A STUDY ON THE EFFECT OF FIBER PARAMETERS ON THE MECHANICAL BEHAVIOR OF BAMBOO-GLASS FIBER REINFORCED EPOXY BASED HYBRID COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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DEPARTMENT OF MECHANICAL ENGINEERING
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ROURKELA 769008

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled ***"A Study on the Effect of Fiber Parameters on the Mechanical Behavior of Bamboo-Glass Fiber Reinforced Epoxy Based Hybrid Composites"*** submitted by **Ojaswi Panda (**Roll Number: **108ME070)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela, is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted elsewhere for the award of any degree.

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A C K N O W L E D G E M E N T

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ABSTRACT

Polymeric materials reinforced with synthetic fibers such as glass, carbon, and aramid offer the advantages of higher stiffness and strength to weight ratio as compared to conventional construction materials like wood, concrete, and steel. Despite these advantages, the widespread use of synthetic fiber reinforced polymer composites has a tendency to decline because of their high initial costs and adverse environmental impact. In recent years, the natural fiber composites have attracted substantial importance among the structural materials. There has been a fast growing interest in using the natural fibers as reinforcements in the composites. The attractive features of natural fibers are their low cost, light weight, high specific modulus, renewability and biodegradability. Among many of the natural fibers (like jute, sisal, bamboo, coir, banana etc.), bamboo fiber is one of the most promising one, because of its low cost, light-weight, short growth cycle and high availability. Use of bamboo fiber can help to reduce the demand for wood fibers and environmental impacts associated with wood fiber harvesting, hence considerably lowering the stress on wood forests. Bamboo fiber reinforced polymer composites have moderate mechanical properties but their properties can be greatly enhanced by mixing of synthetic fibers or by the treatment of fiber in the alkali medium. Attempts have been made in this research work not only to explore the potential utilization of bamboo fiber but also a means of mixing of other synthetic fiber in the polymer composites for making value added products. Nine different types of hybrid composites (bamboo and glass fiber) have been prepared by hand lay up technique for physical and mechanical characterizations.

The untreated bamboo/glass composites have three different fiber loading i.e 5:15 wt.% (bamboo: glass fiber loading), 10: 10wt.% (bamboo: glass fiber loading) and 15: 5 wt.% (bamboo: glass fiber loading) by varying the fiber length in each fiber loading from 0.5cm to 1.5cm respectively. The hardness of the three different series of hybrid composites varies from 13.21Hv to 15.95Hv for 0.5cm

fiber length, 9.75Hv to 18.51Hv for 1cm fiber length and 19.61Hv to 21.25Hv for 1.5cm respectively.

Mechanical properties like tensile strength, tensile modulus, flexural strength and flexural modulus have been measured along with the surface characterizations of the all the fiber reinforced epoxy composites. It has been observed from this work the tensile strength of the composites slightly increase in all the three different fiber loading irrespective of fiber lengths. The maximum tensile strength among all the composites is 24.41MPa for 0.5cm fiber length i.e 5wt.% bamboo fiber and 15wt.% glass fiber reinforcement respectively. Whereas, in case of tensile modulus is concerned 1.5cm fiber length shows maximum modulus among all the composites. However, Flexural strength of these composites increases for all the fiber length. Whereas, flexural modulus is concerned the modulli trend slightly varies as compared with flexural strength of the hybrid composites

Scanning electron microscopy (SEM) has been performed on the samples to study the fracture mechanisms on the composite surface in all the nine different sets of the samples.

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C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

With the recent technological advances in engineering, material science has assumed a position of utmost importance. The interest in advanced materials is increasing rapidly, both in terms of their research and application. It is a truism that technological development depends on advances in the field of materials. One does not have to be an expert to realize that the most advanced turbine or aircraft design is of no use if the adequate materials to bear the service loads and conditions are not available. Whatever the field may be, the final limitation on advancement depends on materials. Composite materials in this regard represent nothing but a giant step in the ever constant endeavor of the optimization in materials [1].

The mechanical shortcomings of homogenous materials and the need for composites were realized in the early 1950s, with the advent of the space age**.** Almost all homogenous materials have their inherent shortcomings in mechanical respect. When they are stiff and sufficiently hard, they are most brittle and hardly processible; when they are ductile and well-processible, they are not stiff and hard enough. By the combination of materials, it proved possible to attain a situation in which the "whole is more than the sum of its parts". Composites were a need in the evolution of engineering materials. The simplest combination is that of only two materials, one acting as reinforcement and the other as the matrix [2].

The composite materials have advantage over other conventional materials due to their higher specific properties such as tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable the structural design to be more versatile. Due to their many advantages, they are widely used in the aerospace industry, in a large number of commercial mechanical engineering applications, such as machine components, Internal combustion engine parts, railway coaches, flywheels, process industries, sports and leisure equipments; marine structures; and biomedical devices [3].

1.2 Definition:

A composite material may be defined as,

"*Composite materials are material systems that consist of a discreet constituent (the reinforcement) distributed in a continuous phase (the matrix) and that derive their distinguishing characteristics from the properties and behavior, geometry and arrangements of constituents and from the properties of the boundaries between the constituents"* [4].

1.3 Constituents of Composite Materials:

Composite materials have two components: the matrix and the reinforcement. The *matrix material* surrounds and supports the reinforcement materials and maintains their relative positions. The *reinforcements* impart their special mechanical and physical properties to enhance the matrix properties. A combination of the two produces material properties unavailable from the individual constituent materials, while the wide variety of available matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. Both the constituents are arranged intimately such that one or more discontinuous phases are embedded in the continuous phase. The discontinuous phase is commonly known as the reinforcement and the continuous phase is the matrix. The bulk of the continuous phase is comprised of the matrix. The matrix helps keep the reinforcing phase in place by maintaining their relative positions. The selection of the matrix and reinforcement affect the properties of the composites in different ways. Composites may be classified as follows, based on the geometry and the physical structure of Matrix and Reinforcement.

