Mechanical Behavior of Chicken Fiber Augmented Epoxy Composites

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Abstract
The primary purpose of this research was to find out a novel yet cost-effective way of putting the chicken feathers, the presumed waste of poultry industry, into some useful applications by developing composites reinforced with differential proportion and form of the fibers. Pure chicken fibers and its nonwoven mat structure were made into composite forms and tested for their tensile strength, compressive strength, flexural strength and impact strength. It was found that composite with least chicken fiber loading was better in tensile strength, while, the flexural strength of all the composites was far better than the controlled sample. The compressive strength was found endurable for low load bearing and economic applications. However, no favorable improvement was observed in the impact strength of all the tested samples. It can, therefore, be concluded that the use of chicken fibers for composite applications must primarily rely on low cost and weight reduction owing to the lump of environmental problems arising due to their unsettlement.

Keywords: Chicken feather fiber, protein fibers, nonwovens, technical textiles, composites

Past years have witnessed extensive and steady progress and being registered in poultry development in the country. In India, the approximate production of poultry meat is about 3.8 million tonne and the estimated domestic per head consumption is approximately 3.6 kg per year [Agrixchange, 2016]. A value growth rate of around 7% was marked over the year 2016-17 as the estimated total broiler meat market size had risen up to Rs. 730 billion in terms of the retail pricing [Ghosal, 2018]. Poultry industry is definitely rising at a good pace, yet, at the time when world is taking initiative towards sustainable development each phase of production process including transportation and disposal counts. The major environmental concern from this industry is massive amount of poultry feathers accumulated annually and which demand cost effective environmentally sound ways for its settlement. Chicken feather is a very problematic and upsetting waste product of the poultry farming industry. It has been reported that the world's use of chickens is around 24 billion tonnes in which feather waste made up around 8.5 billion tonnes, and in particular India's input alone is 400 million tonnes. India was positioned the fifth largest poultry producer in the world [Jagadeeshgouda *et al*., 2014]. The only reason for mentioning the statistics for poultry meat consumption is to drive the attention towards the most undermine by-products that can be utilized for betterment of the environment and society, the chicken feathers. Another report estimated that 400 million chickens are processed each week worldwide. Typically as every bird carry upto 125 gram of feather, it ends up producing about 3000 tonnes of feather waste weekly. Clearance of this voluminous waste is a global ecological crisis as its settlement often causes pollution of land and underground water supply [Prasanthi1 *et al*., 2016]. In addition the unpleasant smell emanation from poultry farms pessimistically affects the quality of surrounding area. The fresh and decayed waste products such as manure, carcasses, feathers and bedding/litter altogether spoil the air quality [Gerber *et al*., 2008]. These presumably good to be nothing feathers however have unique structure and mechanical properties owing to their keratin nature [Chinta *et al*., 2013]. Chicken feathers mainly have an equal proportion of fiber and quill by weight and a full feather is made up of about 90% of keratin, which has a structural characteristic of materials of high mechanical strength [Subramani *et al*., 2014; Belarmino *et al*., 2012]. The presence of ordered α-helix or β-helix structure stabilize the three dimensional protein structures and are very difficult to break [Mishra *et al*., 2009; Thyagarajan *et al*., 2013]. The structure and properties of barbs of chicken feathers make them preferable for many applications. The lightness of chicken fibers coupled with high thermal insulation, excellent sound absorption, non-abrasive behaviour makes them a preferable supporting material for polymer composites [Oladele *et al*., 2018]. The chicken fiber has the lowest mass about 0.8 g/cm^3 compared to the all organic and man-made fibres [Uzun *et al*., 2011, Reddy and Yang, 2007]. Light weight, strength comparable to that of wool, cross section with honey comb pattern and many other properties favour the exploration of this poultry by-product for diverse technical applications rather than disposing it into landfills or incineration plants [Belarmino *et al*., 2012].

