EVALUATION OF MECHANICAL PROPERTIES OF HUMAN HAIR-BOMBYX MORI SILK FIBER REINFORCED EPOXY BASED BIOCOMPOSITE

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ABSTRACT

Awareness about environmental degradation and a need for a consistent sustainable development for the betterment of the environment has a direct influence over replacement of synthetic fibres by natural fibres. Extensive research work has been carried out on plant fibre based biocomposites. Hence our research work is based on fabrication and investigation of mechanical properties of animal fibre based biocomposites. Out of a wide variety of animal fibres, the fibres chosen by us for this research work were Bombyx mori silk and human hair which constitutes the dispersed phase, and the matrix phase is formed by epoxy resin. One of the reasons for selection of hair as a reinforcement material is due to the fact that human hair is continuously generated as waste in large quantity and there is a need to devise a novel method to effectively utilize this waste. Silk fibre was selected owing to the extensive properties possessed by it. Fabrication was done by hand layup technique in which three samples were manufactured. One sample was silk based biocomposite, another was hair based biocomposite and the third was hybrid biocomposite made from hair and silk fibre. Alternate vertical and horizontal orientations of fibres was introduced to improve the mechanical strength at inter laminar level. The biocomposite was tested for mechanical properties like tensile strength, compressive strength, flexural strength, impact strength and hardness. Mechanical tests conducted showed that silk based biocomposite was better in compression, flexural and impact strengths. Hair based composite showed higher tensile strength and it had highest break load. Hardness was same among all the three composites as it is a property exhibited by the matrix material constituted by epoxy resin. Analysis of hybrid composite showed that properties of hybrid composite were in between that of silk and hair composite. Hence it is suggested that hair may be included in the composite to reduce the overall cost of the composite, considering the exorbitant cost of silk.

Keywords: biocomposites, animal fibres, Bombyx mori silk composite, human hair composite.

1. INTRODUCTION

Engineering materials play a vital role in development of modern technology. Material is the only channel through which the designer puts forward his ideas to practice. Human beings ever since evolution have been using materials for their needs and comforts. They have developed new materials time to time so as to keep on par with the developing technology and the challenging requirements posed by it. In order to face these challenges, several unique features are anticipated from the materials. Firstly, the materials that are used should have higher performance efficiency and reliability. Secondly the weight of material must be as less as possible. Thirdly the material must have combination of properties, so that it remains as a common engineering material and is not confined any particular application alone. Composite material is the category of material which satisfies all the above requirements. Concern about environmental degradation has an influence over replacement of synthetic fibres by natural fibres. Generally plant and animals are the major sources of natural fibres. Plant based (cellulose) composites are widely available for research work and a wide variety of materials using fibres like kenaf, hemp, manila, jute and abaca are available [1-4] But animal fibre based composites are not available much. Hence our work is based on animal fibre based composite. Among the various animal fibres, silk was selected owing to the extensive properties possessed by it both mechanically and physically. Human hair was selected in order to devise a new method to effectively use it, which is getting accumulated as waste in large quantities. The matrix phase is constituted by epoxy resin due to its extensive commercial usage in composites. Filler materials are general used in composite materials to increase the properties of the material. But in most of the cases they are used to reduce the volume fraction of the resin. But they tend to reduce the mechanical properties of the material. Hence fillers were not used in this material. This work mainly concentrates on identifying the mechanical properties of Silk and human hair fibre based composites which can be commercially used for replacement of metals in certain high performance materials.

2. EXPERIMENTAL DETAILS

Materials

The materials used in this composite material can be distinguished as materials constituting the matrix phase and dispersed phase. Matrix phase is constituted by epoxy resin and the dispersed phase is constituted by glass fibres, silk fibres and human hair.

a) Glass fibre

Glass fibre consists of extremely fine fibres of glass which consists of fusion of calcium, aluminium and alkali metals. They are commonly available in the forms of rovings, woven rovings and chopped strand mats. Woven rovings possess a benefit of higher strength due to the inter woven structure. Glass fibres used in composites provide higher mechanical strength to the material. They offer a wide mix of mechanical, thermal, chemical, optical and electrical characteristics and is unaffected by water and other reactive liquids.

