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Mechanical Characterization of a Composite Material Using Epoxy Resin and Bamboo Mat

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Abstract—*The goal of bamboo-reinforced geopolymer composites is to provide environmentally friendly building materials. Bamboo fibres orientated randomly from the Amazon region were used to reinforce a composite formed of potassium-metakaolin geopolymer. Because of bamboo's potential, viability, and notably quick growth, it was included in the composition. Alternative methods of material development have become necessary due to the high cost of production and products developed from synthetic fibres like carbon, glass, kevars, etc. This has also influenced the creation of composite materials by using bamboo fibre that is readily available locally.The utilisation of natural fibre as reinforcement has made it more affordable and sustainable than synthetic materials like carbon, glass, and fear. The goal of this effort was to use bamboo fibre polymer to create, research, and evaluate a composite material's mechanical properties.*

The development of polymer composites based on bamboo is presented in this article as of right now. In addition, this paper addresses several bamboo fibre treatments that enhance fiber-matrix adhesion and their impact on the mechanical performance of the resulting composites that are moisture-sensitive. The goal of those treatments is to impart hydrophobic qualities to the bamboo fibres in addition to altering their hydrophilic characteristics. It is anticipated that the full potential of bamboo material will be realised as a substitute natural fibre reinforced material for composites based on polymers in a wider range of applications.

By employing maceration and chemical digestion techniques, the long bamboo fibre was removed. Bamboo fibre was used as reinforcement and epoxy resin as the matrix in the composite's production. The mechanical characteristics, such as tensile, hardness, and compressive strengths, were tested. The outcomes were examined and contrasted with traditional materials, and it was determined that the created material's suitability for structural uses strongly depended on its mechanical characteristics.

Keyword: *Bamboo Composites, Mechanical Properties, epoxy resin & hardener, laminate cover etc.*

1. INTRODUCTION

Organic compounds having lots of repeating units are called polymers. After polycondensing aluminosilicate solids and activating them with a concentrated aqueous solution of silicate or alkali hydroxide, geopolymeric materials are created.

Cements with reduced carbon dioxide emissions are one of the noteworthy applications of high technology and additional value for geopolymers that have arisen. These materials can be produced by substituting minerals or other natural materials with aluminium silicon sources, such as fly ash. Fly ashes are fine-textured ashes that are carried away by combustion gases during the burning of coal that has been ground into pulverised form in thermoelectric power plants. To create an environmentally friendly cement, fly ash and OPC are combined to a maximum of 60% by volume.

The usage of natural fiber-reinforced polymer (NFRP) composites, which are made from renewable resources, is becoming more and more popular. These materials are currently being used extensively in a wide range of industries, from cars to household goods. Natural fibres are readily available and reasonably priced, requiring less energy to create than synthetic fibres including bamboo, sisal, banana, jute, oil palm, and kenaf. They are also more renewable and can be burned for energy recovery at the end of their lives due to their high calorific values [1].

Natural fibres have several benefits over synthetic fibres, including low cost, biodegradability, high specific strength, low density, and excellent thermal insulation [2].Microdevices and medical prostheses may find widespread application. Compared to the most popular metallic alloys, such as steel and iron, composites have exceptional fatigue resistance, superior corrosion resistance, high strength, durability, stiffness, and light weight, making them crucial materials.

The ability to construct, enhanced mechanical qualities, low coefficients of thermal expansion, and good dimensional stability are among the benefits of composites. Recently, bamboo polymer composites (BPC) have drawn the attention of numerous researchers and producers. To create BPC, bamboo fibres, blades, and weaves are combined with polymers, either thermosetting (polyester, vinyl ester, epoxy) or thermoplastic (polyethylene, polypropylene, PVC, etc.). Bamboo grows quickly in most tropical regions, including Indonesia, taking only five years to reach maturity [3].

It was well known that bamboo fibre had stronger and more resilient mechanical qualities than wood. There are numerous papers [4–8] on the characterisation of bamboo reinforced composites, most of which use fibre that is taken from the culm.

The usage of bamboo composites as substitute materials in a variety of applications is growing in popularity due to its benefits in mechanical qualities and environmentally friendly renewable resources [9]. In the field of building construction, bamboo-based composites have been utilised as a wood substitute material in the form of lumber, medium density fibre board, and ply bamboo.

