

# Fabrication and Study of Mechanical Properties of Bamboo Fibre Reinforced Bio-Composites

Honey Banga<sup>1</sup>, V.K. Singh<sup>2</sup>, Sushil Kumar Choudhary<sup>3</sup>

1B.Tech Student, Department of Mechanical Engineering, GBPUA&T, Pantnagar, UK, India,  
Corresponding Author, Email: honey14344@gmail.com

2Associate Professor, Department of Mechanical Engineering, GBPUA&T, Pantnagar, UK India,  
Email: vks2319@yahoo.com

3Research Scholar, Department of Industrial & Production Engineering, GBPUA&T, Pantnagar, UK, India  
Email: Sushil\_think@rediffmail.com

## Abstract

In the present work experimental investigation has been carried out to study the effect of bamboo fibres at different weight percentages (20, 30 and 40) to modify epoxy resin. Tests are conducted on 100 kN servo-hydraulic universal testing machine under displacement mode of control, digital Rockwell hardness testing machine and impact testing machine. Modifying epoxy resin through bamboo fibres and improve mechanical properties is main focus of this study. Bamboo fibres at different wt% (20, 30 and 40) are filled in epoxy resin and the effects of mixing bamboo fibres on mechanical and physical properties are studied. On the basis of mechanical testing results it is found that 30 wt% of bamboo fibre mixed epoxy is giving optimum mechanical properties. The addition of bamboo fibres has improved tensile, flexural and impact properties of epoxy resin and increased water absorption of the material. On the basis of overall study the epoxy modified with 30% of bamboo fibre is found to be better than other combinations.

**Keywords:** Bamboo fiber, MMC, CMC, PMC, BFGC, SIPN BJRP, BFRP

## I- INTRODUCTION

India endowed with an abundant availability of natural fiber such as jute, pineapple, bamboo, banana etc. has focused on the development of natural fiber composites primarily to explore value-added application avenues. Such natural fiber composites are well suited as wood substitutes in the housing and construction sector. The development of natural fiber composites in India is based on two pronged strategy of preventing depletion of forest resources as well as ensuring good economic returns for the cultivation of natural fibers. The developments in composite material after meeting the challenges of aerospace sector have cascaded down for catering to domestic and industrial applications. Composites, the wonder material with light-weight; high strength-to-weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, wood etc. The material scientists all over the world focused their attention on natural composites reinforced with jute, pineapple etc. primarily to cut down the cost of raw materials.

### A-Definition of composite

The most widely used meaning is the following one, which has been stated by Jartiz [1965] "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form". The weakness of this definition resided in the fact that it allows one to classify among the composites any mixture of materials without indicating either its specificity or the laws which should given it which distinguishes it from other very banal, meaningless mixtures. Kelly [1967] very clearly stresses that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength to resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them. Beghezan [1966] defines as "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings", in order to obtain improved materials. Van Suchetclan [1972] explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

## B- Characteristics of the composites

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the ‘reinforcement’ or ‘reinforcing material’, whereas the continuous phase is termed as the ‘matrix’. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may be spherical, cylindrical, or rectangular cross-sectioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties.

## C- Components of a composite material

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the ‘matrix’), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

- **Matrix** -Many materials when they are in a fibrous form exhibit very good strength property but to achieve these properties the fibers should be bonded by a suitable matrix. The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibers in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration.
- **Reinforcement**-The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways. For most of the applications, the fibers need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways for assembling fibres into sheets and the variety of fibre orientations possible to achieve different characteristics.
- **Interface**-It has characteristics that are not depicted by any of the component in isolation. Then interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical, chemical etc. The matrix material must “wet” the fibers. Well “wetted” fibers increase the interface surfaces area. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibers via the interface. This means that the interface must be large and exhibit strong adhesion between fibers and matrix. Failure at the interface (called debonding) may or may not be desirable.

## D-Classifications

Composite materials can be classified into many categories depending on the type of matrix material, reinforcing material type etc. According to the type of matrix material they can be classified as follows:

- Metal matrix type composites: MMC are composed of a metallic matrix (Al, Mg, Fe, Co, Cu)
- Ceramic matrix composites: CMC is a material consisting of a ceramic combined with a ceramic dispersed phase.
- Polymer matrix material: PMC are composed of a matrix from thermosetting (unsaturated polyester, epoxy) or thermoplastic (nylon, polystyrene) and embedded glass carbon, steel or Kerler fibres (dispersed phase).
- Particle composites- particle reinforced composites consist of a matrix reinforced by a dispersed phase in the form of particles. It can be either of random orientation or preferred orientation.
- Fibrous composite-.Short fiber: they consist of a matrix reinforced by a dispersed phase in the form of discontinuous fibers either of random or preferred orientations.
- Long fiber- they consist of a matrix reinforced by a dispersed phase in the form of continuous fibers. They can be either unidirectional or bidirectional.

- Laminate composites- when a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer composite.

Apart from that the two broad classes of composites are (1) Particulate composites and (2) Fibrous composites.