b) Silk fibre

Silk fiber is a naturally occurring protein based fiber [5]. On studying the metamorphosis from larvae to moths, the silk worm tends to produce polyamino acid based cocoons [6]. Silk is spun around the larvae to protect it from its predators [5].Process associated with retrieval of silk fiber from cocoon is called reeling. The silk fibers consists of two fibroin brins which are binded by sericin binder which is an amorphous protein polymer which maintains the integrity[7].Continuous fiber can be spun only when sericin coating is removed by a process called degumming.[8]. Presence of sericin from the cocoon, can isolate the physical bonding between matrix and fiber there by reducing the mechanical property of the laminate [9]. But at the same time, fractographic analysis of silkworm silk revealed that degummed silk possessed voids in the burns and cracks on the surface of fiber which might be the reason for the fracture whereas silk with sericin coating maintained the structural unity during deformation [10].In addition, silk has the capacity to withstand chemical actions of organic nature.[11]. Alkaline treatment increases surface roughness, which offers better mechanical interlocking[12] Orientation of silk fibres had an influence over mechanical properties[13], hence alternative orientations of horizontal and vertical were introduced. Usage of silk as a reinforcement fiber finds application in the fields like, textile industries, tissue engineering, bio technology, biomedical industries as suture material. From this it can be concluded that silk fibers are not used commercially as polymer reinforcement. Hence there is a need to identify the advantages of using silk as a reinforcement material rather than using plant based fibers and synthetic fibers considering the properties possessed by it [14-16].

c) Human hair

Human hair has the following composition. Proteins constitute 65-95% by weight, 32% water and the rest is constituted by lipid pigments and other compound. Keratin is the type of protein that is almost 80% responsible for the formation of hair [17].Structural analysis of hair shows it consists of three different layers. They are cuticle, cortex and medulla. The surface properties of hair depend on cuticle which forms the outermost layer by cross linked cystine [18].The medulla contains highly concentrated lipid and less cystine. It is in the form of cylinder and forms the innermost hair thread. Usage of hair as a reinforcement material is a new attempt as it evolves a new method to utilize the material which is available in large quantities. It can be used as a reinforcement material due to its capacity to resist stretching and compression [20].Investigation of mechanical properties on fibre composites were done and it was concluded that hybrid composites exhibits high strength [21,22,23].

d) Resin and hardener

The matrix phase is required to bind the various layers of the fibres. The matrix phase is constituted by epoxy resin and 1 part of hardener was added to 10 parts of resin to improve the curing rate. The commercial grade of resin used was Araldite LY556 and hardener used was Huntsman HY951.

e) Fabrication procedure

The fabrication is done by hand layup technique. For the fabrication of silk composite, the following procedures were followed. The silk threads were taken and cleaned thoroughly. Then they were dried in shade. At the start of fabrication, the mould was cleaned and kept dust free. A layer of Poly Vinyl Alcohol was applied on the mould surface. This was done in order to facilitate easier removal of the laminate after fabrication. Then the epoxy resin (Araldite LY556) and hardener (Araldite HY955) were taken and mixed in a proportion 10:1. After that, the resin was applied in the mould using a brush. The woven glass fibre, cut to the size of the mould was placed over the applied resin. It was set firmly over the resin layer with the help of a roller. Then the resin was applied over it till it became tachy. The silk threads were taken and laid on it as horizontal fibres. Care was taken to avoid the overlapping of fibres as it can lead to the variation of thickness of the finished composite. The roller was then used to set the silk fibres over the previous layer of resin and to remove air bubbles between. Then the resin was applied again on the silk layer with the help of the brush. Again the same amount of silk fibres were taken and laid over the resin layer, but in a vertical orientation. This was done to increase the overall strength of the composite, since change in orientation has the capacity to defend the material from the propagation of the applied forces. Then a layer of woven glass fibre cut to the size, was laid over the previous layer and then set firm by the roller. The laminate was allowed to cure for a time of nearly one hour. A load was applied over the surface of the composite in order to avoid the formation of air bubbles. After ensuring that the resin has completely cured, it was removed carefully from the mould and cut to the required dimensions. The same procedure was followed for all the samples. Three samples were fabricated and they had fibres in different orientations as shown in Figure-1.

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Figure-1. Schematic diagram of composites.

3. TESTING OF COMPOSITES

a) Tensile test

The laminate was taken and the profile of the standard test specimen was cut from it based on ASTM: D638. The dimensions of the sample is shown in Figure-2. The test is done in a FIE-UTN 40 Universal Testing Machine at room conditions. Tests are repeated on specimens obtained from three samples made with Silk-Glass, Hair-Glass and a hybrid of Silk-Hair-Glass. Tensile force is applied at the ends by clamping the specimen in the UTM. The tensile breaking load corresponding to each sample is obtained. The variation of tensile stress with strain is plotted.

