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Research paper

Experimental Studies on Behavior of Keratin Based Human Hair Fiber - A New Reinforcing Material for Composites

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Abstract

Composite materials are formed by two or more constituents at macroscopic level. Type and form of fiber plays a vital role in imparting required properties to the composite. Many researchers contributed to the development of artificial fiber composites which are not environmental friendly in nature. Sizable research is also done in the area of natural fiber composites. Human hair is a non-biodegradable waste available in abundant quantity across the world, but is rarely explored for applications in engineering fields. In the present study, a review on behavior of human hair fibers was made to understand their suitability as a reinforcing material in composites. Morphology of the hair fibers is reviewed and the density of the hair fibers was determined using Archimedes principle. Tensile strength of the hair fibers is experimentally estimated. Chemical resistivity and burning tests were conducted. Tensile and flexural properties of hair fiber reinforced polyester composite were experimentally determined and compared.

Keywords: *Animal fiber; Composites; Feather fiber; Hair fiber; Properties*

1. Introduction

Continuous technological advancements have helped mankind improve their standards of living, with the rapidness of development and research. However, certain technology also creates a negative environmental impact. Manufacturing of composites using artificial fibers such as glass fibers, carbon fibers etc., have provided novel materials with high strength to weight ratio. But they also pose a threat to the environment due to their non- biodegradable nature. Therefore efforts are invested in making use of naturally biodegradable and sustainable material that exist in nature rather than creating a new material. Bio-fibers serve as reinforcement in bio-composites enhancing the strength and stiffness to the resulting composite structures. Animal fibers such as chicken feather, human hair, hairs of other birds and animals are commonly described as a waste by-product and they are contributing to environmental pollution due to the disposal problems. There are two main animal fiber disposal methods that exist. i)Burning and ii)Burying. Both of them have negative impact on the environment. Nature, source, origin and their physical and chemical composition of different natural fibers have been reviewed [1, 2]. Much research has been done towards cellulose from vegetal sources but little focus is made in other potentially interesting compounds like keratin, which can be found in hair, nails, and feathers. In spite of good strength, low density and biodegradability, keratin has been studied only from the medical and textile point of view. A.L. Martinez-Herna et al. have carried spectroscopic analysis on keratin based chicken feather fiber [3].

Recent studies on the chicken feather waste demonstrated that waste can be a potential composite reinforcement. The composite reinforcement of the animal fibers offer much more effective way to solve environmental concerns compared to the traditional disposal methods. Some of the advantages of the animal fibers are - inexpensive, renewable, and readily available in abundant quantity. The chicken feather fibers (CFF) as a composite reinforcement have certain desirable properties including lightweight, high thermal insulation, excellent acoustic properties, non-abrasive behavior and excellent hydrophobic properties. The CFF has the lowest density value compared to the all natural and synthetic fibers [4-7]. S. C. Mishra et al.[8] have studied the mechanical properties of feather fiber composites and identified possible chemical reactions taking place during composite making. Poultry feather behavior was analyzed and its mechanical properties were estimated by KB Jagadeeshgouda el al. [9]

Hair is a complex tissue consisting of several morphological components as shown in figure1 [10]. Each component in turn consists of several different chemical types. Therefore, hair is an integrated system in terms of its structure and its chemical and its physical behavior. The frictional behavior of hair is primarily related to the cuticle. The tensile behavior of human hair is determined by the cortex.

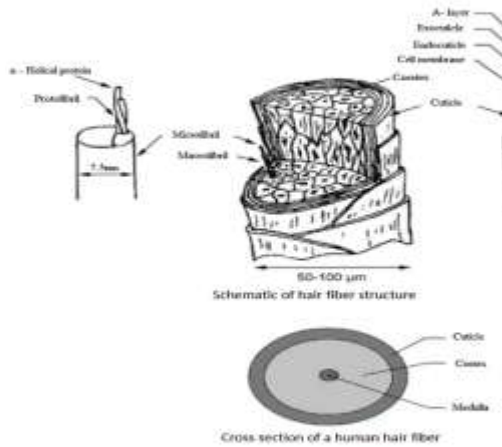

Fig. 1: Structure of Hair fiber [10]

Keratin is the primary constituent of human hair fiber. These keratins are proteins, polymers of amino acids. Keratin proteins form the cytoskeleton of all epidermal cells. Keratin proteins comprise 65-95% of the total hair fiber by weight. Mostly hair fibers are made of hard keratins which do not dissolve in water. Hard keratins are highly resistant to photolytic enzymes. Hair fiber durability and resistance to degradation under environmental stress comes from the linkage between the cystine molecules and keratin proteins that form disulfide chemical bonds. These bonds are very strong. Raw elements present in hair fiber are shown in table 1 and amino acids with their quantities present in normal hair fiber are shown in table 2 [10-12].

