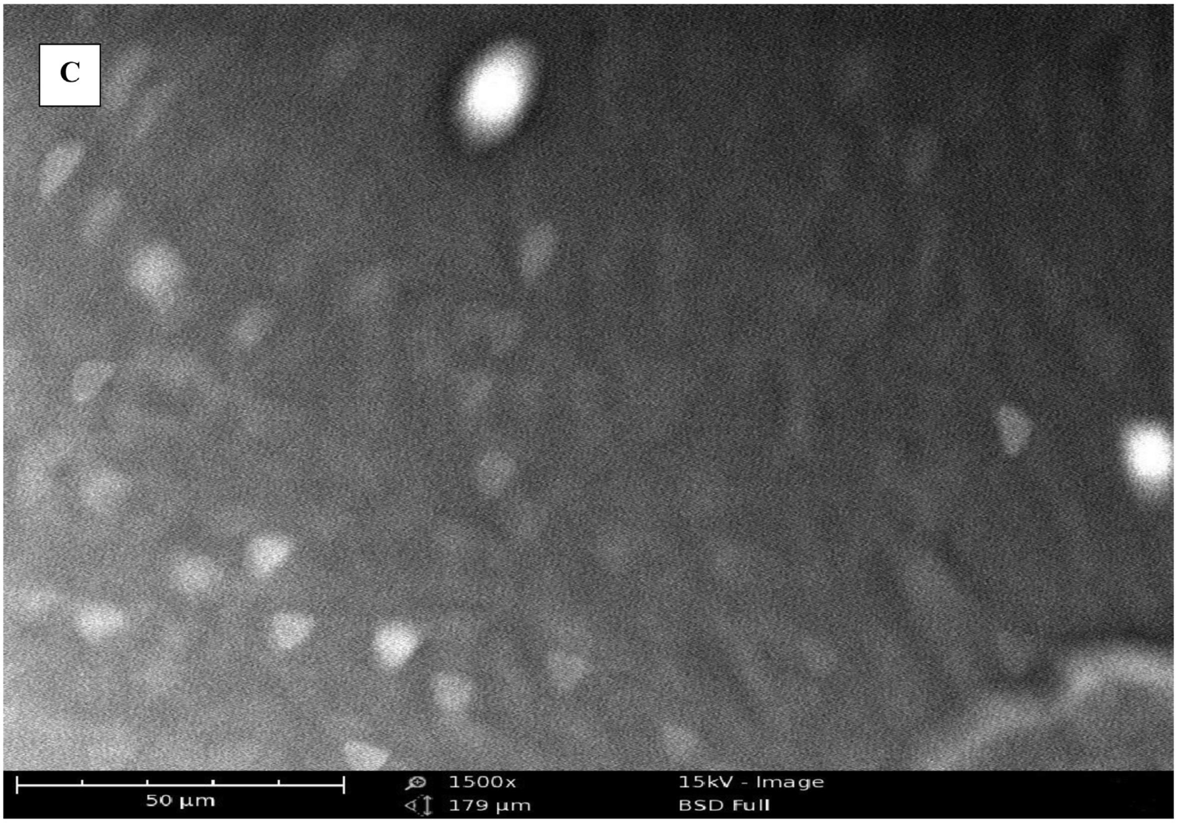
The results of this research are comparable to the report by (Nanda and Satapathy, 2017) on the tensile strength of PP reinforced with 3, 5, and 8 wt.% of the human hair fiber. The tensile strength result produced by their analysis climaxed at 8% fiber loading but the study on PP/human hair tensile strength by (Oladele et al., 2015b) showed there was enhancement by the hair fiber up to 5% fiber dosage after which the tensile property began to decline. This is in line with tensile studies

SEM image of human hair PP composite



SEM image of sheep hair PP composite

Fig. 4. SEM images of human, sheep and cow tail hair fibers of PP composites.
SEM image of human hair PP composite.
SEM image of sheep hair PP composite.
SEM image of cow tail hair of PP composite.



