Evaluation of the mechanical properties of chemically modified chicken feather fibres reinforced high density polyethylene composites

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ABSTRACT
Despite the effectiveness and advantages of natural fibres from plants as reinforcement in the production of composite materials, it has been observed that such fibres have limitation of a high rate of absorption of moisture. In most cases, this weakens the properties of the composites. So, there is need to divert attention into the use of other source of natural fibres such as avian fibres. In this research, brown avian fibres from chicken feathers were utilized to reinforce high density polyethylene (HDPE) for structural applications. The brown avian fibres were extracted from chicken feathers by trimming after which they were treated with 0.1 M NaOH solution. The treated and untreated fibres were analysed to ascertain their elements, crystallinity index and morphology by using Atomic Absorption Spectrophotometer, X-Rays diffraction (XRD) and scanning electron microscopy (SEM), respectively. The composites were produced by varying fibre ratio as; 2, 4, 6, 8 and 10 wt% with HDPE matrix. The composite samples were characterized to ascertain their tensile and flexural properties in accordance with ASTM D3038M-08 and ASTM D7264M-07 standards, respectively. Morphology of the composites was analysed and it revealed that chemical treatment of the avian fibres is potential by means of enhancing the properties of their corresponding composites. Composite samples reinforced with modified avian fibres displayed the best mechanical properties in terms of tensile properties and flexural modulus.

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1. Introduction
Over the past three decades, composite materials have been the dominant emerging materials. The needs for sustainable engineering materials and environmental considerations have given opportunities for rigorous research in the field of natural fibre-reinforced composites. In recent times, demand for cost effective and efficient materials which are polymer based composite has seen massive advancements. There has been a proliferation of research into the development of natural fibre-reinforced polymeric composites with the aim of replacing more expensive synthetic fibres [1].

Natural fibres are advantageous over conventional synthetic fibres as reinforcement or filler materials because of their unique environmental relevance which includes raw material utilization at the source and easily disposable of the biodegradable fibres [2,3]. Apart from their unique environmental benefits, natural fibres also possess some advantages such as low cost, low density, enhanced toughness and reasonable specific strength [4]. However, the use of natural fibres has few limitations such as poor compatibility with a thermoplastic matrix, high moisture absorption and lower thermal stability [5,6]. To overcome such limitations, natural fibres are subjected to surface modifications such as mercerization or physical treatments [7,8].

Currently, attractive properties of hair fibres have prompted researchers to reconsider the economic importance of hair fibres. This has uncovered new materials for industrial applications as reinforcements for the synthesis of novel composite materials [9,10]. Examination of animal fibres, particularly, keratin-based fibres for composites development has manifested in quite remarkable but not exhaustive number of investigations with encouraging results [11,12]. Significant improvement in the mechanical properties of the developed composites was achieved when human hair fibre was used to reinforce polypropylene [13]. Also, flexural properties were improved when cow hair fibre was used to reinforce high-density polyethylene (HDPE) composites [14].

Various works have been done to buttress the fact that chicken feather fibres (CFF) are potential reinforcing materials. Since their structures are made up of twisted micro-fibrils forming a helix that is responsible
for fibre high mechanical strength and resilience properties. They are also hydrophobic and hygroscopic in nature with unique honeycomb structure which is accountable for their high thermal resistance properties [15]. CFF can be modified by grafting to enhance some of its naturally poor properties such as dimensional stability, rub resistance, oil and water repellency, tensile properties, abrasive and peeling resistance [16–19]. CFF have been used to reinforce a number of different polymeric materials for diverse applications. The mechanical and morphological properties of polymethyl methacrylate-based composite was enhanced by reinforcing it with CFF for dental application. Improvement in strength and modulus was revealed from the morphological studies of the composites due to uniform distribution of CFF in the polymer matrix [20].

Contemporary HDPE which is used for manufacturing furniture has been identified to possess some limitations in terms of poor mechanical properties which have resulted in their continuous failure in service. Researchers have shown that the response of hair fibres to mechanical stresses is highly dependent on stability of cortical keratin of hair fibre structure. This stability often depends on heat and chemical treatments [21]. Recent research findings have also shown that appropriate chemical treatments can significantly improve the structural integrity of hair fibres without deteriorating their intrinsic properties [22,23]. However, influence of fibre colour has not been considered to know whether individual or mixed colours possess special effect on the composites properties. This research evaluates the effect of chemically modified brown CFF as reinforcement on the mechanical properties of HDPE composites for furniture applications.

