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Investigation of Tensile properties of Bambusa Vulgaris Reinforced Unsaturated Polyester Resin

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The investigation of the mechanical behaviour of Bamboo fibre (Bambusa Vulgaris) reinforced unsaturated polyester resin has been carried out in this work. The composites have been fabricated manually using the hand lay-up method. The purpose of the work is to develop a suitable alternative as a replacement for synthetic materials in industries. Five different weight fraction of fibre/matrix have been developed and investigated for their mechanical properties such as tensile strength and tensile modulus in accordance to test standard of ASTM D3039/D3039M-17. The ratio used for bamboo fibre and unsaturated polyester resin is 10:90, 15:85, 20:80 and 25:75. The pulping pre-treatment process was used to extract the fibre. The surface failure of the specimen has been determined from the tensile test and fractography failure is also discussed in this study. The results from this research will provide understanding of bamboo composite properties for future flooring.

Keywords: Polyster, Bamboo, Tensile strength, Fibre, Bambusa

1 Introduction

The synthetic fibre has been used as reinforcement due to its good mechanical properties such as high stiffness and tensile strength[1]. However, high production cost and disposability of the fibre are the disadvantages associated with the use of synthetic fibres. It has been reported by researchers that the natural fibres such as kenaf, jute, bamboo, flax, *etc* are being widely used as compared to synthetic fibres due to their high strength, high stiffness, low cost, low production energy requirement, availability in abundance, and attractive environmental advantages of being renewable, biodegradable and sustainable[2]. Since today's era is of research and innovation, thus scientists and researchers have been exploring these synthetic fibres along with natural fibres.

An emerging material, Bamboo has many benefits and has been used in large scales as a construction material especially in flooring. As compared to the other natural fibres, bamboo fibres also exhibit low density and high strength. In addition, the specific strength of these materials is three to four times the specific strength of mild steel. Due to its properties, bamboo fibre has been considered by scientists as the best replacement for glass which is not environmental friendly[2-3]. It has over 1200 varieties throughout the world and is the prospective material for the construction industry. Due to the change in the properties of bamboo material within its species, it has not been standardized. However, the researchers have started associating bamboo with other materials and exploring the properties of the developed composites[4]. Bamboo was expected to retain the intrinsic strength of the raw material and thus led to minimal change in the properties[5]**.** The conversion of the bamboo into a laminated structure has become popular now. Research is being carried out in the fabrication of laminates with different methods to enhance their properties. The high strength of these anisotropic materials in the direction of the fibre is due to the longitudinal alignment of its fibre to its body[2]. The high strength of the bamboo fibre is also attributed to its high lignin and cellulose content along with the relatively small micro-fibril angle of the bamboo plant.

In this paper, unsaturated polyester resin is reinforced with bamboo fibre in different ratios and a composite has been developed. The paper aims to investigate the mechanical properties of the developed composites to assess its potential for green flooring.

2 Materials and Methods

2.1 Materials

The composites in the present study have been developed with bamboo fibre (Bambusa vulgaris) as reinforcement and unsaturated polyester resin as the

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matrix (Fig. 1). The fibre has been extracted from bamboo and has been arranged in discontinuous random orientation. The bamboo has been obtained from Kampung Ratau, Menggatal in Kota Kinabalu, Sabah. The bamboo has been subjected to pulping chemical pre-treatment process to obtain the fibres.

Table 1 lists the properties of the unsaturated polyester resin used in the present study which has been procured from Singapore Highpolymer Chemical Product Pte Ltd. In order to avoid any fungal attack, the bamboo chips have been subjected to air drying method until 12% moisture content was left. The drying is carried out as per Indian Standard IS 6874 *i.e.*, the specimens shall be weighed and then dried in a hot-air oven at a temperature of 103 ± 2°C for 24 hours in order to measure the moisture content. The extraction of the bamboo fibre has been carried out through a chemical treatment wherein a pulping process is used which included alkali retting, hydro pulping, screening, and beating process (Fig. 2).

Alkali retting

During this process, the dried bamboo is soaked in 2% sodium hydroxide solution as shown in Fig. 2(a).