The process of producing bamboo composite, or BPC, is becoming more and more popular. It finds use not only in construction but also in other industries, such as the manufacturing of wind turbine blades for electricity production [10, 11] and interior and exterior component materials for the transportation sector [7, 12, 13].

The influence of liquid absorption normally does not cause major changes in the polymer material as a composite matrix; nevertheless, natural fibres derived from cellulose fibres do contain certain hydroxyl groups that can absorb water.

Natural fibres in composites have a hydrophilic quality that makes them readily draw water, which has a substantial impact on the deterioration of the mechanical and physical qualities of the resulting composites [14, 15]. Additionally, it causes the matrix and reinforced materials in the composite to differ in their hydrophilicity, which makes it challenging to properly wet the fibres with the polymer matrix during composite processing. Poor interphase between the fibres and the matrix is the outcome of this discrepancy [16]. Bamboo's hydrophilicity has been shown to be comparable to that of other natural fibres since, at ordinary humidity levels, it also absorbs a substantial quantity of moisture [17]. Anisotropic dimensional expansion occurs in both the width and thickness directions as a result of the moisture sorption within the bamboo strips.

When it comes to serving as reinforcements in composite materials, natural fibres are now thought to be a competitive substitute for glass fibre. Among their benefits are their low cost, low density, high strength-to-weight ratio, low energy content, resistance to breaking during processing, and recyclability. Numerous factors, including fibre combinations, processing methods, fibre volume fractions, aspect ratios, water absorption, etc., can alter or modify the properties of natural fiber-based composites. The process parameters and their impact on the final properties vary depending on the fiber-matrix combinations. The fabrication method has a major influence on the properties that are produced. There are several processing methods available for natural fibre composite materials, including compression moulding, injection moulding, extrusion moulding, and hand lay-up. Injection moulding increases the tensile and flexural properties by improving the fibre dispersion, whereas extrusion and injection moulding have a negative impact on the properties of natural fibres.

Bamboo fibres have become a popular and affordable replacement for synthetic fibres like carbon and glass, which are utilised as reinforcement in structural elements. They are similar to glass fibre in that they have high specific qualities including stiffness, impact resistance, flexibility, and modulus. Bamboo can be utilised in its entirety, in sections, in strips, and in fibre form for reinforcement. These different varieties of bamboo have been used in applications like wind and earthquake resistance in low-rise construction, composite bamboo mats used in place of wood for beams, and shear walls in low-rise construction. Additionally, bamboo fibre can be used as reinforcement with different thermoplastic and thermoset polymers.

According to Du et al. [18], bamboo fibre significantly raises the water uptake level of bamboo-HDPE composites. Additionally, as the water content of natural fiber-based composites increases, degradation of the material's characteristics may be seen [19]. The issue of natural fiber's susceptibility to humid environments was well-known, but there haven't been many studies done on the quantitative relationship between the water content during composite processing and the final composite's mechanical performance [16, 17, 20]. By physically and chemically treating the fibres, it is possible to manage moisture, which causes voids and poor fibre matrix adherence, hence increasing the fiber-matrix interaction [21].

The following is a summary of this work's goals:

- To construct epoxy composites reinforced with bamboo fibre, both treated and untreated.
- To assess the generated composites' mechanical characteristics for various volume ratios. The mechanical qualities listed below are assessed:

  1. Strength of tensile bonds

  2. Relative strength

To assess the produced composites' water absorption percentage.

2. LITERATURE REVIEW

The purpose of this literature review, in my opinion, is to highlight the significance of the current study and to give background knowledge on the topics that this thesis will be discussing. This dissertation covers a wide range of polymer composite topics, paying particular attention to their wear and erosion properties.

Bamboo-Reinforced Polymer Composite:

Because bamboo fibres can provide higher specific strength and stiffness in plastic materials than other known natural fibres like jute, coir, sisal, straw, and banana, their anatomical properties, ultrastructure, and plant fracture mechanism have led to a growing interest in bamboo fibres [22, 23]. Bamboo's cellulose fibres encased in lignin that runs the length of the plant is another important factor that encourages the use of bamboo fibres as reinforcing material in polymer composites [24, 25].