EXPERIMENTAL DETAILS

2.1. Materials

Chicken feathers (only contour type) were sourced from a poultry processing facility of G. B. Pant University of Agriculture & Technology, Pantnagar (Uttarakhand, India). Epoxy resin (Araldite CY-230) and hardener (HY-951) were procured from M/s CIBATUL Limited, Mumbai (Maharashtra, India). The ease of processing epoxy under a range of conditions and its favourable mechanical, chemical and thermal characteristics made it a first choice among other polymer matrices to be used for present work.

2.2. Processing and Treatment of Fibres

Unprocessed feathers were cleaned by washing with unionized soap solution (genteel 5%) followed by rinsing and dried. The dried feather were then sterilized with 95% ethanol (21^{o}C, 30 minute) to ensure absence of any sort of bacteria then again rinsed and dried [Fan, 2008]. The sterilized feathers were then processed to get fibers by manually stripping the barbs from the rachis (central thick part of the feather) with the help of scissor and followed by opening the fibers in a household blender (Figure 1, a-c).

Fig 1 (a)
Chicken Feathers

Fig 1 (b)
Barbs Stripped from Rachis

forc

Fig 1 (c)
Chicken Feather Fibers after Opening

re fabricated by hand la

(Figure 3) were casted with preferred reinforcement type. The details of the composites are given in Table 1.

Fig 2 Nonwoven Mat made with Chicken Fibers

Fig 3 Composite Specimens

A glass mold of 160x160x10 mm^3 was used for casting purpose. Calculated amount of fibers and the nonwoven mat were used in combination with epoxy resin to fabricate the polymer composites. Hand lay up technique was employed and fibers/mat was layered between the polymer coatings. The samples were allowed to set at room temperature for about 48 hours.

Table 1 Designation and Composition of the Composites

S. No.	Designation	Composition
1	CFF1	1% Chicken feather fiber loading in epoxy resin
2	CFF2	2% Chicken feather fiber loading in epoxy resin
3	CFM	Chicken fiber nonwoven mat (1.70 mm thickness, 6.88 g wt.) reinforced epoxy resin

The composite specimens were tested for their mechanical performance and were compared against the standard neat epoxy composite to establish their characteristics.

2.4 Composite Characterization

The tensile strength, compression, flexural strength and impact were measured using a tensile tester to determine the mechanical properties of the prepared specimens. The tensile and compression tests were performed according to the ASTM D 638 at a cross head speed of 1mm/min and 5mm/min respectively. A three point bending test was carried out based on the ASTM D-790 to measure the flexural strength at a cross head speed of 5mm/min. The Charpy impact test method was carried out on composites in accordance with ASTM E23 using impact testing machine.

2.5 Product Development

According to the test results of the developed composites, products for assorted field of technical textiles were prepared to add value to the waste chicken feathers. It may be noted however, that the products developed under the present study have novel composition which is presently not available commercially. So, it is not possible to make direct comparison of the developed products with commercially available products. Therefore, an effort was made to utilize the waste chicken fibers to make products with nearly commercial properties required for the proposed applications.

RESULTS AND DISCUSSION

3.1 Effect of CFF on Tensile Stress-strain Behavior

The ultimate strength and modulus of epoxy composite reinforced with 1% of CFF was higher (40.86 MPa, 0.74 GPa) when compared to other composite specimens (Figure 4 a-c, Table 2). As the fraction of CFF was further increased to 2%, a sharp decline in strength (23.21 MPa) and modulus (0.22) was observed. However, for all tested materials, the ultimate tensile strength was lowest for CFF mat reinforced composite (17.69 MPa) with 0.23 GPa modulus.