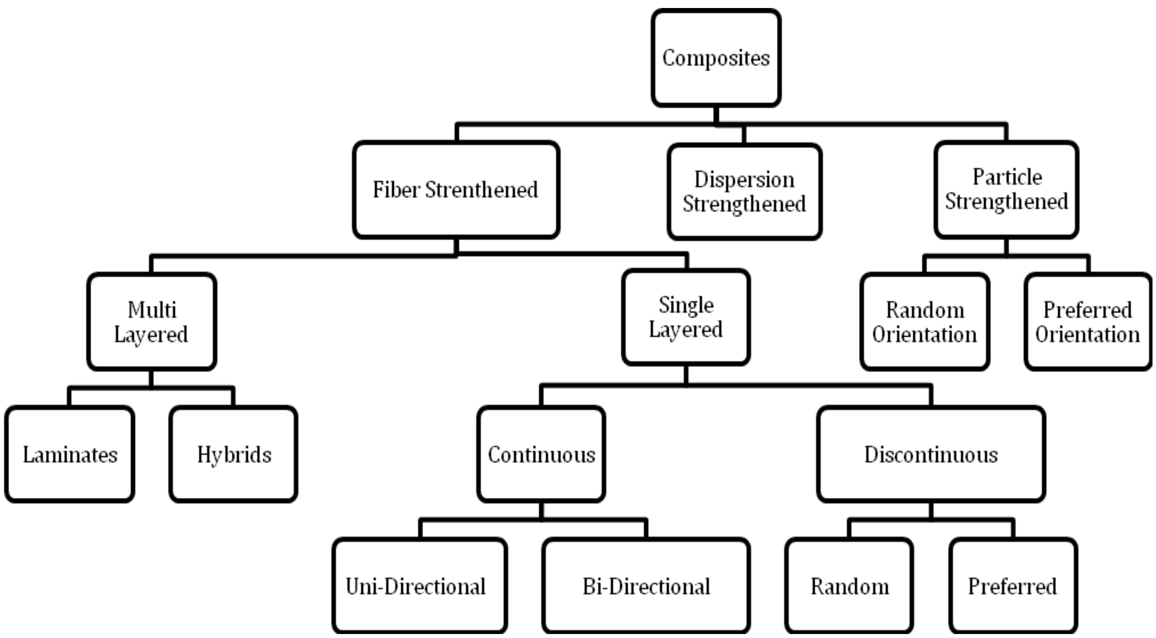

Figure1.1. Classification of Composites based on Geometry and Physical Structure of matrix and reinforcement [5]

1.4 The Matrix

The following types of matrices are most commonly used:

➢ *Metal Matrix Composites*: Metal matrices are generally used up to 1000 ^{0}C. They have improved thermal resistance as compared to pure metals and alloys. They also have high ductility, strength and fracture toughness. They have superior electrical, thermal conductivity and magnetic properties. Due to a low thermal expansion coefficient, they also possess a high dimensional stability. High density, complicated fabrication processes and high cost of production are the disadvantages of Metal matrices.

- *Ceramic Matrix Composites*: Ceramics are used to refer to a wide variety of non-metallic inorganic materials. They are generally processed at high temperatures. Most notable properties of CMCs include high resistance to heat, chemical abrasion and wear. Due to these reasons, it is also difficult to fabricate them economically. CMCs can be used up to temperatures of 1500 ^{0}C. The main objective of using CMCs is to get increased toughness.
- *Polymer matrix Composites*: This is the most widely used group of matrices. A polymer is a long chain molecule having one or more repeating units of atoms joined together by strong covalent bonds. In solid state, the polymer the polymer molecules may be visualized as being frozen in space. They may either be oriented in a random fashion (amorphous polymers) or in a mixture of random fashion and orderly fashion (as found in semi-crystalline polymers). They have extremely good properties such as high stiffness and fracture toughness, good corrosion and abrasion resistance.

Polymer matrix composites are the subject of growing interest in recent times due to the immense versatility in their applications. They can further be classified into the following two types:

- Thermosetting Resins: The most commonly used resins are Epoxy, Unsaturated Polyester and Vinyl Ester. The liquid resin is generally converted into a hard solid by the process of chemical cross linking. This leads to the formation of a tightly bound three dimensional network, which lends the strength to the polymer block. The mechanical properties of various resins depend on the molecular units making up the networks. They also depend on the length and density of the cross links. The most notable property of the thermosetting resins is they have lower strains to failure. These may be essentially considered to be brittle materials.

- Thermoplastics: These polymers do not have a cross linked structure. They derive their strength and stiffness characteristics from the properties of the individual monomer units as well as the very high molecular weight. The advantage of thermoplastics is that in amorphous thermoplastics, there is a high concentration of molecular entanglements. These act like cross-links. Although, a degree of molecular order and alignment can be seen in semi crystalline materials. Heating of thermoplastics leads to the disentanglement of molecules and thus it turns from solid to a slightly liquid (viscous) state. An amorphous Viscous liquid is formed on heating the crystalline materials. These materials have anisotropic properties. They have good chemical resistance and good thermal stability. Many thermoplastics are also resistant to water absorption. The most common property is that all thermoplastics undergo large deformation before the final fracture. Commonly used thermoplastics are Nylon, polypropylene, acrylics, etc.

1.5 The Reinforcement

Fiber reinforced composites are the most widely used class of polymer composites. Recently, fiber reinforced polymer matrix composites have found applications in various areas such as automotive, marine, aerospace etc. due to their high specific stiffness and strength [6]. The fibers are the most important constituents of the FRCs. They occupy the largest volume fraction in the laminate. Thus they bear a major portion of the load acting on the composite structure. The fibers in a fiber reinforced composite influence the following aspects [7].

- ✓ Density
- ✓ Tensile Strength and Modulus
- ✓ Compressive Strength and modulus
- ✓ Fatigue strength and Failure mechanisms
- ✓ Electrical and Thermal conductivities
- ✓ Cost of composite structure

As such, the fiber reinforced composites have generated much research interest, owing to their ability to enable customization of properties and hence the ability to replace conventional materials in recent technological advances.

The properties of the fiber reinforced composites depend on various fiber parameters, the most important being fiber length, fiber orientation and fiber loading. Fiber orientation is one of the crucial parameters of the composite material. Fibers show excellent tensile properties in the longitudinal direction. Thus the direction of orientation enables us to tweak the anisotropic properties of the composite material. The material will show better ductile properties along the direction of orientation of the fibers. Similarly, it can be safely assumed that the randomly oriented fibers have isotropic properties, as the fibers are then oriented in all possible directions. Another important parameter is the fiber loading. Fiber loading refers to the percentage of fiber present in the composite. Amount of fiber present in the composite is an important parameter as with the increasing volume of fibers, we can get an increase in strength and stiffness. However with increasing amount of fiber, there is also a chance of it not bonding properly with the matrix base. Thus the fiber loading ratios need special attention during their design. Similarly fiber length is also an important parameter which can influence various properties of the composite [8] [9].

Table 1.1: Comparative properties of some of the widely used Fibers [10, 11]

Fiber	Specific Gravity	Tensile Strength (MPa)	Tensile Modulus (GPa)
Jute	1.3	393	55
Sisal	1.3	510	28
Flax	1.5	344	27
Sun-hemp	1.7	389	35
Pineapple	1.56	170	40
Bamboo	0.863	520	36
Glass Fiber E	2.5	3400	28
Kevlar 29	1.44	2860	64
Carbon Fiber (AS-4)	1.8	4000	245

Some commonly used fibers are Aramid Fibers (polymeric fibers), Glass Fibers, Carbon Fibers and Natural Fibers. Of these, the synthetic fibers generally have superior properties, but are extremely costly to fabricate and synthesize. Due to this reason, the applications of fiber reinforced composites are limited to high end engineering products. On the other hand, natural fibers are cheap, eco friendly and easily available. The comparative properties of some of the most commonly used fibers are shown in the Table 1. 1.

