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Review Article
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Human Hair: A Biodegradable Composite Fiber – A Review

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Abstract

Biological fibers have recently became eye-catching to researchers, engineers and scientists as an alternative reinforcement for FRP (fiber reinforced polymer) composites, due to their low cost, fairly good mechanical properties and high aspect strength. One of the immaculate biological fibers is the human hair. On the whole, three to four tons of human hair fibers are wasted in India annually; hence they pose an environmental challenge. In order to find commercial application the wasted human hair fibre is nowadays finding its use in the field of material science. Human hair is basically a nano-composite biological fiber with well characterized microstructures. Different techniques and technologies have been employed to study the different characteristics of the human hair to prove it a biological composite fiber. The main component of hair is keratin which is tough, insoluble and incredibly strong. An important aspect is that a single strand of hair can withstand the load of 100-150 grams. Hair is elastic and it is capable of regaining its original position on removal of the deformation load. Therefore, the present review paper reports the current scenario of human hair as biological composite fiber and its application in various fields.

Keywords: Human hair; Composite; Mechanical properties and fiber

Introduction

Biological fibers have been already used some 3000 years ago in composite systems in the ancient Egypt, where straw and clay were mixed together to build the walls. In the last few years, biological fibers have become an attractive reinforcement for polymeric composites from economical and ecological point of view. There is an increase in the environmental awareness in the world which has aroused an interest in the research and the development of biodegradable materials. Biological/Natural fibers can be obtained from natural resources such as plants, animals or minerals (Figure 1).

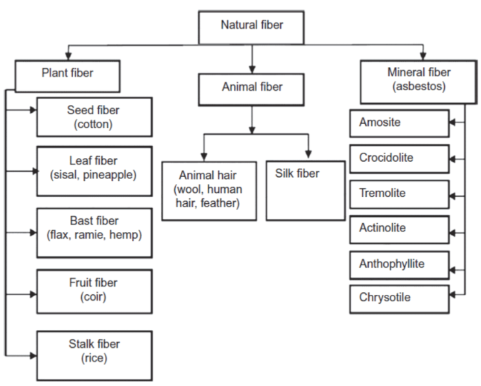

Figure 1: Classification of natural fibers [1].

With the increase of global energy crisis and ecology risk, the unique advantages of biological fibers such as its abundance quantity, non-toxic, non-irritation of the skin, eyes, or respiratory system, non-corrosive property, biological fiber reinforced polymer composites have attracted much interest owing to their potential of serving as alternatives reinforcement to the synthetic ones [2]. The lower weight and higher volume of the biological fibers as compared to the synthetic fibers improve the fuel efficiency and reduced emission in auto applications [3,4].

Hair is a protein filament that grows from follicles found in the dermis or skin. It is one of the defining characteristics of mammals. The human body, apart from areas of glabrous skin, is covered in follicles which produce thick terminal and fine vellus hair. Most common interest in hair is focused on hair growth, hair types and hair care, but hair is also an important biomaterial primarily composed of protein, notably keratin. Keratins are proteins, long chains (polymers) of amino acids. In terms of raw elements, on an average, hair is composed of 50.65% carbon, 20.85% oxygen, 17.14% nitrogen, 6.36% hydrogen, and 5.0% sulphur. Amino acid present in hair contain cytosine, serine, glutamine, threonine, glycine, leucine, valine and arginine [5].

The word "hair" usually refers to two distinct structures:

The part beneath the skin called the hair follicle or when pulled from the skin, called the bulb. This organ is located in the dermis and maintains stem cells, which not only re-grow the hair after it falls out, but also are recruited to regrow skin after a wound.

The shaft, which is the hard filamentous part that extends above the skin surface.

The cross section of human hair shaft may be divided roughly into three zones:

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The cuticle, which consists of several layers of flat, thin cells laid out overlapping one another as roof shingles.

The cortex, which contains the keratin bundles in cell structures that remain roughly rod like.