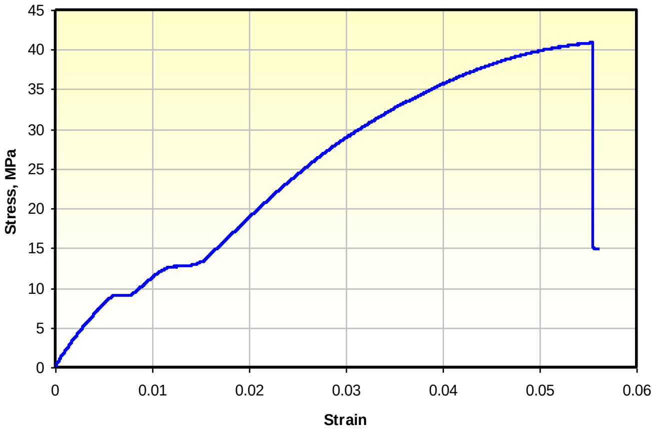

Fig 4 (a) Stress Strain Diagram for 1% of CFF Reinforced Composite

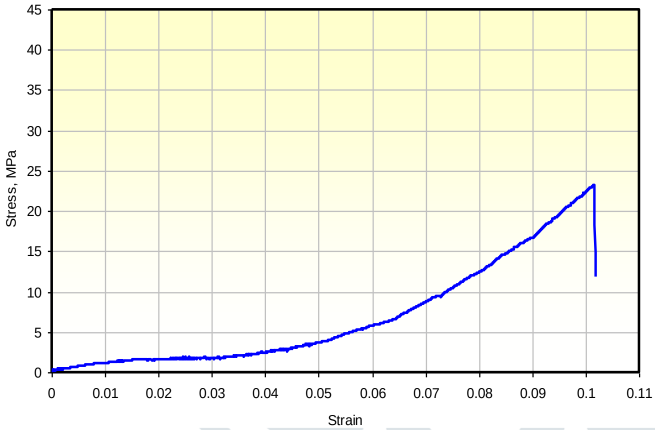

Fig 4 (b) Stress-strain Diagram for 2% of CFF Reinforced Composite

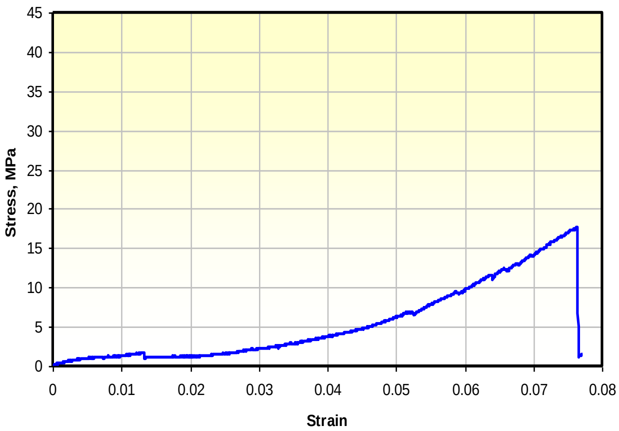

Fig 4 (c) Stress-strain Diagram for Chicken Mat Reinforced Composite

Table 2: Tensile Strength of CFF Reinforced Composites

S. No.	Composition	Tensile strength (MPa)	Tensile modulus (GPa)
1	CFF1	40.86	0.74
2	CFF2	23.21	0.22
3	CFM	17.69	0.23
4	Neat Epoxy CY-230	35.79	1.40

The reason for improved tensile strength at 1% fiber loading was due to the proper wetting of chicken fiber into matrix resulting in better adhesion between the two components. But increase in fiber content led to weak interfacial bonding between CFF and epoxy and hence resulted in low strength. The similar pattern was observed in tensile behavior of high density polyethylene composites strengthened with cow hair and chicken fibers. A comparative analysis of mechanical properties of these composites was done and it was reported that 1-3% addition of chicken fibers yielded the best results due to sufficient wetting and mixing of fibers in polymer resin and further raising the fiber content can bring down the values for tensile stress at maximum loading [**Oladele *et al.*, 2014].**