2. Materials and methods

Avian fibres were extracted from chicken feathers that were purchased from poultry in Akure, southwestern Nigeria. HDPE pellets which were used as matrix was purchased from Eurochemical in Lagos State, Nigeria.

2.1. Extraction of avian fibres

Chicken feathers were sorted out, washed and sun dried for 10 days. The dried chicken feathers were trimmed using pair of scissors to remove the avian fibres (barbs) from the rachis part of the feathers. Figure 1(a, b) shows the chicken feather and the extracted fibres.

2.1.1. Chemical modification of the avian fibres

In this research, trimmed avian fibres were divided into two parts in which one part of them was treated with 0.1 M NaOH solution. The treatment was carried out in shaker water bath that is set to a temperature of 50°C and maintained for 4 hours. Then, the treated fibres were washed with tap water and finally rinsed with distilled water to obtain neutral status followed by sun drying for 10 days.

2.1.2. Mineral analysis for the fibre

The minerals analysis of the avian fibre was done by acid digestion of 2 g of the fibre sample which was subjected to ground form (ash). The fibre was mixed with a mixture of nitric acid, sulphuric and perchloric acid in the ratio 4:1:1 until a clear solution was obtained. Then, the mixture was allowed to cool down and transferred into 100 ml beaker which contains de-ionized water. Copper, iron, zinc and magnesium were determined using Atomic Absorption Spectrophotometer analyser while potassium was determined by titrimetric method. The potassium was got by utilizing the ash form of the avian fibre. The ash was brought up to 100 ml with distilled water. 1 ml of the solution was taken and diluted again to 100 ml. The flame photometer was adjusted to give a reading of 100 with the standard 10 ppm solution and read the sample solution. The carbon content was obtained by subtracting the ash content from 100. The mineral content of the avian fibre was read in part per million (ppm).

Figure 1. Chicken feather (a) and extracted fibres (b).
2.1.3. X-Ray diffraction analysis of the fibres
Untreated and treated brown avian fibres was chopped into fine particles and compressed into disks using a cylindrical steel mould (Ø = 15 mm) with an applied pressure of 32 MPa. A Philips X’Pert diffractometer fitted with a ceramic X-ray diffraction tube was used to assess the influence of the alkaline treatment on fibres crystallinity. The diffracted intensity of Cu K radiation (wavelength of 0.1542 nm) was recorded between 5° and 40° (2θ angle range) at 40 kV and 40 mA.

2.2. Production of composites
Composite samples were produced by hand lay-up method using compression moulding machine. The HDPE used has a melt flow index (MFI) of 8 g/10 min (XZ 89712–00 RD, 10140182040), molecular weight of 168,000 g mol⁻¹, melting point of 130°C, and density of 0.954 g cm⁻³. Randomly dispersed fibre orientation was used with varied fibre mass of 2, 4, 6, 8 and 10 wt% as shown in Table 1 for both treated and untreated brown fibre-reinforced composites. To produce the composites, each mixture is placed in pre-heated compression moulding machine which was set to a temperature of 135°C and left for 7 minutes so as to flow in the mould. The samples were formed into the flexural and tensile moulds and allowed to cool before they were stripped from the moulds. The flexural mould used has a dimension of 250 × 200 × 3 mm while the tensile mould is 200 × 150 × 3 mm.

The designations are as stated below:
C – denotes the neat sample which contains only HDPE without any reinforcement.
BFU – denotes the composite samples that contain HDPE and untreated brown avian fibres. BFTNa – denotes the composite samples that contain HDPE-and NaOH-treated brown avian fibres.

2.3. Tensile test
The stress–strain behaviour and tensile properties of the composites were evaluated by performing the tensile test in accordance with ASTM D3038M-08 [24]. The test was performed at room temperature using the universal testing machine, Instron incorporated USA model; Instron-series 3369 operated at a crosshead speed of 0.3 mm/mm and at a strain rate of 10⁻³/s. Three repeat tests were performed for each composition of the composites to check for repeatability and reliability of the data generated [1].