Fibrous Composite-A fiber is characterized by its length being much greater compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having along dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices. Man-made filaments or fibers of non-polymeric materials exhibit much higher strength along their length since large flaws, which may be present in the bulk material, are minimized because of the small cross-sectional dimensions of the fiber. In the case of polymeric materials, orientation of the molecular structure is responsible for high strength and stiffness. Fibers, because of their small cross-sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites.

## II- LITERATURE REVIEW

Composites have been a field of great interest in the last two decades and a lot of researchers are working in this area. This becomes very important to discuss the prominent works related to the polymer composites and their properties. The purpose of literature review is to provide background information on the issues to be considered in this thesis and to emphasize the relevance of the present study. Various aspects of polymer composites have been considered with reference to development as well as characterization of polymer composites. Existing literature related to the physical and chemical properties of the composites have been reviewed and a special emphasis has been given to erosion wear characteristics. Knowledge gap in the earlier investigations has been presented to outline the need and objectives of the present work.

### A- Bamboo fiber reinforced polymer composites

Natural fiber reinforced polymer composites have raised a great attention and interest among scientists and engineers in recent years due to the consideration of developing environmental friendly materials [29]. They are high specific strength and modulus materials, low priced, recyclable and are easily available. It is known that natural fibers are non-uniform with irregular cross sections which make their structures quite unique and much different with man-made fibers such as glass fibers, carbon fibers etc [24]. Various researchers have worked on the natural fibers containing polyolefins, polystyrene, polyester and epoxy resins [17], [18]. Properties like low cost, light-weight, high specific strength, free from health hazard are the unique selling points of these composites. Though the presence of hydroxyl and other polar groups in the natural fibers leads to the weak interfacial bonding between the fibers and the hydrophobic polymers, these properties can be significantly improved by interfacial treatment [19]. Among the various natural fibers, bamboo fiber is a good candidate for use as natural fibers in composite materials. Jindal [16] has observed that tensile strength of bamboo-fiber reinforced plastic (BFRP) composite is comparatively equivalent to that of the mild steel, whereas their density is only 12% of that of the mild steel. Hence, the BFRP composites can be extremely useful in structural applications. Jain and Kumar [32] have investigated that a uniform strength can be achieved in all directions of the composites by using multidirectional orientation of fibers. Considerable interest has been generated in the manufacturing of thermoplastic composites due to their good fracture toughness and thermal stability [26]-[7], and [23]. With more stringent demands for recycling standards, thermoplastic polymers are substituting thermosetting polymers as matrix materials for high volume consumer-driven composites [31]. Thermoplastic matrix composites materials offer an extended solution in different applications in automotive industry, construction, electrical appliances and home/urban furniture. Miet al. [9] have promoted the interaction between Polypropylene (PP) and bamboo fiber, by using a reactive agent maleic anhydride (MAH). Bio-degradable resins have received a considerable attention as earth conscious materials in the present day engineering society. They offer very little environmental load because they can be resolved in both water and carbon dioxide after perfect biodegradation by micro-organisms. However, most of the biodegradable resins have relatively low strength, making them a poor choice for the high strength structural applications. Thus, a lot of research is focused to strengthen the biodegradable resins by combining with string natural fibers like hemp, bamboo, pineapple etc. Kori et al. have fabricated bamboo fiber reinforced Polybutylenes Succinate (PBS) biodegradable polymer composites [11]. Homogeneous nucleation of PBS spherulites was obtained at temperature above 150°C. Authors have shown that the size of spherulites increases with addition of bamboo; however the spherulites are

not generated from the surface of bamboo fibers with or without treatment at any kneading temperature. The kneading temperature influences the melt visco elasticity above the melting point of PBS.

## **B-Mechanical properties of composites**

The attractive physical and mechanical properties that can be obtained with bamboo fiber reinforced composites, such as high specific modulus, strength and thermal stability, have been well documented in the literature. Jain et al. [25] have compared the Bamboo fiber reinforced epoxy composites (BFRP) epoxy with Bamboo fiber reinforced unsaturated polyester composites (BFRP) USP in terms of their cost and mechanical strength. Cost of unsaturated polyester (USP) was found to be only 20% to that of the epoxy resin, whereas the mechanical properties of these two composite were comparable. Thus giving an edge to the USP based composites. BFRP composites have shown more elongation and 10% high tensile strength. These composites can be used for a variety of commercial application such as crash helmet, low cost housing and wind mills. Kumar et al. [5] have studied the effect of coating bamboo fibers with Polyurethane (PU) and Polyurethane/Polystyrene Interpenetrating Network (PU/PSIPN) on tensile property of the composites. Both the untreated / alkali treated bamboo fibers were coated with polyethylene glycol based PU and its semi inter penetrating network (SIPN) with PS. It was found that tensile strength of bamboo has increased after coating with PU and PU/PS system. PU/PS coating on alkali treated bamboo fibers has shown a rise (74%) in the tensile load at break than PU (11%) coating on alkali treated fiber. Lee et al. [26] have fabricated bio-composites of poly (lactic acid) (PLA)/bamboo fiber (BF) and poly (butylene succinate) (PBS)/bamboo fiber (BF). They have investigated effect of lysine based diisocyanate (LDI) as coupling agent On properties of bio composites .They have reported that tensile properties and water resistance were improved by addition of LDI. These improvements were due to enhanced interfacial adhesion between polymer matrix and bamboo fiber. Results of enzymatic degradation showed that biodegradability could be adjusted by controlling degree of interfacial adhesion using LDI. They have observed that these bio-composites are beneficial in areas where biocompatibility and environmentally responsible design and construction are required.