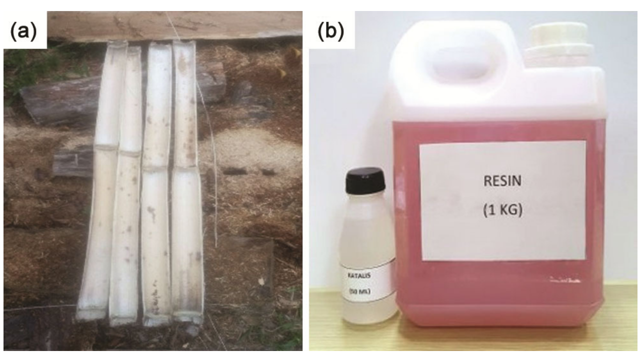

Fig. 1 — (a)Bambusa vulgaris (b) Unsaturated polyester resin and MEPK hardener

Fig. 2 — (a) Alkali retting (b) Hydro pulping (c) Screening (d) Beating (e) bamboo fibre

The soaking is carried out for 6 hours at 60°C in order to partially remove the lignin and hemicellulose. After that, pre-treated bamboo chips are washed so that the soapy substance of sodium hydroxide can be removed.

Hydro pulping

The dried fibre is then completely cooked and converted to pulp fibres. The completely cooked pulp is washed and disintegrated using a hydro pulper. The hydro pulp was then drained into bucket (Fig. 2(b)).

Screening

During the screening of the pulp (Fig. 2(c)), the unwanted fibres (waxy skin, foreign materials, *etc*) are separated based upon the size of the screening machine. All the pulp from the machine is screened using the mesh net and squeezed to remove extra water. The screened pulp was put into the plastic bag to avoid drying.

Beating

The valley beater is used for beating the pulp and it is half-filled with water (Fig. 2(d)). Once the bedplate is balanced, the beater is drained, and after 5 to 7 minutes, the pulp from the beater is collected using the mesh net (Fig. 2(e)).

2.2 Methodology

The amount of bamboo fibre and resin is taken in weight fractions. The weighed bamboo fibre is put in a container with the resin. The hardener is already mixed with an unsaturated polyester resin of the ratio 100:1. The type of hardener used is MEPK hardener. Table 2 shows the amount of fibre and matrix used for each sample. Three samples for each composition have been developed.

Table 1 — Properties of Unsaturated Polyester resin

Appearance	Clear
Viscosity at 30 °C	3-5 poise
Gel time at 30 °C	4-7 mins
Cure time at 30 °C	15-25 mins
Peak exothermic temperature	110- 120 °C
Stability in the dark below 25 °C	6 monts
Density	1.140 g/Ml

Table 2 — Ratio of matrix/ fiber in each sample

Sample	Composition
T1	Resin/hardener (90 wt%) + Bamboo fiber (10 wt%)
T2	Resin/hardener (85 wt%) + Bamboo fiber (15 wt%)
T3	Resin/hardener (80 wt%) + Bamboo fiber (20 wt%)
T4	Resin/hardener (75 wt%) + Bamboo fiber (25 wt%)

Both matrix/fibre mixture is stirred manually by gloved hand to make a proper mixing. Then, the mixture of matrix and fibre is charged into the mould having the dimensions of 250mm x 150mm x 5mm as shown in Fig. 3(a). The composite is produced by applied a hand lay-up moulding method. The samples for tensile testing are then cut as per ASTM standard D3039 using a universal cutting machine (Fig. 3(b)).

The rectangular-shaped samples for the tensile test are produced as shown in Fig. 3(c). Twelve samples in total are prepared for the tensile test and are then marked as T1, T2, T3 and T4.The tensile testing has been carried out on a Gotech make Universal Testing Machine (UTM) Al-7000 LA 10 (Fig. 4).

3 Result and Analysis

3.1 Mechanical properties

The results of the tensile tests carried out on the developed specimens have been shown in Table 3. The tensile strength, peak load, elongation and tensile modulus exhibited by the specimens has been shown in the table 3. The average values have been plotted graphically for better understanding (Fig. 5).

The highest tensile strength is exhibited by the T4 specimen (Fig. 5(a)) and it has been observed that with the increase in fibre content in the resin, tensile strength also increased. With the increment of 5wt% in bamboo fibre, a significant increase in strength has been observed. This increase is attributed to the stiffness and higher strength of the fibres. Ku *et al.*[6] and Jain *et al.*[7] have also reported that bamboo fibre can significantly increase the strength of the composites as compared to that of sisal and jowar. It has been observed that T2, T3, and T4 specimens have shown an increase of 30, 31, and 40% in the tensile strength as compared to T1 specimen. This may due to the improvement in the interlocking and bonding between the materials.

