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Effect of Variation of Bamboo Volume Fraction on Tensile Strength and Modulus of Bamboo Composite

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Abstract:
Synthetic fibres are being used in composite all industrial sectors which are costly and creating environmental problems. Bamboo fibres are good alternate which are cost efficient and bio degradable. Bamboo composite has been developed based on bamboo fibres but utilization bamboo strips as reinforcement is yet not investigated. The paper work includes fabrication of bamboo composite by using intermodal bamboo strips and epoxy which is prepared by hand layup method. Bamboo volume fraction was varied to investigate its effect on strength and stiffness. Values of young's modulus obtained by experimentation were compared by analytical values. Increase in bamboo volume fraction from 30% to 50%, increases tensile strength and stiffness. Experimental and analytical values of stiffness are close to each other, this represents that strip reinforced composite behave like fibrous composite.

Keywords: Bamboo strip, Bamboo composite, Biodegradable, Strength, Volume fraction.

I. INTRODUCTION

Synthetic fibres such as glass and carbon fibres are most common reinforcement material in composites.These fibres are costely, non degradable and requires high amount of energy for extraction. Natural fibres can be a good alternate of synthetic fibre becuase they have good specific mechanical properties, low density, low cost.Natural fibres are bio degradable and energy required for extraction is low[1]. Natural fibres generally used in composites are jute, hemp sisal, bamboo and banana. Amongst all natural fibres bamboo has highest mechanical properties and lowest density .Bamboo is one of the fastest growing plant which attains its complete mechanical properties within 3-5 years [2]. Density of bamboo is 0.9g/cm^3 comparable with 2.5 g/cm^{3}of glass fibre[3]. Mechanical and physical properties depend upon fibre volume fraction. Fibre volume fraction is high in outer region 65%, in inner region 18% and increases linearly with height by 20-40%.[5,6].Mechanical properties of bamboo are inferior to glass fibre but specific properties are comparable. There are number of researchers who worked on utilisation of bamboo as reinforcement. Bhavna Sharma investigated effect of processing methods such as bleaching and caramelisation on mechanical properties of bamboo [2]. Parnia zakikhani et al described different methods for fibre extraction and their effect on physical and mechanical properties[3]. Shah Huda prepared light-weight composite with bamboo strip and polypropylene web as matrix and he found that bamboo strips show potential to replace fiber glass[4]. C.S.Verma investigated mechanical properties of bamboo strip selected from different region of culm and he determined strength and stiffness of developed bamboo composite [5, 6]. There are number of papers on charecterisation of bamboo composite, very few papers on utilisation of bamboo strip for reinforcement in composite available in the litrature . Tensile properties of bamboo strip composite need to be determined compeletely so that it can be used for differenr applications. In this work bamboo strips were tested under tension to determine ultimate tensile strength and youngs modulus. Unidirectional composites were developed using bamboo strips and epoxy by hand layup method.Bamboo volume fraction in composite was varied to investigate its effect on tensile strength and stiffness.Values of young's modulus obtained by experiments were compared with values obtained by strengthof material appraoch.

II. MATERIAL AND METHOD

Mature Bamboo was purchased from local market in Maharashtra, India. The bamboo culm had an average length of 7 m, diameter of bottom culms was 89 mm, the diameter of the top culms was 35 mm, and the average distance between the nodes was 22 cm at the bottom and 30 cm at the top. The thickness of the wall was 25mm at the bottom and 8 mm at the top. The bamboos were manually split along the longitudinal direction into long and fine strips.. Average dimensions of intermodal strip are 300mmX11mmX0.5 mm. After cutting bamboo strips, they were dried in sun light for 1 week this was done to remove moisture and to ensure better adhesion between bamboo and epoxy. Density of bamboo culm is 0.8 g/cm^{3}was taken from literature. [7] The epoxy (520 F) with curing agent/hardener (EH 408) was used as matrix for preparation of bamboo composites. The suggested ratio of epoxy and hardener is 100:50 by weight. Weighing machine which had least count of 1mg was used to ensure exact mixing ratio of epoxy and hardener. Curing time for epoxy was around 24 hours at room temperature. Properties of epoxy available in technical data sheet are shown in table 1.