Takagi et al. [7] have studied the effect of fiber content and fiber length on mechanical properties of bamboo fiber reinforced green composites (BFGC). Fiber length up to 15mm has given positive effect on tensile strength and flexural strength. It was observed that tensile strength and flexural strength increase with increase in fiber content. Mechanical properties of BFGC were similar to those composites made from bamboo powder and biodegradable resin. These results showed that bamboo fiber with aspect ratio of 20 acts as filler and not the reinforcement. Tokoro et al [23] have chosen three different categories of bamboo fiber to prepare Bamboo fiber-Polylactic acid composites and investigate the method to improve mechanical properties of BF/PLA composites. Three types of bamboo fibers were extracted from raw bamboo by either NaOH treatment or steam explosion. Amongst them, Highest bending strength was obtained when steam exploded filaments were put into PLA matrix. Impact strength was improved when medium length fiber bundles were put into PLA. Thermal properties and heat resistance of composite were improved by annealing. Chen et al. [31] have fabricated bamboo reinforced polypropylene (PP) composites. Polypropylene was modified with maleic anhydride. Modified polypropylene was Prepared by solution grafting [16]-[9] and it was named as maleated polypropylene (MAPP). They have investigated the effect of bamboo fraction, MAPP content and bamboo sizes on mechanical properties of unmodified and modified Bamboo Fiber/PP composite. Tensile modulus of modified composite increased with bamboo content up to 65 wt% but modulus of unmodified composite was not affected by changing bamboo fraction. Tensile strength of modified composite has increased at about 50 wt% bamboo fiber but for unmodified composite, tensile strength has decreased slightly. Increase in bamboo size has negative effect in both unmodified and modified composite. These results showed that maleic anhydride has improved bonding between bamboo fiber and polypropylene. Okubo et al. [11] have fabricated bamboo fiber reinforced polypropylene composites for ecological Purposes. Polypropylene was modified with maleic anhydride and bamboo was extracted with conventional method and steam explosion method. Poor adhesion was reported between the bamboo fibers and matrix. The modified polypropylene was insufficient to fabricate applicable composite. To reduce the number of voids in composite, it was necessary to decrease the diameter of fiber bundles by dividing these into single fibers. This was possible only by steam explosion technique. Steam explosion technique reduces number of voids in bamboo fibers and helps in impregnation of resin into fiber. Authors have studied the impact of steam explosion technique on mechanical properties of bamboo composites. Tensile strength and Young modulus of steam exploded BFEC increased about 15% and 30% respectively in comparison with conventional BFEC. Thwea and Liao [7]-[8] have fabricated the bamboo reinforced polypropylene (BFRP) and bamboo-glass reinforced Polypropylene (BGRP) composites. They have studied the

effect of fiber content, fiber length, bamboo to glass ratio, coupling agent (Maleated polypropylene) on tensile and flexural properties of these composites. They have also studied the sorption behavior and retention in mechanical properties of composite after environmental aging. It was observed that flexural strength, flexural modulus and tensile modulus increases with increase in bamboo fiber length. They have reported that poor adhesion between the matrix/fiber decreased tensile strength at higher bamboo fiber content in BFRP. Fiber content increased the void formation during processing, which further leads to micro crack information under loading, hence reducing the tensile strength. Incorporation of glass fiber and Compatilizers has improved the tensile strength and tensile modulus. It was reported that moisture absorption of BFRP during aging can be reduced by replacing bamboo fiber with glass fiber and by using Compatilizers. Mechanical properties of BFRP and BGRP have degraded after aging in water.

### C-Water absorption

New applications and end uses of composites for decking, flooring, and outdoor facilities with strong exposure to atmosphere or contact with aqueous media have made it necessary to evaluate the water uptake characteristics of natural fiber composites. Because of the hygroscopic nature of natural fibers, water uptake of composites containing these fibers as fillers and/or reinforcement can be a limiting parameter for a number of applications of the composites. Water absorption can adversely affect a number of mechanical properties and can also buildup the moisture content in the fiber cell wall and in the fiber–matrix inter phase region.

