DESIGN AND MECHANICAL ANALYSIS OF FIBRE REINFORCED POLYMER COMPOSITE CONTAINING BAMBOO

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ABSTRACT

In recent year bamboo fibre reinforced polymer composite receive much attention because of their many advantages as light weight, nonabrasive, nontoxic, low cost, unlimited availability, low effect of environment and their biodegradable properties. The world wide availability of bamboo fibre is over thirty million tons per year. Bamboo fibre are extracted from its stem using retting and mechanical extraction procedure, the limitation of bamboo fibre it have high moisture absorption, poor wet ability and poor fibre-matrix adhesion so chemical treatment of the bamboo fibre can clean the bamboo fire surface, stop the moisture absorption process, chemically modify the surface properties and increase the surface roughness. These extracted fibres are used as reinforcement in resin matrix which is thermoplastic and thermo set for making partially green biodegradable material composite via hand lay-up technique. The experimental result showed that bamboo fibre has sufficient specific strength, which is equivalent to conventional glass fibre and their mechanical properties are strongly influence by a number of parameter such as volume fraction of the fibre, fibre length, fibre aspect ratio, fibre orientation and stress transfer at the interface so both matrix and fibre properties improving mechanical properties of the composite. The availability, renewability, low density and price as well as satisfactory mechanical properties of bamboo fibre make them an attractive ecological alternative to glass, carbon and manmade fibre used for manufacturing of composite. Bamboo fibre reinforced composite are advantageous over the metal when excellent corrosion resistance required.

Keywords: *Composite manufacture, Bamboo Fibre, Matrix, Retting, Fibre orientation, Alkali treatment, Mould, ASTM standards, Tensile strength, Impact strength*

1. INTRODUCTION

Fibre Reinforced Polymer (FRP) composite is defined as a polymer matrix, either thermo set or thermoplastic, that is reinforced (combined) with a fibre or other reinforced material with sufficient aspect ratio (length to thickness) to provide a discernible reinforcing function in one or more direction or "A composite material is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent. It has characteristics that are not depicted by any of the components in isolation". Recently, composite materials have successfully substituted the traditional materials in several light weight and high strength applications. The reasons composites are selected for such applications are mainly their high strength-to weight ratio, high tensile strength at elevated temperatures, high creep resistance and high toughness. The primary phase of composite material having a continuous character is called matrix. Matrix is usually less hard and more ductile. The matrix forms the bulk part. The secondary phase is a discontinuous form is embedded in the matrix. The dispersed phase is generally harder as compared to the continuous phase and is called reinforcement.

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Depending on the type of matrix materials used, composite materials can be classified into three categories such as metal matrix composites, polymer matrix composites and ceramic matrix composites. Each type of composite material is suitable for different applications. Most commonly used matrix material in composite materials is polymer. The bamboo fibres are consisting of cellulose, hemi-cellulose, lignin, pectin, waxes and water soluble substances. Among the natural fibres, bamboo finds widespread use in housing construction, storage and packaging around the world, and is considered as a promising housing material in underdeveloped and developed countries. Bamboo, a naturally occurring composite material, abundantly grows in most of the tropical countries.

Currently, the total bamboo forest area in the world has reached 22 million hectares. The worldwide availability of bamboo fibre is over 30 million tons per year [1]. Bamboo fibres have emerged as a renewable and cheaper substitute for synthetic fibres such as glass, carbon etc. which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, modulus and flexibility and are comparable to those of glass fibre. Several forms of bamboo can be used for reinforcement, such as the whole bamboo, sections, strips, and fibres. The bamboo has already been used for various applications. The shortcomings of bamboo fibre reinforced composites have been their high moisture absorption, poor wet ability and poor fibre-matrix adhesion. Therefore, chemical treatments are considered in modifying the fibre surface properties. To this end, the present research work is undertaken to study the processing, characterization of bamboo fibre reinforced polyester composites. Bamboo is a widespread plant family occurring in all countries. In Asia, it is used for constructing houses, in artificial handicrafts, pulp industry, storage and packaging and paper manufacturing. Due to its importance, many studies have been aimed at the anatomical structure, chemical composition and various mechanical properties [2] [3]. Development of composite materials for buildings using natural fibres as bamboo with high tensile strength is an interesting alternative which would solve environmental issue and energy concern. They are also renewable and have relatively high strength and stiffness.