SEM image of cow tail hair of PP composite

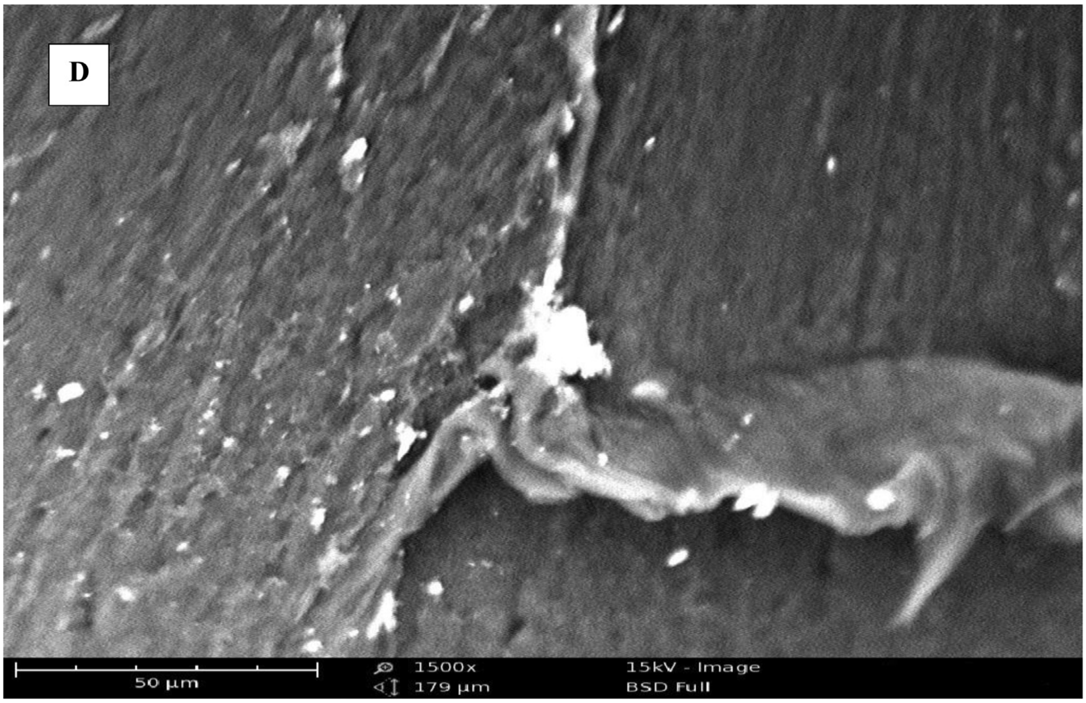
Fig. 4. Continued

on random oriented human hair fiber-reinforced polyester composites carried out by (Rao et al., 2017) that reported that the tensile strength increases with an increase in fiber weight ratio up to 20% and then decreases with a further increase in the fiber loading. They noted that it may be due to improper impregnation of fiber beyond 20% fiber loading. A similar result was also observed by (Wilems and Boten, 2016) on investigating the effects of surface treatment on hair fiber as reinforcement for HDPE composites using 0.25 and 0.5 N NaOH at 0.5, 10, 15, 20, and 25% fiber loadings. The results of the mechanical test revealed that the alkali treatment of human hair fiber-reinforced HDPE composites showed remarkable improvement in the tensile and flexural properties of the composites. The maximum mechanical improvement was at 15% fiber loading and 0.25 N NaOH fiber treatment. This enhancement in the ultimate tensile strength can be linked to improved interfacial adhesion which allows a better transfer of stress along the fiber-resin interface. The linear increase in the ultimate tensile strength with an increase in fiber loading is due to more fiber availability for increased stress transfer. The decrease in the tensile property at higher fiber loading can be ascribed to the increase in fiber-fiber interaction; imperfect alignment of the fiber with polymer and poor dispersion of fiber in the matrix. The lack of statistical significance in the obtained data indicates that the ultimate tensile strength of the three hair fibers was not solely dependent on the fiber content but on the extent of adhesion of the fiber to the matrix. The tensile strength of all the composites is seen to be below 75 MPa, which is the target for semi-structural automotive applications (Uzun et al., 2011).

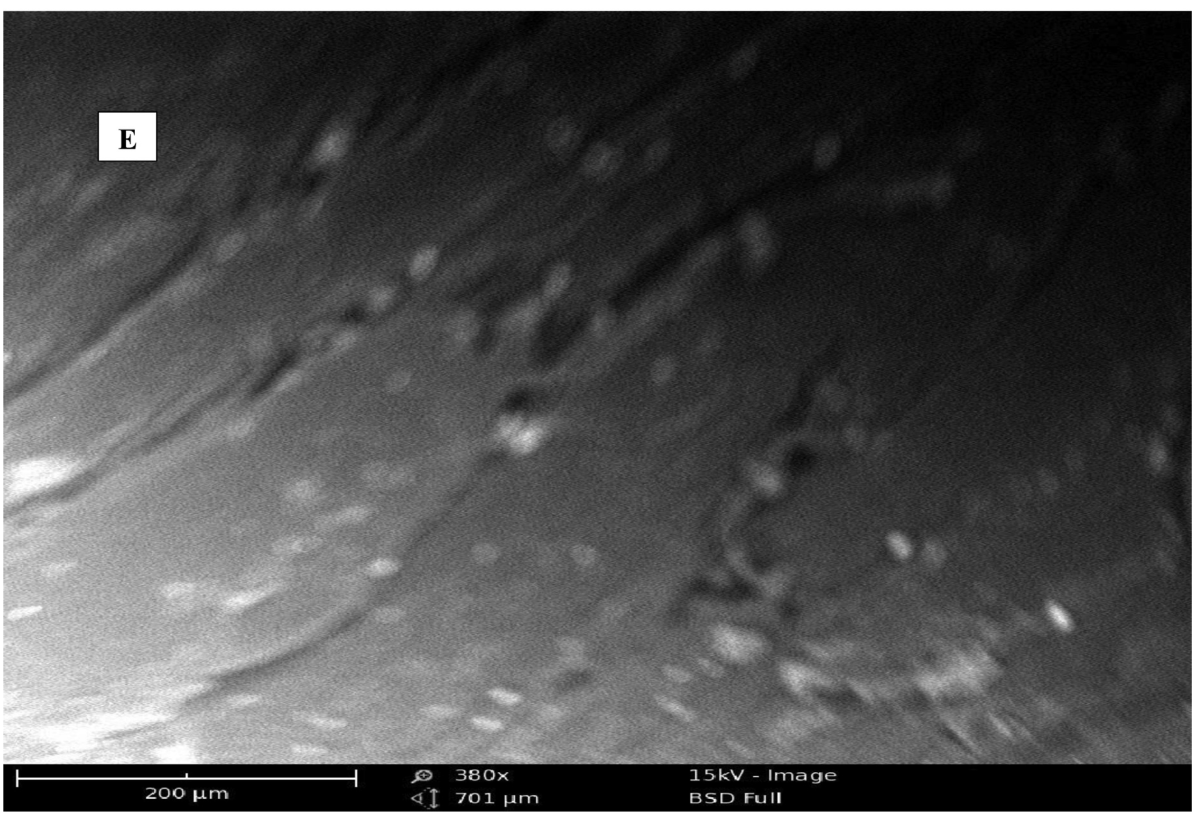
The effect of different fiber loading on the tensile modulus of virgin PP for all the hair fibers is shown in Fig. 7. Human hair gave the highest tensile modulus enhancement (213%). Cow tail and sheep hair fibers yielded an increase of 138% and 79% from the control value of 364.82 N/mm^2. A decrease in the tensile modulus of human hair at 4% fiber loading was observed, sheep hair at 4% whereas, cow tail is at 2, 4, and 8% fiber loadings. The statistical analysis shown in Table 1, discloses that all the data for the three sets have about the same spread. The test result produced F and P values of 1.11 and 0.372 respectively. This is a clear indication that the means of the data are not significantly different. The noted increase in the tensile modulus of the hair fiber composites, especially for human hair, is a result of the increased adhesion between the fiber and the polymer coupled with the good fiber dispersion in the polymer matrix. This was also according to the recent findings of the study on the mechanical properties of maleic anhydride-modified coir fiber/PP composites by (ASTM D3800-16 2008). The tensile modulus of all the composites falls short of the 5.5 GPa (5500 MPa) target according to the PolyOne Corporation report (Uzun et al., 2011).