Fig. 3 — (a) Mould for specimen preparation (b) Specimen cutting machine (c) Fabricated Specimens

Fig. 4 — Universal Testing Machine

Table 3 — Mechanical Testingof the developed composites

No.	Specimen	Tensile strength (N/mm^2)	Max Load (N)	Elongation (mm)	Tensile modulus (N/mm^2)
1	T1	7.65	668.88	2.45	156.19
		5.89	514.54	2.83	104.11
		8.50	691.14	1.85	229.73
		7.35	624.85	2.38	163.34
2	T2	10.75	928.85	1.54	349.13
		9.99	805.56	2.45	203.79
		10.62	927.05	1.75	303.33
		10.45	887.15	1.91	285.42
3	T3	9.70	1057.59	1.90	255.33
		10.91	1102.40	1.08	504.92
		11.47	1031.05	1.03	557.98
		10.69	1063.68	1.34	439.41
4	T4	11.44	1191.59	0.96	596.06
		14.99	1299.61	0.70	1070.57
		10.58	1105.69	1.01	523.30
		12.34	1198.96	0.89	729.98

Figure 5(b) shows the maximum load to which the specimens have been subjected. This load corresponds to the beginning of the crack formation in the tested specimens. As depicted in Fig. 5(b), the highest load absorption (1198.96N) is shown by the T4 specimen. Here also, it is evident that with the increase in wt% of fibre, the load absorption capacity of the specimens increased. Shah. *et al*.[8] has also reported that higher fibre content can hold maximum load. Fig. 5 (c) shows the elongation exhibited by the composites until their failure point. The elongation also brings forth the resilience of the developed material. The elongation in the T1 specimen is more than the rest of the composites. It has also been observed that the elongation decreases with the increase in the fibre content, and this has been attributed to the decrease in the ductility of the composites. It is also observed that the addition of bamboo fibre to the resin resulted in decreased ductility, and thus caused an increase in the brittleness of the fabricated specimen. Petroudy[9] also concluded in his work that increase in the natural fibre concentration will result in increased tensile strength and water vapour permeability but decreased elongation.

Tensile modulus also known as Young's modulus is a measure of the stiffness of any system and is normally used to characterize the materials. The tensile modulus of the develop composites has been shown graphically in Fig. 5(d). The tensile modulus was calculated by dividing the stress by the strain. The strain is obtained by diving the elongation by the guage length (50 mm). It is observed from the Fig. 5(d) that the tensile modulus increased with the increase in the fibre content in the developed composites. The lowest value of modulus *i.e*., 163.34 N/mm^2 is observed in T1 specimen and the highest in T4 with a value of 729.98 N/mm^2. The increase in modulus can be attributed to the stiffness of the composite which in the present case has increased with an increase in fibre content. Similar results have been reported by researchers[6] where they stated that the modulus of elasticity of the natural fibre reinforced polymer composites increases with the increase in fibre loading.

3.2 Comparison of tensile properties based upon different reinforcements

Table 4 shows the comparison of the mechanical properties of the bamboo fibre-reinforced resin-based composites with the other composites developed previously by the researchers. The value of the tensile strength of bamboo fibre reinforced polyester composite is quite low as compared to other natural fibre-reinforced composites such as woven banana, sisal, hybrid sisal, jute, and okra, woven jute and coconut fibre[10-14]. However, the strength of the bamboo reinforced composite is more than the untreated sisal and coconut reinforced polyster composites[7,13]. For the tensile modulus, the results showed that sisal/polyester and hybrid sisal, jute, and