The medulla, a disorganized and open area at the fiber's center ([6]) (Figure 2).

Review of Biological Fiber

Mechanical properties of human hair fiber

Ganiron [7] investigated the effects of human hair additives in compressive strength of asphalt cement mixture and concluded that addition of hair to the asphalt cement mixture greatly improves its capability to bear more loads applied to it. Choudhry and Pandey [8] studied the mechanical behaviour of polypropylene matrix and human hair fiber and founded that composite with 3-5 wt.% of human hair fiber shows higher flexural strength, flexural modulus and Izod impact strength than non-reinforced polymer but at 10-15 wt.% it lowers the flexural strength, flexural modulus and Izod impact strength as compared to the non-reinforced polymer. Fueghelman [9] examined the mechanical properties and structure of alpha-keratin fibers such as wool, human hair and related fibers and concluded that the human hair possesses the highest tensile strength amongst the compared fibers. He further unlocked the exceptional properties of human hair such as its unique chemical composition, slow degradation rate, high tensile strength, thermal insulation, elastic recovery, scaly surface, and unique interactions with water and oils that has led to many diverse uses of the corresponding fiber.

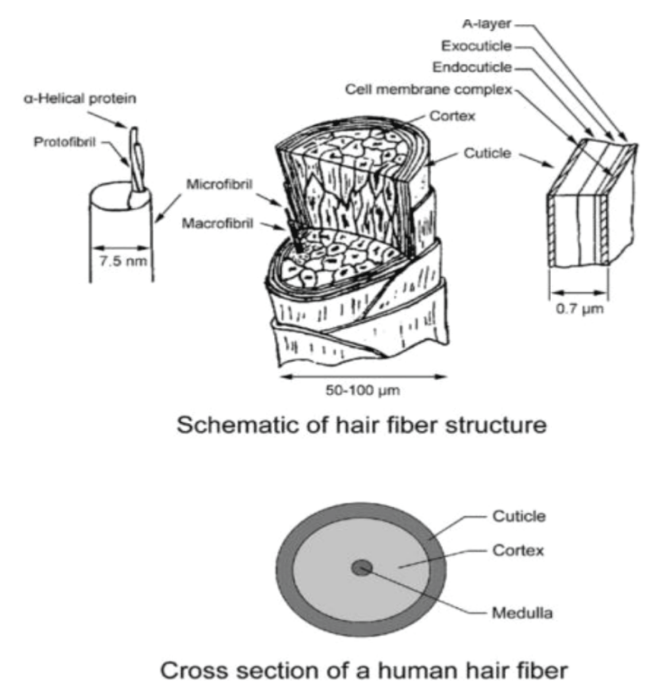

Figure 2: Schematic of human hair structure and cross-section (Wei et al. [6]).

Thompson [10] manufactured a hair based composite material by manipulating a plurality of cut lengths of hair to form a web or mat of hair and combining with a structural additive to form the required composite material. Jain and Kothari [11] studied on human hair fiber reinforced concrete and concluded that there is tremendous increment in properties of concrete according to the percentages of hairs by weight of in concrete. The addition of human hairs to the concrete improves various properties of concrete like tensile strength, compressive strength, binding properties, micro cracking control and also increases spalling resistance. Barone [12] has also shown that the human hair fiber is a non-homogeneous complex material made of keratin fibers oriented along the longitudinal axis which offer anisotropic mechanical properties. According to them, it is possible to measure the mechanical properties of hairs with the classical tests, but most often, these tests are destructive and make hard to measure the influence of some external factors or treatments on the behaviour of a same hair fiber. They utilized vibrations induced by a non-contact impact as a representative response of the mechanical behaviour of hair. The characteristics of the vibratory response allow measuring the variation in the mechanical properties and the instantaneous effect of an external factor on the properties of a same sample. First, load relaxation tests have been performed on hair samples after moisturisation and for different times of an air-drying process in order to characterize the change in the visco-elastic behaviour of hair during the water desorption. The vibratory response has then been correlated to the mechanical properties of the hair fiber.