Table 1
ANOVA results.

Analysis	Tensile strength	Tensile modulus	Elongation at break	Flexural strength at break	Flexural modulus	Impact strength	Brinell hardness
ADj SS	131.3	242,257	130.80	13,790.40	69.18	0.00	2058
Adj MS	65.66	120,129	65.41	6895.21	34.59	0.00	1029
F-Value	1.74	1.11	1.55	103.00	269.54	0.00	0.83
P-Value	0.23	0.37	0.26	0.001	0.001	1.00	0.466



SEM image of human hair PP composite interface at maximum fiber loading



SEM image of sheep hair PP composite interface at maximum fiber loading

Fig. 5. SEM images of the PP-composites interface at maximum loading.
SEM image of human hair PP composite interface at maximum fiber loading.
SEM image of sheep hair PP composite interface at maximum fiber loading.

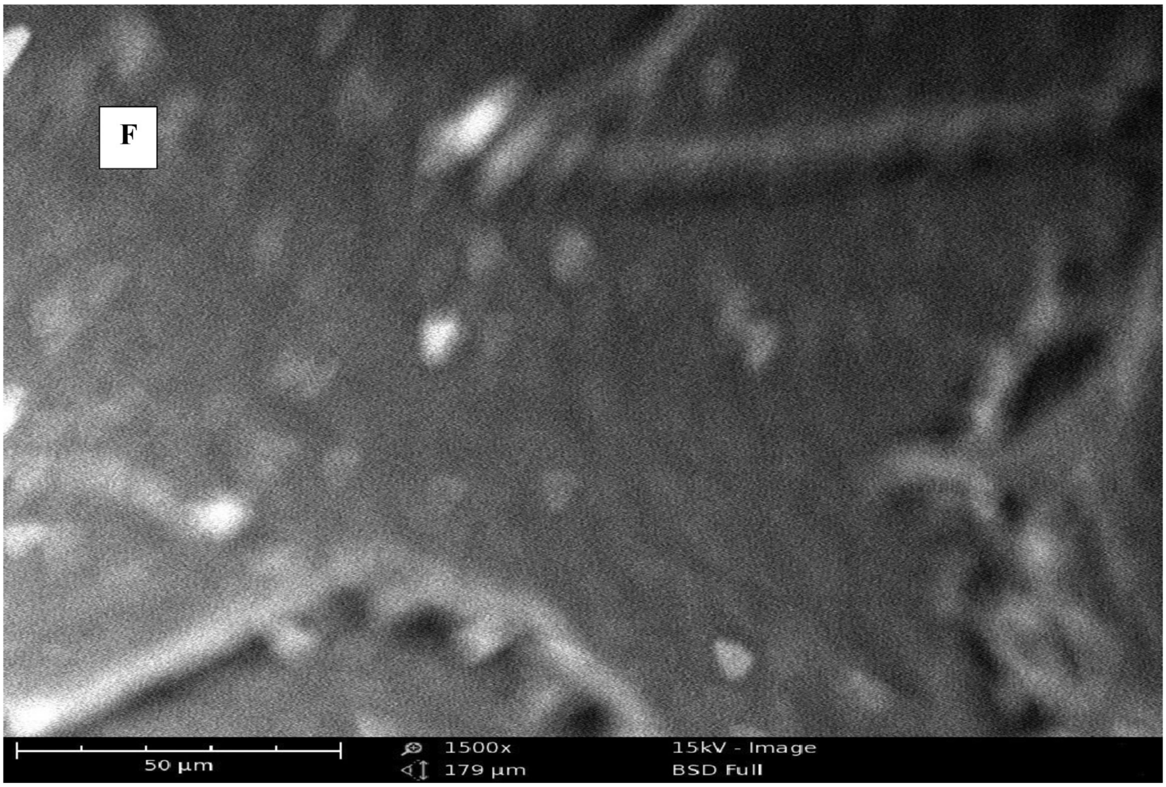


Fig. 5. Continued

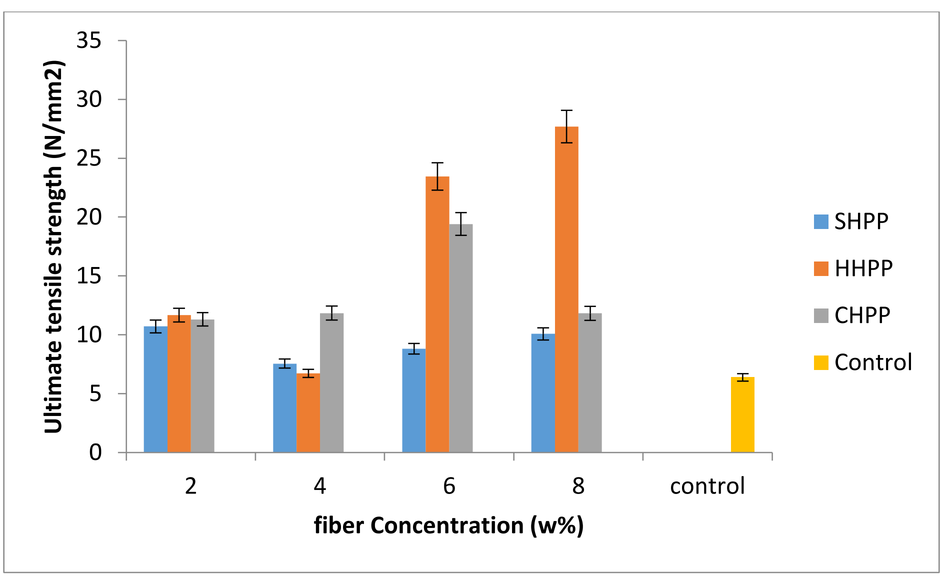


Fig. 6. The variation of ultimate tensile strength with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced with polypropylene composites.

From the elongation at break results of the different PP/hair fiber composites shown in Fig. 8, it can be seen that cow tail hair gained upper hand with a superlative enhancement of 882% from the control value of 1.797 N/mm^2 at 2% fiber loading. 