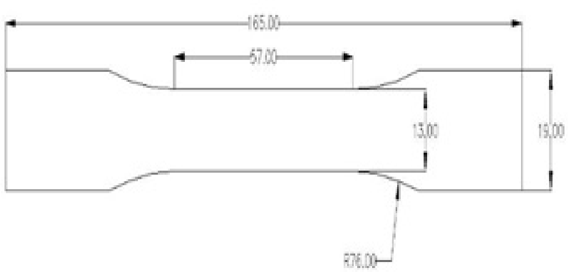

Figure-2. Dimensions of tensile test specimen.

b) Compressive test

The laminate was taken and the profile of the standard test specimen was cut from it based on ASTM:D695. The test is done in a FIE-UTN 40 Universal Testing Machine at room conditions. Tests are repeated on specimens obtained from three samples made with Silk-Glass, Hair-Glass and a hybrid of Silk-Hair-Glass. Compressive force is applied at the ends by clamping the specimen in the UTM. The compressive breaking load corresponding to each sample is obtained. The variation of compressive stress with strain is plotted.

c) Flexural test

The laminate was taken and the profile of the standard test specimen was cut from it based on ASTM:D790. The dimensions of the standard test specimen is shown in Figure-3. The test is done in a FIE-UTN 40 Universal Testing Machine at room conditions. Tests are repeated on specimens obtained from three samples made with Silk-Glass, Hair-Glass and a hybrid of Silk-Hair-Glass. Flexural load is applied at the middle of the specimen while the ends are supported. The flexural breaking load corresponding to each sample is obtained. The variation of flexural stress with strain is plotted.

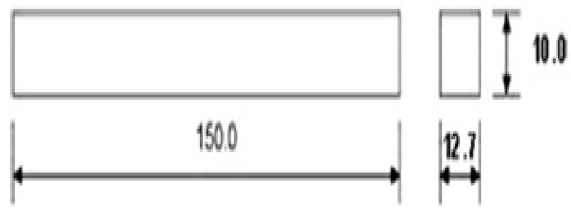

Figure-3. Dimensions of flexural test specimen.

d) Impact test

Impact test gives the maximum energy that the material can withstand. Test is carried out on a Charpy Impact Machine based on ASTM:D 256.The specimens are cut according to the dimensions shown in Figure-4. The specimen succumbs to the heavy blow offered by the hammer and the load ar which the material fails gives the impact energy undertaken by the material. Tests are repeated on specimens obtained from three samples made with Silk-Glass, Hair-Glass and a hybrid of Silk-Hair-Glass.

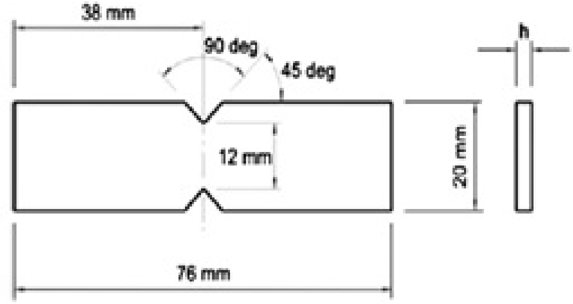

Figure-4. Dimensions of impact test specimen.

e) Hardness test

The Shore D^{o} Hardness Test evaluates the indentation hardness of polymer based materials. The test is done as per ASTM: D2240 standard. The specimen is indented using a hardened steel indenter with certain force and geometry. Hardness is a measure of displacement of indenter tip.

4. RESULTS AND DISCUSSION

a) Tensile properties

The fabricated sample was tested as per the ASTM: D638 standard. The change in tensile stress with respect to the strain was recorded and plotted in graph. A sample stress strain plot for hair composite is shown in Figure-5. From the test results, the ultimate tensile strength and the break load were obtained and from these the tensile moduli of the specimens were calculated. The tensile properties are summarized in Table-1 for different specimens. From Table-1, it is observed that hair composite has better tensile properties. Inspite of tensile strength being higher, hair composite has lower tensile modulus than that of the silk and hybrid composites. This is because, the tensile strength depends on the cross section area of the specimen, while the modulus depends on the elongation percentage of the specimen. Thus these two parameters are independent from each other. The tensile modulus is the ratio of stress variation with respect to strain variation in the linear region of the graph. It can also be seen that, silk composite withstands more load before failure. Also the elongation percentage is higher for the silk composite, which shows that the silk composite can withstand more tensile load than the other two composites before failure. Figure-6 shows the delaminated samples after being subjected to a tensile load.