Barone [12] and Ahmad [13] prepared composites taking human hair as the fiber and polymers as the matrix and firmed that the human hair is an emerging engineering composite fiber. They collectively wrapped up with the conclusion that the tensile and flexural properties decrease when the fiber loading percentage increases. Utilizing whole fiber not only provided good properties but will also eliminate the need for processing the fiber leading to lower costs and superior characteristics. The tensile properties can be enhanced with the increasing percentage of the human hair fiber and also with different matrix. Another way to enhance the composite properties is to determine an effective treatment to eliminate lack of adhesion between matrix and fiber, which was approved by Ganiron [7] and Belani et al. [14] who took concrete and fly ash respectively, as the matrix. Due to the above discussed incomparable mechanical properties of human hairs, which are in relative abundance in nature and are non-degradable, are providing a new era in field of fiber reinforced composites.

Chemical experimentations on human hair fiber

Hair is a proteinaceous fiber with a strongly hierarchical organization of subunits, from the α-keratin chains, via intermediate filaments to the fiber, as suggested by Popescu and Hocker [5]. Thomas et al. [15] determined that the hair contains a high amount of sulphur because α-amino acid cysteine ($HO_2CCH(NH_2)CH_2SH$) is a key component of the keratin proteins in hair fiber, focused on the comparative study of chemical composition of the human hair on different races of different continents. Hu et al. [16] studied on protein based composite biomaterials which can be formed into a wide range of biomaterials with tunable properties, including control of cell responses. They provided new biomaterials which is an important need in the field of biomedical science, with direct relevance to tissue regeneration, nano-medicine and disease treatments. Volkin and Klibanov [17] identified and characterized the processes leading to destruction of cysteine residues. They compared proteins from different species, including those of thermophilic bacteria living near the boiling point of water.

Hernandez and Santos [18] studied on keratin which is a fiber, found in hair and feathers. Keratin fiber has a hierarchical structure with a highly ordered conformation, is by itself a bio-composite, product of a large evolution of animal species. Through their research it was concluded that the keratin fibers from chicken feathers shows an eco-friendly material which can be applied in the development of green composites. Hernandez et al. [19] have previously developed a matrix solid phase dispersion (MSPD) method and it proved to offer quantitative results when isolating cocaine, benzoylecgonine (BZE), codeine, morphine and 6-monoacethylmorphine (6-MAM) from human hair samples which further determined the chemical composition of human hair. Overall they scrutinized the dynamical, mechanical and chemical analysis of polymeric composites reinforced with keratin biological fiber from human hair composites and founded the capability of human hair as a proficient fiber in the industry.

Renju et al. [20] founded an innovative chemical technique of improving the soil fertility by using human hair fibers. Robbins [21] described the hair as a protein filament that grows from follicles found in the dermis, or skin. Most common interest in hair is focused on hair growth, hair types and hair care, but hair is also an important biomaterial primarily composed of protein, notably keratin.

Finite element investigations of human hair fiber

Jager et al. [22] using the mathematical concepts carried out the terminal differentiation of hair matrix keratinocytes and tried to optimise the percentage of human hair fiber in different matrixes. With further advancement in technology, Matthew et al. [23] executed the finite element modelling of composite materials and structures using the ANSYS and ABAQUS modules. Soden et al. [24] achieved the success in performing the experiments related to lamina properties, lay-up configurations and loading conditions for a range of fiber reinforced composite laminates. Mangalgiri [25] studied the composite materials for aerospace applications using the human hair as the fiber. They altogether concluded that if the composition of the laminate structure is known enough, the FEA (Finite Element Analysis) look like well suited for predicting the mechanical response of composite structure. However, if the composition of laminate structure is unsure, the difference between simulation and experimental results can logically be even 100% and it is supported by the results obtained from their investigation.