3.2 Effect of CFF on Compressive Strength of Composite

The comparative results of ultimate compressive strength of different forms of CFF reinforced composites are shown in Figure 5. It can be seen that CFF improved the ultimate compressive strength of the composite materials at 1% fiber loading i.e. 51.29 MPa but the values of compressive strength decreased with 2% fiber loading i.e. 49.55 MPa and with CFF mat reinforcement i.e. 47.43 MPa. The reason for maximum compressive strength at 1% fiber loading may be due to the proper wetting of fiber in matrix causing increased bonding between fiber and resin. However the reduction in compressive strength at 2% fiber loading can be attributed to the haphazard short fiber allocation in the polymer matrix leading to feeble alliance between the two.

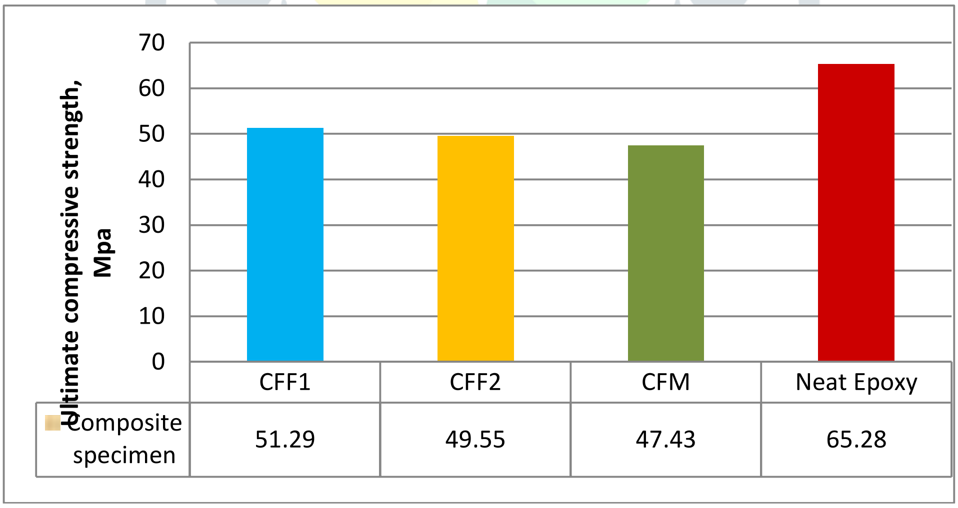

Fig 5 Compressive Strength of CFF Reinforced Composites

The main concern for short fiber reinforced composite is the complexity in organizing the random fibers within the composite and therefore the physical properties of the composite can be noticeably reduced. In addition, higher loading of short length chicken fiber may have caused greater fibrillation which in turn may have introduced more fiber ends for crack initiation. This relatively higher quantity of fiber ends could have lowered the stress transfer at the interface [Uzun *et al*., 2012].

3.3 Effect of CFF on Flexural Yield Strength of Composite

The effect of fiber content and form on flexural yield strength of CFF reinforced epoxy composites has been represented in Figure 6. It can be seen that flexural strength went up from 37.42 MPa to 40.62 MPa

(Table 4) with an increase in the amount of chicken feather fibre from 1% to 2% respectively. A sharp decline in strength (23.53 MPa) was noticed for CFF mat reinforced composite. The reason for improved flexural strength with fiber content may be due to the favorable mixing of matrix with filler material resulting in improved load transfer and sharing between fibre and matrix. Oladele *et al*. (2014) observed an increment of 8.75 and 8.65 N/mm^2 in flexural strength of high density polyethylene composites when reinforced with 1-2% of chicken fiber respectively. The improvement in flexural strength was comparable to the control sample with a value of 8.42 N/mm^2.