723% and 481% increases were observed for sheep hair and human hair fibers respectively at 4% fiber loading. In addition, sheep hair fiber produced an elongation at break, which is 17.2% lower than the control value at 6% loading. The report of elongation at break of the PP/human hair composites by (Choudhry and Pandey, 2012) was found to decrease with increased fiber dosage. In a related study, (ASTM D638-08 2008) discovered the same trend of elongation at the break while investigating the mechanical behavior of PP/human hair composite. The statistical analysis as depicted in Table 1 revealed that an outlier exists for only sheep hair composite. The F and P values, which are given as 1.55 and 0.263 clearly indicate that the mean of the data sets is significantly different. The result of the statistical analysis was found not to be statistically significant suggesting that the elongation at break of the different hair fibers was more a product of fiber-matrix adhesive strength and not completely based on the fiber content. In other words, the PP/hair fiber composite elongation at break was basically a product of fiber-resin synergy.

Figure 9 indicates that human hair fiber PP composite gave the overall best result of flexural strength with a 233% increase from the con-

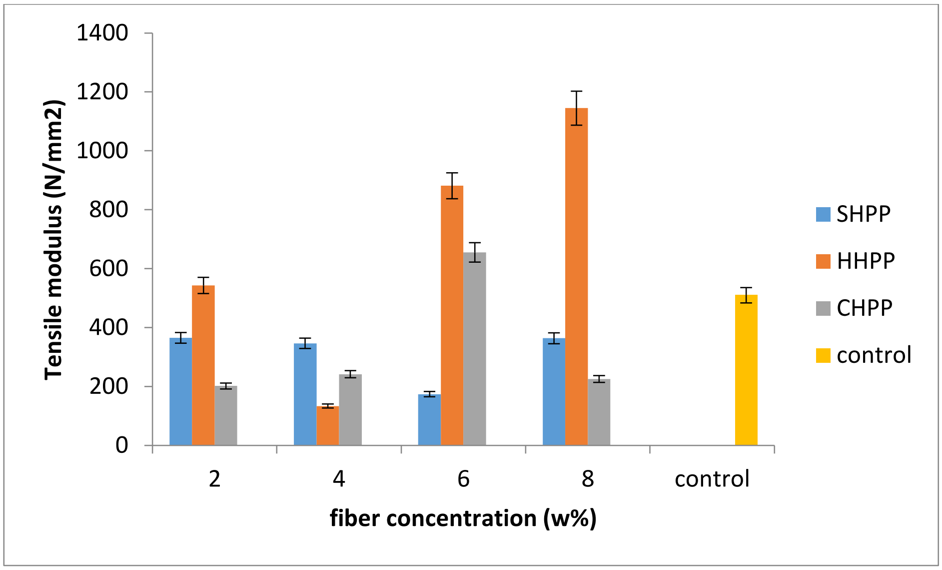


Fig. 7. The variation of tensile modulus with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

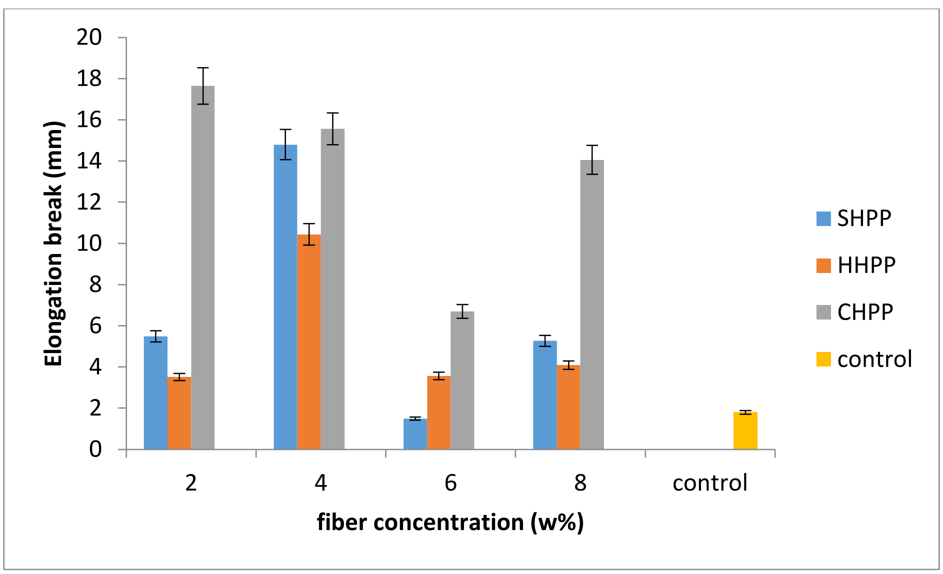


Fig. 8. The variation of elongation at break with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