Table.1. Properies of Epoxy

Properties	Values
Young's modulus	3700 Mpa
Ultimate tensile strength	58 Mpa
Poisson's ratio	0.33
Density	1.1g/cm^3

2.1 Fabrication of composite

Unidirectional laminates were fabricated using intermodal strips from upper region. It is noted that width of strips were generally less due to circular cross section of bamboo culms. Therefore strips were arranged side by side with the help of teflon tape to make layer of strips as shown in figure 1(A). A die cavity was created with the help of 4mm thick glass plates .Dimension of cavity are 230mmX150mmX4 mm. To avoid adhesion between epoxy and die, polythene sheets were used in between as shown in figure 1 (B). Brush was used to apply epoxy on strips.

(A) (B)

Figure.1. (a) arranged bamboo strips by teflon, (b). Mold made of glass plate

First, epoxy was applied in the die on polythene sheet and epoxy coated layer of bamboo strip was placed inside die, again epoxy is applied on first layer of bamboo strip. Similarly second epoxy coated layer was placed over first layer and appropriate amount of adhesive was applied .Number of bamboo strip layer were used to achieve required bamboo volume fraction, then some amount of extra epoxy was poured in die . Laminate was sandwiched between plates of die and pressure was applied by using dead weight. This ensured straightness of strips during solidification of adhesive and it squeezed out excess adhesive. The sample was left for 24 hours at room temperature for solidification.

2.2 Controlling bamboo volume fraction

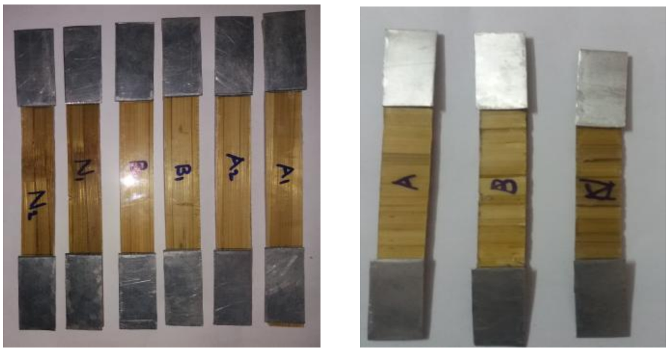
Three bamboo composite plates with different bamboo volume fraction were fabricated .It was difficult to control volume fraction directly, hence weight fraction was controlled first and by using rule of mixture equations, volume fraction was calculated

$$V_f = \frac{w_f / \rho_f}{w_m / \rho_m + w_f / \rho_f} \qquad (1)$$

Where V_f is volume fraction of bamboo and w_f ,w_m are weight of bamboo and epoxy respectively and ρ_f ,ρ_m are density of bamboo and epoxy .By using equation (1) volume fraction of bamboo is calculated .three plates were fabricated having bamboo volume fraction as 30% ,38% .50% .

2.3 Test specimen

Bamboo composite of volume fraction 30% ,38%,50% were cut using cross cutting and grinding machine .Two specimen along the fibre (at 0^0 angle) and one specimen across fibre (at 90^0 angle) from each plate were cut as per ASTM standard D3039 . The specimens were in the form of constant rectangular cross section of 200 mm overall length, 100 mm gauge length and 20 mm wide with a thickness of 4.2–4.8mm. In addition, 1 mm thick aluminum tabs were glued at both ends of the tensile specimen to prevent damage caused by gripping .Chamfer is provided on aluminum tab to avoid stress concentration. specimen for tension are as shown in figure 2.



(A) (B)

Figure.2. (A) Test Specimen Along Fibre (B) Across Fibre

Tensile test specimen of bamboo strip was also prepared from bottom and top of the culm . The specimens were in the form of constant rectangular cross section of 200 mm overall length, 100 mm gauge length and 10 mm wide with a thickness of 0.45-0.65 mm. Emery paper tabs were used to avoid slip and damage caused by gripping as shown in figure3.