Bamboo is a type of grass (Scientific name: Bambuseae) and is among the fastest growing plants on the planet. One Japanese species rockets skywards at a rate of a meter a day. Some bamboos can reach a lofty 35 metres in height while others are only half a meter tall. It is economically important to humans as a building material. There are 1,500 different species of bamboo. 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 structural design to be more versatile. Due to 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 engines; automobiles; thermal control and storage and packaging etc. Composites are made up of individual materials referred to as constituent materials. The constituents of a composite are generally arranged so that one or more discontinuous phases are embedded in a continuous phase. The discontinuous phase is termed as the reinforcement and the continuous phase is the matrix. The matrix phase generally comprises the bulk part of a composite. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. There are two major classes of polymers used as matrix materials such as thermoplastics and thermoset. Fibre reinforced polymer matrix composites can be simply described as multi-constituent materials that consist of reinforcing fibres embedded in a rigid polymer matrix.

The properties of these composites are significantly related to the properties of composite constituents, i.e. matrix, fibre and the interface between them. Properties of fibre reinforced polymer composites are determined by many factors such as properties of the fibres, fibre length, concentration of the fibres, orientation of the fibres, fibre-matrix interface strength, properties of the matrix etc. There are many factors to be considered when designing with composite materials. A crucial parameter for the design with composites is the fibre content, as it controls the mechanical and thermo-mechanical responses. The strength and stiffness of a composite can increase to a point with increasing the volume content of reinforcements. However, if the volume content of reinforcements is too high there will not be enough matrices to keep them separate, and they can become tangled. Similarly, the fibre length is a very important parameter which affects the various properties of composite material. Therefore, in order to obtain the favored material properties for a particular application, it is important to know how the material performance changes with the fibre content and fibre length under given loading conditions. The bamboo column consists of many vascular bundles and xylem. A vascular bundle includes four sheaths of fibres, two vessels and some sieve tubes. Xylem surrounds each vascular bundle. The sheath consists of many single fibres whose diameter is 10-20 mm each in average [4]. The percentage of fibres decreases from the bottom to the top of the column [5]. The mechanical properties of different natural fibres such as sisal, vakka, banana, bamboo are compared and it is found that the bamboo fibres have much higher tensile and flexural properties than other fibres [6]. Bamboo fibres have emerged as a renewable and cheaper substitute for synthetic fibres such as glass and carbon, which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, flexibility, and modulus and are comparable to those of glass fibre. Therefore, bamboo fibres are often called 'natural glass fibre'. Several forms of bamboo can be used for reinforcement, such as the whole bamboo, sections, strips, and fibres.

Table 1. The mechanical properties

Fibre	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm3)
Bamboo	140-230	11-17	-	0.6-1.1
Sisal	511-635	9.4-22	2.0-2.5	1.5
Jute	393-773	26.5	1.51.8	393-1.3
Kenaf	930	53	1.6	-
Cotton	287-597	5.5-12.6	7-8	1.5-1.6

2. STRUCTURE AND CHEMICAL CONSTITUENTS OF BAMBOO FIBRE

All plant species are built up of cells. When a cell is very long in relation to its width, it is called a fibre. The components of natural fibres are cellulose, hemi-cellulose, lignin, pectin, waxes and water-soluble substances [7] [8]. The cellulose, hemicellulose and lignin are the basic components of bamboo fibres, governing the physical properties of the fibres. Cellulose forms strong and stiff crystalline regions, cellulose and hemicellulose form semi-crystalline regions which provide necessary flexibility while the amorphous regions of lignin give toughness and cohesion.

Table 2. Composition of few natural fibres

Natural Fibre	Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)
Bamboo	26-43	21-31	15-26	1.7-5
Sisal	47-62	7-9	21-24	0.6-1
Jute	41-48	21-24	18-22	0.8
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

Bamboo fibres have always found wide applications from the time they gained commercial recognition. Their versatility is based on the following desirable material properties [9]:

- Bamboo fibres are renewable raw material and their availability is more or less unlimited.
- Very good mechanical properties, especially tensile strength in relation to its weight.
- Very good heat, acoustic and electrical insulating properties.
- Bamboo fibre is the bad conductor of heat.
- The abrasive nature of bamboo fibre is much lower compared to that of glass fibre, which leads to advantages in regard to technical, material recycling or processing of composite materials in general.
- Bamboo fibre provides good insulating properties.
- It is the environment friendly.
- *Biodegradability*: as a result of their tendency to absorb water, natural fibres will biodegrade under certain circumstances through the actions of fungi and/or bacteria.
- *Reactivity*: the hydroxyl groups present in the cell wall constituents not only provide sites for water absorption but are also available for chemical modification (e.g. introduce dimensional stabilities).