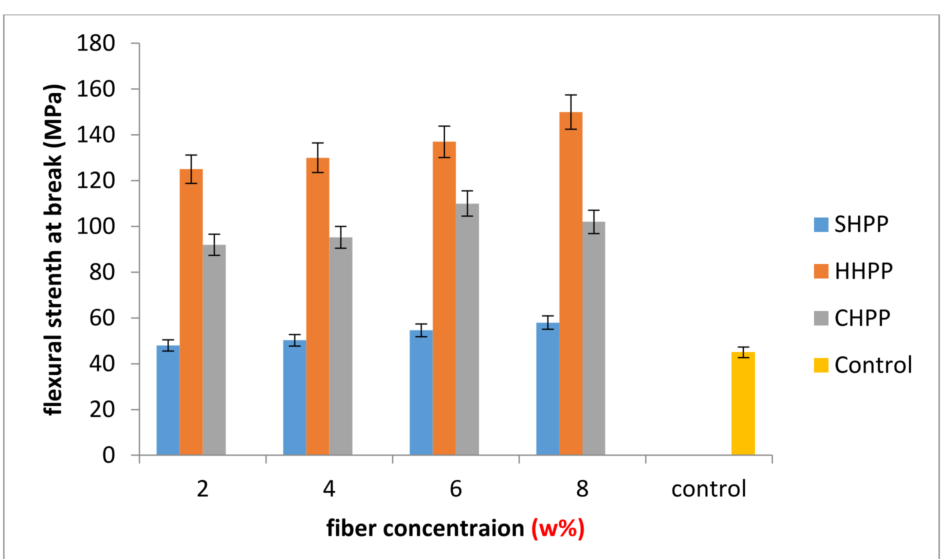


Fig. 9. The variation of flexural strength at break with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

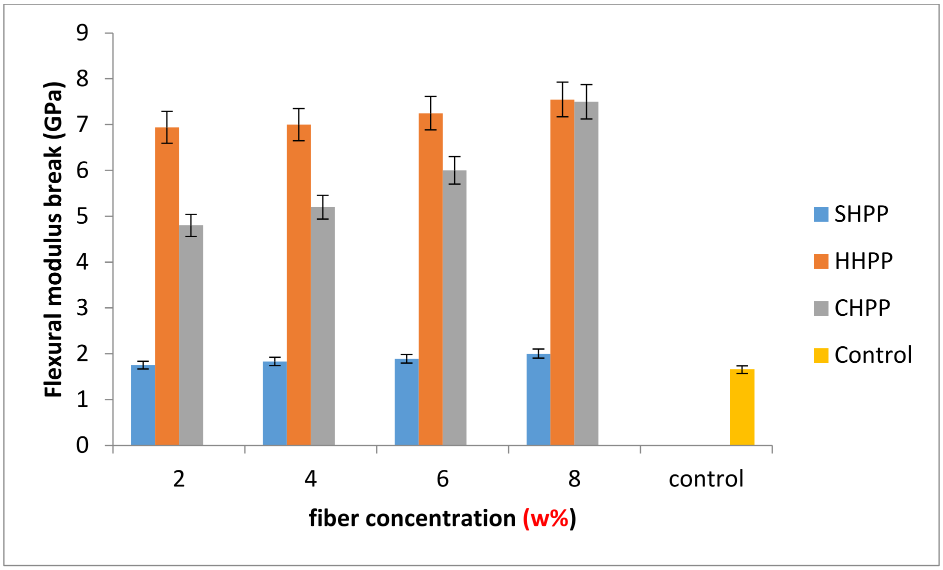


Fig. 10. The variation of flexural modulus at break with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

trol value of 45 MPa obtained with the virgin polymer to 150 MPa at 8% fiber loading. Sheep hair fiber produced its best flexural strength result at 8% (58 MPa) fiber loading with a 29% increase from control (45 MPa). Cow tail hair fiber on the other hand gave its highest flexural strength at 6% fiber loading with an increase of 144% from a control value of 45 MPa to 110 MPa. The statistical analysis indicates that at the significance level of 0.05 with F (2.9) = 103.00 and $P = < 0.001$, the mean in the data set is significantly different. The epoxy reinforcement with short human hair by (Oladele et al., 2014) yielded the best flexural strength result at 8% fiber loading. This is comparable to the result obtained with the human hair fiber in the present research. On the other hand, research performed by (ASTM D790-07 2008) on polypropylene reinforcement with wood flour showed that flexural strength depreciated by increased fiber loading. The result obtained by (Kumar et al., 2019) on the flexural strength behavior of horse hair reinforced with PP-based composite at 0%, 10%, 20%, and 30% indicate an increase of up to 20% in the weight percent of horse hair increases the flexural strength correspondingly but at 30%, the flexural strength decreases. The researcher said that this could be because of horse hair composites' shortage of resin material owing to the formation of an improper interfacial bonding between the hair mat and PP. The flexural strength of cow tail and human hair PP composite in this research can be seen to exceed the 100 MPa target for semi-structural automotive applications as recommended by (Uzun et al., 2011). The statistical analysis result is an indication that fiber content is the determining factor of flexural strength. This can be compared to the result of PP reinforcement with wood flour by (ASTM D790-07 2008) in which a significant difference was obtained for the mean value of the composite flexural properties.