Table-1. Tensile properties of materials.

Sample	Break Load (kN)	Maximum Displacement (mm)	Elongation %	Tensile Strength		Tensile Modulus	
				In kN/mm^2	In MPa	In kN/mm^2	In MPa
GFRP + Silk	5.82	9.20	18.4	0.05332	53.32	0.277	277
GFRP + Hair	3.61	7.45	14.9	0.06053	60.53	0.212	212
GFRP + Silk + Hair	5.05	7.95	15.9	0.04500	45.00	0.278	277

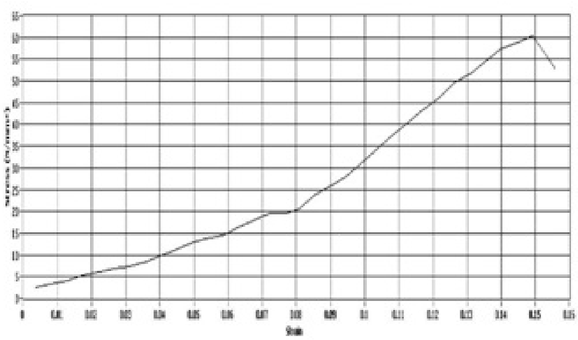

Figure-5. Stress vs. strain plot for hair composite in tension.

Figure-6. Delaminated tensile test samples.

b) Compressive properties

As per the ASTM: D695 standard, the test was performed and the change in compressive stress with respect to the strain was recorded and plotted in graphs. A sample stress strain plot for silk composite is shown in Figure-7. The test results of the compression test were obtained and is summarized in Table-2. It can be concluded that the silk composite has superior properties comparatively in all the parameters calculated. The compressive strength as well as the break load were higher for the silk composite. The compressive strength was about 3.2 times and 1.46 times higher than the hair and hybrid composites respectively, while, the break load was 2.83 times and 1.48 times higher than the hair and hybrid composites respectively. The compressive modulus, on the other hand was higher for the hybrid composite by a margin than the silk composite. Figure-8 shows the delaminated samples after being subjected to a compressive load.

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Table-2. Compressive properties of materials.

Sample	Break Load (kN)	Maximum Displacement (mm)	Compression %	Compressive Strength		Compressive Modulus	
				in kN/mm^2	in MPa	in kN/mm^2	in MPa
GFRP + Silk	33.50	5.73	11.45	0.08637	86.37	0.7543	754.3
GFRP + Hair	10.48	2.03	4.05	0.02702	27.02	0.6671	667.1
GFRP + Silk + Hair	26.74	3.88	7.75	0.05926	59.26	0.7647	764.7

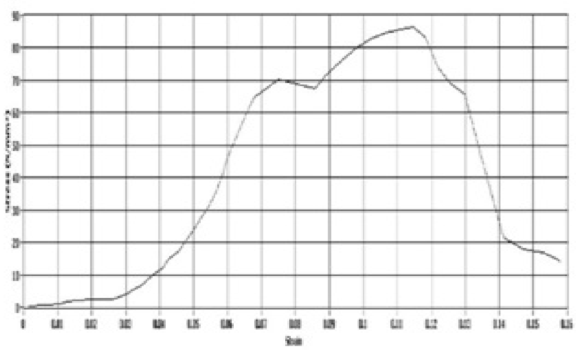

Figure-7. Stress vs. strain plot for silk composite in compression.

Figure-8. Delaminated compressive test samples.

c) Flexural properties

As per the ASTM: D790 standard, the test was performed and the change in flexural stress with respect to the strain was recorded and plotted in graphs. A sample stress strain plot for silk-hair hybrid composite is shown in Figure-9. The test results of the flexural test were obtained and summarized in Table-3. This test is done in order to obtain the bending characteristics of the specimens when subjected to a load. From the results, it can be seen that the silk composite has scored in all the areas. Though both the hair and hybrid composite lag behind it, it can be seen that the hybrid composite is far better in the flexural properties than the hair composite. Figure-10 shows the delaminated samples after being subjected to a flexural load. A contrast of tensile, flexural and compressive strengths of the three materials are presented in Figure-11.