Moisture buildup in the cell wall could result in fiber swelling and affect the dimensional stability of the product. If necessary, the moisture absorbed in the fiber cell wall can be reduced through the acetylation of some of the hydroxyl groups present in the fiber [21]. Good wetting of the fiber by the matrix and adequate fiber–matrix bonding can decrease the rate and amount of water absorbed in the interphone region of the composite [6]. For Water absorption test, composite samples are weighed and then weighed samples are immersed in the distilled water at room temperature. The samples are taken out periodically and weighed immediately after wiping out the water on the surface of the sample, using a precise four digit balance to find out the content of water absorbed. All the Samples are dried until constant weight with four digit balance, previous to immersing in water. Percentage of water uptake is calculated by the following equation-

$$WA(\%) = \frac{(W_2 - W_1)}{W_1} * 100 \quad (1)$$

W1 = initial weight of specimen g

W2= specimen weight after N hours of water soaking, g

Water absorption behavior of natural fiber thermoplastic composites have been studied by a number of researchers and the effectiveness in reducing the amount and rate of water absorption has been well-documented in the literature[22]-[3]-[8]. Tajvidi et al. [13] have investigated the long-term water absorption behavior of various natural fiber (wood flour, kenaf fiber, rice hulls, newsprint etc.) polypropylene composites and have also studied the effect of natural fiber type and fiber content. Authors have found that the Chemical composition of the natural fibers is responsible for the different water uptake behavior. It appears that the RH/PP has the lowest water absorption. This behavior can be attributed to the higher amount of extract and ash and lower amount of cellulose and pentose in rice hulls [10]. Kenaf fibers are rich in cellulose and hemicelluloses and they possess low lignin content. Hence, their higher water absorption can be explained by the higher amount of cellulose and pentosan and lower amount of lignin. Rashdi et al. [1] have studied the effects of water absorption on the mechanical properties of Kenaffibre reinforced unsaturated polyester composites. A decrease in the tensile properties of the composites was observed of the water-saturated samples compared to the dry samples. The percentage of moisture uptake increased as the percentage of the fibre weight increased due to the high cellulose. Water absorption behavior of natural fiber thermoplastic composites have been studied by a number of researchers and the effectiveness in reducing the amount and rate of water absorption has been well-documented in the literature[22]-[3]-[8]. Tajvidi et al. [13] have investigated the long-term water absorption behavior of various natural fiber (wood flour, kenaf fiber, rice hulls, newsprint etc.) polypropylene composites and have also studied the effect of natural fiber type and fiber content. Authors have found that the Chemical composition of the natural fibers is responsible for the different water uptake behavior. It appears that the RH/PP has the lowest water absorption. This behavior can be attributed to the higher amount of extract and ash and lower amount of cellulose and pentose in rice hulls [10]. Kenaf fibers are rich in cellulose and hemicelluloses and they possess



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### III-MATERIAL PREPARATIONS

Raw materials are the starting point for development of new materials and quality of new material itself is dependent upon the raw materials. Then come the role of processing techniques to fabricate the new materials and characterizations techniques to ensure their quality. This Section describes the materials and methods used for the processing of all the composites under this investigation. It presents the details of the characterization techniques in terms of mechanical and chemical properties of the composite samples under study.

This section describes about the material used in casting of hybrid composite, their physical properties and chemical properties etc. In this section, the method used to determine the mechanical, physical properties are also discussed.

#### A. Material

The materials which are used to fabricate the biocomposite material such as matrix, reinforcing material and other materials which are used to modify the epoxy resin are discussed below.

##### 1. Matrix material

Matrix material is the material, which holds the relative position of the filler material. The composites shape, surface appearance, environmental tolerance and overall durability are dominated by it.

##### 2. Epoxy resin (CY-230)

Epoxy resin has wide range of industrial applications because of their high strength and mechanical adhesiveness characteristic. Araldite CY-230 is a liquid solvent free epoxy resin. Curing takes place at atmospheric pressure and room temperature after addition of hardener. Generally, curing shrinkage is very less and may further be reduced by the addition of fillers such as bio-particles, China clay etc. The resin can be easily coloured. Mechanical, electrical properties and higher resistance to chemical and atmospheric attack of fully cured mixture are excellent. Ageing characteristics of the castings are good. Resin can be stored for at least a year if they are stored under cool, dry conditions in the original containers.

TABLE-1 Physical and chemical properties of CY-230

Resin (Araldite CY-230)	
Physical Properties	Yellow-brown, odourless, tasteless and completely nontoxic
Chemical Properties	Plasticized condensation product of bisphenol-A and epichlorohydrin.

Epoxy is also good solvent and it has good chemical resistance over a wide range of temperature. In the present investigation CY-230 purchased from M/s CIBATUL Limited, India has been used as matrix material. The physical & chemical properties of CY-230 are given in table-1.

##### 3. Hardener HY-951

Hardener HY-951 is a yellowish-green coloured liquid. Hardener (HY-951) was purchased from M/s CIBATUL Limited; India has been used as curing agent. In the present investigation 9 % wt/wt has been used in all material developed.

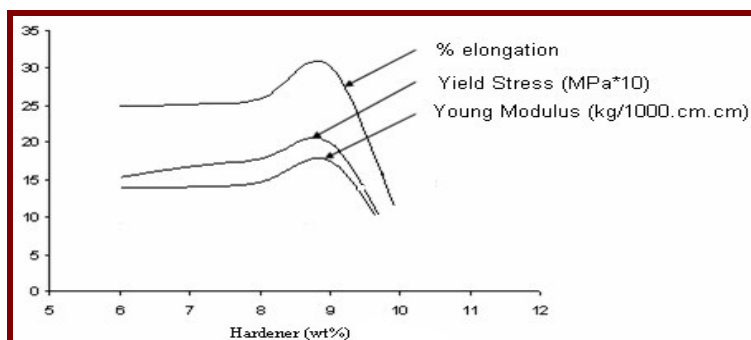


Fig.1, Effect of wt% of Hardener (HY-951) on Mechanical Properties (Singh V.K., 2002)

#### 4. Reinforcing Element

The addition of reinforcing agents to the resin improves the properties of the material. Bamboo fibers are used as reinforcing agents to improve the different properties of the composites material.