The results obtained in this research for flexural modulus at the break in Fig. 10 show that human hair performs best at 8% fiber loading with a 358% increase from the control value of 1.65 GPa to 7.55 GPa. At 8% fiber loading, sheep hair yielded its best with a 21% increase from the control (i.e., 1.65 GPa to 2.00 GPa), while cow hair composites, on the other hand, gave a 355% increase from the control value of 1.65 GPa to7.50 GPa at 8% fiber loading. Similar to these results, the flexural modulus of PP reinforced with wood flour, as was obtained by (ASTM D790-07 2008), was observed to increase with increasing fiber content. They reported that the fiber treatment improved the interfacial adhesion between lingo-cellulosic filler and the polymer matrix, leading to fewer micro-voids and fiber polymer de-bonding in the interphase region. Therefore, the increase in the flexural modulus suggests an efficient stress between the polymer and fiber which was enhanced with fiber treatment. The optimal target set for the flexural modulus of materials that applies to automotive applications (i.e., 4.5 GPa), according to (Wilems and Boten, 2016; Uzun et al., 2011), was surpassed by cow tail and human hair PP composites. Statistically, the stiffness of the different hair fibers played a significant role in the flexural modulus of the composites.

Figure 11 revealed that human hair-reinforced PP produced the overall best impact strength result with a 100% increase at 4% fiber loading from the control value of 8 kJ/m^2. Sheep hair reinforced polymer produced its best result of a 75% increase from the control value of 8 kJ/m^2 at 6% fiber loading while cow tail hair achieved the same feat of 75% impact strength enhancement of PP at 8% fiber loading. The results obtained by (Choudhry and Pandey, 2012) on the mechanical behavior of PP reinforced with human hair fibers at different fiber loadings 3, 5, 10 and 15% showed that the impact strength of the composites was highest at 5% fiber loading and decline drastically from 10 to 15% fiber loadings. The statistical analysis shows that the means of the data sets are all equal at a significance level of 0.05. The results indicate that, although the impact strength of PP was generally enhanced by the three hair fibers, there was an immense contribution from the resin's toughness and the stacking arrangements of the hair fibers in the polymer matrix. The optimal target for the notched Charpy impact strengths of semi-structural automotive applications was 2 KJ/m^2 according to (Uzun et al., 2011). Therefore, the obtained impact strength results for the notched samples in this research is opined to be satisfactory.

Figure 12 depicts the variation of the Brinell hardness of PP composites with different hair fiber loading percentages. It can be visualized that there was an upshot of the hardness of the polymer at all the levels of reinforcement. However, at 2% fiber loading, cow tail hair can be seen to yield the best increase of all the hair fibers; which is 52% better than that of the virgin polymer. Sheep hair produced a 36% increase while human hair gave a 32% increase at 6% and 4% fiber loadings respectively. Also at a significant level of 0.05, the statistical test, in Table 1 had 0.32 and 0.737 values for the F and the P values as respectively, an indication that the means of the data sets were not significantly different. The statistical analysis results obtained in this research is also related to that of the polypropylene-wood flour reinforcement by (ASTM D790-07 2008) in which no significant difference was observed for the mean of the data. The dynamic hardness results and the no significant difference in the means of the data obtained in the statistical analysis, point to the fact that the hardness of the composites was determined more by the fiber-polymer synergy.

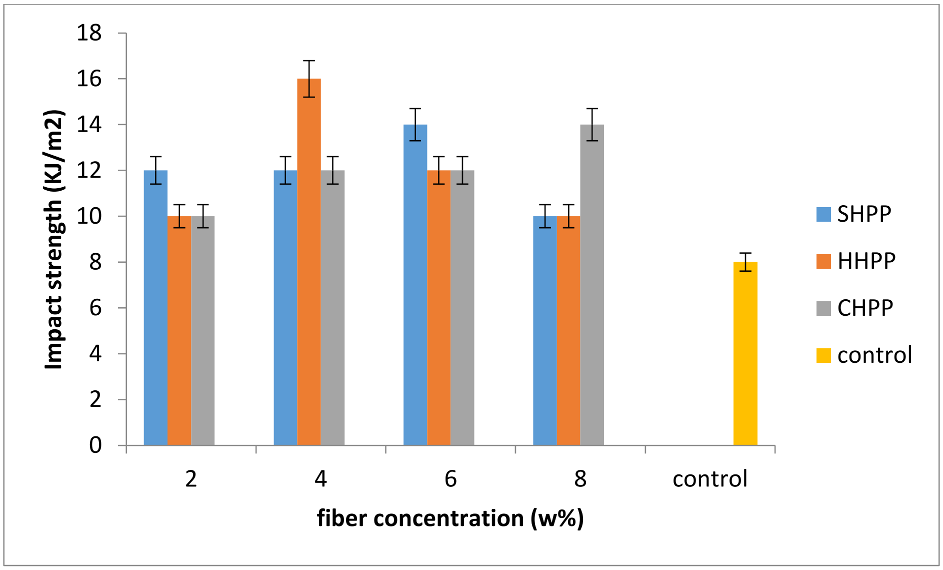


Fig. 11. The variation of impact strength with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

