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Experimental Investigation of Mechanical properties of Silk Reinforced Modified Polymer Matrix Composites

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ABSTRACT
Composite material has been an important contributor to modern industrial revolution. But with the emphasis given on environmentally sustainable technologies, importance of development of composites with natural materials is more than ever. As silk fiber is natural and can be obtained from it is renewable resources in abundance, it should be a good substitute with economic and environmental impact. In this work, we studied the performance and characteristics of composite made of Silk fiber and modified polyester matrix. The research covers silk and unsaturated polyester with matrix modification for a different range of wood crumble scientifically named as Tectona Grandis. A simple hand layup technique was used to make composites. We fabricated composites of three different volume fraction of silk fiber, polyester and wood crumble (silk v/v%: wood crumble v/v%: polyester v/v% =2.94: 0:97.06, 3.01: 6.23: 90.76 and 3.17: 31.78: 65.05. Tensile and flexural strength and thermal conductivity of the different compositions have been measured. Wood crumble free composition having silk v/v%: wood crumble v/v%: polyester v/v% =2.94%: 0%: 97.06% is found to have the highest flexural strength among the samples studied. The results showed an increase in strength with added wood crumble of the ratio silk: wood crumble: polyester= 3.01%: 6.23%: 90.76%. Although the thermal conductivity increases with the quantity of more wood added, young modulus of the composite decreases.

Keywords: Composite, Silk, Wood Crumble, Modification, Mechanical Analysis

1. Introduction

Environmental awareness has been increased drastically in the world because of pollution and changing weather patterns. An increasing need for environmentally friendly materials has become both Government and International Organizations priority. One of the most important creations is a composite material that meets the need for material instead of single material. However, synthetic fiber composite materials are used mostly as reinforcing the composite. The most significant problem of synthetic fibers, they are not biodegradable and contributes to long term pollution. Using natural fiber as reinforcing fiber can resolve this problem. In the last decades, natural fiber has gained considerable interest. Natural fiber like Silk, Jute, Coir, Banana, Sisal, Bamboo, etc. are used as a substitute to man-made fibers such as Glass fiber mat, Carbon, Aramid, Kevlar fiber, etc. Composite materials are used, such as troy, fencing, furniture, industrial, air cruft, military, etc. Natural fiber has thousands of sources, but few have economic value. Natural fiber reinforced polymer composites have been identified in recent years as an innovative modern fiber reinforced technology for industrial business and biomedical applications. Among the numerous forms of natural fibers with documented potential applications for polymer reinforcement.Silk fiber, is one that has recently received special attention from researchers. It is often assumed that because of their environmentally sustainable properties, silk-based composites are ideal candidates for replacing conventional materials in the immediate future. Silk fiber serves as a strong polymer insulation, improving the polymers' mechanical properties.

Noishiki et al. (2002) briefed that, increased mechanical strength at a 20–30 wt.% fibroin content, with breaking strength and ultimate strain about five times those of the constituent materials is showed by composite films of cellulose whisker and fibroin (silk) [1].

Hybridization of more than one form of fiber in the same matrix introduces another layer to the overall utility of fiber-reinforced composite materials. The hybrid composite properties cannot be the result of a simple consideration of the separate properties of the individual components. Hybrid composites of randomly focused short sisal and silk fibers were developed by Noorunnisa Khanam et al. (2007). The hand layup method was used for the fabrication of composites and unsaturated polyester resin was used as the matrix. They reported that 2 cm fiber length composites have higher tensile properties than 1 and 3 cm fiber length silk and sisal fiber improve the tensile properties of unsaturated polyester resin [2]. Padma Priya and Rai (2006) reported that the tensile strength and modulus of epoxy is increased by silk fabric. The tensile strength and modulus increased with increased fiber loading in the epoxy matrix when they took the fiber volume up to 25%. The silk/glass fiber-reinforced hybrid fiber epoxy composites were made by them and studied the tensile

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strength and modulus with varying weight percentage of silk fabric for these hybrid composites. They reported that with the increment of glass fiber volume % in silk epoxy, tensile strength and modulus increase. This research shows that by hybridization of silk fiber with synthetic fiber, we can improve the mechanical properties of the polymer composites. This increment is because of the transfer of load from silk to the glass fiber [3]. The word composite in the term composite material signifies that two or more materials are combined on a microscopic scale to form a useful third material. It contains matrix and reinforced composite. The individual material that makes up a composite called constitutes. Binder matrix and dispersed phase of reinforcement, two constitute material makes the most common composite. The reinforcement is stronger and stiffer compared to matrix. The matrix helps to transfer load among the reinforcement because this reinforcement is discontinued. The silk fiber is used as a reinforcing agent in synthetic material like as Polyester. Polyester as matrix and wood crumble for matrix modification is added. The effect of fiber treatment and matrix modification of mechanical properties of flex fiber composite is studied. Composites are produced by employing two compounding ways: internal mixing and extrusion. A scanning microscope investigates fracture surfaces. Result suggests that matrix modification lead to better mechanical performance as long as fiber surface modification. Tectona Grandis is selected as matrix modifier because it has very strong, durable, natural resistance to termites and insects, moisture resistance, high dimensional stability, and compatible with iron and other material.