Figure.3. Test Specimen Of Bamboo Strip

III. RESULTS AND DISCUSSION

The experiments were performed on universal testing machine. The stress–strain curves were obtained for each specimen from the automatic computerized recorder with the help of software inbuilt in machine. Extensometer was used to determine young modulus. Tensile test was conducted at a test speed of 5 mm/min and at standard laboratory atmosphere (temperature:26±3°C; relative humidity: 50±10%) according to ASTM D3039.

3.1 Tensile test of bamboo strip

Tensile test were carried out for nodal and inter nodal strip selected from bottom and upper part of bamboo culm. Typical recorded tensile stress–strain curve is shown in Fig. 4.

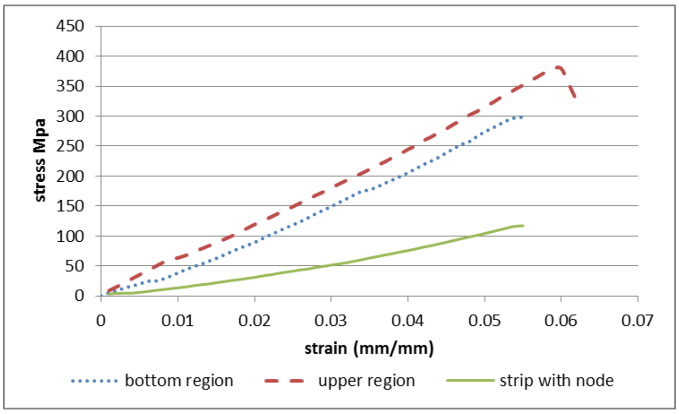


Figure.4. Stress –strain curve of bamboo strips

It is clear from graph that young modulus and ultimate strength bamboo strip from upper region of culm is higher than the bottom region. Tensile strength of nodal strips is comparatively very low. Hence inter nodal strips selected from upper region were used for reinforcement. Tensile properties of bamboo strips obtained from experiments are shown in table 2.

Table. 2. Tensile Properties of Bamboo Strips

Bamboo strip	Specimen No	Tensile strength(MPa)	Young's modulus(Mpa)
Upper region	1	379.85	22928
	2	320	19280
Bottom region	1	280	-
Nodal strip	1	117.18	-

3.2 Tensile test of bamboo composite

Analytical solution for young modulus by strength of material approach is given in equation (2).

$$E_1 = E_{1f} * V_f + E_m * V_m \qquad (2)$$

Where E_1 E_{1f} is modulus along fibre of composite, and fibre respectively ,E_m modulus of epoxy .V_f ,V_m are volume fraction of bamboo and epoxy respectively .

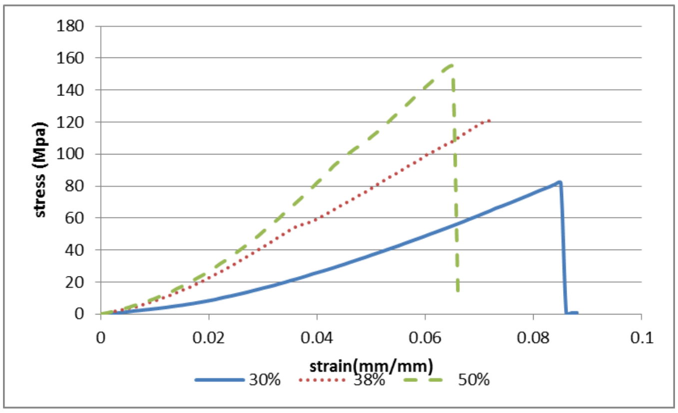


Figure.5. Strength Along Fibre Direction Of Composite

Figure 5 shows typical tensile stress–strain behavior of bamboo composites. Tensile stress increased with increasing strain until the point of ultimate load and brittle fracture .Test result of all specimen of bamboo composite are available in table 3