#### 5. Bamboo fibers

Bidirectional bamboo fiber has been used as a reinforcing material in all composite. These are collected from local sources. Bamboo belongs to grass family Bambusoideae. It is a natural Lignocellulosic composite, in which cellulose fibers are embedded in the lignin matrix. The average length of a bamboo fiber is about 2 mm and average diameter is between 10-20 $\mu$ m. Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries and has been used widely for household products and industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs etc. It finds a variety of building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses etc. It is also used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffolding. Bamboo grows with a very high speed in the first year and stops growing completely within five years.



Fig.2 Bamboo fiber

### B-Methodology

#### Preparation of Material

##### 1. Fiber

The bamboo sticks used in the present investigation was arranged from local market. The process of fiber extraction is shown below:

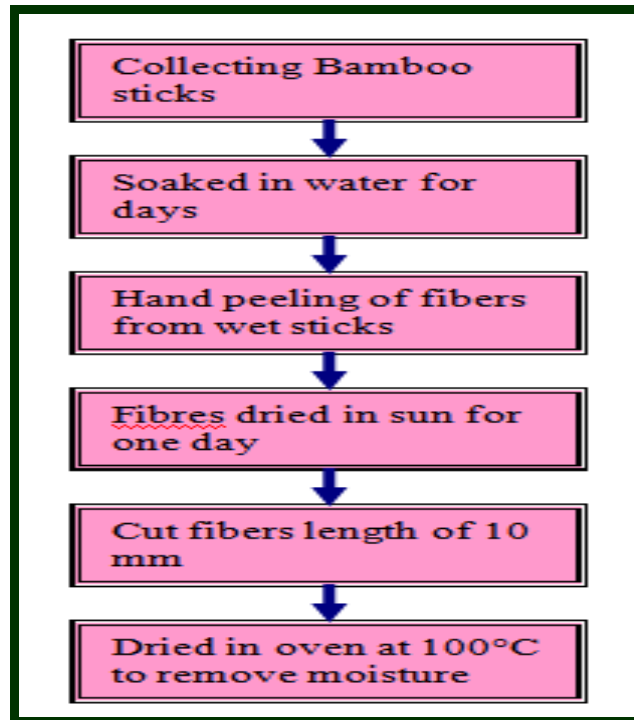


Fig.3 Preparation of bamboo fibers

## 2. Moulds

The mould was made having a simple base and top made of plastic plate having dimensions 220mm×200mm×20mm which was cut from plastic sheet all three sides of sheet was surrounded by a thin strip of plastic having dimension: 2 strips of dimension 220mm×30mm×5mm and 2 strips having dimensions 140mm×30mm×5mm which are fixed to the strip through nut and bolts.



Fig.4 Mould for plate casting

## 3. Preparation of composite

Epoxy resin (CY-230) will be kept in the furnace at a temperature of  $90\pm 10$  °C for approximately one hour to remove or vaporize if any moisture or water in the resin and then cooled down to 45°C, after the temp reaches 45 °C, 10wt% hardener (HY-951) which acts as the curing agent is added to epoxy resin. Then bamboo fibers are added in different ratios of 20, 30, 40 wt% as seen from past investigations and studies. The whole solution is then stirred manually or with the help of mechanical stirrer and then poured in the mould.

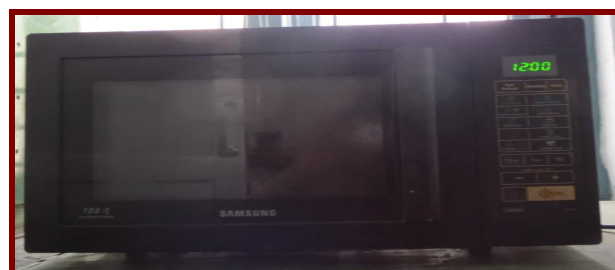


Fig.5 Convection oven



#### 4. Casting technique

Casting technique used will be simple hand layup technique followed by post curing by application of load. The whole mixture is poured in the mould is assembled together with the bolts and then held vertically in bench-wise for 24 hours after that it is post cured by pressing the mould with a 25kg weight for 2-3 days and then removed from the mould and left unloaded at normal room temperature for 2-3 days and then the samples of different sizes are cut from it.

TABLE-II Compositions of epoxy filled with bamboo fibers

Designation of Composition	Epoxy Resin (CY230), Wt%	Hardener (HY951), wt%	Bamboo fiber wt%
Neat	100	10	0
20C	100	10	20
30B	100	10	30
40A	100	10	40

### IV. RESULTS AND DISCUSSIONS

#### A. Mechanical Properties

##### 1. Tensile Test

The tensile properties of the bamboo fiber filled epoxy resin composite material were determined by 100 kN universal testing machine at fixed strain rate 1 mm/min under displacement control mode. The results are presented in figures 6.