The main demerit of the synthetic fibers is their high cost of processing and fabrication. With everyday technology developing at a rapid pace, the development of products that are more economic, with a small compromise in their properties has led to research in many alternative fiber options. The natural fibers have got the lion's share of the scientific attention. Being widely and easily available, being exceptionally cheap, eco-friendly, renewable and having a high specific mechanical performance are some of the most important properties of natural fibers, which make it a favorite option for the replacement of Synthetic fibers. The term 'natural fibers' may refer to a very wide category of fibers. All the fibers are derived from natural sources. They may either be Animal fibers (animal hair, chicken feather etc.) or Plant Fibers (Leaf, seed, etc.).

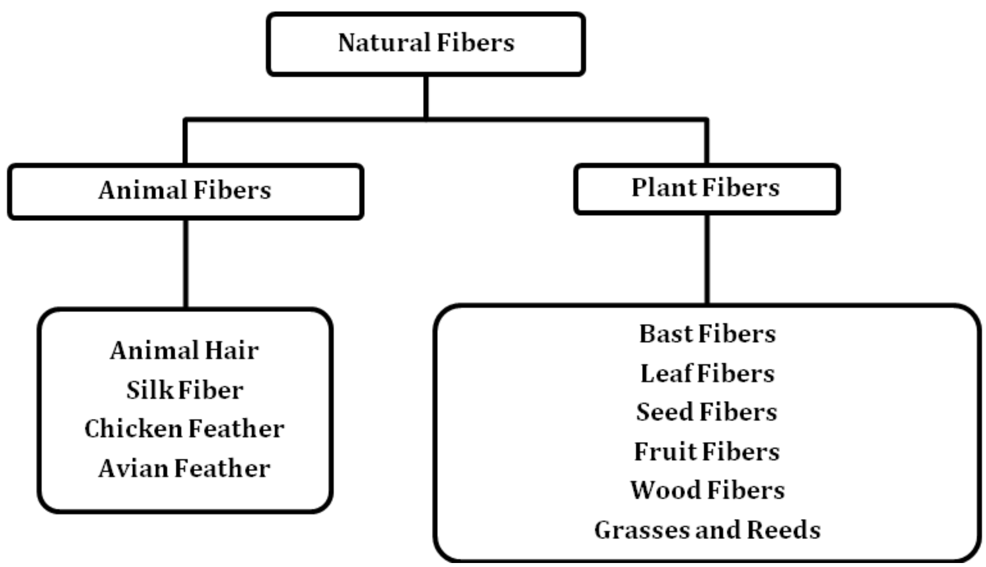

Figure 1.2. Classification of Natural Fibers [12]

The natural fibers are highly complex structures. Their three dimensional structure is found to consist of Cellulose, Hemicelluloses, Pectin and Lignin. They contain hydroxyl ions, and are distributed throughout the fiber wall. Interestingly, natural fibers may be considered as being tiny fiber reinforced composites on their own. They are made up of mainly cellulose fibrils (acting as fibers) embedded in a matrix of lignin. Apart from these, they also contain various extraneous compounds such as low weight extractives and inorganic ash.

The main reason natural fibers are used is when they are added to plastic or polymer matrices, they significantly improve mechanical performance. An improvement in strength and stiffness is obtained without significant increase in density or the cost of the material. Table 1.2 shows the composition of a few natural fibers

Table 1.2. Composition of a few Natural Fibers [13, 14]

Natural Fiber	Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)
Coir	43	45	-	-
Banana	65	5	-	-
Sisal	47-62	7-9	21-24	0.6-1
Jute	41-48	21-24	18-22	0.8
Bamboo	26-43	21-31	15-26	1.7-5
Kenaf	44-57	15-19	22-23	2-5
Cotton	85-90	0.7-1.6	1-3	0.8-2
wood	40-45	26-34	7-14	<1

1.6 The Need for Hybrid Composites

A hybrid composite is one which has two or more than two different reinforcement fibers inside the matrix. The interest in natural fibers was generated due to the high material and processing cost, toxicity and specific gravity of the synthetic fibers. But, the use of natural fibers has been somewhat restricted as they have poorer mechanical properties as compared to the synthetic fibers. Some of these drawbacks are namely, high moisture absorption, poor wettability, limited thermal stability and poor adhesion properties of natural fibers [15]. Hybridization allows the composite designers to tweak the properties of the composite material as per their specialized requirements. As the whole idea behind composites is to get the best of all constituents, hybrid composites allow an excellent opportunity to get the best cost and performance ratio.

Randomly oriented hybrid fibers are gaining much popularity. The constituent fibers are intimately mixed such that no clusters of either type are present in the composite. Kalaprasad *et al.* [16] [17] have observed a considerable improvement in the in the mechanical properties of Low Density Polyethylene (LDPE) based short banana-glass fibers. Yang *et al.* [18] have studied and reported an increase in the Impact strength of PVC based banana-glass fiber hybrid composite.

In the present work of study, an Epoxy based Bamboo-Glass Fiber Hybrid composite has been considered for study. Bamboo is a widely available Natural Fiber, which can grow abundantly in numerous climatic conditions. It can be found in the hot regions of the world, such as Australia, West India, Sub-Saharan Africa, Argentina and Chile to the cold regions of the world, such as East Asia and Northern United States. Another advantage of Bamboo fiber is that it reaches full growth in just about a few months and attains its maximum mechanical properties in a few years. Thus bamboo is widely available and has tremendous economic advantages. The hardness of the column of bamboo depends on the number of fiber bundles and the manner of their scattering.

The mechanical properties of bamboo such as stiffness, impact strength and flexibility are high and are comparable to the synthetic fibers such as glass fiber. The potential for development of structures made of bamboo has already been researched; however its application in composite materials has been somewhat limited. In the present work, the properties of bamboo fiber (also known as 'natural glass fiber') in combination with synthetic glass fiber in an epoxy based matrix have been studied.

The present research work is undertaken to develop a new class of natural fiber reinforced polymer composite filled with ceramic filler and to study their mechanical and erosion wear behaviour. Attempts have been made to explore the potential use of bamboo fiber as reinforcement in polymer composites. The specific objectives of this work are clearly outlined in the next chapter.

