Processing and characterization of epoxy composites reinforced with short human hair

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Abstract: Human hair is a biological fiber with well characterized microstructure. It has many unique properties like high tensile strength, thermal insulation, unique chemical composition, elastic recovery, scaly surface etc. But due to its slow decomposition, it creates many environmental problems. Although a number of utilization avenues are already in place, hair is still considered as a biological waste. In view of this, the present work makes an attempt to explore the possibility of fabricating a class of polymer composites reinforced with short human hair fibers. Epoxy composites with different proportions of hair fiber (0, 2, 4, 6 and 8 wt.%) are prepared by simple hand lay-up technique. Mechanical properties such as tensile, flexural and compressive strengths were evaluated by conducting tests as per ASTM standards. It was found out that with the increase in fiber content, the tensile and flexural strength of the composite were increasing significantly while the compressive strength improved marginally. Scanning electron microscopy was done on these samples to observe the microstructural features.

Key words: Epoxy composite, hair fiber, microstructure, biological waste

1. Introduction

Primary constituent of human hair fiber is keratin protein. Keratin protein is made up with long chain of amino acids like cytosine, serine, glutamine, threonine, glycine, leucine, valine and arginine. Hair fiber is composed of three main structures cuticle, cortex and medulla. The cuticle is the outermost part of hair fiber. Cortex is the cylindrical part after the cuticle, which occupies 75% of area. Medulla is the thin cylindrical layer located at the center of human hair. A no. of studies on the mechanical and physical characterization of human hair have been reported [1-2]. Aniruddha et al. [3] studied the nanomechanical and micromechanical properties of human hair. Bhushan et al. [4] studied the friction and wear behavior of human hair and skin at a range of loads, speeds and skin area. Carmen et al. [5] studied the tribological behavior of human hair and skin using atomic force microscopy. Guohua et al. [6] studied the nanomechanical properties of human hair including hardness, elastic modulus and creep using nanoindentation technique. Use of hair fiber in different possible field of applications also researched by many researchers [7]. Jain et al. [8] studied the effect of human hair on plain cement concrete on the basis of its compressive, crushing and flexural strength. Bagadiya et al. [9] studied the use of keratin waste, derived from human hair as short fiber for elastomer.
Numerous works have been reported on the characterization of human hair and its use on different fields. But its use as a reinforcing element in polymers has not been adequately researched. In view of this, the present work includes the investigation of the physical, mechanical and micro structural characteristics of epoxy composites reinforced with short hair fiber (SHF) in different proportions (0, 2, 4, 6, 8 wt.%).

2. Experimental details

2.1 Composite Fabrication
Raw hair fibers were collected from a nearby saloon. These fibers were thoroughly washed in detergent and dried in sunlight for few hours. Fibers were cut into approximate length of 3-4 mm with scissor. The low temperature curing epoxy resin (LY556) and corresponding hardener (HY 951) were mixed in the ratio of 10:1 by weight. The short hair fibers were then mixed with various weight percentages to prepare the composites by hand lay-up technique. The mixture was thoroughly mixed until uniform dough was formed. The dough was then slowly decanted into a rectangular mold of size 200 mm length, 100 mm width and 4 mm thickness, and also on a cylindrical mold of 10 mm diameter and 60 mm depth. The casting was put under load for 24 hours and after that composite specimens were taken out from the mold. Specimens of required size were cut for physical and mechanical characterization.

2.2 Density and Void Fraction
The actual densities of the composites were measured by using the Archimedes principle. According to this principle, when an object is immersed in a liquid, the apparent loss in its weight is equal to the weight of the liquid it displaces. To conduct the test distilled water was taken as the medium. This method is covered in ASTM standard D792. The density of the composite was obtained by using the following equation.

\[ \rho_a = \frac{\rho_w W_a}{W_a - W_w} \]

Where,
- \( \rho_a \) is actual density of composite,
- \( \rho_w \) is the density of distilled water,
- \( W_a \) is weight of the sample in air and,
- \( W_w \) is weight of the sample in water.

The theoretical density \( (\rho_t) \) of the composite material can be determined by using the following equation given by Agarwal and Broutman [10].

\[ \rho_t = \frac{1}{(w_f/\rho_f)+(w_m/\rho_m)} \]

Where
- \( w_f \) is the weight fraction for fiber,
- \( w_m \) is the weight fraction for matrix,
- \( \rho_f \) is the density of fiber and,
- \( \rho_m \) is the density of matrix.

Volume fraction of voids can be calculated by using the following equation [10]:

\[ v_v = \frac{(\rho_t-\rho_a)}{\rho_t} \]
Where $\rho_t$ and $\rho_a$ represents the theoretical density and actual density of the composite, respectively.

### 2.3 Tensile Strength
Composite samples of size 150 mm×20 mm×3 mm were prepared to conduct tensile test as per the ASTM E 1309 standard. Uniaxial load was applied through both ends. The test was performed in universal testing machine Instron 1195 at a cross-head speed of 10 mm/min and the results were used to calculate the tensile strength of the composite samples. Three tests were conducted for each composition and the mean value of the three replications was reported as the tensile strength of the composite.