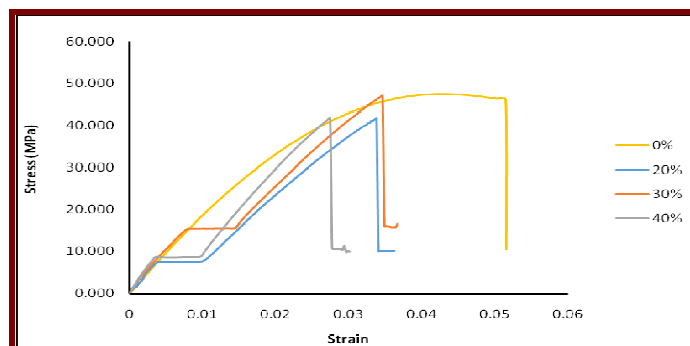


Fig.6 Stress-strain diagram for different wt% of bamboo fibers

The tensile stress-strain curve for unfilled epoxy resin (10 wt% HY-951 hardener and CY-230 resin) and bio-composite material containing 20, 30 and 40 wt% bamboo fibers is shown in the figure 6.

The variations in tensile strengths of the composites are shown in Fig.6. The tensile strength of the bamboo-epoxy composites decreases at 40wt% fiber loading. This decrease in tensile strength is due to the maximum void contents and weak interfacial adhesion in case of composites i.e. when the material is stressed in tension test it tends to elongate and when the material elongates the bond between bamboo fibers and epoxy resin weakens and leads to the loosening of bamboo fibers and leads to fracture of material.

##### 2. Flexural Test

The flexural properties have a very important role in structural applications. The flexural properties obtained at different weight percentage of bamboo fibers have been shown in figures, 7, 9. The effect of wt% of bamboo fibers on flexural strength is shown in figure 7.

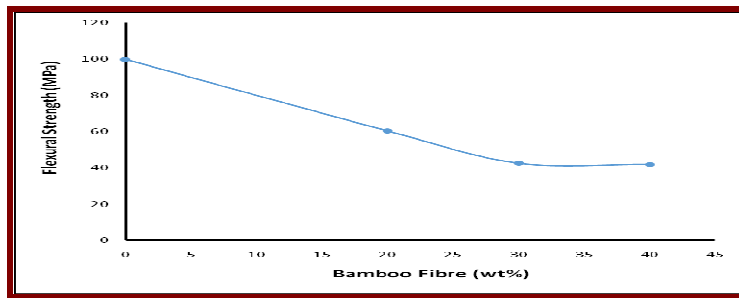


Fig.7 Effect of bamboo fiber (wt %) on flexural strength

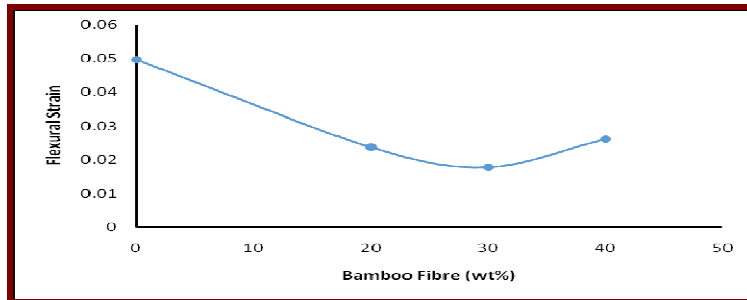


Fig.8 Effect of bamboo fiber (wt %) on flexural strain

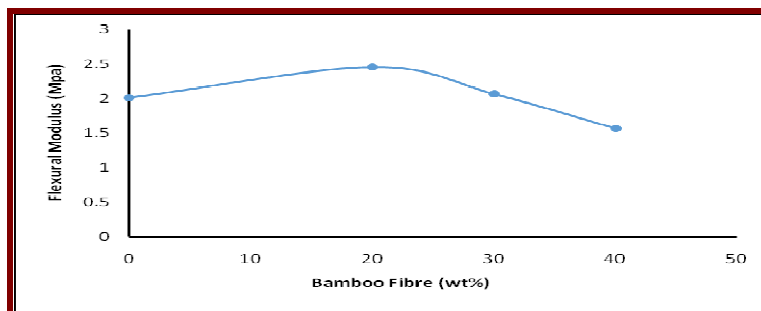


Fig.9 Effect of bamboo fiber (wt %) on flexural modulus

It is observed that flexural strength decrease with an increase in bamboo fiber wt% in epoxy resin. It is observed that flexural strain first decreases with an increase in bamboo fiber wt% in epoxy resin and then increases with an increase in wt% from fig.8. In fig.9 flexural modulus decreases with an increase of wt% of bamboo fiber in epoxy resin. Bamboo fibers provide a resistance initially due to which the gradient of initial straight line of load-displacement curve is more which leads to increase in flexural modulus.

### 3. Hardness Test

In this study the hardness test have been conducted on L scale on Digital Rockwell hardness testing machine.