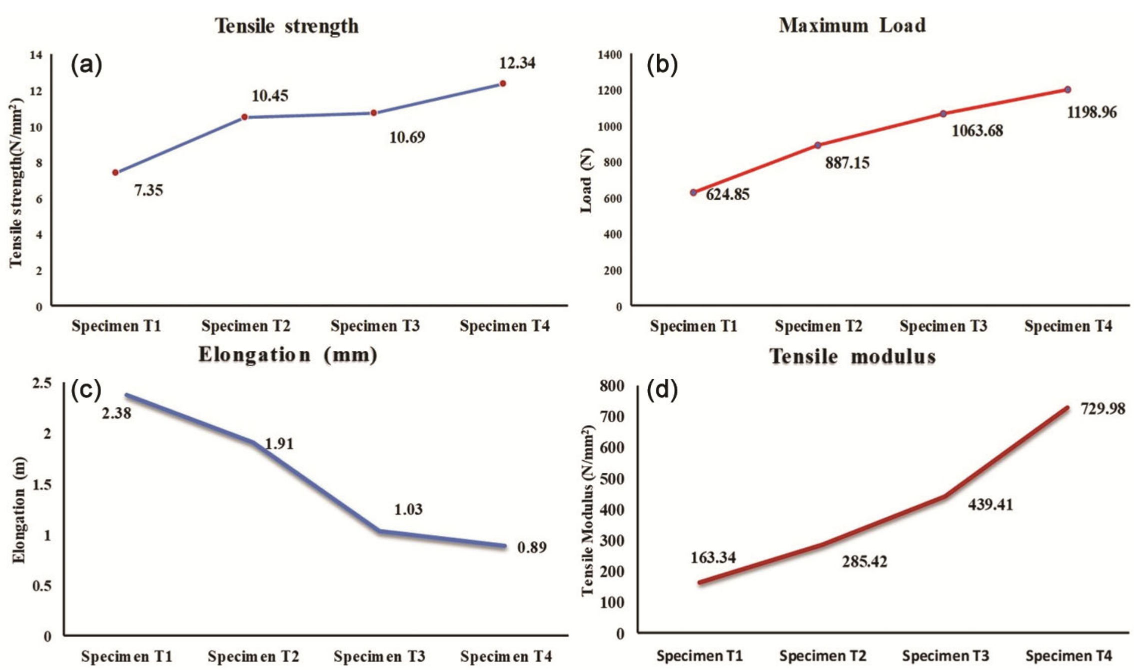

Fig. 5 — (a) Tensile strength (b) Maximum load (c) Elongation (d) Tensile modulus of the specimens

okra/ polyester, and woven jute have a higher value as compared to bamboo composites. However, the value of bamboo fibre reinforced polyester resin has a higher tensile modulus of 729.98 MPa compared to coconut fibre reinforced polyester resin which is 318.8 MPa.

The value of tensile strength and tensile modulus is also affected by the presence of the air bubble in the specimen. Cracks normally develop at a region where there is a contained stress concentration (air bubble) during the fracture process. It has been reported by the authors[12] that trapping of air bubbles took place during the mixing of resin and coconut fibre. Thus, on the application of load/stress at that region, a crack develops and propagates, thus causing failure. During the hand layup procedure, there are regions that are not properly flattened by rollers and they result in unstable fibre content in that area. This causes the fracture to occur at those thin regions, and the least value of applied force is sufficient to break the specimen during the tensile test.

3.3 Comparison of the tensile strength based upon the different treatments.

The tensile strength of bamboo reinforced composites with pulping pre-treatment and other treatments carried out previously has been shown in Table 5. It is found that the bamboo reinforced composites treated with pulping pre-treatment exhibited a tensile strength of 12.34 MPa, which is higher than the tensile strength (11 MPa) of untreated bamboo composites[8]. In addition, the bamboo fibre with pulping pre-treatment method also exhibited the lowest tensile strength and tensile modulus as compared to composites fabricated through other treatment such as chemical treatment[15], retting with mechanical, grinding bamboo chips with maleic anhydride grafted polypropylene (MAPP), mechanical decortications method, and milling machine with razor blade treatments[16-17]. It has also been observed that after alkaline treatment, the process of screening and beating reduced the cross-section of the fibre. The reduction of fibre diameter influenced the bonding strength between the fibre and the matrix. Excessive extraction of the lignin and hemicellouse took place during the treatment which resulted in the weakening of the bonding strength between the fibre and matrix. On the contrary, the researchers have reported that fibrillation process increases the diameter or length and thus developed a good fibre-matrix adhesion and enlarges the contact surface area resulting in higher strength[18].

Puglia[15], in his work has shown that using alkali treatment on bamboo fibre reinforced unsaturated polyester resin is far better than using pulping pre-treatment method. As reported[15], with only 20% of volume fraction of fibre content and 4 wt.% NaOh of chemical treatment, the composites have shown a 36% and 78% increase in tensile strength and tensile modulus respectively as compared to the pulping pre-treatment composite. It has also been reported that the mechanical properties of composites improved by using alkali-treated fibres[19].