It offers maximal stiffness in that direction as well as tensile and flexural strength. Bamboo, being the fastest-growing renewable plant, has the potential to significantly lower manufacturing costs when it comes to polymer matrix composites. Indonesia is the third-largest producer of bamboo in Asia, behind China and India, with almost 2 million hectares of bamboo forests [26]. The contribution of each nation to the global production of bamboo is shown in Figure 1. Bamboo material is widely available, but its potential as a reinforcing component for polymeric composites has not yet been completely realised**.**

There are several ways that bamboo can be utilised as a reinforcement material in composites: as powder [27], strips [28–30], fibres [31, 32], textiles [33], and woven mat [34]. An illustration of a laminate composite with epoxy resin serving as the matrix and bamboo woven mat serving as the filler is shown in Figure 2. Among the various varieties of bamboo forms, bamboo strips are said to have a higher cohesive strength [9].

Thermoplastic matrices are recommended over thermoset ones if a composite material needs to have both high damage tolerance and recyclables. Thermoset resins, on the other hand, are recommended when a composite material with both chemical and high temperature resistance is needed [35]. Bamboo fibre reinforced composites made of PLA—a polyester made from renewable resources—have drawn a lot of interest [23, 36].

The adhesion between the fillers and the matrix, the parameters of the manufacturing process, and the kind of matrix and reinforcing material all affect the material properties of polymer-base composites [37].

Dry fibre is manually inserted into the mould during the hand lay-up process, and then the resin matrix is applied. Hand lay-up technique was employed by Gupta et al. [38] to fabricate epoxy composites reinforced with bamboo fibre.

Vacuum assisted resin transfer moulding was used by Kim et al. [39] to create bamboo/vinylester composites.In order to prevent voids and poor fibre matrix adherence, bamboo mesh, like other natural fibres, needs to be treated before processing.

The strength of jute-epoxy composites was found to be lowered by 35% when jute fibres with a moisture content of 5.2 weight percent were used [21]. The natural fibres' hydrophilic nature in their initial extracted form lessens their compatibility with the hydrophobic polymer matrix.

Huang and associates (2017) Bamboo culm's material properties and dimensions are consistent due to its growth features, which include joints, diameter, hollowness, etc. As a result, the majority of current research on bamboo and its applications in construction is focused on bamboo culm or little processing for later use [44].

Sharma and associates (2015) Laminated bamboo is the most typical in terms of development and use among bamboo materials. In addition to being made of natural materials, laminated bamboo is environmentally beneficial and has good mechanical qualities [45].

(2012) Echavarria et al. Relevant research have shown that the qualities of laminated bamboo are comparable to those of wood, and the two materials have been compared in the fabrication of structural beams [46].

The aim of this research is to chart the evolution and advancement of studies encompassing, among other topics,

1. Bamboo fibre types for composite materials,
2. Characteristics of fibre extraction and processing parameters
3. The kinds of resins, the laminae's shape, the fibre ratios and matrices, and the longitudinal, random, and woven fibres' orientation
4. The composite processing parameters, including the volume fraction, temperature and pressure, and fibre shape choice fifth, the composite material's mechanical and physical attributes.

3. OBJECTIVE AND METHODOLOGY

3.1 Objective

To Investigate and analyze the mechanical properties of a composite material using bamboo fiber. To explore the processing feasibility of bamboo mat fiber composites by different techniques and to study the resulting fiber and composite properties. To carry out a systematic study of the influence of processing parameters on the mechanical properties of bamboo fibers. The long bamboo mat fiber was extracted using chemical digestion method. The fabrication of the composite was carried out using epoxy resin as the matrix and the bamboo mat fiber as reinforcement. Tests were carried out to determine the mechanical properties such as tensile, hardness and compressive strengths**.** The results were studied and compared with the conventional materials and it process that the material developed can be used in structural applications with strong dependence on its mechanical properties. 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 hardness of the column of bamboo depends on the number of fiber bundles and the manner of their scattering.

3.2 Bamboo mat fiber Composite

Poly epoxies, or epoxy resins, are a type of reactive polymers with excellent mechanical, chemical, and thermal resistance. Epoxy is used in many different applications, such as structural adhesives, fiber-reinforced plastic composites, high tension electrical insulators, electronics and electrical components, and metal.