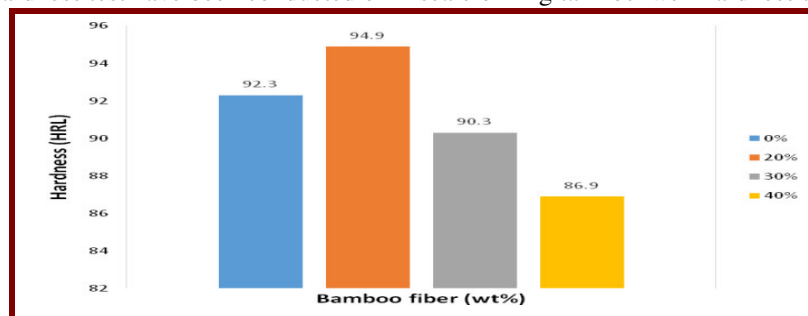


Fig.10 Effect of wt% of bamboo fibers on hardness

From figure10 this can be seen that hardness of bamboo fiber reinforced composite decreases with the increase in wt% of bamboo fiber. This may be due to the softness or low hardness of bamboo fiber.

#### 4. Impact Test

The results obtained by the impact tests are shown in table 3. The impact strength is calculated by the formula given in equation 4.1. Fig.12 shows impact strength with different wt% of bamboo fibers.

TABLE-III Impact properties of bamboo fiber filled epoxy resin composite

Bamboo fiber (wt %)	Impact energy (J)	Impact energy/Width (J/m)	Impact strength (kJ/m <sup>2</sup> )
0	0.1198	26.66	2.5266
20	0.2226	44.52	4.51
30	1.50263	212.232	18.38
40	0.3731	74.616	5.862

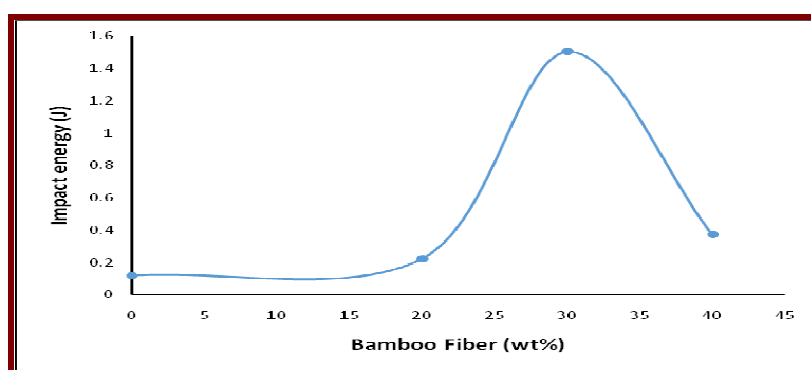


Fig.11 Effect of wt% of bamboo fibers on impact energy

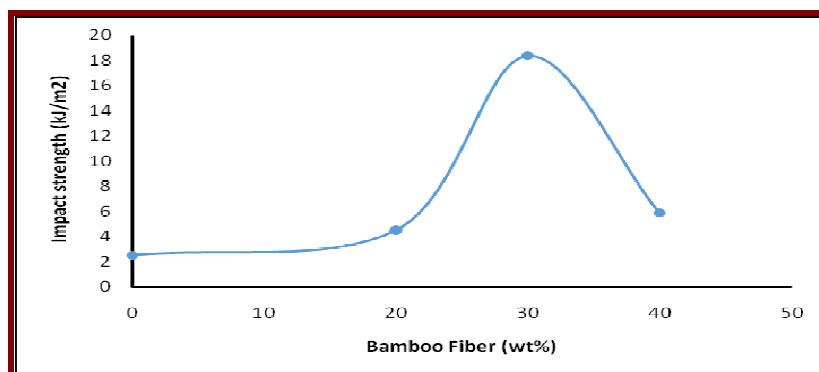


Fig.12 Effect of wt% of bamboo fibers on impact strength

#### B. Water Absorption Test

Water absorption is a very important test for natural particles and fibers reinforced composites to define their potential for outdoor working. The performance of these composites may suffer while they are exposed to environmental conditions for long time. The water absorption test provides information about the adhesion between the particles and the matrix in the interface region, as higher the adhesion between the matrix and the particles fewer will be sites that could store water and will lead to lower water absorption. Fig.13 shows the percentage of water absorbed at different time intervals.