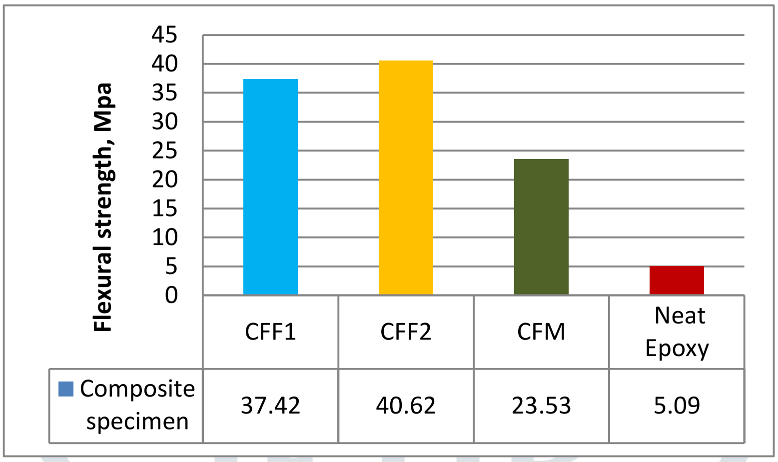

Fig 6 Flexural Strength of CFF Reinforced Composites

3.4 Impact strength

The impact strength of composite reinforced with chicken fiber mat was 2.90 J. Rest of the specimens exhibited zero resistance to impact (Table 3). However, these observed values may or may not be zero. This may be due to the limitation of machine. Comparatively mat reinforced composite showed better impact strength than other samples which may be attributed to fairly good bonding strength between mat and matrix and flexibility of interface region that slowed down initiation of cracks by absorbing and dispersing some fraction of energy. The results of SEM fractography (Figure 7 a-c) analysis also confirmed to the proposed observations.

