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Human Hair Fiber as a Reinforcement Material in Composite Structures

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Abstract **–** In the last century, there has been an ever-increasing demand for novel materials namely known as composites. Biological fibers are reinforcement materials of composite structures owing to their economic and ecological advantages. Among these fibers, plant fibers are mostly preferred as reinforcement materials. However, studies using animal fibers are also noteworthy. Human hair, which considered as a waste material, is a favored biological non-degradable fiber in the field of advanced engineering materials in recent years. Their low cost, elasticity, smoothness and tolerable mechanical properties ascended their usage rates in composite structures. In addition to the utilization in thermoplastic and thermoset resins, human hair fiber also used in concrete materials. In this study, brief information about human hair fiber and its usage in composite materials are given and general information about the previous studies about human hair reinforced composites are discussed.

Keywords *– textiles, composites, recycling, human hair fiber, concrete*

I. Introduction

Natural fibers are one of the most preferred reinforcement materials in composite structures owing to their properties such as; low cost, high toughness and fairly high mechanical performance [1]. The first usage of natural fibers in composite structures was straw reinforced clay walls in Egypt 3000 years ago [2].

Although plant fibers are mostly preferred in composite materials, some animal fibers are also utilized. Human hair, which is a non-degradable waste material, is one of these fibers. Waste human hair causes health and environmental problems. So, by using human hair as a reinforcement material not only the performance of construction enhanced but also the disposal problem of waste hair is prevented [3].

Some properties of human hair fiber that makes it a potential reinforcement material is its superior tensile strength, slow degradation rate, hydrophilic properties, low cost, unique chemical composition and elastic recovery properties [3-8]. Main properties of human hair fiber is given in Table 1.

Table 1. Properties of human hair fiber [9].

Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio
1.34	200	1.74 – 4.39	0.37

Human hair is composed of three main structures called cuticle, cortex and medulla (Fig. 1). The cuticle is the outermost part of hair strand while the cortex is the middle part occupying 75% of the total area. The medulla is thinnest cylindrical part as the innermost layer of human hair [6].

The general composition of hair is 45.68% carbon, 27.9% oxygen, 6.6% hydrogen, 15.72% nitrogen and 5.03% sulphur. Approximately 91% of hair is protein made up of long chain amino acids of cytosine, serine, glutamine, threonine, glycine, leucine, valine, arginine [1]. Proteins in α- helix structure offer improved structural strength and elasticity for the hair and cortex keratin is responsible for the strength and elasticity of human hair owing to its long chains [5]. Keratin which do not dissolve in water, is highly resistant to proteolytic enzymes. Durability of human hair and its resistance to degradation under environmental stress results from the linkages between the cysteine molecules and keratin proteins that form disulfide chemical bonds which are very strong [9].

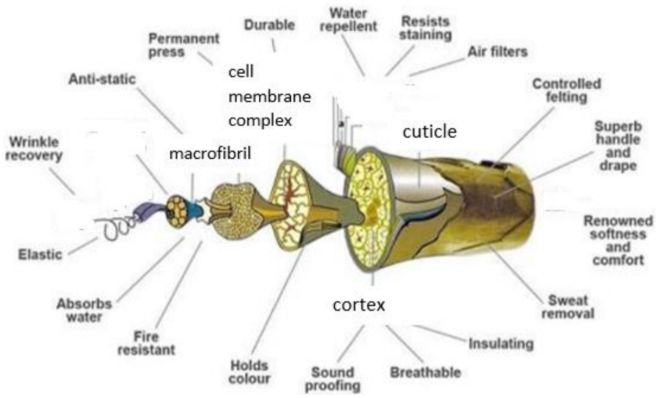

Fig. 1 Micro structure of human hair fiber [10].

Besides its micro-structure, macro-structure of the human hair (fiber diameter, fiber length, fiber cross-section, etc.) have great influence on the mechanical properties of the human hair strand and these geometrical properties of hair may vary due to its origin. For instance, Caucasian hair is oval, Asian hair is circular, Afro hair is elliptical in cross-sectional shape [11]. Generally, a single hair strand can withstand around a load of 70g [9]. On the other hand, hair strand has similar tensile strength with copper wire, if both the wire and hair strand are of same diameter [12].