2. EXPERIMENTAL INVESTIGATION

The experimental investigation was done to study mechanical properties of Silk Reinforced Modified Polymer Matrix Composite. The variable considered in this study include three different values of volume fraction (v/v%) of silk fiber, polyester resin and wood crumble.

1.Silk: polyester = 2.94%: 97.06%,
2.Silk: wood crumble: polyester = 3.01%: 6.23%: 90.76% and
3. Silk: wood crumble: polyester = 3.17%: 31.78%: 65.05%

3. MATERIALS

Silk Mat: Mulberry Silk. Density was calculated 1.4 gm/cm^3**.**

Unsaturated Polyester resin: Polyester resin is used as matrix. Matrix binds the silk mat together and protect them from environmental effect and handling. Density was calculated 1.16 gm/cm^3.

Methyl ethyl ketone peroxide (MEKP): MEKP are used as the catalyst which initiates the cross-linking of unsaturated polyester resins used in silk-reinforced plastic and casting.

Matrix Modifier: Wood crumbles (Tectona grandies) is used for matrix modification. Density was calculated 0.1533964 gm/cm^3. This wood crumbs is selected because 1. Very Strong 2. Very Durable 3. Natural resistance to termites and insects. 4. Moisture-resistant 5. High dimensional stability 6. Goes well with iron and other metals.

4. PROCEDURE

A simple hand layup technique is used for making three types of combination of silk, wood crumble, polyester reinforced modified matrix composition mentioned earlier. The manufacturing process known as 'hand layup' involves the manual laying down of a type of reinforcement known as 'prepreg' by individual layers. This is made up of thousands of fibers that are preimpre gnated with resin and packed into tows, arranged or twisted together in a single unidirectional ply. The layup method involves manipulating each ply by hand into shape and then firmly stuck on the previous layer or mold surface, leaving no air pocket between plies. For Tensile and Flexural test there are 5 pieces of specimens for every types of composite. Both Tensile and Flexural test has been performed in the UTM machine (HOUNSFIELD H10KS) by switching jaw. ASTM D3039 [4] (Length = 250mm Width = 25mm Thickness = 4mm) specification is used for Tensile Test Tensile test has been done and young's modulus has been calculated. The results were found to be consistent and varied specimen wise. Flexural strength has been calculated. Typical materials tested includes plastics, composites, metal, ceramics and wood. ASTM D790 [5] (Length = 127 mm Width = 12.70 mm Thickness = 4 mm) specification is used for Flexural Test. For doing the tensile test a tensile clamp was designed because the clamp in the machine could not hold the composite straight. To maintain the straight axis the tensile clamp was designed. Thermal Conductivity test of the specimens was also performed in machine known as Polystat cc1 to find out the heat conductivity of the specimens 90mm diameter disc is prepared to complete this test according to Lee's Method [6]. QMAT software was used to analyze the data of tensile and flexural test. The software was synced with the testing machine and a load cell was used to acquire the calibrated tensile and flexural load data. Integrated displacement sensor of the machine provided the extension of test sample with respect to the applied load.

Fig 1. Tensile Test Setup

Fig 2: Flexural Test Setup

Fig 3: Thermal Conductivity Test Setup

Fig.4 Specimens Before Test

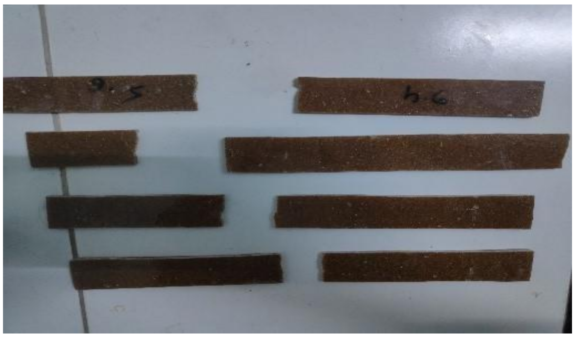

Fig.5 Specimens After Tensile Test

5. Result and Discussion

5.1 Tensile Strength Analysis

While stretching the sample, the stress (σ) is obtained through the amount of force (F) applied is measured and then, by dividing the force by the cross-sectional area (A) of the sample.

$$\sigma = \frac{F}{A} \tag{1}$$

This equation was used for Tensile Strength calculation. All the values in the table are calculated and submitted as mean average value.

Table 1 All Combinations' Tensile Properties

Sample	Maximum Tensile Stress (MPa)	Elastic Modules (MPa)	Energy at Break Point (J)
Silk+ Matrix	22.65 ± 2.7	328.4± 30.6	6.33 ± 0.8
Silk+5gmWood +Matrix	33.24± 3.05	256.17± 39.4	13.02± 3.2
Silk+24.13gm Wood+ Matrix	22 ± 5.2	400 ± 127	6.547 ± 2

For silk composite, the tensile strength generated is less than that of the modified matrix with 5 gm wood and almost the same as that of the modified matrix with 24.13 gm wood. The composite with silk and modified matrix with 5gm wood has the highest tensile strength, suggesting that the ratio between wood crumble and polyester played a significant role which enabled the matrix to have higher bonding capacity with the silk resulting in higher tensile strength.