2.1 Properties of Polyester Resin

Any resin system for use in a composite material will require the following properties:

- Good mechanical properties
- Good adhesive properties
- Good toughness properties

2.2 Role of Polyester Resin in Composite

In a composite the matrix is required to fulfill the following functions:

- To bind together the fibres by virtue of its cohesive and adhesive characteristics.
- To protect them from environment and handling.
- To disperse the fibres and maintain the desired fibre orientation and spacing.
- To transfer stresses to the fibres by adhesion and/or friction across the fibre-matrix interface when the composite is under load, and thus to avoid any catastrophic propagation of cracks and subsequent failure of the composites.
- To be chemically and thermally compatible with the reinforcing fibres.
- To be compatible with the manufacturing methods which are available to fabricate the desired composite components.

3. STRUCTURE AND PROPERTIES OF COMPOSITES

A composite may be defined as any substance which is made by physically combining two or more existing materials, selected filler or reinforcing agent and a compatible matrix binder, to produce a multi-phase system with different properties from that of the starting materials but in which the constituents retain their identity. Each of this constituent material plays an important role in the processing and final performance of the end product. The resin is the glue that holds the composite together and influences the physical properties of end product.

The reinforcement provides mechanical strength. The filler and additive are used as process or performance aids to import special properties of the end product. The surface adhesion between the fibre and the polymer plays an important role in the transmission of stress from matrix to the fibre and thus contributes towards the performance of the composite. The properties of the composite cannot be achieved by any of the components acting alone. Overall, the properties of the composite are determined by:

- The properties of the fibre
- The properties of the resin
- The ratio of fibre to resin in the composite (Fibre Volume Fraction)
- The geometry and orientation of the fibres in the composite
- The surface interaction of fibre and resin (the 'interface')
- Manufacturing process
- Service condition

3.1 Advantages of Bamboo Fibre Composites

The main advantages of bamboo fibre reinforced composite are:

- Low specific weight, resulting in a higher specific strength and stiffness than glass fibre.
- It is a renewable source, the production requires little energy, and CO2 is used while oxygen is given back to the environment.
- Producible with low investment at low cost, which makes the material an interesting product for low wage countries.
- Reduced wear of tooling, healthier working condition, and no skin irritation.
- Good thermal and acoustic insulating properties.
- It is nontoxic and decreased environmental pollution.
- Directional strength.
- FRP composite have many benefit to their selection and use the selection of material depend of the performance and intended use of product.

A summary of composite material benefits include:

- Light weight
- High strength to weight ratio
- Corrosion resistance
- Weather resistance
- Dimensional stability
    - Low thermal conductivity
    - Low coefficient of thermal expansion
- Non- magnetic
- High impact strength

- High dielectric strength(insulator)
- Small to large part geometry possible
- Non- magnetic
- High impact strength
- High dielectric strength(insulator)
- Small to large part geometry possible

4. LITERATURE REVIEW

This provides the background information on the issues to be considered in the present research work and to focus the relevance of the present study. The purpose is also to present a thorough understanding of effect various chemical treatment on mechanical behavior of bamboo fibre reinforced composites. In fibre reinforced polymer composites, the reinforcing phase can either be fibrous or non-fibrous in nature. Many investigations have been made on the potential of the natural fibres as reinforcements for composites. Various treatments are used to improve the matrix-fibre adhesion in bamboo fibre reinforced composites.