Hair fiber shows good elastic property either in wet or dry conditions. Generally, dry human hair thread stretches 20-

30% of its length. When it is in contact with water, this elongation values can reach up to 50%. Human hair absorbs water in both liquid and steam form. Keratin has an affinity for water thus it absorbs water up to 40% of its own weight. The water absorption depends on environmental parameters such as relative humidity rate and some physical properties of human hair like stretching ability, diameter and internal viscosity of the fibers etc. Water absorption in the human hair is followed by a swelling action that results in 15-10% increase in thread diameter and 0.5-1.0% in thread length [11].

II. Previous Studies

In the literature, there are a growing number of studies about human hair fiber reinforced composites. In this review, the previous studies are collected under two main titles. These are; studies related to polymer based composites and studies related to cement based composites.

A. Studies Related to Polymer Based Composites

In a study of Senthilnathan et al., hybrid composite structures are designed by using various reinforcement materials (coconut fiber, human hair fiber and glass fiber) in a matrix of epoxy resin. Six different composite designs including Glass fibre reinforced plastic (GFRP); Coconut coir reinforced plastic(CCRP); Human hair reinforced plastic (HHRP); Glass – Coconut coir - human hair- Glass hybrid composite (GCHGRP); Coconut coir-glass- human hair-coconut coir hybrid composite (CGHCRP) and human hair-coconut coir-glass-human hair hybrid composite (HCGHRP) are produced by hand layup method and tensile, flexural, shear, impact and hardness tests are performed. Results indicate that although CCRP is having the maximum tensile load capacity, HCGHRP exhibits highest flexible test characteristics. Moreover, HCGHRP shows almost maximum double shear strength comparing to other composites while it shows considerable impact strength values comparing to other composites. On the other hand, CGHCRP hybrid composite has the higher hardness value, then the others. As a summary, the use of HCGHRP seems to be a promising candidate for the applications of aircrafts, automobiles and other areas of manufacturing due to its improved flexibility, impact and double shear strength and also environmentally friendly properties [13]. In another study Choudhry and Pandey produced human hair fiber reinforced polypropylene composites by compression molding technique. Fiber weight ratios are defined as 3%, 5%, 10% and 15 %. Results show that composites up to 5% wt ratio of human hair fiber show higher flexural strength, flexural modulus and Izod impact strength than pure PP while above 10 % wt. ratio of fiber content, the flexural strength, flexural modulus and Izod impact strength values tend to decrease. Moreover, tensile strength of the composites reduces with the increment of the fiber ratio. Possible reason for this can be the poor adhesion between humar hair fiber and the PP matrix [1]. Selvan et al. manufactured jute fiber and human hair fiber reinforced five different composite designs using hand layup technique. Epoxy resin is used as matrix material. The mechanical properties are tested. Results indicate that tensile, flexural, double shear and impact properties are improved with the increase of human hair content in jute fiber reinforced composite. On the other hand, SEM images reveal that the bonding between resin and reinforcement materials (25% jute and 75% human hair fiber) is poor which results in poor mechanical properties [14]. In a study of Vengatesan et al., human hair fibers that treated with NaOH with various percentages (5%, 7.5%and 10%) are used to produce epoxy resin based composites. The