Comparision of Mechanical properties of bamboo mat fiber composite and glass fiber

S. No	Fiber	Volume Fraction (Vf %)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Density (g/cm^3)
1.	Bamboo Fiber	22-28	495-572	26.8-38.9	1.8-3.5	100-160	10-14	1.25-1.58
2.	Bamboo mat fiber + Epoxy	65	89-170	3-18	1.78-2.5	110-145	11-14	1.19-1.30

Table

Composition of several natural fibers

Types of fiber	Microfibril angle (deg)	Cellulose (%)	Lignin (%)
Coir	30-49	43	45
Banana	11.1	65	6
Sisal	20-25	70	11.9
Jute	8.1	64	11.5
Bamboo	2.1-10	60.9	32.1

Structure and chemical constituents of bamboo fiber

Every kind of plant is composed of cells. A cell is referred to be a fibre when it is exceptionally lengthy relative to its breadth. Natural fibres are made up of water-soluble compounds, waxes, cellulose, hemicellulose, lignin, and pectin. The main constituents of bamboo fibres that control their physical characteristics are cellulose, hemicellulose, and lignin. While cellulose and hemicellulose form semi-crystalline regions that offer the essential flexibility, cellulose produces strong, rigid crystalline sections; lignin's amorphous regions contribute toughness and cohesiveness.

Since bamboo fibres first became well known in the marketplace, they have been used for a variety of purposes. The following desirable material features serve as the foundation for their versatility:

As a renewable raw resource, bamboo fibres are essentially always available.

- Excellent mechanical qualities, particularly in terms of tensile strength.
- Excellent electrical, acoustic, and thermal insulation qualities in proportion to weight.
- Bamboo fibre is a poor heat conductor.
- Bamboo fibre has excellent insulating qualities and is environmentally friendly.
- Its abrasive nature is significantly lower than that of glass fibre, which results in advantages in terms of technical, material recycling, or processing of composite materials in general.

Properties of Epoxy resin

The following qualities are necessary for every resin system to be used in a composite material:

- Good mechanical properties
- Strong adhesive qualities
- Good qualities of hardiness

Epoxy resins role in composite:

The matrix in a composite must do the following tasks:

- To bind the fibres together by virtue of its cohesive and adhesive properties
- To shield them from handling and surroundings.
- To distribute the fibres while preserving the appropriate fibre spacing and orientation.
- To prevent the catastrophic spread of cracks and consequent failure of the composites by transferring stresses to the fibres through adhesion and/or friction across the fiber-matrix
- interface while the composite is under load.
- To be compatible with the reinforcing fibres both thermally and chemically.
- To be in line with the existing production techniques for creating the required composite

  Components?

Advantages of bamboo mat fiber composites:

The following are the primary benefits of bamboo fibre reinforced composite:

- Low specific weight, which raises the greater strength and stiffness than glass fibre. Its manufacture takes less energy and only uses CO2, returning oxygen to the environment. It is a renewable resource.

- The material is affordable and easily produced, making it a desirable product for nations with low wages.
- No skin irritation, better working conditions, and less tool wear.
- Good insulating qualities against heat and sound.
- It reduces environmental pollutants and is harmless.
- Strength in direction

FRP composites offer numerous advantages in terms of material selection, which is contingent upon performance.intended application of the item. Benefits of composite materials are summarised as follows:

- High strength to weight ratio / light weight
- Resistance to weather and corrosion
- Low thermal conductivity, low coefficient of thermal expansion, and dimensional stability
- High impact strength, non-magnetic; • High dielectric strength (insulator); • Possibility of small to big part geometry

Composition of few natural fibers [47,48]