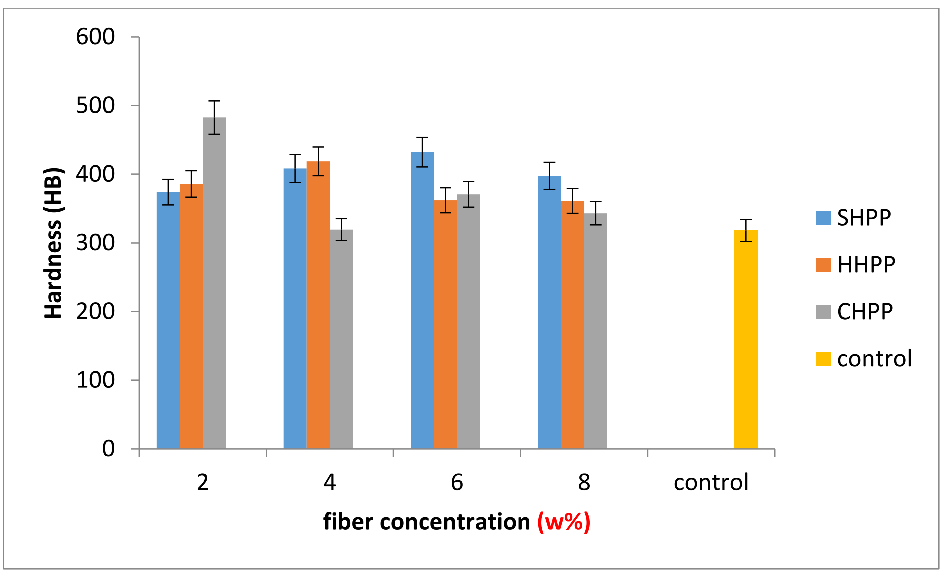


Fig. 12. The variation of Brinell hardness with percentage fiber loading for cow tail hair (CH), sheep hair (SH) and human hair (HH) reinforced polypropylene composites.

Conclusion

This research tackled some of the challenges of reinforcement of natural fibers polymer composites. This was achieved by conveniently reinforcing PP polymer with three natural polymers (human hair, sheep hair, and cow tail) with reduced fiber length using an injection molding technique operated at low temperature. Hence, this study provided a high-performance, yet less expensive natural fiber alternative for thermoplastic reinforcement. Human hair fiber gave the best overall result while sheep hair gave the least. It can be drawn from this research that human, cow tail, and sheep hair fibers reinforced PP composite can be successfully prepared by injection molding method through fiber length reduction. Human hair generally contributed the most to the improvement of mechanical properties in the tensile strength, flexural strength, modulus, and impact strength of the PP composite. However, cow tail hair on the other hand performed best in the elongation at break and hardness. Sheep hair was observed to offer the minimum improvement of the polymer's mechanical strength. SEM image of the cow tail hair fiber is the only image that showed air entrapment. From the analysis of variance results, the response of the composites to flexural stress can be said to be more dependent on the fiber type while their tensile properties, impact strength and hardness were basically not due to fiber type but the fiber matrix synergy. PP composites of human and cow tail hair fibers can be considered alternatives for conventional materials for automotive and other applications.

Declaration of Competing Interest

All the author agree in the submission of this manuscript and declare no conflict of interest in this work

Data availability

Data will be made available on request.

References

Ahmad, S., 2014. Preparation of eco-friendly natural hair fiber reinforced polymeric composite (FRPC) material using Polypropylene and Fly-Ash: a review. Int. J. Sci. Eng. Res. 5 (2), 969–970.

Ansari, A.A., Dhakad, S.K., Agarwal, P., 2020. Investigation of mechanical properties of sisal fifiber and human hair reinforced with epoxy resin hybrid polymer composite. Mater. Today: Proc. 26, 2400–2404.