tensile strength, flexural strength and impact strength tests in addition to SEM analysis of composites are carried out. According to the results it is seen that the maximum tensile strength is 36.994 N/mm^2 for composites with 5% NaOH treatment while the minimum tensile strength is 14.392 N/mm^2 for the composites with 10% NaOH treatment. Similarly, highest flexural test result (28.048 MPa) is achieved with 5% treated fiber reinforced composites while the lowest flexural strength (11.185 MPa) is achieved with nontreated fiber content composites. Lastly, the impact strength of 5% NaOH treatment is the highest (0.7 J) while the lowest impact strength (0.55 J) belongs to the composites including nontreated fibers [5]. Nanda and Satapathy produce epoxy composites reinforced with short human hair fibers with different proportions (0, 2, 4, 6 and 8 wt.%) by hand lay-up technique. Mechanical properties such as tensile, flexural and compressive strengths are evaluated. Owing to the mechanical test results the increase in fiber content significantly increases the tensile and flexural strength of the composites while it improves the compressive strength marginally. This work thus opens a new avenue for the utilization of human hair fiber as a kind of bio waste [6]. In a study of Rao et al., composite structures are manufactured by randomly oriented and chopped human hairs with varied weight ratios and fiber lengths in a matrix of polyester. The composites are prepared by hand lay-up method and pressed under compression mould. The influence of fiber weight ratio and length on the mechanical properties are examined. It is observed that tensile strength is increased up to the 30 mm fiber length and reach to its maximum (31.45MPa) for 30mm fiber length. Further increase in fiber length results in decrease in tensile strength. On the other hand, maximum tensile strength is recorded at 20% fiber weight ratio and further increase in fiber weight ratio results in decrease of tensile strength for all fiber lengths. Lastly, maximum tensile modulus value of 4.13 GPa is observed at 20% fiber loading [9]. Kumar examined the mechanical properties of human hair fiber (with various weight ratios: 0%, 10%, 20% and with different fiber lengths: 0.5, 1, 1.5 and 2 cm) reinforced epoxy composites. Results reveal that both fiber weight ratio and fiber length are effective on mechanical properties of composites. Highest flexural strength, tensile strength and impact strength results are achieved with the composite structure that reinforced with 20wt% fiber loading with a fiber length of 1.5cm [8]. In a study of Ragul et al., human hair fiber reinforced recycled high density polyethylene (HDPE) composites are produced by compression molding technique. Before production, both human hair fibers (weight ratios are defined as 3%, 5% and 10%.) and recycled HDPE granules are mixed by hand roughly then, they are mixed by two roll mill at 185°C to allow HDPE be molten. The mixed content is molded under 65 psi at 200°C. Tensile tests are carried out while the results are compared with pure HDPE, as control samples. According to the outcomes, the maximum tensile strength is achieved as 192 kgf/cm^2 for 3% fiber reinforced composites thus the optimum fiber weight ratio is defined as 3% for tensile properties. Although tensile strength decreases for further increase of fiber weight ratio, the rigidness of the samples are improved with the increment of fiber weight ratio. Therefore 10% wt. human hair fiber reinforced composite has the maximum peak modulus of 304 MPa among all other samples. The promising application areas are stated as sewage pipes, plastic lumbers, coaxial cables and other areas where elasticity and tensile strength are required at the same time from HDPE [15].