Table 1: Raw elements present in Hair [10-12]

Element Name	Quantity
Carbon	50.65%
Oxygen	20.85%
Nitrogen	17.14%
Hydrogen	6.36%
Sulfur	5.00%

Table 2: Amino acids present in Human hair [10-12]

Amino Acid	Amount in residues extracted
Cysteine	17.5
Serine	11.7
Glutamic acid	11.1
Threonine	6.9
Glycine	6.5
Leucine	6.1
Valine	5.9
Arginine	5.6
Aspartic acid	5
Alanine	4.8
Proline	3.6
Isoleucine	2.7
Tyrosine	1.9
Phenylalanine	1.4
Histidine	0.8
Methionine	0.5

2. Experimental

2.1Cleaning of Human Hair

Male and Female Indian Hindu religion people always offer their hair by shaving their head to the God as sacrifice upon fulfilling their wishes by the God. Most of the hair in India comes from the temples and rural villages. Hair from India is considered to be the highest quality as most of these women in rural India have natural, high quality hair that may have never been treated with chemicals. In the present study, human hair ranging from 8 - 16 inches length was collected from different women pilgrims in the age group of 35- 40 years. These hair samples were procured from barbers working at a local temple located at Palasa, Srikakulam district, Andhra Pradesh, India. Collected human hair was thoroughly cleaned with detergent, washed with distilled water and then sun dried.

2.2 Estimation of Diameter and Density of Hair Fiber

Diameter of the hair fibers were measured using optical microscope at Lucid laboratories Pvt Ltd, Balanagar, Hyderabad and are shown in figure 2. The average readings of ten samples were presented in the table 3. Similar results were also reported by Zhenxing Hu et al.[13]

Fig. 2: Measurement of Hair diameter

Table 3: Hair Diameter and its Mechanical Properties

Sample No	Diameter (Micro meter)	Breaking Load in (grams)	Elongation at break in %	Tensile Stress (MPa)
1	90	86.2	21.5	132.991
2	80	82.2	31.6	160.506
3	80	80	33.3	156.21
4	70	82.9	38	211.426
5	70	80.9	27.3	206.325
6	70	83.2	35.2	212.191
7	60	68.7	32.4	238.481
8	70	80	28.2	204.03
9	80	76.4	32.9	149.181
10	73	78.3	25.0	183.618
Average	80	81.63	30.54	180.826

Density of the hair fibers is estimated experimentally using Archimedes principle as shown in figure 3. Five samples of hair were taken and mass is measured using electronic balance. The samples were then immersed in glass tubes of known volume. The increase in volume was recorded and the density is estimated using equation 1 and shown in table 4.

$$\text{Density of hair} = \text{Mass of hair} / \text{Volume of hair} \quad (1)$$

Fig.3: Measurement of Hair density using Archimedes principle

Table 4: Hair density

Sample No.	Mass of Hair (Grams)	Initial reading of water level in the glass tube in cc or ml	Final water Level when hair is immersed in the water completely in cc or ml	Net volume of hair (cc)	Density of hair = M/V (g/cc)
1	12.23	40	49	9	1.36
2	24.11	50	68	18	1.34
3	16.98	40	52.5	12.5	1.36
4	2.74	28	30	2	1.37

5	1.31	51	52	1	1.31
Average Density of hair					1.34

2.3 Aspect ratio of Hair Fibers

A fiber is characterized not only by its length to diameter ratio but by its near crystal sized diameter. Strength to density and stiffness to density ratios also indicate the effectiveness of a fiber in case of weight sensitive applications. Hair diameter commonly varies along the length. Length of the hair fiber varies with in a person and from person to person. Therefore aspect ratio of the human hair varies from 317.5- 6985 for general range of fiber lengths of 1inch - 22 inch respectively. Aspect ratios for a chicken feather fiber are reported as 600-3667 [9].

2.4 Fiber Strength

Tensile strength of the human hair fibers was measured on a universal testing machine at CIPET, Hyderabad. Fibers were held by adhesive tape and tested with a cross head speed of 1.3mm/min. Fiber diameter measured with optical microscope is used to find the area of the fiber. The tensile strengths ranged from 150 MPa to 238MPa and the results are tabulated in 3.