Natural Fiber	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

4. MATERIAL

4.1 Bamboo Fiber

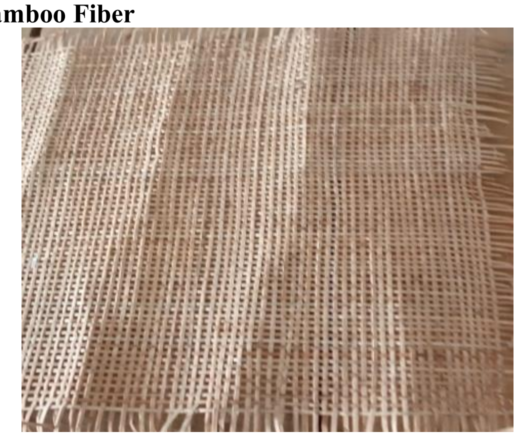


Figure- Bamboo mat fiber

4.2 Epoxy Resin

Figure- Epoxy Resin

Poly epoxies, or epoxy resins, are a type of reactive polymers with excellent mechanical, chemical, and thermal resistance. Epoxy is used in many different applications, such as structural adhesives, fiber-reinforced plastic composites, high tension electrical insulators, electronics and electrical components, and metal coatings.
The raw materials used in this work are as follows:

- Bamboo mat fiber
- Epoxy resin
- Hardener and accelerator

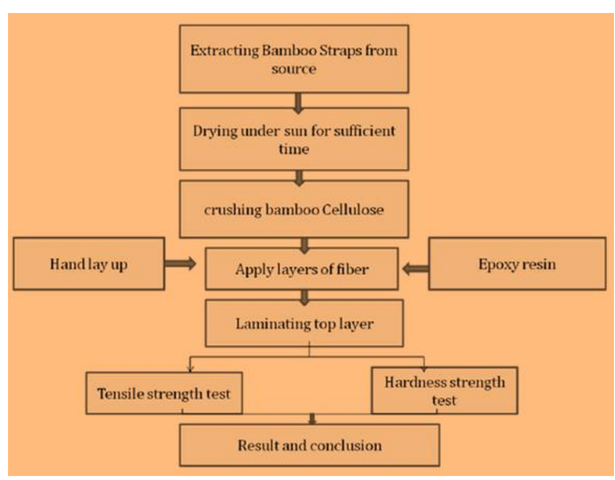
5. METHODOLOGY

Procedure of fabrication of composite

The approach that I took to fabricate the composite is as follows. The process for fabricating is described in detail in the actions listed below:

This includes:

- Preparing the fibre;
- Treating the fibre chemically;
- Creating the mould;
- Curing the mould after it is created;
- Extracting the specimen from the mould and cleaning it; and
- Testing the specimen's mechanical qualities.



Hand Lay –Up Technique

The hand layup process is utilised in the fabrication of the composite. An open mould that is the same size as the specimen must first have a tiny layer of the release agent applied to its interior surfaces. As a hardener, 1% methyl ethylketone peroxide catalyst is used with Epoxy resin. Bamboo fibre was placed within the mould, mixed resin was poured over it, and the resin was brushed over the bamboo fibre to spread it. Next, another longitudinal bamboo fibre was added to the mould to support the weight. The procedure is carried out repeatedly until the desired thickness is reached. The produced samples underwent a 24-hour curing period at room temperature. A range of weight fractions, from thirty to forty percent, were used to build specimens for bamboo fibre reinforced composite.

5-Testing and Analysis Procedure

Tensile Test

Using a universal testing machine model 3039, the tensile test is carried out on specimens cut in accordance with ASTM D3039-76.The velocity of the cross head was kept at 5 mm/min, with a 50% humidity level and a 23 °C temperature. For every instance, three samples were examined, and the mean value was noted. Hot pressed composite panels were used to cut and fabricate tensile bar specimens measuring 160 mm x20 mm x6 mm (thickness). Using wedge action grips, the tensile specimen is pulled at the suggested crosshead speed inside the testing apparatus. Up until the specimen breaks, the load and strain are continually recorded. The maximum load and the initial cross-sectional area are used to compute the specimen's tensile strength,

Impact Test:

Toughness, or a material's ability to absorb and release energy in the event of an impact or shock loading, is represented by its impact characteristics. The As seen in Figure , an impact test is conducted in accordance with ASTM D 256A utilising an Izod impact tester, pendulum-style model. By breaking the V-notched specimen with a pendulum hammer, measuring the energy used, and comparing it to the specimen's cross section, the pendulum impact testing equipment determines the material's notch impact strength. According to ASTM D 256, the standard specimen size is 75 mm × 10 mm x 10 mm, with a 2 mm depth behind the notch. The impact energy levels of various specimens are directly recorded from the dial indicator.