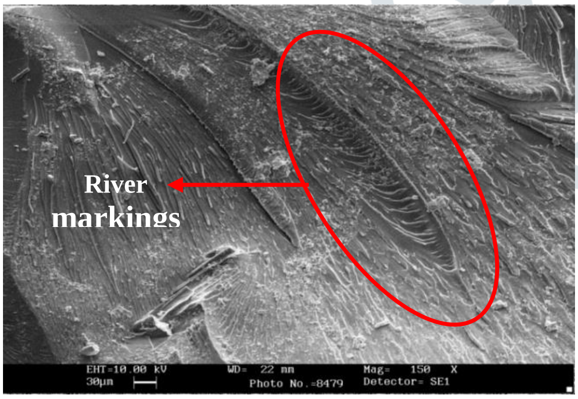

Fig 7 (a) SEM Micrograph for 1% CFF-Epoxy Composite

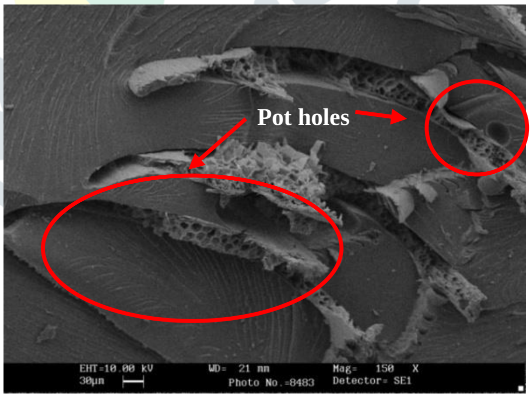

Fig 7 (b) SEM Micrograph for 2% CFF-Epoxy Composite

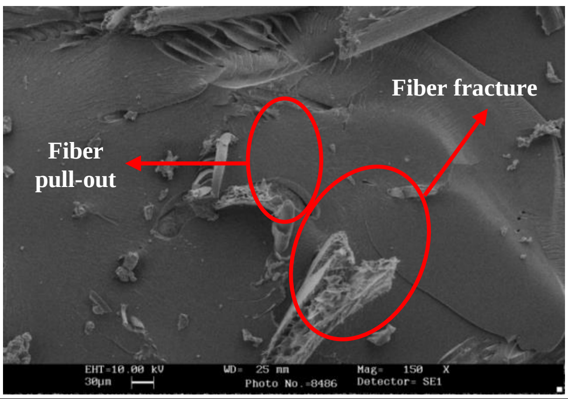

Fig 7 (c) SEM Micrograph for CFF Mat-Epoxy Composite

It can be seen in Figure 7 (c) that a few fiber breaks and fiber pull out along with matrix micro cracking were evident. However no mark of cracks or voids were seen which indicated better incorporation of fiber in the matrix. This confirms better adhesion between the two phases. The constituent fibers of the mat are rightly held by the matrix which was followed by the rupture of the fibres, may be due to the enclosed stress and strain fields in the fibrous composite.

Table 3: Impact Strength of CFF Reinforced Composites

S. No.	Composition	Impact strength (MPa)
1	CFF1	0
2	CFF2	0
3	CFM	2.90
4	Epoxy CY-230	22.07

For other samples, the random orientation of fibers in the matrix could be a major reason to affect impact strength. Impact strength of composites is governed mainly by two factors: first, the capability of the filler to absorb energy that can stop crack propagation and second, poor interfacial bonding which includes micro-spaces between the filler and the matrix resulting in easy crack propagation [Sumaila *et al.*, 2013].

3.5 Application of Developed Composite in Technical Textiles

It was found from the results that the developed composites may be suitable for light load bearing buildtech and hometech applications like window and door panels, partition boards, false ceiling, roofing sheets etc. These composites were made with natural fibers, so will primarily help in reducing the cost and weight of the developed products. The resultant product will also be partially biodegradable. However, in the absence of any standards for the developed product, the test results could not be compared.

3.5.1 Corrugated roofing sheet for Buildtech

The main objective of roofing sheet is to provide shelter from the natural elements (sun, rain, air etc.). The commercially available roofing materials ranges from natural products (thatch and slate) to commercially produced products such as tiles and polycarbonate sheets etc. Depending on the type of protection needed from the roofing material and as per their application in a particular type of surroundings, these may vary in structure, composition, style and some other technical parameters. In the present context, metal and cement roofing sheets are mostly used commercially and are becoming increasingly more common in residential application. However, none of these commercially available sheets are biodegradable and require lot of energy for their production.

Fig 8 Corrugated Roofing Sheet

Application of mat made with waste chicken fibers as reinforcement in thermoset resin will help in the settlement of the abundant poultry waste at one hand and on the other hand, will help in cost and energy saving of the pure material.

3.5.2 Table top for Hometech

Table top (Figure 9) was prepared with chicken fibers as reinforcement media because of their moderate mechanical properties. This composite material was found suitable to use as table top as it showed good compression resistance along with improved flexural rigidity. Also the developed composite material is having a smooth surface, which makes it appropriate to be used as tabletop. The textured appearance of the table top was aesthetically good to use.

Fig 9 Table Top

CONCLUSIONS

The experimental investigation involved processing composites with different proportions and forms of chicken fibers and establishing their mechanical properties. The study led to the following conclusions.

- Chicken fibers can successfully be fabricated into composites with epoxy without unnecessary coupling or chemical agents.
- Composite with minimum chicken fiber loading was stronger (40.86 MPa) as compared to mat reinforced composite.
- Flexural strength went up with an increase in the amount of chicken fibres from 1% to 2% respectively. A sharp decline in strength (23.53 MPa) was noticed for CFF mat reinforced composite.
- Comparatively mat reinforced composite showed better impact strength than other samples, however, the improvement was negligible compared to controlled sample.

Therefore, it can be concluded that chicken fibers can be a sustainable alternative to reinforce polymer composites and can easily be utilized for applications where cost and weight of raw material is of crucial importance with endurable mechanical properties.