5.2 Flexural Strength Analysis

$$\sigma = \frac{3\,FL}{2\,bd^2} \tag{2}$$

This equation was used for Flexural Strength calculation. where F is the maximum load (in N), b is the width of the specimen (in millimeters), and d the thickness (in millimeters). L is the distance between the supports (in mm),
All the values in the table are calculated and submitted as mean average value.

Table 2 All Combinations' Flexural Properties

Sample	Flexural Strength (MPa)	Elastic Modulus (MPa)	Energy at Break Point (J)
Silk+ Matrix	32.06 ± 4.45	563 ± 8	1.2 ± 0.086
Silk+5gm Wood +Matrix	30.47 ± 0.22	626 ± 7	0.7 ± 0.1
Silk+	28.61 ± 0.44	51 ± 0.3	0.996 ± 0.02

24.13gm
Wood
+Matrix

For silk composite the flexural strength is quite high compared to the others. Since flexural loading combines both tensile and compressive loads, it implies the silk composite has the highest compressive load carrying capacity. But for the composites with modified matrix shows almost the same flexural strength. 24.13gm modified matrix with silk has the lowest value. So, to sum it up, wood makes a little difference when it comes to flexural strength. The main strength depends on silk and polyester matrix. It is difficult to explain the exact reason, but we believe it to be due to the complex structure of wood crumble and further study is needed.

5.3 Thermal Conductivity Analysis

$$k = \frac{QL}{A\Delta T} \quad (3)$$

This equation is used for thermal conductivity calculation. Where K is denoted as Thermal conductivity, L is Length of Span, ΔT is Temperature Difference, Q is Amount of heat transfer through material. All the values in the table are calculated and submitted as mean average value.

Table 3 Thermal Conductivity

Sample	Thermal Conductivity, K (W/m-K)
Silk+ Matrix	0.959 ± 0.014
Silk+5gm Wood +Matrix	1.129 ± 0.031
Silk+ 24.13gm Wood +Matrix	1.712 ± 0.024

Thermal conductivity of silk is 0.846 W/m-K[7], polyester is 0.577 W/m-K[8] and wood crumble is 0.085 W/m-K[9]. For silk composite the thermal conductivity is the lowest because polymers exhibit a low thermal conductivity because of their low atomic density, weak interactions [10].
For the other samples where matrix is modified with wood crumble the interactions between the matrix particles and contribution off the high intrinsic thermal conductivity of the wood crumble are believed to lead to an improved heat transfer through the composites. Checking the individual thermal conductivity's value, it is clear that experimental value is more than expected. The density, moisture and grain size of wood can affect the result of thermal conductivity [11]. So, further study is needed on this matter.

5.4 Young Modulus Analysis

$$E = \frac{F/A}{\Delta L/L} \quad (4)$$

This equation is used for Young Modulus calculation.

Table 4 Young Modulus

Sample	Young Modulus (GPa)
Silk+ Matrix	1.2433 ± 0.083
Silk+5gm Wood+ Matrix	0.9843 ± 0.00529
Silk+ 24.13gm Wood+ Matrix	1.1104 ± 0.0015

For silk composite the young's modulus generated is quite high which shows the composite is stiffer compared to the other composite samples. Silk provide a good amount of inter-molecular bonding with polyester [12]. Which enables the composite to absorb high stress with low deformation. For silk composite modified with 5gm wood has lower young's modulus. Because of the wood crumble is bonded two ways with both silk and polyester. So, the stress generated is not absorbed as well as the silk composite. For silk composite modified with 24.13 gm wood the young's modulus is higher than modified matrix with 5 gm wood. The streets in this case was lower with respect to strain.

6. Conclusion

Natural fiber and Polymer base composites have beneficial properties for their environment friendly, biodegradable and cost-effective properties also provide alternatives for utilization in a commercial application comparable with synthetic composite. Modifying the matrix by adding wood crumble (Tectona Grandis) 5gm is increased the tensile strength of the composite material, which means the internal bonding is stronger compared non-modified matrix composite. Flexural modulus identifies high stiffness as well as the extent of deformation of the material when it is subjected to bending stress and gives a measure of the ductility of the material. Only silk polymer matrix composite has the highest flexural strength compared with modified silk, wood crumble and polymer matrix. Thermal conductivity is increased when compared with silk polymer composite. Adding wood crumble with silk and polyester is shown better thermal conductivity. The ratio of wood crumble (*Tectona Grandis*) and polyester is played a vital role in influencing different mechanical properties of the composites.

8. References

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9.NOMENCLATURE

σ : Stress, N/m^2
F : Force, N
A : Area, m^2
L : Length of Span, m
ΔT : Temperature Difference, k
Q : Amount of heat transfer through material, W
b : Wide, m
d : Thickness, m^3