Table.3. Tensile properties of bamboo composite along fibre direction

	Trail No.	Maximm stress (Mpa)	Exp. Young's Modulus (Mpa)	Analytical Young's Modulus (Mp)	Error %
30 %	1	82.5	7080	8921	26
	2	86.7	8021	8921	11.2
38 %	1	127.08	9110	9869	9.2
	2	104.5	10500	9869	6
50 %	1	159.68	13130	12402	5.5
	2	141.2	8533	12402	45

Tensile tests were carried out across fibre direction (90^0 angles) for 30%, 38%, 50%. .Stress-strain curves are as shown in figure 6.

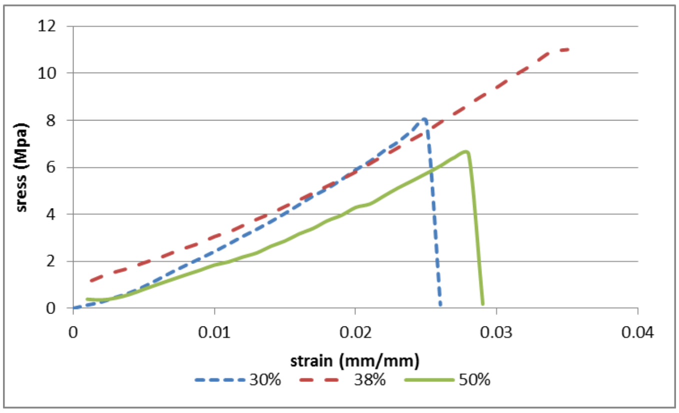


Figure.6. Stress –strain curve across fibre direction of composite

Average tensile properties of composite across fibre are shown in table 4

Table.4. Tensile Properties of Bamboo Composite across Fibre Direction

	Maximum stress(Mpa)	Experimental Young's modulus.(Mpa)
30%	8.35	720
38%	11.3	560
50%	6.55	500

Strength and stiffness across the fibre is very low because there are no fibres to resists applied load. After all these experimentation it is clear that bamboo composite shows acceptable strength and stiffness for structural application. Comparison of results is as shown in figure 7.

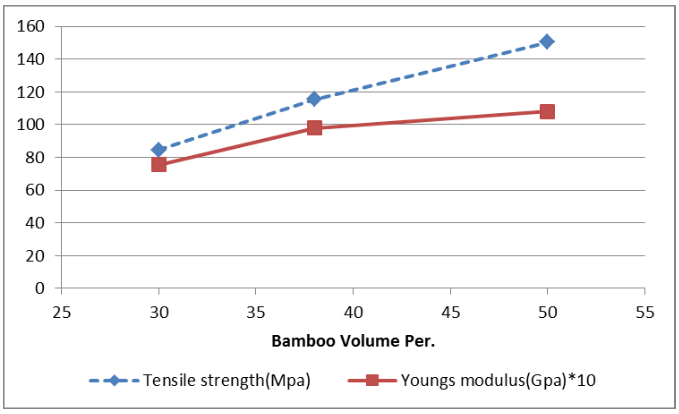


Figure.7. Comparison of Tensile Properties Of Composites

Strength and stiffness of bamboo is inferior to glass fibre but specific strength and stiffness is comparable to glass fibre Shown in table 5.

Table. 5. Comparison of Bamboo And Glass Fibre

Properties/fibre	Glass fibre	Bamboo
Density (gm/cm^3)	2.5	0.8
Strength (Mpa)	1350	350
Modulus (Gpa)	70	21.104
Specific. Strength	540	437
Specific. Modulus	28	26.3

IV. CONCLUSION

1. The experimental investigation confirms that strength is higher in upper region of culm and nodes are weakest portion of culm.
2. Stress and stress curve of bamboo strip shows straight line up to failure and a sudden fracture.
3. By increasing bamboo volume fraction from 30% to 50%,tensile strength increased by 77%and young's modulus increased by 44% .
4. The difference between experimental values of longitudinal young's modulus and theoretical is around 11%.

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