The specimen used in this test has a 45^0 conventional V-shaped notch. During the impact loading, the notch is situated on the specimen's tension side. Typically, the depth of the notch is calculated as t/5 to t/4, where t represents the specimen's thickness. There are two reasons why the notch is kept on the tension side. The first reason is that elastic stress concentration causes the stress to rise to a peak value near the base of the notch. The second is that the action of plastic and elastic forces increased the yield stress. When a specimen has a sharp notch, the two effects work together to provide a brittle fracture that occurs more radially than when the specimen is not notched.

6. RESULTS AND DISCUSSIONS

The epoxy composites bonded with bamboo fibre were created in this work using a manual lay-up approach. Next, test specimens were made in accordance with ASTM guidelines, and they underwent testing to determine mechanical characteristics such impact strength, flexural strength, and tensile strength.

Figure (a)

Figure (b)

Figure (c)

Tensile Test Result:

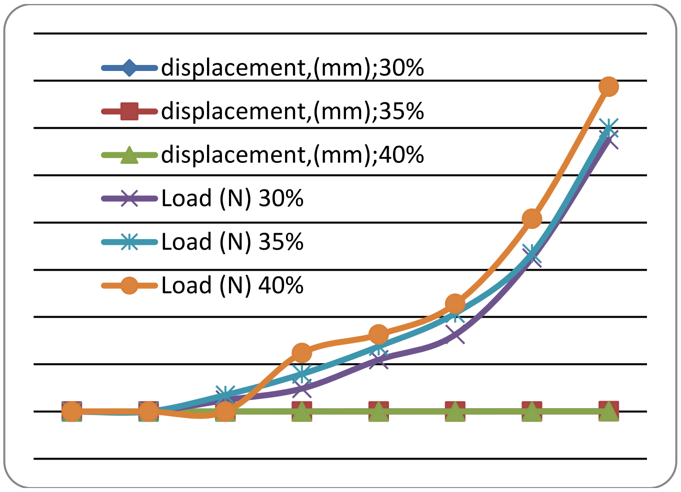
Figure illustrates how the fibre volume fraction affects the composite's tensile strength. The weight percentage of fibre contributes to the progressive growth in the composite material's tensile strength. The highest recorded tensile strength of 49.248 MPa was noted at a 40% by weight fibre volume fraction.

Experimental values of Displacement/Load 30%, 35% and 40% of Bamboo mat fibre reinforced

Composite

S.No	displacement, (mm);30%	displacement, (mm);35%	displacement, (mm);40%	Load (N) 30%	Load (N) 35%	Load (N) 40%
1	0	0	0	0	0	0
2	0.1	0.1	0.1	0	0	0
3	0.2	0.2	0.2	48	69.6	0
4	0.3	0.3	0.3	97	158.8	248
5	0.4	0.4	0.4	218.6	275.4	325.4

6	0.5	0.5	0.5	325.4	415.6	455.8
7	0.6	0.6	0.6	650	668.4	815.4
8	0.7	0.7	0.7	1150	1200	1375



Load v/s Displacement curve Experimental values of Stress and Strain in tensile test with variation of BF %

S.No	Strain 30% BF	Strain 35% B F	Strain 40% BF	Stress (MPa) 30% BF	Stress (MPa) 35% BF	Stress (MPa) 40% BF
1	0	0	0	0	0	0
2	0.18	0.2	0.18	0%	0	0
3	0.358	0.358	0.358	0.88	1.25	0
4	0.548	0.55	0.552	1.78	2.85	4.48
5	0.715	0.715	0.718	3.9	4.95	5.856

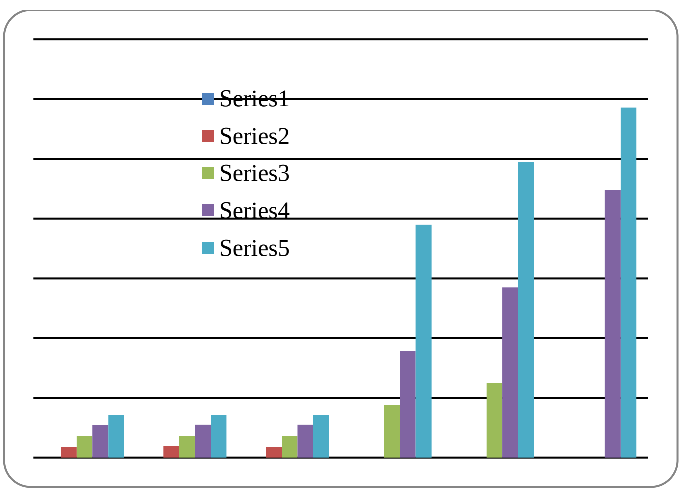


Figure Stress and Strain curves with 30%, 35% and 40%BF Reinforced composite in tensile test