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CHAPTER 2

LITERATURE SURVEY

This section focuses on the research work that has already been carried out for testing the mechanical properties of the Fiber Reinforced Hybrid composites. Literature review of such work needs to be done in order to understand the background information available, the work already done and also to show the relevance of the current project. This chapter presents a general idea of the factors which affect the mechanical properties of hybrid fiber reinforced polymer composites.

In polymer composites, the matrix is the major load bearing component. In order to increase this load bearing capability, the reinforcements are introduced into the matrix. Bledzki *et al* [33] have investigated the effect of introduction of Flax and jute fibers on the mechanical properties of the composites. Increasing the fiber content results in an increase in the shear modulus and impact strength of the composites. Many similar studies on natural fibers such as bamboo, flax, hemp and kenaf [19] [20] [21] [22] reveal that the mechanical properties of Fiber reinforced composites depend on several fiber parameters such as fiber length, fiber loading, fiber aspect ratio, fiber orientation and fiber matrix adhesion.

The use of cellulosic fiber reinforced polymer composites is beneficial as they are cheap, light weight, and pose no health hazards to people working with them. This has a potential for structural applications. But, despite these benefits, the natural fiber polymer matrix composites have numerous disadvantages such as lower modulus, low strength and poor moisture resistance. It has been seen from previous studies that the moisture causes the degradation of natural fibers faster than synthetic fibers, owing to their organic nature [23] [24] [25]. Thus the hybridization of natural fibers with synthetic fibers, which are stronger and more corrosion resistant are gaining much interest. The idea is that by using two types of fibers in a hybrid composite, the shortcomings of one can be compensated by the advantages of the other. Through proper material design, a balance in properties may be achieved.

The degree of mechanical reinforcement that can be obtained by the addition of Glass fibers in bio-fiber reinforced polyester composites has been studied by Mishra *et al* [26]. It was found that the addition of relatively small amounts of glass fiber to the polyester matrix based pineapple leaf fiber and sisal fiber-reinforced enhanced the mechanical properties, resulting in a positive hybrid effect. Optimum glass fiber loadings for PALF/glass hybrid polyester and sisal/glass hybrid polyester composites are 8.6 and 5.7 wt. percentage respectively. It has also been found that the degree of moisture absorption of hybrid composites is less than that of single fiber composites.

Jacob *et al* (2003) [27] studied the effects of concentration of fibers, fiber ratio and the modification of fiber surface in sisal/oil palm hybrid fiber reinforced rubber composites. Increasing the concentration of fibers resulted in reduction of tensile strength and tear strength. At the same time, an increase in modulus of the composites was also seen. The vulcanization parameters, processability characteristics, and stress–strain properties of these composites were analyzed. The rubber/fiber interface was improved by the addition of a resorcinol-hexamethylene tetramine bonding system. It was revealed from the fiber breakage analysis that the extent of breaking was low. It was also found that the mechanical properties of the composites in the longitudinal direction of the fibers were superior to that in the transverse direction.

The mechanical properties of a composite laminate based on natural flax fiber reinforced recycled high density polyethylene under conditions of tensile and impact loading were investigated by Singleton *et al* (2003) [28]. They determined the stress–strain characteristics, of yield stress, tensile strength, and tensile (Young's) modulus, of ductility and toughness as a function of fiber content experimentally. It was seen that by changing the fiber loading and by controlling the bonding between the layers of the composite, improvements in strength and stiffness combined with high toughness can be achieved. The mechanical properties were found to be optimum for 15 – 20 % of flax fiber loading. It was also seen that material properties show greater degree of variation at higher fiber volume fractions, due to fiber clumping.

Velmurugan *et al* (2007) [29] studied the mechanical properties of randomly mixed short fiber composites and estimated the optimum fiber length and fiber loading. They dealt with the properties of randomly mixed palmyra fiber and glass fiber reinforced rooflite hybrid composites. Mechanical properties such as tensile, impact, shear and bending properties of the composites were studied. The mechanical properties of the composites are found to be improved on account of the hybridization of the fibers used for reinforcement. The composites reinforced with 50mm fibers and having a fiber loading of 50% were found to have the best mechanical properties. The properties were found to be increasing continuously due to the addition of the glass fibers. It was also found that the water absorption decreases considerably with the addition of glass fibers.

Joshi *et al* (2009) [30] investigated the effect of hybridization of chopped glass fibers with small amounts of mineral fibers. It was found that hybridization makes the glass fiber composites more suitable for technical applications. This study was based on the performance of polypropylene based short wollastonite fiber (injection molded) and chopped glass fiber reinforced hybrid composites. Results showed that properties of the hybrid glass fiber and wollastonite composite was found to be comparable to that of polypropylene glass fiber composites. Fiber length distribution and fracture surface analysis was done to study the fiber breakage fracture mechanism. It was found that the tensile, flexural, and impact properties of the filled polypropylene were considerably higher than those of unfilled polypropylene composites. With the addition of 30% glass fibers, the tensile strength, flexural strength, tensile modulus and the flexural modulus increased sharply in contrast to non hybrid composites. This showed the stiffening effect of the glass fibers. On the other hand, the addition of the wollastonite fibers from 10% to 30%, the above values decreased gradually. Athijayamani *et al* (2009) [31] studied the variation of mechanical properties of roselle and sisal fibers hybrid polyester composite at dry and wet conditions were studied. Properties such as tensile, flexural, and impact strengths were taken into consideration. The composites of roselle/sisal polyester-based hybrid composites with different weight percentages of fibers were prepared. Roselle and sisal fibers at a ratio of 1:1 had been incorporated in unsaturated polyester resin at various fiber lengths. They found that when the fiber content and length of the roselle and sisal fibers were increased, the tensile and flexural strength of the composite increased.

Valente *et al* (2011) [32] studied the mechanical properties of recycled glass fiber-wood flour reinforced composites. The properties studied included flexural modulus and strength, hardness (which was studied as a function of temperature), screw withdrawal resistance and water absorption behavior. It was fond that the flexural modulus and hardness increased as a function of increasing wood flour and glass fiber content. In contrast, the flexural strength and screw withdrawal resistance decreased as a function of increasing wood flour content, although the resistance was unaffected by wood flour content up to 35 wt%. Although it was found that the addition of glass fibers has a positive effect.

Thwe *et al* [34] compared the fatigue behavior under cyclic tensile load and the hygrothermal ageing of Bamboo fiber reinforced polypropylene (BFRP) and bamboo-Glass fiber reinforced polypropylene (BGRP). The results showed that with respect to stiffness and retention of tensile strength, the BGRP samples have better resistance to environmental ageing as compared to BFRP composites. It also showed that the BGRP has better fatigue resistance than the BFRP composites at all load levels. Thus it shows the improvement in the mechanical properties due to hybridization.