Most of the studies made on bamboo fibre composites reveal that their mechanical properties are strongly influenced by a number of parameters such as volume fraction of the fibres, fibre length, fibre aspect ratio, fibre-matrix adhesion, fibre orientation and stress transfer at the interface. Therefore, both the matrix and fibre properties are important in improving mechanical properties of the composites. A strong fibre matrix interface bond is significant increasing mechanical properties due to effective transfer of stress from the matrix on to the fibre [10]. It has been reported by few investigators that the mechanical properties of the composites gets improved with increment in interfacial strength. Chemically treated natural fibre reinforced thermoset composites offered enhanced mechanical and physical properties under extreme conditions. Tensile properties such as tensile strength and tensile modulus of chemically treated bamboo fibre reinforced composites with different fibre loading has been studied [11].Tensile strength increases with increasing the bamboo fibre content by weight. Chemical treatments such as benzoylation, alkali, silane and peroxide treated flax fibre composites showed better physical and mechanical property owing to better adhesion adaptability between fibres and matrix. The chemical treatment of the bamboo fibre increases the roughness of bamboo fibre. Chemical treatments such as benzoylation, silane and peroxide treated flax fibre composites showed better physical and mechanical property owing to better adhesion adaptability between fibres and matrix [12].

5. MATERIAL

The raw materials used in this work are as follows:

- Bamboo fibre
- Polyester resin
- Hardener and accelerator

6. METHODOLOGY

6.1 Procedure of Fabrication of Composite

The following is the procedure adopted here towards the fabrication of the composite. The steps involved in the fabrication is elaborated in the following steps:

- Preparation of the Fibre
- Chemical treatment of the Fibre
- Preparation of mould
- Post curing of the mould
- Removing specimen from mould & cleaning
- Test the specimen for mechanical properties.

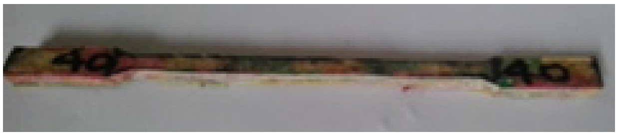
6.2 Hand Lay –Up Technique

The hand lay-up technique is the oldest, simplest and large fibre reinforced plastic products. A flat surface, activity or appositive shaped mould, made from wood, metal, plastic or combination is used. Fibre reinforcement and resin are placed manually against the mould surface. RTM (Resin Transfer Moulding) is unique technique that permits the manufacturer of high performance composite part of essential unrestricted geometry with fast cycle times. A dry reinforcement perform is placed in the mould. The perform is impregnated with a thermo set liquid resin which is injected into the mould. The injection is done by an applied pressure different created by an external source of elevated pressure or use of brush for spread the resin on the fibre and finally mould is closed and require load is applied on the mould.

The composite are fabricated using the hand lay-up technique. First, the inner surfaces of an open mould (the same size as the specimen) are coated with a thin layer of the release agent. The Polyester resin is mixed with 1wt% methyl ethyl ketone peroxide catalyst as hardener. Bamboo fibre put in the mould and mixed resin poured on it and brushes over the bamboo fibre to spread the resin and after that put another longitudinal bamboo fibre on it and provide the load on it. The process is done continuously till the require thickness is achieved. The prepared samples were cured at room temperature for 24 hours. Specimens were fabricated with different weight fractions ranging from 30 % to 40 weight% for bamboo fibre reinforced composite.

(a)

(b)



(c)

Fig 1. Specimen in different composition of bamboo fibre reinforced composite for tensile test and impact test

7. TESTING AND ANALYSIS PROCEDURE

7.1 Tensile Test

The tensile test is performed on specimens, cut according to ASTM D3039-76; on a universal testing machine model 3039.The cross head speed was maintained 5mm/min, at a temperature 22 degree Celsius and humidity 50%. In each case, three samples were tested and average value is recorded. Tensile bar specimen with dimension of 165mm × 19mm × 6.4mm (thickness) were cut and machined from the hot pressed composite panels. The tensile specimen is held in a testing machine by wedge action grips and pulled at a recommended crosshead speed. The load and strain are recorded continuously until the specimen breaks. The tensile strength of the specimen is calculated from the maximum load and original area of cross-section and expressed in force per unit area (N/mm^2 or MPa).

7.2 Impact Test

The impact properties of a material represent toughness, i.e. its capacity to absorb and dissipate energies under impact or shock loading. The impact test is done according to ASTM D 256A by using izod impact tester, pendulum type model. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V notched specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. The standard specimen size as per ASTM D 256 is 75 mm× 10 mm × 10 mm and the depth under the notch is 2mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator. In this test the specimen have standard V-shaped notch of 45 degree. The notch is located on the tension side of the specimen during the impact loading. Depth of the notch is generally taken as t/5 to t/3 where 't' is the thickness of specimen. Purpose of keeping notch on the tension side is double fold. First purpose is that the stress rises to a peak value at the base of the notch due to elastic stress concentration. Second is that the yield stress rises due to elastic and plastic action. The two effects combine together and break the specimen due to brittle fracture more readily in presence of a sharp notch than in and un-notched specimen.