2.5 Chemical test of human Hair fibers

Human hair fiber samples of known weight were tested with 5% NaOH, 2% Na_2CO_3, 1%HCl and normal mineral water. The samples were soaked in different solutions in reagent bottles for time duration of 1hr, 6hrs, 12hrs and 24 hrs. The setup is shown in figure 4. After the specified time durations, the samples were reweighed and the results are summarized in table 5.

Fig. 4: Experimental arrangement of chemical test

Table 5: Chemical Test results of hair fibers

Sample No	Net weight of hair fiber	Soaking solution				Weight of fibers - 1hr soaking	Weight of fibers - 6hr soaking	Weight of fibers - 12 hr soaking	Weight of fibers - 24 hr soaking	Weight loss in grams	% weight loss	Weight Loss/ gain
		Water	5% NaOH	2% Na_2CO_3	1% HCl							
s1	0.77		√			0.51				0.26	33.8	Loss
s2	0.78		√				0.08			0.7	89.7	Loss
s3	0.94		√					0.03		0.91	96.8	Loss
s4	1.51		√						completely dissolved	1.51	100	Loss
s5	1.89				√	1.84				0.05	2.65	Loss
s6	1.73				√		1.67			0.06	3.47	Loss
s7	1.07				√			1.05		0.02	1.87	Loss
s8	1.02				√				0.98	0.04	3.92	Loss
s9	2.44			√		2.34				0.1	4.1	Loss
s10	3.76			√			3.79			-0.03	-0.8	Gain
s11	2.25			√				2.3		-0.05	-2.22	Gain
s12	2.2			√					2.7	-0.5	-22.7	Gain
s13	2.38	√				2.33				0.05	2.1	Loss
s14	2.93	√					2.92			0.01	0.34	Loss
s15	1.53	√						1.54		-0.01	-0.65	Gain
s16	1.38	√							1.4	-0.02	-1.45	Gain

2.6 Burning test

Burning test was conducted to know the behaviour of the hair fibers when they are exposed to burning.

2.7 Preparation and testing of Human hair reinforced polyester composite sheet

Hair fibers cut into 40mm length and were spread with random orientation in the mould. The polyester resin along with the catalyst and accelerators in required quantities were mixed thoroughly as per the procedure and poured in to the mould to fill it. Sufficient care was taken to have uniform distribution and full impregnation of fiber in the resin. The mould was then closed with other half part of mould, clamped tightly and was kept for 24 hours at room temperature as polyester cures completely in 24 hours of time. The composite sample sheets of 40mm fiber length with different weight ratios were fabricated in the present study to test its mechanical properties.

2.7.1 Tensile Test

Test specimens were cut from the completely cured composite sheet as per ASTM D638 standard. The tensile tests were carried out at CIEPT using Autograph AG15, Shimazdu 0-50 kN range with an accuracy of 0.1N and cross hear speed of 1.3mm/min. For each test, 5 specimens were used, and the average value of these results is tabulated in table 6. Test specimen under test is shown in figure 5.

2.7.2 Flexural Test

Composite specimens were prepared as per the standard test methods for three - point flexural tests. The composite samples of rectangular shape were prepared according to ASTM D 790 for three-point flexural test [14]. Flexural tests were conducted on a Nano Servo Hydraulic UTM Plug N Play machine (ITW BISS make) of 25kN capacity available at CBIT, Hyderabad with a cross head speed of 1.5mm/ min with 64 mm support span. The test results are summarized in table 6. Values given in the table represents average readings of five test specimens. All the tests were conducted at room temperature. Test specimen under test is shown in figure 5.

Fig. 5: Tensile and Flexural Testing of composite

Table 6: Tensile and flexural properties of Human hair composite

S.No.	Fiber weight Ratio (%)	Tensile Stress (MPa)	Flexural stress (MPa)
40HHRC05	5.1	12.00	28.4
40HHRC10	9.85	17.87	35.6
40HHRC15	15.62	22.12	43.2
40HHRC20	20.6	27.00	37.6
40HHRC25	26.2	25.30	36.0
40HHRC30	31.4	18.64	27.1
40HHRC35	35.5	11.52	13.6

3. Results and Discussions

It is observed from the table 3 that average density of human hair fibers is 1.34g/cc. The difference in density among different samples may be due to the fact that hair samples collected from different people. The hairs of different people will have different density values depending upon the structure of the fiber. Compared with other natural fibers, like wool 1.3g/cc, silk 1.17g/cc, cotton 1.5-1.6g/cc, jute 1.3g/cc and coir 1.2gcc, density of hair fiber is in line with its counter fibers.

Generally, the aspect ratio of the hair fibers is much higher when compared to that of chicken feather and other bird feathers. Higher aspect ratios of fibers lead to better performance when impregnated into the resin.