Thermal analysis of human hair fiber

Chai et al. [26] are over and done with the thermal properties of human hair and tried to wind up the flammability of bio-derived composite materials with human hair as the fiber. Adding to the thermal analysis, Chapple and Anandjiwala [27] reviewed the flammability of natural fiber-reinforced composites and strategies for fire retardancy. Kozlowskiy and Przybylak [1] endeavoured to cram the flammability and fire resistance of composites reinforced by natural fibers such as the human hair. Manfredi et al. [28] had design a methodology to study the thermal degradation and fire resistance of unsaturated polyester modified acrylic resins and their composites with human hair fibers. They all carried out their inspections by using the Thermo Gravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) tests.

Intervention of nanotechnology and other techniques to study the human hair as a biological fiber

Most recently, Ray and Okamoto [29] investigated on the human hair using the nano-indentation technique and concluded that the hardness and elastic modulus of hair decreased as the indentation depth increased. They also found out that the mechanical properties of hair surface decreased from root to tip. Also, Wei et al. [6] reviewed the cross section and elasticity of human hair fiber and keratin using Atomic Force Model (AFM) and pointed out that although it is possible to extract nano-mechanical information like elastic modulus or elasticity from AFM but it is very difficult to measure hardness using an AFM. They also studied the nano-mechanical properties of hair as a function of hair composition, microstructure, ethnicity, damage and treatment and presented the systematic study of nano-mechanical properties of human hair including hardness, elastic modulus and creep, using the nano-indentation technique.

Meredith [30] had a trial with the morphology of fibers including the human hair fiber. He saw it with the help of Scanning Electron Microscopy (SEM) and tried to give the surface properties of human hair. Adding to it, Poslusznya et al. [31] studied the chromatography of the human hair fiber.

Ecological importance of human hair

Human hair is considered as a waste material in most parts of the world and it is found in municipal waste streams which cause numerous ecological issues. Gupta [32] studied on human hair as a waste and its utilization and concluded that the human hair has a large number of uses in areas ranging from agriculture to medicine to engineering industries. Hybrid composites are materials which are made by combining two or more different types of fibers, fiber-particle or particle-particle in a common matrix. Hybrid composites offer some advantage over the use of one type of fibers or particles alone in a polymer matrix. The natural fibers like human hair, jute, sisal, hemp, banana, etc. And natural particulates like almond, coconut, walnut, wood, etc. Are renewable, economic and can be incinerated for energy recovery. This swot was demonstrated by Morton and Hearle [33]. Further, Babu et al. [34] studied on the biological based polymers and concluded that it has widely increased the attention due to environmental concerns and the realization that global petroleum resources are finite. Finally, Saxena et al. [35] has valued the human hair fiber potential and forecasted its value ability as the most promising ecological fiber in the near future.

Conclusion

After the elaborate study of the literature presented, various conclusions have been drawn and summarized as: Firstly, it is clear that human hair is the well accepted choice as a composite fiber in the field of advanced engineering materials science. The experimental results discussed in the literature for various fabricating processes show that the effect of adjoining human hair in the matrix is not showing a fixed pattern in different operating conditions. In such cases, more scientific experimental studies are needed for different range of operating parameters. Secondly, considerable experimental studies have been carried out to examine the effect of human hair as a composite fiber in different matrixes. Researchers have well tested the feasibility and applicability of the human hair as a composite fiber in diverse conditions and have found many achievements in their relevant fields. So, finally it can be concluded from the above results that the human hair is applicable for various manufacturing processes and also, more research is needed in the field of weather forecasting of various composites taking the human hair as their chief fiber. Till now, none of the studies have inspected the human hair with various sizes/lengths in different ambient conditions to understand the basic physics of this god gifted composite fiber. So exploration of this area can be used to exploit the human hair as a more competent biological composite fiber in future.

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