8. RESULTS AND DISCUSSIONS

In this work, the bamboo fibre reinforced polyester composites were fabricated by hand lay-up technique. Then test specimens were prepared as per ASTM standards and were tested to evaluate mechanical properties like tensile strength (TS), and flexural strength (FS),impact strength and water absorption.

8.1 Tensile Test Result

The effect of fibre volume fraction on the tensile strength of the composite is shown in Fig. 2 As the weight fraction of fibre increases, the tensile strength of the composite material increases gradually. The maximum value of tensile strength of 39.375MPa was observed at a fibre volume fraction of 40% by wt.

Table 3. Experimental values of Displacement/Load 30%, 35% and 40% of Bamboo fibre reinforced Composite

S.No	Displacement (mm) 30% Bamboo Fibre	Displacement (mm) 35% Bamboo Fibre	Displacement (mm) 40% Bamboo Fibre	Load (N) 30% Bamboo Fibre	Load(N) 35% Bamboo Fibre	Load(N) 40% Bamboo Fibre
1	0	0	0	0	0	0
2	0.1	0.1	0.1	0	0	0
3	0.2	0.2	0.2	49	68.6	0
4	0.3	0.3	0.3	98	156.8	245
5	0.4	0.4	0.4	215.6	274.4	323.4
6	0.5	0.5	0.5	323.4	411.6	450.8
7	0.6	0.6	0.6	637	666.4	813.4
8	0.7	0.7	0.7	1127	1196.6	1372

Experimental value is given Displacement/Load 30%, 35% and 40% of Bamboo fibre reinforced composite in the Table 3. It shows that the volume fraction by weight of bamboo fibre increases then the load require for break also increases. Thus the experimental value indicates that 40% of bamboo fibre in composite is superior as compared to other, it means 40% bamboo fibre reinforced composite provide better tensile strength.

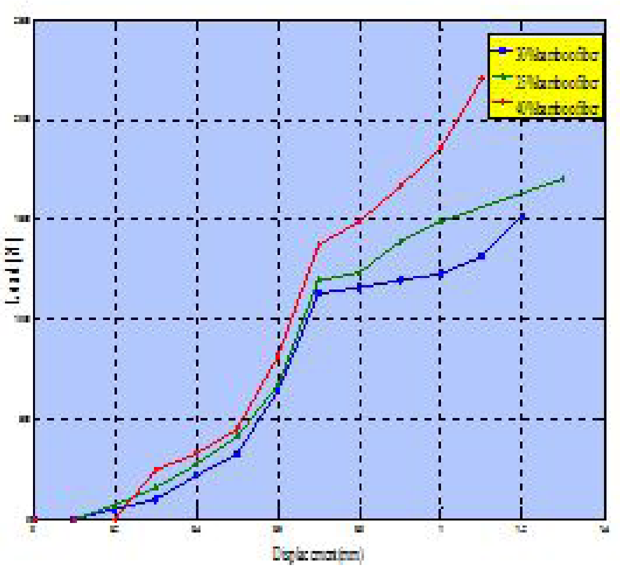


Fig. 2. Load v/s Displacement curve

Table 4. Experimental values of Stress and Strain in tensile test with variation of Bamboo fibre percentage

S. No.	Strain 30% Bamboo Fibre	Strain 35% Bamboo Fibre	Strain 40% Bamboo Fibre	Stress(MPa) 30% Bamboo Fibre	Stress(MPa) 35% Bamboo Fibre	Stress(MPa) 40% Bamboo Fibre
1	0	0	0	0	0	0
2	0.17	0.17	0.17	0	0	0
3	0.357	0.357	0.357	0.875	1.225	0
4	0.535	0.535	0.535	1.75	2.8	4.35
5	0.714	0.714	0.714	3.85	4.9	5.775

Experimental values of Stress and Strain in tensile test with variation of Bamboo fibre percentage in the Table 4. The experimental value indicate the 30% bamboo fibre reinforced composite gives the stress 27.125 (MPa) just before the fracture and 35% gives the 31.3 (MPa) stress and the finally 40% bamboo fibre composite indicated the experimentation value of stress is 39.375 (MPa). The experimental values indicate that if the fibre content increases in the composite then the tensile strength also increase at a limit. When fibre increases more than a limit then the adhesion between bamboo fibre is not proper so voids are created and the tensile strength decreases or composite is found lesser tensile strength which is due to lack of wet ability of fibre with the matrix.