The value of the experiment is given. The experimental results show that the 40% of bamboo fibre in the composite is superior to the other, meaning that the 40% bamboo fibre reinforced composite provides better tensile strength. The displacement/load of the 30%, 35%, and 40% of bamboo fibre reinforced composite in the table indicated that the volume fraction by weight of bamboo fibre increases then the load required for break also increases.

Tensile test experimental values for stress and strain with a variation in the proportion of bamboo fibre are shown in the table. The experimental value shows that the 30% bamboo fibre reinforced composite shows a stress of 27.125 (MPa) just prior to fracture, the 35% bamboo fibre reinforced composite shows a stress of 31.3 (MPa), and the 40% BF composite eventually shows an experimental value of stress of 41.248 (MPa).

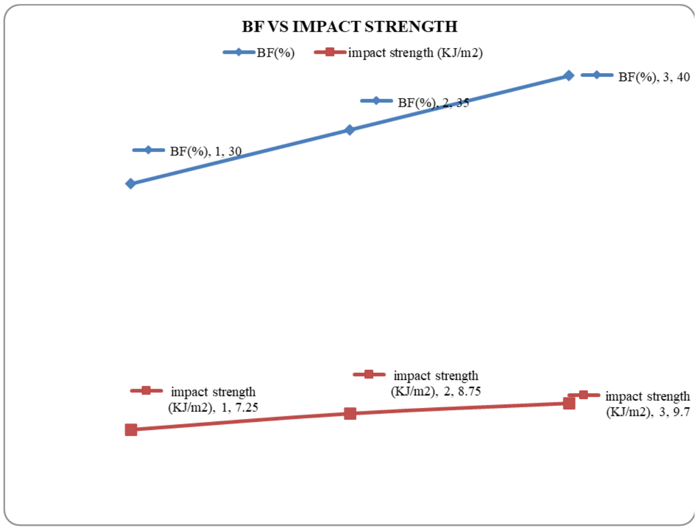
The experimental results show that when the amount of fibre in the composite increases, the tensile strength likewise increases up to a certain point. If the amount of fibre increases beyond this point, the adhesion between the BF becomes improper, causing voids to form and a decrease in tensile strength. Alternatively, the composite's lower tensile strength can be attributed to the fiber's lack of wett ability with the matrix.

The impact of the composite's weight percentage of fibre on its tensile strength is demonstrated. The tensile strength of bamboo fibre composite is slightly higher than that of lower weight percentage of composite as the weight fraction of fibre increases in the composite.

Impact Test Result:
The composite materials exhibit a 40wt% increase in impact strength. The cause of the loss in impact strength or lesser variance in strength may be the introduction of micro-spaces between the fibre and matrix polymer. When impact occurs, this leads to a large number of micro-fractures, which facilitate the propagation of cracks and reduce the impact strength of the composites.

Impact strength at different% of bamboo fiber

S.NO	BF(%)	impact strength (KJ/m^2)
1	30	7.25
2	35	8.75
3	40	9.7



Graph between impact strength and %of bamboo fiber

The impact strength of 30% bamboo fibre yields an experimental result of 9 KJ/mP, that of 35% bamboo fibre is 8.6 KJ/mP, and that of 40% bamboo fibre yields an experimental value of 9.8 KJ/mP. According to this experimented value, 40% bamboo fibre yields better results and is preferable to other.

7. CONCLUSIONS

The following findings are derived from this study's experimental examination of the impact of fibre loading on the mechanical behavior of Epoxy composites reinforced with bamboo fibres:

1. 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 fiber loading.
2. The present investigation revealed that 40wt% fiber loading shows superior tensile strength and impact strength.
3. Maximum tensile strength of 41.3Mpa was found for 40% loaded bamboo mat fiber reinforced Epoxy composite.

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