2.4. Flexural test
The flexural strength of the composites was evaluated by performing a flexural test on three-point bending tests platform. The test was performed at room temperature using the universal testing machine, Instron incorporated USA model; Instron-series 3369 operated at a crosshead speed of 0.3 mm/mm and at a strain rate of 10⁻³/s. The testing procedure and flexural strength determination were performed in accordance with ASTM D7264M-07 standard [25,26].

2.5. Scanning electron microscope imaging
The treated and untreated fibres as well as the fractured surfaces of the composite samples were examined by Hitachi S-4100 field emission scanning electron microscope (SEM) operated at 5 kV. Samples were mounted on aluminium stubs with carbon tape and then sputter coated with platinum and palladium to make them conductive prior to SEM observation.

3. Results and discussions
3.1. Elemental composition of avian fibres
Elemental composition of the avian fibre utilized for this research is presented in Table 2.

3.2. XRD results of the avian fibres
The X-ray diffractograms of untreated and NaOH-treated brown avian fibres were shown in Figure 2. The X-ray diffractograms results of the untreated and treated avian fibres were as shown in Figure 2 and Table 3. It was observed from the results that, the major crystalline peak of each profile occurred at around 2θ = 19.63°. X-ray diffractograms show that intensity of the crystallographic plane was increased significantly as a result of alkaline treatment of avian fibres.

\[ Ic = \frac{I_k - I_{am}}{I_k} \times 100 \]  

where, \( I_k \) is the maximum intensity of diffraction of the peak at a 2 angle of between 15 and 25 and \( I_{am} \) is the intensity of diffraction of the amorphous material, which is taken at a 2 angle between 13 and 18 where the intensity is at a minimum [27].

Table 1. Formulation of the avian fibre-reinforced HDPE composites.

| Designation of the composite samples | Matrix (wt.%) | Reinforcement (wt.%) |
|------------------------------------|--------------|---------------------|
| C                                  | 100          | –                   |
| BFU2                               | BFNTa2       | 98                  | 2       |
| BFU4                               | BFNTa4       | 96                  | 4       |
| BFU6                               | BFNTa6       | 94                  | 6       |
| BFU8                               | BFNTa8       | 92                  | 8       |
| BFU10                              | BFNTa10      | 90                  | 10      |

Table 2. Elemental Composition of Avian Fibres.

| Elemental composition | Mg   | Zn   | Fe   | Cu   | K    | C    |
|-----------------------|------|------|------|------|------|------|
| Amount (ppm)          | 3.65 | 2.90 | 1.54 | 0.08 | 201.50 | 99.86 |
The fibres crystallinity index (Ic) of the treated and untreated avian samples were calculated using Equation (1) in accordance to [28] and the results are summarized in Table 3. It should be noted that the crystallinity index is useful on a comparison basis as it is used to indicate the order of crystallinity rather than the crystallinity of crystalline regions [29]. It can be seen from Table 3 that the crystallinity index of avian fibres was improved by alkaline treatment. This might likely be due to better packing and stress relaxation of polypeptide chains as a result of the removal of other amorphous constituents (lipid 1% and water 8%) from the fibres which possesses 91% keratin [20].

Other well-defined peaks that were present on the X-ray diffractograms are at 2θ = 8.5° and 2θ = 45°, respectively. When the crystalline content is high, these two peaks were more pronounced but when the fibres contain large amounts of amorphous material (such as lipid and water), these two peaks were smeared and appear as one broad peak. The peaks for NaOH-treated fibres were better defined than those of the untreated fibres which indicate that the NaOH treatment was responsible for the removal of a greater amount of amorphous content from the fibres.

### 3.3. SEM image of the avian fibres

The SEM image of the brown avian fibres is shown in Plate 1: (A and C). Plate 1 (A) and (C) show that the micro-fibrils are in twisted form as helix which is likely responsible for the improved mechanical properties of the composites. It was also seen from the images that the barbs are having branches known as barbules, which can enhance the resilience properties of the avian fibres. The cleave lines or striations along the fibres give rise to a certain surface roughness, which aids the enhancement of interfacial bonding strength. These features of the fibres make it a potential reinforcing material for composites development. From Plate 1 (C), it was also observed that the micro-fibrils are twisted to forming a helix that aid good mechanical properties like the untreated fibres. However, it was observed that the chemical treatment of the fibres with NaOH solution reduced the amount of lipids, threonine and serine which are responsible for the hygroscopic nature of the avian fibres, thereby, enhancing the aspect ratio of the fibres. Also, the chemical treatment enhanced the fibres morphology and the stiffness by increasing the number of crystalline phases that are present within the fibres. This shows the reason why NaOH-treated avian fibres gave the best outcome when used as a reinforcing material for composites production.