Nayak *et al* [35] studied the effect of addition of bamboo- glass fiber reinforcements to the polypropylene matrix (BGRP). Comparisons were made between the BGRP and the virgin polypropylene. Fiber loading was taken as a parameter. Results showed that the composites prepared at 30% fiber loading with 2% MAPP concentration showed optimum mechanical performance. As compared to the virgin polypropylene, at a glass fiber: bamboo concentration of 15:15, the tensile strength, flexural strength and the impact strength increased by around 69%, 86% and 83% respectively. Also, in the case of BGRP, less fiber pullout was noticed in case of hybrid composites.

Rao *et al* [36] studied the effect of bamboo/glass fibers reinforcement in the epoxy matrix on the flexural and compressive properties. These hybrid composites were found to exhibit good flexural and compressive properties. The effect of alkali treatment on these fibers was also studied.

2.1 The Knowledge Gap:

A thorough review of the literature survey shows that the hybrid composites have a lot of potential as advanced materials in various diverse sectors such as structural, automotive, aerospace and marine applications. However owing to their recent discovery, not much research has been done on the effects of the fiber parameters such as fiber length and fiber loading on the mechanical performance of the polymer composites. Moreover, there exist very few literatures on the effect of bamboo- glass fiber reinforcement on polymer composites.

2.2 Objective of the Present Research Work:

Keeping in view the above mentioned knowledge gaps, the following objectives were chosen for the present research project work.

i. Fabrication of a new class of epoxy based hybrid composites reinforced with randomly oriented short glass fibers and bamboo fibers.
ii. Evaluation of mechanical properties such as tensile strength, flexural strength and micro hardness for these composites.
iii. To study the influence of fiber parameters such as fiber length and fiber loading on the mechanical behavior of the composites.
iv. To study the surface morphology using SEM study.

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CHAPTER 3

MATERIALS AND METHODS

This chapter details the materials used and methodologies adopted during the fabrication, sample preparation, mechanical testing and characterization of the hybrid composites. The raw materials used in the study are:

- Epoxy resin
- Short bamboo Fiber
- Glass Fiber (E-Glass)
- Hardener

3.1 Sample Preparation:

The short bamboo fiber which is taken as reinforcement in this study is collected from local sources. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. Wooden moulds having dimensions of 180 x 180 × 40 mm^3 were first manufactured for composite fabrication. The short bamboo fiber and E- Glass fibers are mixed with epoxy resin by simple mechanical stirring and the mixture was poured into various moulds, keeping in view the requirements of various testing conditions and characterization standards. The composite samples of nine different compositions (S-1 to S-9) are prepared. The composite samples S-1 to S-9 are prepared in three different percentages of Glass and bamboo fibers (5 wt %, 10 wt % and 15 wt %). This is done while keeping the epoxy content at a fixed percentage (i.e. 80 wt %). Three different lengths of short bamboo fiber are used (0.5 cm, 1 cm, 1.5 cm), while keeping the length of the glass fiber constant (1.2 mm). The detailed composition and designation of composites are shown in Table 1. A releasing agent is used on the mould release sheets to facilitate easy removal of the composite from the mould after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 h at a constant load of 50 kg. After curing, the specimens of suitable dimension are cut using a diamond cutter for mechanical tests as per the ASTM standards. The composition and designation of the composites prepared for this study are listed in the following table. The samples have been prepared by varying the fiber length and fiber loading for the two fibers.

Figure 3.1 shows short bamboo fibers and bamboo fiber reinforced epoxy composite.

Table 3.1. Designation of Composites

Composites	Compositions
S-1	Epoxy (80 wt%)+Bamboo fiber (5 wt%, 0.5 cm)+Glass fiber (15 wt%)
S-2	Epoxy (80 wt%)+Bamboo fiber (10 wt%, 0.5cm)+Glass fiber (10 wt%)
S-3	Epoxy (80 wt%)+Bamboo fiber (15 wt%, 0.5cm)+Glass fiber (5 wt%)
S-4	Epoxy (80 wt%)+Bamboo fiber (5 wt%, 1.0cm)+Glass fiber (15 wt%)
S-5	Epoxy (80 wt%)+Bamboo fiber (10 wt%, 1.0cm)+Glass fiber (10 wt%)
S-6	Epoxy (80 wt%)+Bamboo fiber (15 wt%, 1.0cm)+Glass fiber (5 wt%)
S-7	Epoxy (80 wt%)+Bamboo fiber (5 wt%, 1.5cm)+Glass fiber (15 wt%)
S-8	Epoxy (80 wt%)+Bamboo fiber (10 wt%, 1.5cm)+Glass fiber (10 wt%)
S-9	Epoxy (80 wt%)+Bamboo fiber (15 wt%, 1.5cm)+Glass fiber (5 wt%)

Figure 3.1: Short bamboo fiber and glass fiber reinforced epoxy based composite

3.3 Mechanical testing of composites

The tension test was performed on all the three samples as per ASTM D3039-76 test standards. The tension test is generally performed on flat specimens. A uni-axial load is applied through the ends. The ASTM standard test recommends that the length of the test section should be 100 mm specimens with fibers parallel to the loading direction should be 11.5 mm wide and.

To find out the flexural strength of the composites, a three point bend test is performed using Instron 1195. The cross head speed was taken as 10 mm/min and a span of 30 mm was maintained. The strength of a material in bending is expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure. In a conventional test, flexural strength expressed in terms of MPa is equal to

Leitz micro-hardness tester is used for micro-hardness measurement on composite samples. A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces is forced under a load F into the sample. After removal of the load, the two diagonals of the indentation (X and Y) left on the surface of the sample are measured and their arithmetic mean L is calculated. The load considered in the present study is 24.54N and Vickers hardness is calculated using the following equation:

$$H_V = 0.1889\frac{F}{L^2} \qquad \text{and} \qquad L = \frac{X+Y}{2} \tag{3.1}$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

3.4 Scanning electron microscopy (SEM)

Scanning electron microscope of Model JEOL JSM-6480LV (Figure 3.2) was used for the morphological characterization of the composite surface. The samples are cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. To enhance the conductivity of the composite samples a thin film of platinum is vacuum evaporated onto them before the micrographs are taken. The fracture morphology of the tensile fracture surface of the composites were also observed by means of SEM.

Figure 3.2 Scanning Electron Microscope Set up

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CHAPTER 4

MECHANICAL CHRACTERISTICS OF COMPOSITES:

RESULTS & DISCUSSION

This chapter presents the results of mechanical properties of short bamboo fiber and glass fiber reinforced epoxy based hybrid composites.

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Bamboo/Glass fiber reinforced epoxy composites

4.1 Mechanical characteristics of hybrid fiber epoxy composites

The mechanical properties of the short bamboo and glass fiber reinforced epoxy composites with different fiber loading under this investigation are presented in Table 4.1. It is evident from the Table 4.1 that at 15:5 wt% of fiber loading show better mechanical properties as compared to others.