B. Studies Related to Cement Based Composites

In a study of Jain and Kothari, human hair fiber is used as a reinforcing material for concrete to examine its effects on the compressive and flexural strength and cracking control in order to economise the concrete and to reduce environmental problems created by the decomposition of hair. Human hair fibers are used as 0%, 1%, 1.5%, 2%, 2.5% and 3% by weight of cement. Results show that remarkable improvement in the mechanical properties of pure cement concrete is achieved with the addition of human hair as a reinforcement material. More specifically, when M-15 concrete with 1% human hair is compared with the plain cement concrete, it is found that there is an increase of 10% in compressive strength and 3.2% in flexural strength. When M-15 concrete with 1.5% hair is compared with the plain cement concrete, it is found that there is an increase of 22% in compressive strength and 8.6% in flexural strength. When M-20 concrete with 1% hair is compared with the plain cement concrete, it is found that there is no increase in compressive strength and 2% increase in flexural strength. When M-20 concrete with 1.5% hair is compared with the plain cement concrete, it is found that there is an increase of 8.8% in compressive strength and 5.5% in flexural strength. When M-25 concrete with 1% hair is compared with the plain cement concrete, it is found that there is an increase of 4.6% in compressive strength and 3% in flexural strength. When M-25 concrete with 1.5% hair is compared with the plain cement concrete, it is found that there is an increase of 11% in compressive strength and 4% in flexural strength [4]. In another study of Butt et al., human hair fibers with average length of 25 mm and average diameter of 50 μm are reinforced to clayey soil with various ratios (0.5, 1.0, 1.5, 2.0 and 2.5 % wt.) to evaluate the effect of human hair fiber on the mechanical behavior of clayey soil. Results show that strength significantly improves with the content of human hair fiber. Moreover, it is seen that with the addition of human hair, cracking is avoided. However, dry density-moisture content relationships of composites are remarkably affected by increasing amount of human hair fiber, which should be taken into consideration. It is also found that 2% fiber content is the optimum for enhancing CBR and undrained shear strength of clayey soil. According to the outcomes of this study, human hair reinforcement may be used in the field for embankments especially for approach roads which connect the bridges to the road. Moreover, it can also be used for the stability of slopes and the sub-grade thickness can be reduced by using human hair reinforcement for flexible pavements. Lastly, it is stated that the use of human hair fiber reduces the cost while avoiding environmental problems such as dumping of human hair waste in open fields [3]. In one of the studies, Sreevani and Ajitha use 0%, 0.5%, 1% and 1.5% wt. ratio of human hair fibers and M-20 cement for producing concrete composites. Mechanical tests are conducted on concrete cubes, cylinders and beams of standard sizes and results are compared with M-20 plain cement concretes. Results reveal that there is a remarkable increment in properties of concrete according to the percentages of hairs by weight of cement in concrete thus optimum hair fiber content is found as 1.5% by weight of cement. The human hair fiber reinforced concrete has higher compressive strength compared to the normal concrete. Moreover with the human hair fiber reinforcement, crack formation and propagation are reduced remarkably. Therefore, the human hair fiber reinforcement can be used for micro crack control and enhancement of binding properties in applications such as seismic resistant constructions [10]. In a study of Gupta and Sharma, human hair fibers in different ratios (1%, 1.5%, 2% and 8%) by weight of cement are reinforced to form concrete composites. Curing periods for the composites are defined as 7, 14 and 28 days. Results reveal that the fiber reinforced concrete shows reduced crack formation thus pre-mentioned application areas [10] like seismic zones' constructions and pavement constructions are also given as promising end uses in this study. The maximum tensile strength is noticed when human hair fibers are used at a ratio of 2% in concrete. Although 10% wt ratio of human hair fiber reinforcement is also tried in the context of this study, poor binding performance is observed thus the production process could not be continued [12]. Manivel et al. utilized human hair (0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% wt. of concrete) and GGBFS (Ground Granulated Blast Furnace Slag) to produce M30 cement based composites and examined the mechanical properties for the prepared concrete cubes and cylinders. According to the results, the optimum human hair fiber ratio is found 2% wt. while the optimum ratio of GGBFS is found 20% v. of concrete. Further increase in ratio of both fibers and GGBFS results in decrement of both compressive and split tensile strengths. Compressive strength and split tensile strength of samples with 2% addition of human hair fiber improved by 28.65% and 9.12% respectively when compared to plain M30 concrete. On the other hand, the use of GGBFS by 20% in volume, the compressive strength and split tensile strength increased by 8.22% and 17.85% respectively. The flexural strength of the composites with the addition of 2% wt. human hair fiber and replacement of 20% GGBFS gives the optimum results against the M30 concrete samples. Lastly it is stated that, the ultimate crack for the samples of GGBFS composites occurred at 82 kN which is 17.14% greater than that of the control samples [2].

III. CONCLUSION

The huge amount of human hair causes environmental risk in open fields due to its non-degradable characteristic. These biological wastes are efficiently utilized in fiber reinforced composites for greener and cost-effective materials. While polymer based human hair fiber reinforced composites can be used in sport equipment, furniture and automobile parts, the most promising end-use areas of cement based ones are civil constructions in seismic zones and in case of pavement constructions.

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