Arinze, R.U., Oramah, E., Chukwuma, E.C, Okoye, N.H., Chris-Okafor, P.U., 2022. Mechanical impact evaluation of natural fibers with LDPE plastic composites: waste management in perspective. Current chemical treatment on the mechanical behaviour of hair fiber-reinforced composites. Res. Green Sustain. Chem. doi:10.1016/j.crgsc.2022.100344.
ASTM D3800-16, 2008. Standard test methods for the density of high-modulus fibers. ASTM Int'l, Wes 1–6.
ASTM D638-08, 2008. Standard test method for tensile properties of plastic. ASTM Int'l, West Conshohocken, PA 1–16.
ASTM D790-07, 2008. Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. ASTM Int'l, West Conshohocken, PA 1–11.
Balachandar, M., Vijaya, R.B., Ashok, K.S., Siva, S.G., 2019. Experimental evaluation on mechanical properties of natural fiber, polymer composites with human hair. Mater. Today: Proc. 16, 1304 –131.
Barone, J.R., 2005. Polyethylene/Keratin fiber composites with varying polyethylene crystallimity. J. Compos. 36, 1518–1524.
Block, W.D., Lewis, H., 1938. The Amino Acid content of cow and chimpanzee hair. J. Bio. Chem. 561–570. Retrieved rom https://www.jbc.org.
Bo'garde, U.S., Shinde, V.D., 2014. Review on natural fiber reinforcement polymer composites. Int'l J. Eng. Sc. Innvt. Tech (IJESIT) 3 (2), 431–436.
Choudhry, S., Pandey, B., 2012. Mechanical behaviour of polypropylene and human hair fibers and polypropylene reinforced polymeric composites. Int'l. J. Mech. Ind. Eng. (IJMIE). 2 (1), 118–121.
Dixit, S., Goel, R., Dubey, A., Shivhare, P.R., Bhalavi, T., 2017. Natural fiber reinforced polymer composites materials- A Review. Polym Renew Resour 8, 71–77.
Faruka, O., Bledzkia, A.K., Finkh, H.P., Saind, M., 2012. Biocomposites reinforced with natural fibers. Prog. Poly. Sc. 37, 1552–1596.
Gerard, K., (2014, Decembre 23). Performance plastics used in the automotive industry. Retrieved from http://info.craftechind.com/blog/bid/3919683/13-High Performance-Plastics-Used-in-the-Automotive-Industry.
Gupta, A., 2009. Human Hair waste and its utilization. Gaps and possibilities". Int. Refract. Metal. Hard Mater. 892 -89.
Gupta, A., 2014. Human hair "waste" and its utilization: gaps and possibilities. J. Waste Manage.
Hollaway, L., 1994. Handbook of Polymer Composites for Engineers. Woodhead Pub. Ltd., England.
Khan, M., Ali, M., 2018. Effectiveness of hair and wave polypropylene fifibers for concrete roads. Construct. Build. Mater. 166, 581–591.
Kumar, T., Goutami, K., Adity, J., Kavya, K., Mahendar, V., Reddy, R., Kaushik, S., 2015. An experimental study on mechanical properties of human hair fifiber reinforced concrete (M-40 Grade). IOSR J. Mech. Civil Eng. 12, 65–75.
Kumar, N., Singh, A., Ranjan, R., 2019. Fabrication and mechanical characterization of horse hair (HH) reinforced polypropylene (PP) composites. Mater. Today: Proc. 19, 622–625.
Lewin, M., 2002. Handbookof Fire Chemistry, 3rd ed CRCPress, New York.
Liu, Y., Xie, J., Wu, N., Wang, L., Yunhai, M., 2019. Influence of silane treatment on the mechanical, tribological and morphological properties of corn stalk fiber reinforced polymer composites. Tribol Interface 131, 398–408.
Moritomi, S., Watanabe, T., Kanzaki, S., 2010. Polypropylene Compounds for Automotive Applications 1, 15.
Mueller, D.H., Krobjilowski, A., 2003. New discovery in the properties of composites reinforced with natural fibers. J. Ind. Textiles 33 (2), 111–130.
Nanda, B.P., Satapathy, A., 2017. Process. Ser.: Mats. Sci. Eng. 178 (2017), 012012.
Nijjar, S., Sudhakara, P., Sharma, S., Saini, S., 2022. Overview on the latest trend and development on mechanical, tribological & microstructural properties of natural fifiber polymer composites. Mater. Today: Proc. 63663–63672.
Nila, V.M., Raijan, K.J., Antony, S., Babu, M.R., Davis, N.R., 2015. Hair fiber reinforced concrete. Int. Conf. Technol. Adv. Struct. Construct. 10–11 2015June.
Oladele, I.O., Omotoyimbo, J.A., Ayemindejor, S.H., 2014. Mechanical properties of chicken feather and cow hair fiber high density polyethylene composite. Int'l J. Sci. Tech. 3 (1), 66–72.
Oladele, I.O., Olajide, J.I., Ogungbadejo, A.S., 2015a. The influence of chemical treatment on the mechanical behaviour of animal reinforced high density composites. Am. J. Eng. Res. 4 (2), 19–26.
Oladele, I.O., Olajide, L.J., Ogunbadejo, S.A., 2015b. Effects of chemical treatments on the physicochemical and tensile properties of cow hair fiber for low load bearing composites development. Int'l. J. Mats Sci. Apps. 4 (3), 189–197.
Prakash, R., Christu, P., 2016. Mechanical properties of natural fiber (human hair) reinforced polymer composite. Asian J. Res. Soc. Sci. Human. 6, 2052.
Rao, P.D., Udaya, K.C., Eshwara, P.K., 2017a. Effect of fiber loading and void content on tensile properties of keratin based randomly oriented human hair fiber composites. Int. J. Compos. Mater. 7, 136–143.
Rao, P.D., Kira, C.U., Prasad, K.E., 2017b. Tensile Studies on random oriented human hair fibers reinforced polyester composites. J. Mech. Eng. 47 (1), 37–44 pp.
Rao, D.N., Mukesh, G., Ramesh, A., Anjaneyulu, T., 2020. Investigations on the mechanical properties of hybrid goat hair and banana fiber reinforced polymer composites. Mater' Today: Proc' 27, 1703–1707.
Reddy, B.M., Reddy, Y.V., Reddy, B.C., 2018a. Effect of alkali treatment on mechanical, water absorption and chemical resistance properties of Cordia-Dichotoma fiber reinforced Epoxy composites. Int. J. Appl. Eng. Res. 13, 3709–3715.
Reddy, M.I., Kumar, M.A., Raju, R.B., 2018b. Tensile and flexural properties of jute, pineapple leaf and glass fiber reinforced polymer matrix hybrid composites. Mter. Today Proc. 5, 458–462.
Rosato, D., Rosato, D., 2004. Reinforced Plastics Handbook. Elvesier Inc. Ltd, New York, pp. 1–8 & 57-59.
Senthilnathan, D., Gnanavel, B.A., Bhaskar, G.B., Gopinath, K.G., 2014. Characterization of glass fiber – coconut coir– human hair hybrid composites. Int'l. J. of Eng. and Tech. (IJET). 6 (1), 75–76.
Sharma, M., Sharma, R., Chandra, S.S., 2021. A review on fibers and fillers on improving the mechanical behaviour of fiber reinforced polymer composites Material Today. Proceedings 46, 6482–6489.
Srivastava, P., Kumar, G.C., Sinha, S., 2018. The influence of chemical treatment on the mechanical behaviour of hair fiber-reinforced composite. Mter. Today Proc. 5, 22922–22930.
Tudu, P., 2009. Processing and characterization of natural fiber reinforced polymer composites. Dept. Mech. Eng. Nat. Inst. Tech. Rourkela, India 1–2.
Uzun, M., Sancak, E., Patel, I., Usta, I., Akalin, M., Yuksek, M., 2011. Mechanical behaviour of chicken quils and chicken feather fibers reinforced polymeric composites. Achiv. Mater. Sci. Eng. 52 (2), 82–86.
Verma, A., Singh, V.K., Verma, S.K., Sharma, A., 2016a. Human hair: a biodegradable composite fiber- a review. Int. J. Waste Resour. 6 (2), 1–4.
Wilems, F., Boten, C., 2016. Influence of processing on the fiber length degradation in fiber reinforced plastic parts. AIP Conf. Procds. 1779 (020003), 2–5.