From table 4, it is observed that Hair fiber load carrying capacity ranges from 150-238MPa. The variation is mainly due to hair quality and thickness variations from person to person and also changes due to chemical treatment of the fibers. Still the hair fibers exhibit higher load bearing capacities under tensile loading. Hence this can be used as a reinforcing material in composite materials. The hair fibers also undergo large elongation before failure. The % elongation ranges from 21-35%.

Moisture sensitivity is one of the major serious problems that is associated with the natural fibers when compared to artificial fibers. Natural fibers either swell or rot when exposed to various solutions. Hair fibers are tested for this behaviour by soaking them in 5% NaOH, 2% Na_2CO_3, 1% HCl and normal mineral water for 1hr, 6hrs, 12hrs and 24 hrs. From table 5, it is observed that human hair gained weight from 0.8% to 22.7% when soaked in 2% Na_2CO_3 for 1hr and 24 hrs respectively. Whereas the weight loss in case of soaking in NaOH is 33.8% for 1hr and human hair was completely diluted when soaked for 24hrs. But for HCl solution the weight loss is only 4% and for water, it is almost non reactant.

Hair is having the tendency of fusing when brought nearer to the flame and fuses and burns when kept in the flame. But when it is taken out of the flame it supports combustion for short period. During burning, it gives odour of burning a chicken feather. Colour of the ash is observed to be very black and is crushed to only size of the sand granules. The burning phenomena are shown in figure 6.

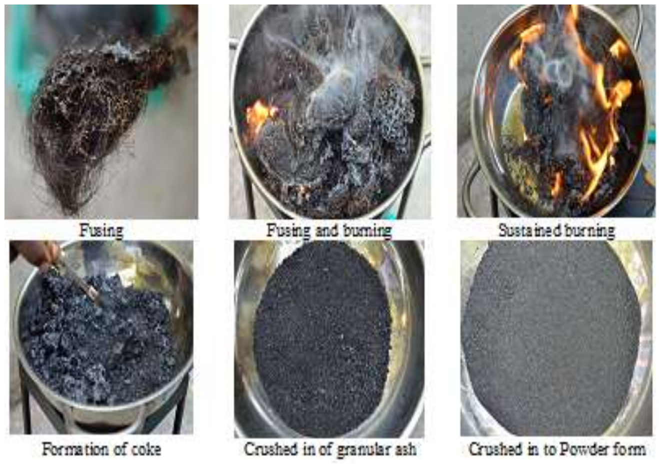

Fig. 6: Burning behaviour of hair fiber

Tensile and flexural stresses of the composite made of 40mm length of fibers for different fiber loadings are shown in figure 7.

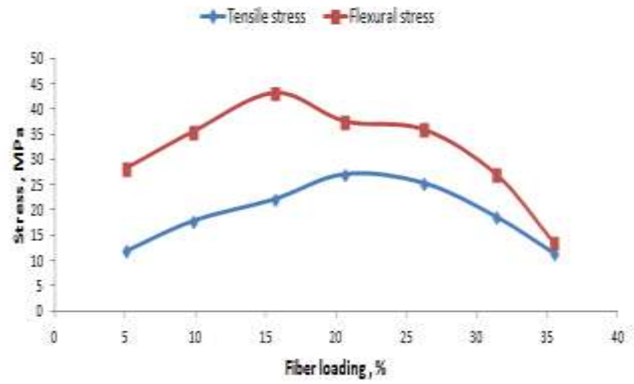

Fig. 7: Variation of Tensile and Flexural Stress with fiber loading

It is evident from the figure 7 that both tensile and flexural stresses are increasing with increasing fiber loading. Maximum stresses are observed between 15%- 20% fiber loadings. Decrease in stresses at higher fiber loadings is due to improper impregnation and high void volume. Also at low fiber loading, even less loads are high enough to break the fibers. These broken fibers can be regarded as an array of holes in the composite. As explained in the composite theory [15], the reinforcing becomes effective only when the fiber loading exceeds the critical value. There is also a maximum fiber content beyond which the properties of the composite tend to deteriorate [12, 13]. This is due to the fact that at higher fiber weight fractions, fiber to fiber spacing becomes so small that the stress transfer between the fiber and matrix becomes ineffective [10].

4. Conclusion

Human hair fiber is a sustainable waste material abundantly available in the market. Its recycling is very essential to the environment due its non-bio-degradable nature. Its low density, easy availability and non reactant to water make human hair as an alternative reinforcing fiber material. Tensile strength of 27 MPa and flexural strength of 43.2 MPa make the human hair reinforced composite material a competitor to other natural and glass fiber composite materials.

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