ISSN: 0974-5823 Vol. 6 No.1 January-June, 2021

International Journal of Mechanical Engineering

Mechanical Properties of Bamboo, Waste Silk Fiber Composites

Renjith R
Cochin University of Science and Technology, renjith499@gmail.com

Rajesh P Nair
Cochin University of Science and Technology, renjith499@gmail.com

Date of Submission: 18th March 2021 Revised:10th April 2021 Accepted: 19th May 2021

How to Cite: **Renjith R., Rajesh P Nair., (2021). Mechanical Properties of Bamboo, Waste Silk Fiber Composites. International Journal of Mechanical Engineering 6(1), pp.25-28.**

Abstract **-Composite materials are more promising in this industrial scenario. But like conventional materials, it poses the same questions about environmental impact and sustainability. In this context, natural fiber composite are now emerging as a new area of attraction. Generally, it is called as NFRP, which means Natural Fiber Reinforced Polymer. Even though one part (matrix) of the natural fiber composite is composed of polymer but unlike conventional composite, the other part is from a naturally occurring one. In this work, an attempt is made to find out the mechanical properties of the NFRP materials. ASTM standard specimens are prepared from NFRP and tested. To manufacture the specimen, rules of mixture equations are used. From these equations, the volume ratio for reinforcement and matrix are calculated. Hand layup and compression moulding techniques are used for manufacturing the specimens. ASTM specimens were cut from the prepared sheet and tested. The calculated properties can be used for and FEA analysis which will eventually reveal the replacement comparison of conventional composite with NFRP**

Index Terms–Natural Fiber Composite, Mechanical Properties, Silk fiber, Compression Moulding

INTRODUCTION

In industrial world quest for new and sustainable materials are increasing. Depleting iron ores are major concern for manufacturing industries. A continuous research is going on to find out alternatives to conventional materials. The output of one such research is composite materials. Among composite materials, natural composite holds a superior position due to its ecofriendly nature. Natural composite is composed of reinforcements from a natural origin and bio/synthetic resin is used as matrix. Bamboo, coir, sisal, silk are some of the reinforcements used in NFRP (Natural Fiber Reinforced Plastic). Mechanical properties of these materials can be altered by adjusting different configurations of fiber laying.

Although Several mathematical models are available for predicting mechanical behavior of the composite, none of them are accurate to experimental results. A closed match is given by PMM (periodic Microstructure) model and Halpin Tsai relations. This is probably due to the peculiar characteristics of natural fibers and their bio composites, such as variable diameter, non-straight shape, and not-perfect alignment of fibers with load due to the lack of suitable fabrics that can guarantee such alignment [1].

Moisture absorption and thermal effects are important parameters in design of NFRP composite. Studies on mechanical degradation of NFRP with hydrothermal loading were conducted by K F Wang [2]. It is found that the elastic module and buckling load decreases monotonously with time, and approaches to a certain value with time. However, the Poisson’s ratio increases firstly, then decreases, finally approaches to a certain value with time.

A multi scale constitutive model is also developed to investigate elastic properties of plain weave fabric composites with twisted single yarns. A finite element analysis also conducted to verify the predicted model. There is a good agreement between the predicted results using the multi-scale constitutive model and the simulation results obtained from the FEA models [3].

Nowadays, because of the growing recognition of environmentally sustainable biomaterials, bamboo fibers have received extensive interest as a possible alternative to synthetic fibers for their composite applications in the building industries [1, 4]. Several studies conducted to find out the properties of Bombyx mori silkworm. All environment-friendly biodegradable silk materials derived from Bombyx mori silkworm can be directly utilized for practical oil-water separation and oil recovery applications [4]. Some research on Bombyx mori silk reveal that both the strength and toughness values increase with the decreases in the diameters and sericin weight contents [5].

NFRP Composite Properties

- **Silk Fiber**: Silk fibers can be incorporated as reinforcements into thermoplastic matrices to create composite materials with a high strain to failure rate. Silk yarn is easily available as a waste product from textile processing, making silk fiber-reinforced composites environmentally friendly and cost effective. Incorporating silk fibers into biopolymer matrices such as epoxy resins produces a 'green' bio-composite. The silk fibers can contribute significantly to impact resistance by ensuring both sufficient strength and good deformability [6].