### 3.4. Evaluation of stress strain behaviour of the developed composite samples

The results for the stress strain behaviours of the developed composite samples are presented in Figures 3.

The general observation is that the tensile deformation behaviour of the composites is similar to that of the unreinforced HDPE. The deformation was seen to progress in three well-defined stages; in which the initial stage was elastic, followed by yielding and a region of plastic deformation, respectively. As shown in Figure 3, sample BFTNa6 shows the highest maximum tensile stress value of 20.00 MPa followed by sample BFTNa4 with a maximum tensile stress value of 19.64 MPa. This culminated to about 13.57% and 11.53% enhancement, respectively compared to the neat sample. The neat sample has a maximum tensile stress value of 17.61 MPa which is an indication that the chemical treatment has enhanced the mechanical properties of the composites.

### 3.5. Tensile properties of the composites

The results of tensile properties are shown in Figures 4 and 5.

Figure 4 showed the results of ultimate tensile strength (UTS) for the composites. From the results, it was observed that UTS of the composites including NaOH-treated fibre was better enhanced than those from the untreated fibre. Also, it was observed that UTS of the chemically treated avian fibre-reinforced HDPE composites increased as fibre content increased from 2 to 6 wt% followed by a reduction in values. The best in this regards was sample denoted as BFTNa6 (which was 6 wt% of NaOH-treated brown fibre-reinforced HDPE) with a value of 20.00 MPa followed
by sample denoted as BFTNa4 with a value of 19.64 MPa. This shows that 6 wt% reinforcement was the optimum value for UTS enhancement with treated fibre. The results showed that treated avian fibres reinforced samples gave about 14% enhancement compared to a neat sample that has a value of 17.61 MPa.

Figure 3. Stress – strain curves for the HDPE composite reinforced with brown avian fibres.

Figure 4. Variation of UTS of the developed composites with weight fraction of the avian fibres in the composites and the neat sample.

Figure 5 shows the tensile modulus of the composite samples which indicates stiffness of composites. Contrary to the response of materials to UTS in Figure 4, it was observed that all the composites possess better tensile modulus properties than the neat sample. From the results, it was observed that...
sample denoted as BFTNa2 possessed the most superior tensile modulus value of 735.60 MPa followed by sample denoted as BFTNa8 with a value of 720.30 MPa. This implies 75% enhancement in the tensile modulus compared to neat sample that has a value of 421.20 MPa. With the exception of sample with the best performance, tensile modulus tends to increase as the treated fibre content increases from 4 to 8 wt%. Chemically modified chicken feather fibre gave the best results in the entire weight fraction considered which may be as a result of improved crystallinity index as shown in Table 3. This is an indication that stiffness of fibres enhanced the overall stiffness of the avian fibres reinforced composites.

Considering weight fraction, low weight fraction is favourable for the development of avian fibre-reinforced HDPE composites with good strength and stiffness. The work showed that, tensile modulus was best enhanced when 2 wt% fibre content was used. This may be due to the possibility of well-dispersed fibre within the matrix without fibre touching that usually led to weak interfacial adhesion which is likely to occur in high fibre content application. Results of this research showed improvement compared to the work of previous researcher where chicken feather quill and fibre were used to reinforce vinylester and polyester [30] as well as when Emu feather fibre was used to reinforce epoxy and polyester [31].

### 3.6. Flexural properties of the composites

The results of the flexural properties are shown in Figures 6.

Figure 6 revealed the flexural strength at peak for the composites. From the flexural strength at peak result, it was observed that the value showed a tendency to increase from 2 to 4 wt% followed by a decrease from 6 to 10 wt%. These suggest that the optimum weight fraction that can aid the enhancement of the property is 4 wt% fibre content as both chemically modified and unmodified fibres gave the best results. However, chemically modified sample denoted as BFTNa4 followed by the unmodified sample BFU4 have the values 16.20 MPa and 14.30 MPa, respectively as compared with the neat sample with a value of 12.55 MPa. 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 [32]. The decrease in flexural strength with increase in fibre loading has been reported by some researchers [10,30–32]. They attributed this phenomenon to increase in fibre–fibre interaction, poor dispersion of fibre in the matrix and low interfacial strength resulting in a lower efficiency of load transfer with increase fibre loading.