Table 4.1 Mechanical properties of the hybrid fiber epoxy composites

Sample no	Fiber Length (cm)	Fiber loading (%)	Tensile Properties		Flexural Properties		Vicker's Hardness (HV)
			Tensile Strength	Tensile Modulus	Flexural Strength	Flexural Modulus	
1	0.5	5:15	15.13	330.78	43.08	4468.25	13.21
2	0.5	10:10	17.81	610.63	34.44	7637.30	14.35
3	0.5	15:5	24.41	625.64	88.61	9311.14	15.95
4	1	5:15	16.15	410.14	51.73	5648.12	9.75
5	1	10:10	16.56	310.22	58.31	6940.47	11.52
6	1	15:5	16.82	250.46	67.12	5555.11	18.51
7	1.5	5:15	14.18	346.70	33.49	18568.97	19.61
8	1.5	10:10	19.72	383.97	32.59	23785.51	19.25
9	1.5	15:5	23.31	632.57	72.91	28125.00	21.25

4.1.1 Effect of fiber loading on hardness of composites

Surface hardness of the composites is considered as one of the most important factors that govern the wear resistance of the composites. Figure 4.1 shows the effect of fiber loading on hardness of composites. The test results show that with the increase in fiber loading and fiber length the hardness value of the fiber reinforced epoxy composites is significantly increasing.

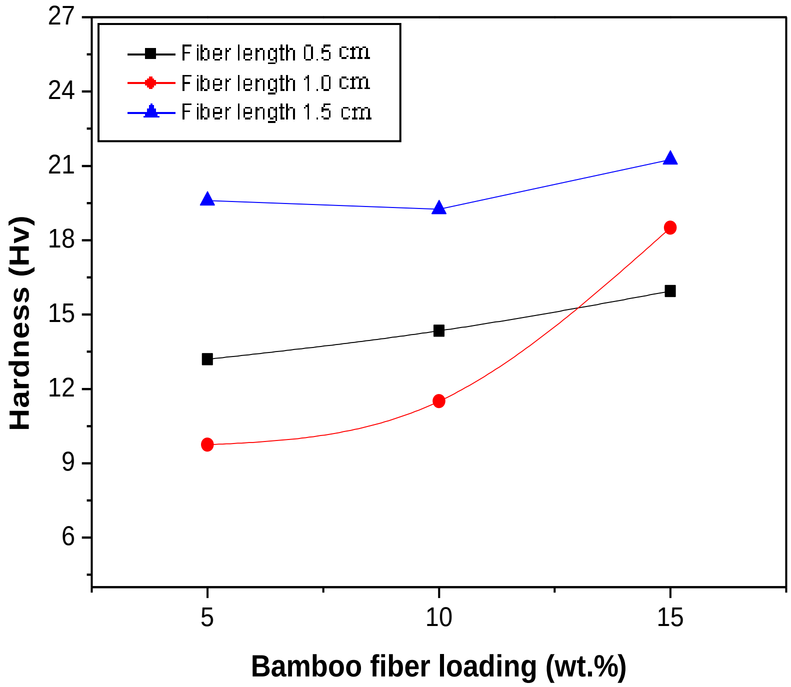


Figure 4.1. Effect of fiber loading on hardness of composites

4.1.2 Effect of fiber loading on tensile strength and modulus of composites

The effect of weight fraction of fibre on the tensile strength of the composite is shown in Figure 4.2. As the weight fraction of fibre increases in the composites up to 15:5 wt%, the tensile strength of composite is increases up to 24.41MPa for 0.5cm fiber length. The tensile properties measured in the present work are well compared with various earlier investigators [37-42], though the method of extraction of bamboo fiber is different. However, with the increase in fiber loading the flexural strength of the hybrid fiber reinforced epoxy composites are increased with fiber length except for 1mm fiber length filled composites show slightly decreasing in trend. This may be due to improper reinforcement or may be at 1mm fiber length the composites are not properly mixed with resin materials.

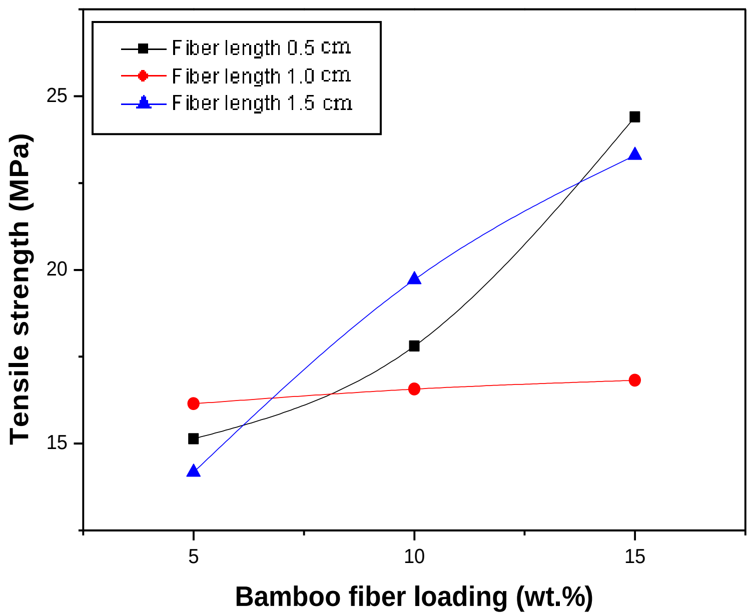


Figure 4.2. Effect of fiber loading on tensile strength of composites

The significant variation of tensile strength for different systems indicates fiber alignment is not the only the major factor which affects the mechanical performance; interfacial adhesion and the bamboo/glass fibers influences epoxy matrix properties also have a significant effect. Generally, modulus reflects the performance of both fiber and matrix interface to transfer the elastic deformation in the case of small strains without interface fracture. Therefore, it is not surprising that the tensile modulus is less sensitive to the variation of interfacial adhesion than the tensile strength which is strongly associated with interfacial failure behaviour. The increase in tensile strength is due to the cross-linking network formation between the fibers and the resin materials in polymer matrix.