Table-3. Results of flexural test.

Sample	Flexural Break Load (kN)	Flexural Strength		Flexural Modulus	
		In kN/mm^2	In MPa	In kN/mm^2	In MPa
GFRP + Silk	2.46	0.01098	10.98	0.1800	180
GFRP + Hair	1.17	0.00843	8.43	0.0766	76.6
GFRP + Silk + Hair	2.59	0.01066	10.66	0.1545	154.5

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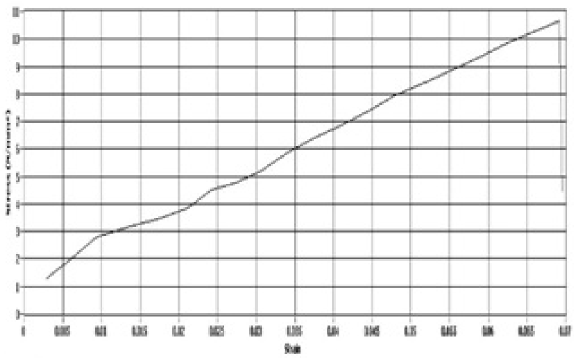

Figure-9. Stress vs. strain plot for hybrid composite.

Figure-10. Delaminated flexural test samples.

d) Impact Properties

Charpy impact machine was used to perform this test. The test results are shown in Table-4.The results show that the silk and hybrid composites have better impact strength than the hair composite. The impact strength is calculated from the energy absorbed by the specimen, when they are subjected to a heavy blow. Resin toughness is the major influencing factor in determining the impact strength, rather than the fibre stiffness and strength. Also the stacking sequence of the fibres plays an important role. Alternate stacking directions of the fibre layers add to the impact properties of the laminate, because the crack propagation is defended by the change in the fiber orientation thus increasing the impact strength of the specimen. Figure-11 shows the delaminated impact test samples.

Table-4. Results of Impact test.

Sample	Energy Absorbed (joules)
GFRP + Silk	8
GFRP + Hair	6
GFRP + Silk + Hair	8

Figure-11. Delaminated impact test samples.

e) Hardness

The test was carried out in a Shore Durometer. The specimens were cut as per the dimensions needed for the ASTM: D2240 standard. Results are tabulated in Table-5. From the results, it can be seen that, all three specimens have almost equal hardness values, since the hardness is mainly dependent upon the properties of the matrix material. However, silk holds a slight edge over the other composite specimens, as can be seen from the results.

Table-5. Results of Hardness Test.

Sample	Shore DHardness
GFRP + Silk	75
GFRP + Hair	73
GFRP + Silk + Hair	73

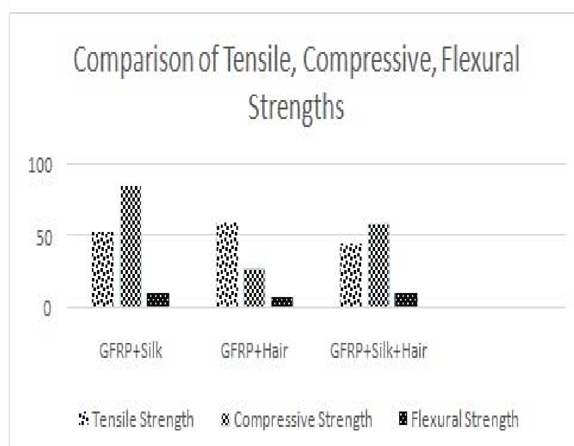

Figure-12. Comparison of tensile, compressive, flexural strengths.

5. CONCLUSIONS

The following conclusions are drawn from the results of mechanical tests carried out on the samples.

- Silk fibres are widely used for biomedical applications and the results prove that it has the capacity to be used as a reinforcement material.
- Silk composites show better compressive, flexural and impact properties. This shows that they can be used in commercial applications.
- Hair based composite exhibited better tensile properties but showed lower elongation percentage indicating that it fails immediately without much yield.
- Hybrid composite between hair and silk has properties lying between individual composites and based on the requirement and application, the material shall be chosen.
- Comparing the cost aspect of the material, hair fibres are very much cheaper than the silk fibre and it has properties very similar to that of silk. Hence hair may be included to reduce the cost of the material.

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