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REFERENCES

1. Agrixchange. 2016. Poultry production in India. http://agriexchange.apeda.gov.in/news/NewsSearch.aspx?newsid=22055
2. Ghosal, S. 2018. ICRA predicts decent growth for domestic poultry industry. https://economictimes.indiatimes.com/news/economy/agriculture/icra-predicts-decent-growth-for-domestic-poultry-industry/articleshow/63613459.cms?from=mdr
3. Jagadeeshgouda, K. B.; Reddy, P. R.; Ishwaraprasad, K. 2014. Experimental Study of Behaviour of Poultry Feather Fiber-A Reinforcing Material for Composites. Int. J. Res. Eng. Technol. 3(2):362-366
4. Prasanthi1, N.; Bhargavi, S.; Machiraju, P. V. S. 2016. Chicken Feather Waste–A Threat to the Environment, Int. J. Innov. Res. Sci. Eng. Technol. 5(9):16759-16764
5. Gerber, P.; Opio, C.; Steinfeld, H. 2008. Poultry production and the environment–a review. http://www.fao.org/ag/againfo/home/events/bangkok2007/docs/part2/2_2.pdf
6. Chinta, S. K,; Landage, S. M.; Yadav, K. 2013. Application of Chicken Feathers in Technical Textiles, Int. J. Innov. Res. Sci. Eng. Technol. 2(4):1158-1165
7. Subramani, T.; Krishnan, S.; Ganesan, S. K.; Nagarajan, G. 2014. Int. Journal of Engineering Research and Applications. 4(12):93-104
8. Belarmino, D.; Ladchumananandasivam, R.; Belarmino, L.; Pimentel, J.; Rocha, B.; Galvão, A.; Andrade, S. 2012. Physical and Morphological Structure of Chicken Feathers (Keratin Biofiber) in Natural, Chemically and Thermally Modified Forms. Mater. Sci. Appl. 3(12):887-893
9. Mishra, S. C.; Nayak, N. B.; Satapathy, A. 2009. Investigation on Bio-waste Reinforced Epoxy Composites. J. Reinf. Plast. Compos. 29(19):3016-3020
10. Thyagarajan, D; Barathi, M.; Sakthivadivu, R. 2013. Scope of Poultry Waste Utilization, IOSR Journal of Agriculture and Veterinary Science. 6(5):29-35
11. Uzun, M.; Sancak, E.; Patel, I.; Usta, I.;Akalın, M.; Yuksek, M. 2011. Mechanical behavior of chicken quills and chicken feather fibres reinforced polymeric composites. http:// www.archivesmse.org/vol52_2/5223.pdf
12. Oladele, I. O.; Okoro, A. M.; Omotoyinbo, J. A.; Khoathane, M. C. 2018. Evaluation of the mechanical properties of chemically modified chicken feather fibres reinforced high density polyethylene composites. Journal of Taibah University for Science. 12(1):56-63
13. Reddy, N.; Yang, Y. 2007. Structure and Properties of Chicken Feather Barbs as Natural Protein Fibers. *Journal of Polymers and the Environment.* 15(2): 81-87.
14. Fan, X. 2008. Value-Added Products from Chicken Feather Fibers and Protein. Thesis, Ph.D. Auburn University, Alabama, https://etd.auburn.edu/bitstream/handle/10415/17/Fan_Xiuling_15.pdf?sequence=1&ts=1433733219 108
15. Oladele, I. O.; Omotoyimbo, J. A.; Ayemidejor, S. H. 2014. Mechanical Properties of Chicken Feather and Cow Hair Fibre Reinforced High Density Polyethylene Composites, Int. J. Sci. Technol. 3(1): 66-72
16. Sumaila, M.; Amber, I.; Bawa, M. 2013. Effect of Fiber Length on the Physical and Mechanical Properties of Random Oriented, Nonwoven Short Banana (MusaBalbisiana) Fibre/Epoxy Composite. Asian Journal of Natural & Applied Sciences. 2(1):39-49