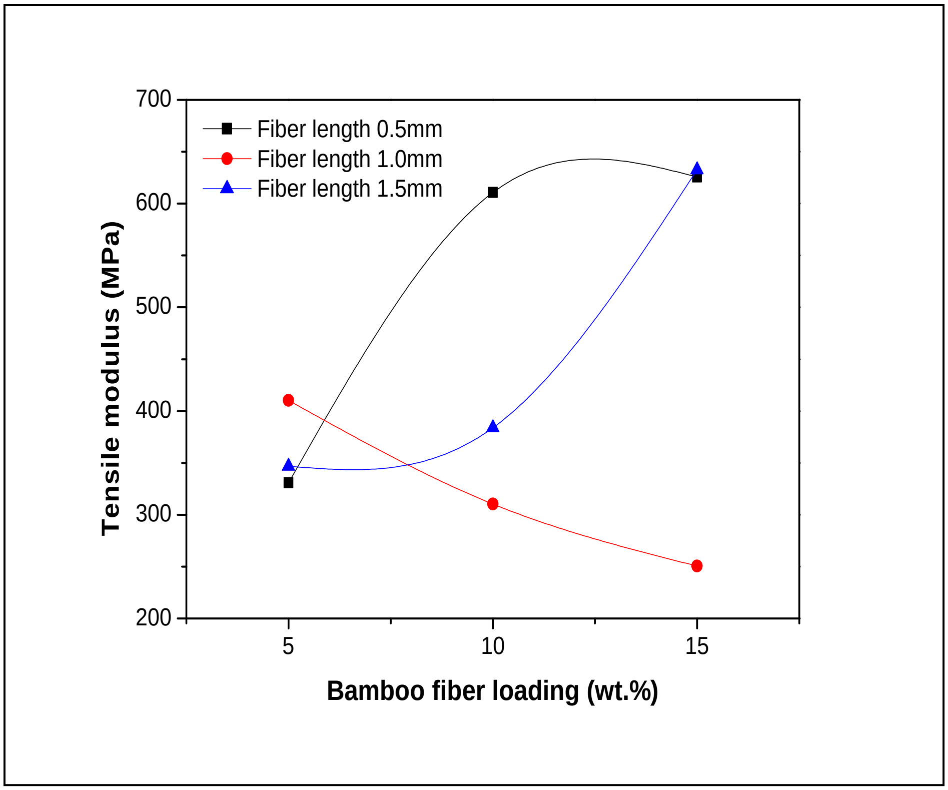


Figure 4.3. Effect of fiber loading on tensile modulus of composites

4.1.3 Effect of fiber loading on flexural strength and modulus of composites

Figures 4.4 and 4.5 show the effect of fiber loading on flexural strength and flexural modulus of hybrid fiber reinforced epoxy composites. The flexural strength of the hybrid composites show poor strength at 1cm fiber length irrespective of fiber loading. However, on increase in fiber loading and fiber length the flexural strength increases from 33.49MPa to 72.91MPa respectively as shown in Figure 4.4. It is also observed from Figure 4.4 that a linearly decreasing in trend up to a certain value of fiber loading (10:10 wt%) and then suddenly increasing due to strong interaction between the hybrid fibers and resin materials. According to Ismail et al. [43] and Yao and Li [44], this decrease is attributed to the inability of the fiber, irregularly shaped, to support stresses transferred from the polymer matrix and poor interfacial bonding generates partially spaces between fiber and matrix material and as a result generates weak structure. As flexural strength is one of the important mechanical properties of the composites. For a composite to be used as the structural application it must possess higher flexural strength. However, as far as flexural strength is concerned the hybrid composites show slightly better behaviour then tensile modulus is concerned.

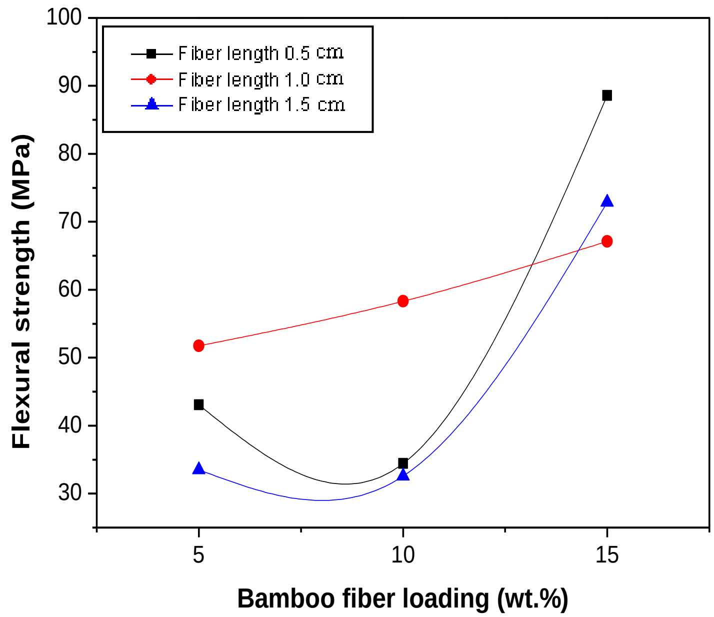


Figure 4.4. Effect of fiber loading on flexural strength of composites

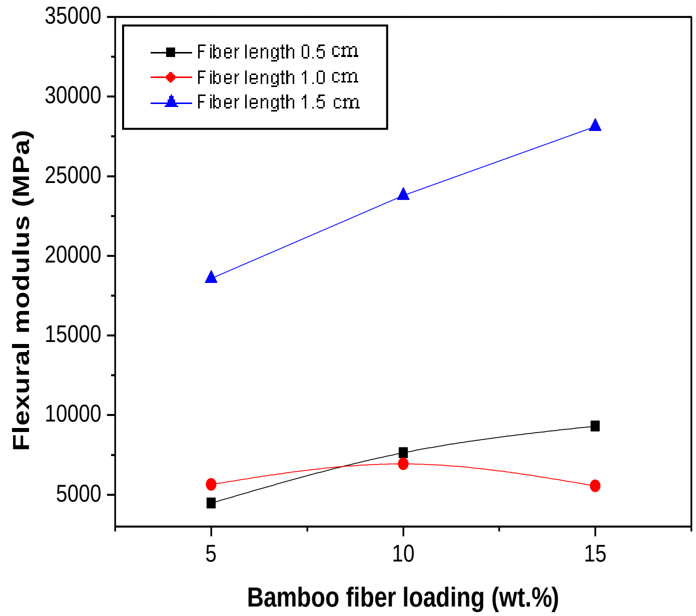
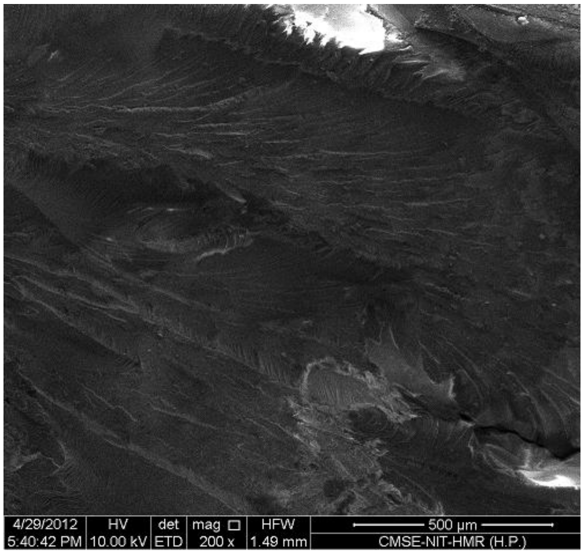