### 2.4 Flexural Strength
Three point bending test was used to obtain the flexural strength. Composite specimens of size 80 mm×20 mm×4 mm were prepared to conduct the test. The tests were conducted using an Instron 1195 universal testing machine while maintaining 40 mm span length and 2 mm/min cross-head speed. Flexural strength of each specimen was calculated using the following formula.

$$FS = \frac{3PL}{2bt^2}$$

Where,
- $P$ is maximum applied load,
- $b$ is the width of the specimen,
- $t$ is the thickness of the specimen and
- $L$ is the span length of the sample.

### 2.5 Compressive Strength
Composite samples of required dimensions (height 10 mm, diameter 10 mm) were used for the uniaxial compression test as per the ASTM D 695 standard. Static uniaxial compression tests were carried out on these specimens using Universal Testing Machine Instron 1195 while maintaining 1 mm/min crosshead speed.

### 2.6 Scanning Electron Microscopy
The micro structural features of the raw human hair and the hair fiber reinforced composite specimens were examined by Scanning Electron Microscope JEOL JSM-6480 LV. The specimens were mounted on stubs with silver paste. To improve the penetration of light and for better surface micrographs, a thin film of platinum was vacuum-evaporated onto the samples before the images were taken.

### 3. Results and Discussion

#### 3.1 Density and Void Fraction
Table 1 shows the theoretical density, measured density and void fraction of epoxy-SHF composites for different weight percentages. It can be observed that the theoretical density was greater than the measured density. This can be attributed to the presence of voids and pores present in the composite during the fabrication process. It was also found that with the increase in SHF content, the measured density of the composite decreased from 1.09 gm/cc at 0 wt.% of SHF content to 1.059 gm/cc at 8 wt.% of SHF content, but the void fraction increased from 0.9% at 0 wt.% of SHF to 1.9% at 8 wt.% of SHF content.
Table 1. Theoretical and measured densities and void fraction of Epoxy-SHF Composites

| SHF content (wt%) | Theoretical density (gm/cc) | Measured density (gm/cc) | Volume fraction of voids (%) |
|-------------------|-------------------------------|--------------------------|-----------------------------|
| 0                 | 1.1                           | 1.09                     | 0.9                         |
| 2                 | 1.095                         | 1.082                    | 1.2                         |
| 4                 | 1.093                         | 1.077                    | 1.4                         |
| 6                 | 1.085                         | 1.066                    | 1.7                         |
| 8                 | 1.08                          | 1.059                    | 1.9                         |

3.2 Tensile Strength
The tensile strength of epoxy composites with different wt.% of short human hair fiber are presented in Table 2. It was seen that the tensile strength of the composite increased with increase in the fiber content. With a reinforcement of 2 wt.% short hair fiber tensile strength of composite increases from 65 MPa to 81 MPa. Further, for the 8 wt. % of short hair fiber, the tensile strength of epoxy composite reached 127 MPa.

Table 2. Mechanical Properties of Epoxy-SHF Composites

| SHF content (wt%) | Tensile Strength (MPa) | Flexural Strength (MPa) | Compressive Strength (MPa) |
|-------------------|------------------------|-------------------------|----------------------------|
| 0                 | 65                     | 58                      | 84                         |
| 2                 | 81                     | 71                      | 87                         |
| 4                 | 94                     | 86                      | 91                         |
| 6                 | 112                    | 99                      | 94                         |
| 8                 | 127                    | 106                     | 96                         |

3.3 Flexural Strength
Effects of SHF loading on the bending strength of the composites have also been studied in this work. Table 2 presents the values of flexural strength for composite with different SHF content. A consistent rise in flexural strength of composite with increase in SHF content was recorded. It was found that the flexural strength of composite increased to 71 MPa with addition of just 2 wt% hair fibers. Similarly, with the addition of 8 wt% fiber, the flexural strength of composite attained a value of 106 MPa.

3.4 Compressive Strength
The compressive strength of epoxy composites with different wt.% of short human hair fibers are presented in Table 2. A marginal rise in compressive strength of composite with increase in SHF content was recorded. It was found that the compressive strength of composite increased to 87MPa with addition of 2 wt % hair fibers. Similarly, with the addition of 8 wt % fiber the compressive strength of composite attained a value of 96 MPa.

Due to the higher tensile strength of hair fibers major portion of the load transmitted from matrix to fiber during the tensile and bending test of the epoxy-SHF composite. However during the compression test of the composite specimen void fraction presents in the composite causes early failure of the composite. Mechanical properties such as tensile, flexural and compressive strengths of...
epoxy-SHF composite increases because of improved interfacial adhesion between the matrix and the fiber though the void fraction of the composite increases with the addition of SHF.

3.5 Scanning Electron Microscopy
Figure 1 presents some SEM images of raw hair fibers and the epoxy composite. Randomly oriented fibers are shown in Fig. 1-a.

![SEM images of raw hair fiber and epoxy-SHF composite specimen](image1)

The surface features of a single fiber body are seen in the magnified SEM image, given in Fig. 1-b. The scaly nature of fiber surface with ridges is evident from this image. Figure 1-c is the micrograph of a typical epoxy-hair composite with 2 wt% fiber content.

4. Conclusions
Successful fabrication of epoxy composites reinforced with short human hair fiber with simple hand lay-up technique is possible. Tensile strength and flexural strength of the composite can be largely modified with the incorporation of short human hair fiber. This work thus opens a new avenue for the utilization of bio waste like human hair fiber.
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