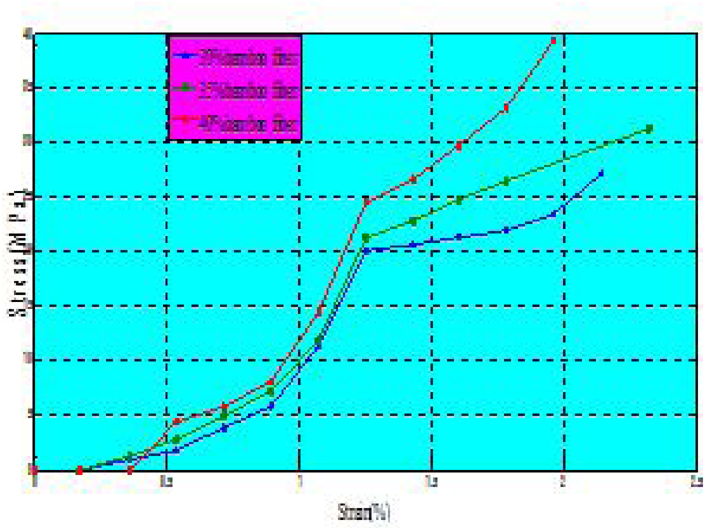


Fig. 3. Stress and Strain curves with 30%, 35% and 40% Bamboo fibre Reinforced composite in tensile test

The effect of weight fraction of fibre in the composite on the tensile strength is shown.

8.2 Impact Test Result

The impact strength of the composites increases up to 40wt%. The decrease in impact strength or smaller variation in strength may be due to induced micro-spaces between the fibre and matrix polymer, and as a result causes numerous micro-cracks when impact occurs, which induces crack propagation easily and decrease the impact strength of the composites.

Table 5. Impact strength at different% of bamboo fibre

S.No.	Bamboo fibre (%)	Impact Strength (KJ/m^2)
1	30	7
2	35	8.6
3	40	9.6

Impact strength of 30% bamboo fibre gives the experimented result of 7KJ/m2 and 35% bamboo fibre gives the 8.6 KJ/m2 and finally the experimented value of 40% bamboo fibre is 9.6KJ/m2. This experimented value indicates 40% bamboo fibre provides better result and it is superior as compared to other.

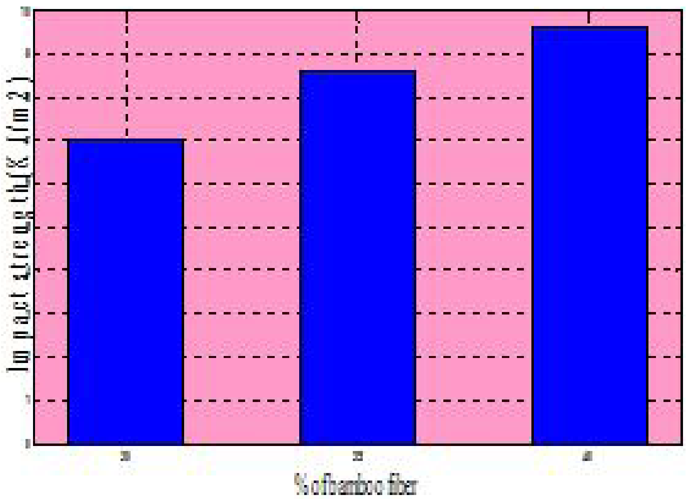


Fig. 4. Graph between impact strength and %of bamboo fibre

9. CONCLUSIONS

The experimental investigation on the effect of fibre loading on mechanical behaviour of bamboo fibre reinforced polyester composites leads to the following conclusions obtained from this study:

- It has been noticed that the mechanical properties of the composites such as tensile strength, and impact strength of the composites are also greatly influenced by the fibre loading.
- The present investigation revealed that 40wt% fibre loading shows superior tensile strength and impact strength.
- Maximum tensile strength of 39.3Mpa was found for 40% loaded bamboo fibre reinforced polyester composite.

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