### 3.7. SEM images of the composites

The SEM micrographs of neat and composites were shown in Plate 2. The images showed that avian fibres were well dispersed into the HDPE matrix as a result of good compatibility and miscibility between both materials which aid proper adhesion at the interface. In order to improve mechanical properties, a good impregnation and dispersion of reinforcement are essential to transfer load between both phases. In this case, avian fibres were wetted by the HDPE and there are no voids surrounding the fibre phases. Since avian fibres keratin contains amino acids, which are predominantly hydrophobic and little hygroscopic
content, the chemical modification has reduced the hygroscopic content thereby, encouraging compatibility with hydrophobic HDPE as shown in Plate 2 (B).

From Plate 2(C), dark spots were found around unmodified fibre within HDPE matrix, which depicts non compatibility as with the case of modified fibre-reinforced composite. It was also observed from the micrographs that avain fibres were well dispersed within the matrix which reflects a good interface between untreated fibres and HDPE matrix. However, there are some voids surrounding the dispersed avain fibres within the matrix. This may be due to the presence of untreated fibres since they are composed of some percentage of serine, theronine and lipids which contribute to the hygroscopic nature of the fibres.

4. Conclusion

This research was carried out to assess the possibility of using avian fibres which are waste materials as an alternative to synthetic fibres for the enhancement of some mechanical properties of HDPE. In the results, it was observed that the composites possessed better properties as compared with the unreinforced HDPE that served as the neat sample. From the results, the following conclusions were deduced;

**Brown avian fibres possessed the best percentage crystallinity index value after treatment:**

- Composite samples that are consisting NaOH-treated brown avian fibres (BFTNa2) possessed the best mechanical properties such as tensile strength and flexural strength.
- There is need to consider other animal fibres colour and evaluate the influence of pigments on the properties of the ensuing composite.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**

[1] Oladele IO, Agbeboh NL. Development of mathematical models and estimation for the mechanical properties of organic fibre reinforced polyester composites. Fibre Polym. 2017;18(7):1336–1345.

[2] Kabir MM, Wang H, Lau KT, et al. Mechanical properties of chemically-treated hemp fibre reinforced sandwich composites. Compos Part B-Eng. 2012;43(2):159–169.

[3] Aziz SH, Ansell MP. The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: part 1 - polyester resin matrix. Compos Sci Technol. 2004;64(9):1219–1230.

[4] Cantero G, Arbelai A, Llano-Ponte R, et al. Effects of fibre treatment on wettability and mechanical
behaviour of flax/polypropylene composites. Compos Sci Technol. 2003;63(9):1247–1254.

[5] Li X, Tabil LG, Panigrahi S. Chemical treatments of natural fibre for use in natural fibre-reinforced composites: A review. J Polym Environ. 2007;15(1):25–33.

[6] Ray D, Sarkar BK, Basak RK, et al. Study of the thermal behavior of alkali-treated jute fibres. J Appl Polym Sci. 2002;85(12):2594–2599.

[7] Mukhopadhyay S, Fangeiro R. Physical modification of natural fibres and thermoplastic films for composites – a review. J Thermoplast Compos Mater. 2009;22(2):135–162.

[8] Xie YJ, Hill CAS, Xiao ZF, et al. Silane coupling agents used for natural fibre/polymer composites: a review. Compos Part A-Applic Manuf. 2010;41(7):806–819.

[9] Batebi Y, Mirzagoltabar A, Shabanian SM, et al. Experimental investigation of shrinkage of nano hair reinforced concrete. Iranica Journal Energy & Environ. Special Issue on Nanotechnology. 2013;4:68–72.

[10] Oladele IO, Omotayoibno JA, Ayemidejor SH. Mechanical properties of chicken feather and cow hair fibre reinforced high density polyethylene composites. Int J Sci Tech. 2014;3:66–71.

[11] Barone JR, Schmidt WF. Polyethylene reinforced with keratin fibers obtained from chicken feathers. Compos Sci Technol. 2005;65:173–181.