  Bamboo Fiber: Bamboo fiber is a regenerated cellulosic fiber produced from bamboo. Starchy pulp is produced from bamboo stems and leaves through a process of alkaline hydrolysis and multi-phase bleaching. Further chemical processes produce bamboo fiber. It is softer than cotton, with a texture like a blend of cashmere and silk. Because the cross-section of the fiber is filled with various micro-gaps and micro-holes, it has much better moisture absorption and ventilation. Moisture absorbency is twice than that of cotton with extraordinary soil release [7].

Fabrication of Test Specimens

Hand Layup and Compression Moulding

There is a wide variety of fiber-reinforced plastic processes. The choice of process depends on many factors, such as type of reinforcement and matrix materials, size, shape, quantity, and cost. There are many specialized processes available, but only the most used commercial process, hand lay-up, has been used here in the preparation of the composites. Hand lay-up is the most common and least expensive open-molding method because it requires the least amount of equipment. Fiber reinforcements are placed by hand in a mold and resin is applied with a brush or roller. This process is used to make both large and small items, including boats, storage tanks, tubs and showers. Production volume per mold is low; however, it is feasible to produce substantial production quantities using multiple moulds. Hand lay-up is the simplest composites molding method, offering low-cost tooling, simple processing, and a wide range of part sizes. Design changes are readily made.

Rules of Mixture Equations

Rule of mixture is concept explains composite property is a combination of properties of matrix and fiber [8, 9]. Main criteria which alter composite property is volume fraction of fiber and matrix.

$$\sigma_c=\sigma_f v_f+\sigma_m v_m \qquad (1)$$

Equation (1) shows calculation of longitudinal strength (σ_c) of composite from its constituents. σ_f and σ_m are tensile strength of fiber and matrix, respectively.

FIGURE 1(A)

FIGURE 1(B)

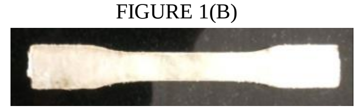

FIGURE 1(C)

A. Fabricated Composite , B. D25-IZOD Impact Specimen , C. D638 -Tensile Test specimen

FIGURE 2 (A)

FIGURE 2 (B)

FIGURE 2 (C)

A. Fabricated COMPOSITE, B. D25-IZOD Impact Specimen , C. D638 -Tensile Test specimen

For preparing the specimens,rules of mixture equations were used. Volume ratio of fiber is taken as 80 % for calculations. First layer of natural fibers was laid over a base plate and epoxy applied over the layer. The base plate was cleared of rust by scrubbing with an abrasive paper. Then, the surface was allowed to dry after cleaning it with a thinner solution. After drying, the surface was coated with silicone gel.

FIGURE 3. D638 LOADED IN TENSILE TESTING MACHINE

FIGURE 4. D256 LOADED IN TENSILE TESTING MACHINE

The surface was given a few minutes to set before the mold lay-up. The company codes for the epoxy semi-polymerized resin and the Hardener/Curing agent were EP-306 and EH-758, respectively. They were mixed in the proportion of 10:1 (EP-306 and EP-758). The silk fiber are laid layer by layer, with each layer separated from each other by a layer of epoxy resin. The curing time or the pot life, which is how it is usually denoted on laboratory charts, was 20 minutes once mixed. Care was taken that the resin did not cure in the curing pot itself. A constant watch was maintained over the blend in the pot with the aid of a stopwatch.

FIGURE 5 (A,B)
A. COMPRESSION MOULDING MACHINE, B. MOULD

After applying epoxy on fiber layer, it is transferred to a compression moulding machine (Figure 5-A). A semi-automatic compression moulding machine was used for making the composite specimen. A hydraulic press is used to apply pressure upon the composite material. The mould size is 200x200x6mm (Figure 5-B). Then the mould is placed in the compression moulding machine and then a pressure of 130bar is applied to the mould for 2.5 hours at room temperature. To prevent the composite from sticking to the mould, a thin sheet of paper is placed between the composite and mould. Bamboo and silk fiber composite and ASTM specimens were shown in figure 1 and 2

CALCULATIONS

The available mould size of the compression moulding machine is 200mm x 200mm with a thickness of 6mm.The proportions used for this study is 80% fiber and 20% matrix. By applying rules of mixture (1) and based on density of composite, mass of fiber and matrix were calculated (2). Where $\rho_f$is density of fiberandρ_m density of matrix. Calculated mass and volume requirements bamboo and waste silk fiber are given in table no 1

Volume of Composite (v_c) = *Volume of fiber* (v_f) + *Volume of Matrix* (v_m) (1)

Composite Density $(\rho_c) = \rho_f v_f + \rho_m v_m$ (2)

Three sample strands of the fiber were taken to get the dimensions of the bamboo and waste silk fiber. Diameter was measured using tool maker's microscope. Length of the samples were measured using Vernier and their weight in weighing machine.