Table 4 — Comparison of tensile properties between bamboo fiber reinforced unsaturated polyester resin and other natural fiber-reinforced composites

Natural fiber	Fiber Volume Fraction (%)	Tensile strength, (Mpa)	Tensile Modulus, (Mpa)	Reference
Bamboo fiber/polyester	25	12.34	729.98	current work
Coconut spathe-fiber	30	7.9 to 11.6	-	[12]
Untreated Sisal/Polyester	25	9.2	-	[7]
Sisal/Polyester	27	63.4	1029	[10]
Hybrid Sisal+jute+okra/polyester	27	72.6	1047	[10]
Woven Jute/ Polyurethane Composite	30	19.964	1895.05	[11]
Coconut fiber/Polyester	25	19.8	318.8	[12]

Table 5 — Composites prepared through different treatment processes

Fiber Extraction method	Matrix	Volume fraction (%)	Tensile strength (MPa)	Tensile Modulus (MPa)	Reference
Pulping pre-treatment method	Polyester	25%	12.34	729.98	Current work
Without treatment	Polyester	30%	11.0-12.0	-	[8]
4 wt.% NaOh Chemical treatment	Polyester	20%	19.45	3307.80	[15]
Retting + mechanical	Polyester	40%	126.0	2600.0	[16]
Grinding bamboo chips + maleic anhydride grafted polypropylene (MAPP)	Polypropylene	30%	17.0	2600	[16]
Mechanical decortications method	Epoxy	40%	23.45	-	[17]
Milling machine + razor blade	Araldite	25%	320	-	[16]

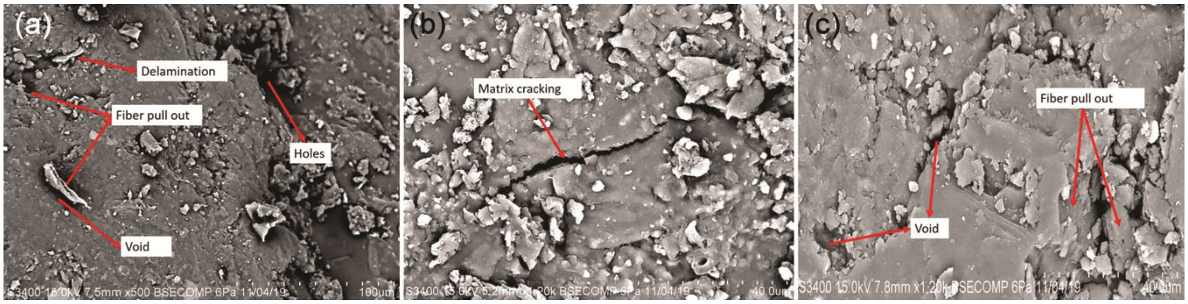

Fig. 6 — SEM images of the fractured sample surfaces

3.4 Scanning Electron Microscope (SEM) analysis

The fracture surfaces of the bamboo fibre reinforced unsaturated polyester resin composites have been analyzed using scanning electron microscopic (SEM) images as shown in Fig. 6. From the SEM images, a clean pull out of fibre has been observed. A clean pull out of fibre has also been observed (Fig. 6 (a-b)) without any resin adhering to the fibre. At certain locations, voids are also observed and they look smooth indicating a complete separation of the fibre and the matrix. Thus the failure occurs at the weak fibre/matrix interface as indicated by low tensile strength. Several failure/damage modes such as fracture surface and matrix cracking are also observed at the failure surface of the composite (Fig. 6(b)). The bamboo fibre fracture is the predominant failure mechanism observed amongst the developed composites. Crack propagation can be seen throughout the unsaturated polyester matrix on the failure surface. These brittle failures of the unsaturated polyester matrix and bamboo fibre fracture are evidence of poor adhesion between fibre and the matrix. It has also been observed from the SEM images that bamboo fibre composite fracture is caused by void and delamination (Fig. 6(a)). Voids are the result of imperfection which occurred during the processing of the material and deemed undesirable. These voids and delamination's reduce the static tensile strength of the bamboo fibre composites, and the same has been reported earlier (ASTM D2734-09, 2009)[20].

4 Conclusion

In the present work, bamboo was reinforced in unsaturated polyester resin in different volume percentages and a composite was developed. The developed composites was subjected to mechanical testing and following conclusions have been drawn from thus study:

1. The addition of fibre content into the composite has shown an increase in the tensile strength with the increase in bamboo volume percentage.
2. The effect of using pulping pre-treatment has shown enhancement in the tensile properties as compared to untreated bamboo composite.
3. The highest value of the load absorbed, tensile strength and tensile modulus of the developed composites was 1198.96, 12.34 and 729.98 N/mm^2 respectively.
4. The specimen with the highest percentage of bamboo fibre exhibited the lowest elongation.
5. The SEM analysis has shown that the fracture failure is initiated by the matrix due to poor adhesion between the fibre and matrix.
6. Based on the properties of the developed composite, it is possible to replace bamboo fibre/ unsaturated polyester resin in flooring application.

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