[12] Dwivedi AK, Darbari AS, Verma VK. Compressive strength evaluation of human hair and polypropylene fabricated reinforced composites. Int J Eng Sci. 2015;4:88–91.

[13] Oladele IO, Olajide JL, Ogunbadejo AS. The influence of chemical treatment on the mechanical behaviour of animal fibre-reinforced high density polyethylene composites. Am J Eng Res. 2015;4:19–26.

[14] Saravanan K, Dhurai B. Exploration on amino acid content and morphology structure in chicken feather fibre. J Textile and Apparel Technol Manage. 2012;7(2):1–6.

[15] Das A, Saikia CN. Graft polymerization of methacrylamide onto Non- mulberry silk-antleraea assama using potassium permanganate oxalic acid redox system. Bioresour Technol. 2000;74:213–216.

[16] Tsukada M, Ffreddi G, Massafra MR, et al. Structure and properties of tussah silk fibres grafted-copolymerized with methacrylamide and 2-hydroxethyl methacrylate. J Appl Polym Sci. 1998;67:1393–1403.

[17] Giri G, Samal RK. grafting onto wool fibres: graft copolymerization of methyl methacrylate onto wool fibres initiated by KHSOS/Fe(III) couple. J Appl Polym Sci. 1991;42(8):2371–2375.

[18] Mishra S, Nayak PL, Sahu GJ. Grafting vinyl monomers onto silk fibres. XV. Graft copolymerization of methyl methacrylate onto silk using thallium (III) as initiator. J Appl Polym Sci. 1982;27:1903–1911.

[19] Salehuddin SMF, Wahit MU, Kadir MRA, et al. Mechanical and morphology properties of feather fibre composite for dental post application. Malays J AnaL Sci. 2014;18(2):368–375.

[20] Lederer R. "Integument, Feathers, and MoL". Ornithology: The Science of Birds, http://www.ornithology.com/lectures/Feathers.html, accessed 6/23/05.

[21] Sinclair DR. Healthy hair: what is it? J Invest Derm Symp P. 2007;122–5.

[22] Nagasawa T, Suzuki H, Koyama M, et al. Development of a novel penetration-enhancing agent for hair products. Journal of Cosmetics, Dermatological Sciences and Applications. 2013;3:129–134.

[23] Oladele IO, Olajide JL, Ogunbadejo AS. Effect of chemical treatments on the physicochemical and tensile properties of cow hair fibres for low load bearing composites development. International Journal of Materials Science and Applications. 2015;4:189–197.

[24] American Society of Testing and Materials. Standard test method for tensile property of polymer matrix composite materials. Philadelphia: ASTM D3039M-08.

[25] American Society of Testing and Materials. Standard test method for flexural property of polymer matrix composite materials. Philadelphia: ASTM D7264M-07.

[26] Oladele IO, Aqababiaka OG. Investigating the influence of mercerization treatment of sisal fiber on the mechanical properties of reinforced polypropylene composites and modeling of the properties. Fibre Polym. 2015;16(3):650–656.

[27] Tserki V, Zafeiropoulos NE, Simon F, et al. A study of the effect of acetylation and propionylation surface treatments on natural fibres. Composite A: Application Science Manufacture. 2005;36(8):1110–1118.

[28] Roncero MB, Torres AL, Colom JF, et al. The effect of xylanase on lignocellulosic components during the bleaching of wood pulps. Bioresources Technol. 2005;96(1):21–30.

[29] Ouajai S, Shanks RA. Composition, structure and thermal degradation of hemp cellulose after chemical treatments. Polym Degrad Stabilization. 2005;89(2):327–335.

[30] Uzun M, Sancak E, Patel I, et al. Mechanical behaviour of chicken quills and chicken feather fibres reinforced polymeric composites. Arch Mater Sci Eng. 2011;52(2):82–85.

[31] Reddy KN, Chanrasekar V, Reddy KT, et al. Performance evaluation of Emu feather fiber reinforced polymer composites. Int J Mech Eng Robot Res. 2014;3(1):272–283.

[32] Choudhry S, Pandey B. Mechanical behaviour of propylene and human hair fibres and polypropylene reinforced polymeric composites. Int J Mech Ind Eng. 2012;2(1):118–121.