TABLE I
MASS CALCULATION DETAILS

	Bamboo Fiber	Silk Fiber
Diameter of strand	0.142mm	0.02 mm
Mean length of strand	76mm	1.78 mm
Mean weight of three samples	1.49mg	3.8 mg
Volume of the strand	1.2035mm3	0.559 mm3
Density	$1.24\text{x}10^3$kg/m3	$6.797\text{x}10^3$kg/m3
Mass of fiber needed for process	0.238kg	1.03kg
Density of epoxy	1115.9kg/m3	1115.9kg
Mass of epoxy needed for process	0.535kg	0.532 kg

MATERIAL TESTING

- **Tensile Test:**Tensile testing is conducted to find out the tensile properties of materials. Figure 3 shows ASTM D638 specimen is loaded in tensile testing machine. A load deformation curve is the output of tensile test. This will be converted to stress strain curve to find out mechanical properties like young's modulus tensile strength etc [10].
- **Impact Test:**Izod impact measures energy required to break a specimen by striking a specific size bar with a pendulum. Izod normally refers to a notched specimen impact.The notch (Figure 4-ASTM D256) acts as a stress concentrator, forcing the bar to break at a specific location. The notch is placed in the clamp and a pendulum is released that impacts the bar, measuring the energy required to break the sample [11].

RESULTS AND DISCUSSION

I Tensile Strength Test

In this study three specimens were used for tensile strength test. The average core width is 11.8mm and thickness is 7.15mm for specimens.

- **Bamboo Fiber:**The average value of tensile strengthcalculated from three specimensare 42.4MPa for bamboo fiber composite. Average deformation at failure of bamboo fiber compositeis3.895 mm. The Load deformation curve is plotted for the specimens shownin figure 6. Ultimate load of bamboo fiber from test is 3.836 kN.
- **Waste Silk Fiber:**The average value of tensile strength calculated from tensile testing is 50.4 MPa for bamboo fiber composite. Average deformation at failure of bamboo fiber composite is 4.358 mm.

Ultimate load of bamboo fiber from test is 4.785kN. Obtained magnitudes of mechanical properties for bamboo and waste silk were listed on table 2.

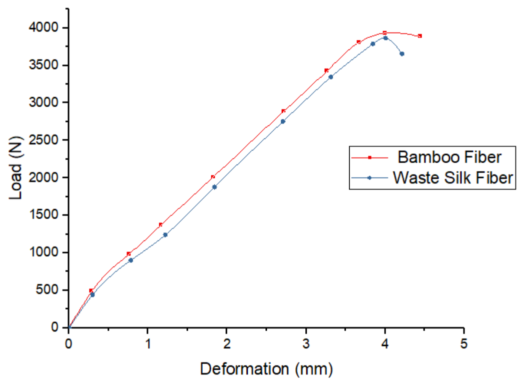

FIGURE 6
LOAD DEFORMATION CURVE

TABLE 2
MECHANICAL PROPERTIES OF BAMBOO AND SILK FIBER COMPOSITES

Sl No.	Test	Material	Results	Unit
1	Tensile Strength	Bamboo Fiber	42.4	MPa
2	Impact Strength	Bamboo Fiber	6.20	kJ/m^2
	Tensile Strength	Waste Silk Fiber	50.4	MPa
	Impact Strength	Waste Silk Fiber	19.45	kJ/m^2

CONCLUSIONS

Natural fiber compositeswere manufactured and tested to find out themechanical properties. The reinforcement material used for the composite were waste silk and bamboo fiber and matrix was Epoxy Resin. NFRP composites manufactured using hand layup and compression molding technique with a proportion of 80 %fiber and 20 % epoxy. Test to find out tensile and impact strength was conducted. Results shows these materials can be used for many industrial applications.As silk fiber used in this study is a waste material of textile industry so it is cheaply available, and it shows the perfect utilization of waste product. Silk fibers are bio-degradable and highly crystalline with well aligned structure and would not induce a serious environmental problem like in synthetic fibers.

It is evident that bamboo fiber is also a promising alternative for structural applications. Bamboo fiber composites are incredibly sustainable. Production of bamboo fiber is relatively simple and cheap. It can be produced in large quantities to meet requirements of composite manufacturing.

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