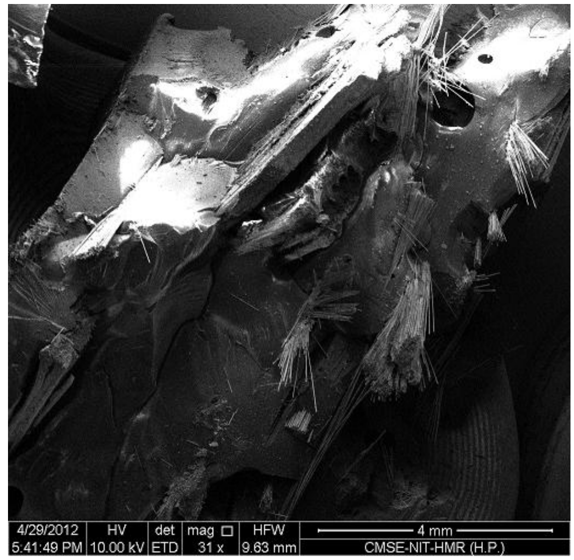
Figure 4.5. Effect of fiber loading on flexural modulus of composites

4.2 Surface morphology of the composites

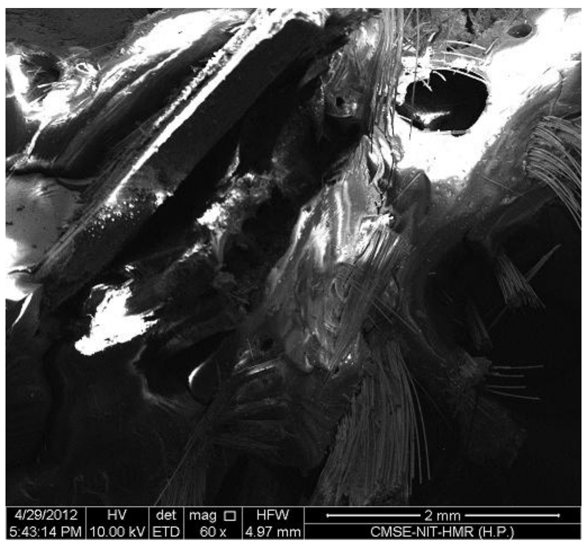
The fracture surfaces study of short bamboo and glass fiber reinforced epoxy composite before and after the tensile test has been shown in Figure 4.6.



(a)



(b)



(c)

Figure 4.6. Scanning electron micrographs of glass/bamboo fiber reinforced epoxy composite specimens before and after tensile testing

Figure 4.6(a) shows the fiber reinforced epoxy composite without tensile test sample. It is observed from the figure that the surface looks very smooth and lesser void content as shown on the upper surface of the composite sample. On applying tensile load on the 5:15wt% (bamboo: glass fiber) of fiber reinforced epoxy composite the fractured surface of composite shows breaking of matrix material under initial loading condition (Figure 4.6(b)). The highest strength was obtained when steam-exploded filaments were used as reinforcement. The SEM photographs of fractured surface after tensile tests are shown in Fig. 4.6.This is because without fibres to retard the crack growth upon external loading, the crack would propagate in an unstable manner irrespective of fiber loading. Besides, it is also observed that there is matrix plastic deformation near the crack tip zone, which contributes to the plastic zone location in the matrix material. However, with the increase in tensile load up to yield point relatively long extruding fibres can be observed, which is depicted by fibre pullout as shown in Figure 4.6(c). It is an important indication of crack deflection on the matrix surface, where the crack path is changed by the fibre and directed along the fibre surface. This leads to fibre debonding, which is an indication of matrix separation around the fibres as crack intersects the fibre-fiber/matrix interface zone. Subsequently, it causes fibre pull-out. Fig. 4.6c shows for 1mm fiber length composites lesser tensile strength this may be due to when bamboo fiber is not chemically or thermally treated and is mixed with glass fiber in the polymer composites there is still lignin on the surface of BF. Therefore, hydrophilic nature weakly sticks on short fiber bundle surface because lignin is not removed due to untreated. It can be removed only after fiber treatment in the alkali medium thereafter prepared a hybrid composites may increase the properties. The highest strength of hybrid composite (for 1.5cm fiber length) among three composites was attributed to the highest interfacial strengths between fibers and matrix material.

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CHAPTER 5

CONCLUSIONS

The experimental investigation on the effect of fiber loading and filler content on mechanical behavior of short bamboo fiber reinforced epoxy composites were conducted. Properties such as the Tensile strength, tensile Modulus, flexural strength, flexural modulus and hardness were evaluated from various experiments. The experiments lead us to the following conclusions obtained from this study:

1. The successful fabrications of a new class of epoxy based composites reinforced with short bamboo and glass fibers have been done.
2. The untreated bamboo/glass composites have three different fiber loading i.e 5:15 wt.% (bamboo: glass fiber loading), 10: 10wt.% (bamboo: glass fiber loading) and 15: 5 wt.% (bamboo: glass fiber loading) by varying the fiber length in each fiber loading from 0.5cm to 1.5cm respectively. The hardness of the three different series of hybrid composites varies from 13.21Hv to 15.95Hv for 0.5cm fiber ength, 9.75Hv to 18.51Hv for 1cm fiber length and 19.61Hv to 21.25Hv for 1.5cm respectively.
3. It has been observed from this work the tensile strength of the composites slightly increase in all the three different fiber loading irrespective of fiber lengths. The maximum tensile strength among all the composites is 24.41MPa for 0.5cm fiber

length i.e 5 wt.% bamboo fiber and 15wt.% glass fiber reinforcement respectively. Whereas, in case of tensile modulus is concerned 1.5cm fiber length shows maximum modulus among all the composites.

4. However, Flexural strength of these composites increases for all the fiber length. Whereas, flexural modulus is concerned the modulli trend slightly varies as compared with flexural strength of the hybrid composites
5. The fracture surfaces study of short bamboo and glass fibers reinforced epoxy composite after the tensile test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.
6. Possible use of these composites such as pipes carrying coal dust, industrial fans, helicopter fan blades, desert structures, low cost housing etc. is recommended. However, this study can be further extended in future to new types of composites using other potential natural fibers/fillers and the resulting experimental findings can be similarly analyzed.

6. 1 Scope for future work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like use of other potential fillers for development of hybrid composites and evaluation of their mechanical and erosion behavior and the resulting experimental findings can be similarly analyzed.

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CHAPTER 6

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