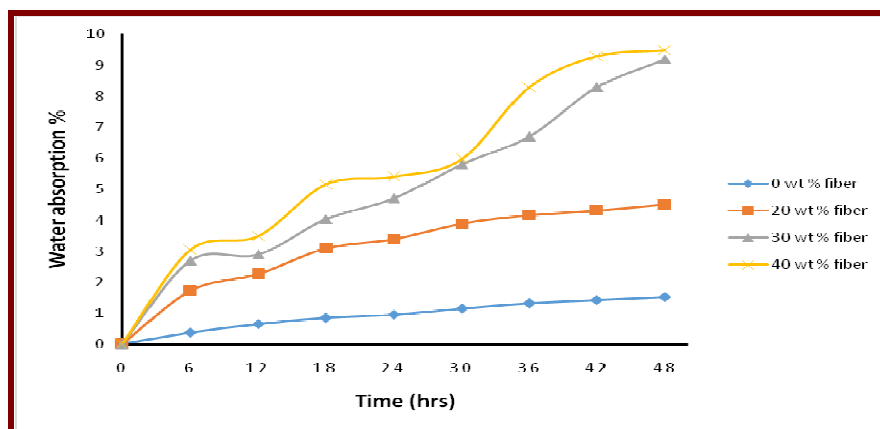


Fig.13 Water absorption for different wt% of bamboo fiber reinforced composite

Fig 13 shows that the rate of water absorption increases almost linearly for neat (0 wt %) fiber and the water absorption increases for all wt % with water being absorbed by 40 wt % specimen being maximum. The rate of water being absorbed decreases with decreasing wt%. This may be because with the addition of bamboo fibers wt%, the voids and cavities in the materials increases. When the specimens are dipped in the water the water would enter into these locations and cause more absorption. The other reason may be that the bamboo fibers absorb water due to which the material is absorbing more water.

## V. CONCLUSIONS

Bamboo fiber reinforced epoxy composites have been fabricated with varying fiber concentration. The experimental analysis has shown that bamboo fiber reinforcement in the epoxy matrix has improved the mechanical properties of composite structure. The composites have been fabricated using the hand-lay-up method, which is one of the simplest methods to fabricate the composites under normal conditions. The fabricated composites are of good quality with appropriate bonding between the fiber and resin. However the presence of voids is unavoidable in composite fabrication, particularly through hand-lay-up route. The presence of pores and voids in the composite structure significantly affect a number of mechanical properties and even the performance of the composites. Higher void contents usually mean lower fatigue resistance and greater susceptibility to water penetration. While studying the fiber variations, the increase in fiber loading has improved the hardness but reduced the tensile strength and flexural strength of the composites. This decrease is attributed to the inability of the fiber to support the stress transferred from the polymer matrix. Also the poor interfacial bonding generates partial spaces between the fiber and matrix material, hence resulting in a weak structure. Impact strength of composites also increased up to 20wt% fiber loading and then decreased at 30wt% fiber loading. Reduction of impact strength at 30wt% fiber loading was due to micro-spaces between the fiber and matrix polymer, and as a result causes numerous micro-cracks when impact occurs, which induce crack propagation easily and decrease the impact strength of the composites. Absorption of composites in water has been tested. Percentage absorption of chemicals in bamboo epoxy composite increased with increase in fiber content. Water absorption of composites increased with increase in fiber loading. The hydrophilic nature of bamboo fibers is responsible for water absorption. Water absorption of particulate filled composites has been found to be less than the unfilled composites.

The analytical and experimental investigation of the present work has been lead to the following conclusions:

- Successful fabrication of unfilled bamboo-epoxy composites is possible by simple hand lay-up technique.
- The mechanical properties such as tensile strength, flexural strength, impact strength and hardness of bamboo-epoxy composites are found to be superior as compare to the neat epoxy composites.
- The composites have also shown a good water resistance to make them suitable for the outdoor applications. Water absorption of the composites saturates after an exposure of 40 days. This means that water has very little effect on composites.

## VI. RECOMMENDATIONS

Manufacturers and engineers are always on the look for the new materials and improved processes to use in the manufacturing of better products, and thus increase their profit margin. The developed composites are a good substitute for a number of petroleum based products and form a very much sustainable resource. They have lot of advantages like low density, low price, recyclable, biodegradable, low abrasive wear, CO<sub>2</sub> neutral and environment friendly. Natural fiber composites are being used in a large number of applications in automotive, constructions, marine, electronic and aerospace. These composite have a lot potential as a low cost polymeric composite material for tribological applications also. Bamboo epoxy composites form a new class of bio-fiber reinforced composites, which may find potential applications in:

- Conveyor belt rollers
- Passenger seat frames (replacing wood/steel) in railway coaches / automobiles
- Pipes carrying pulverized coal in power plants
- Pump and impeller blades
- Household furniture and also as low cost housing materials.
- Helicopter fan blades
- Trim parts in dashboards
- Door panels and Seat Cushions
- Parcel shelves
- Seat cushions
- Backrests and Cabin linings

## VII. FUTURE SCOPE OF WORK

Bamboo-Epoxy composites have a lot of research potential, considering the present day environmental concerns. The work of the present thesis can be extended by a number of different ways. Considering the raw materials, unidirectional short bamboo fibres has been used for fabrication of the composites in the present work. However bi-directional bamboo can also be used as reinforcement in the composites. Fiber length can be one of the variables in the composite fabrication and their effect can be studied on the mechanical, chemical and erosive properties. Other thermosetting polymers like polyesters polyurethane and thermoplastics like polypropylene can also be used as resins in the bamboo based polymer composites. As far as the fabrication method is concerned, the hand up lay up method has been used for fabrication of composites in the present work. It is recommended that the use of injection moulding to fabricate composites samples for testing is more precise and it reduces much of human errors. The chemical resistance and water absorption of composites have been studied in the present work; however the effect of temperature on the water absorption can be explored as future work. Effect of chemicals on the mechanical properties of the composites can also be a good problem to study. Other chemical properties like Moisture absorption and swelling behavior of bamboo epoxy composites can also be studied wear behavior of composite can also be explored.

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