A Comparison Analysis on Mechanical Properties between 355 μm Bamboo Fiber, Chopped Strand Mat and Epoxy Hybrid Composite Versus 500 μm Bamboo Fiber, Chopped Strand Mat and Epoxy Hybrid Composite

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Abstract. In order to increase the utilization of polymer composite technology, natural fiber reinforced composites are required. Because of its exceptional mechanical qualities, bamboo culm fiber in hybrid composites has drawn the rigorous attention of researchers and producers. Gigantochloa Scortechinii, a particular species of bamboo, was obtained for this investigation from the Bukit Larang hamlet in Melaka, Malaysia. In these trials, a 5 mm thick metal mold was used to manually lay-up epoxy, chopped strand mat, and bamboo fiber. The 355 μm and 500 μm composite bamboo fibers were made. There was a range in the percentage of bamboo fibers from 1% to 5%. After that, the specimens were examined utilizing a variety of methods, including as impact, flexural, and tensile testing. Comparing the 500 μm bamboo hybrid composite to the 355 μm bamboo hybrid composite, the results showed improvements in tensile and impact strength of 22.3–42.3%. For the flexural strength, however, the reverse trend was seen (34.8-36.25%). These results imply that bamboo fiber, which is based on a hybrid composite of chopped strand mat and epoxy, produces outstanding mechanical qualities and can be a good substitute for reinforcing fibers made of composite materials.

Introduction

The use of blends of natural fibers and thermoplastics/thermoset in composite formulations has increased recently due to increased environmental consciousness [1]. Due to the advantageous qualities of natural fiber, natural fiber polymer composites are becoming more and more popular. Due to their unique biodegradability, natural materials can be used to produce composites and hybrids at a lower cost while simultaneously minimizing environmental contamination [2]. For this reason, natural fibers are in high demand. These benefits elevate natural fiber composites to the status of high-performance materials with superior physical qualities combined with financial and environmental benefits. For example, short plant fibers that are only a few millimeters long and tens of microns wide may be employed in the reinforcing phase [3].

Because of its narrow microfibrillar angle and relatively low cellulose content, bamboo fiber exhibits good mechanical characteristics and high-volume resistivity when compared to other natural fibers [4]. Most tropical countries have an abundance of bamboo, which is renewable [5]. Giant, quickly spreading grasses with woody stalks are called bamboo plants. Bamboo was frequently used as a structural element in pre-industrial construction in South American and Asian nations [6]. Additionally, due of their great impact strength, bamboo fiber is of special relevance, according to [6]. High-strength materials like bamboo can occasionally be utilized as concrete reinforcement [7]. Bamboo structures are generally highly distinctive and useful from the roots to the branches. Bamboo fibers are frequently referred to as "natural glass fibers" because of their exceptional strength, according to Okubo et al. [8]. Bamboo has a strength to weight ratio that is higher than that of lumber and plain steel, its tensile strength is around twice as strong as that of timber, and its compressive strength is about 1.5 times more [2]. In certain applications where very, high load bearing capabilities are not required, glass may be replaced by bamboo fiber composites [9]. Bundles of bamboo fibers may be able to serve as the polymer matrix's reinforcement [8]. The composite constructions reinforced with bamboo fiber have demonstrated favourable mechanical characteristics. Therefore, to enhance the mechanical characteristics of the hybrid composite, this study concentrated on two distinct types of bamboo fiber, measuring 355 µmm and 500 µmm. The next sections discuss the impacts of bamboo fibers in chopped strand mat and epoxy hybrid composite.

Experimental Procedure

This study used untreated bamboo fibers. A Gigantochloa Scortechinii bamboo type is extracted from the third section of the base. Then the internode is cut between its segment and the most outer and most inner layer of the clum is removed. Then the selected segment is cut into strip dimensions of 120 mm x 30 mm x 6 mm. For improve adhesion between bamboo, chopped strand mat and epoxy the strips are washed and dried. The interfacial strength of the final composites can be significantly weakened by exposure to high humidity during material storage and composite manufacturing [10]. This contrasts with moisture exposure after fabrication. The bamboo strips are dried in an oven at 60 °C for 24 hours, which the moisture content will be about 25% during the test prior to the crushing process is performed using bamboo crusher machine. The weight of the bamboo strip was measured and the percent moisture content, Mc is calculated by Equation 1.

$$Mc = \frac{Ma - Mb}{Ma} \times 100\% \qquad (1)$$

Where Ma is the mass of the real bamboo strip, Mb is the mass of the bamboo strip after it has dried in the oven, and Mc is the percentage moisture content. The bamboo strip were peeled cut into small sizes of between 2 cm to 3 cm and were grinder to a smaller size and sieve to get the bamboo fiber size according to specification 355 µm and 500 µm. Table 1 shows the designations of the compositions.

Table 1. Designations and compositions.

Ratio 60:40 Chopped Strand Mat 50% (2.5 mm)		Epoxy + Chopped Strand Mat 50% (2.5 mm)			
Chopped Strand Mat	Epoxy	Epoxy	500 µm bamboo fiber	355 µm bamboo fiber	Total
30%	20%	49%	1%	1%	50%
30%	20%	48%	2%	2%	50%
30%	20%	47%	3%	3%	50%
30%	20%	46%	4%	4%	50%
30%	20%	45%	5%	5%	50%

Specimens Preparation

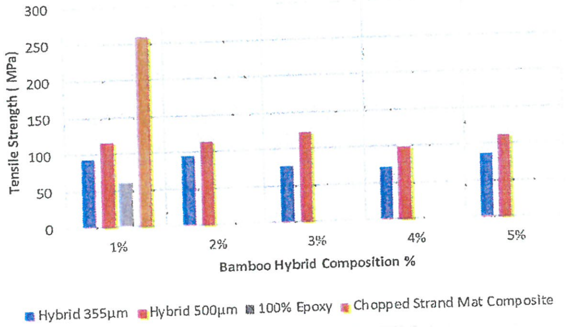
Hand lay up technique is one of the easiest ways to produce laminated composite panels as most fibers are readily available in mats. The bamboo fiber (355 µm & 500 µm) and chopped strand mat fiber were then subjected to the hand lay-up process to produce the composite panel. The mould are made of steel to control the dimensions of the panel to be produced. The mold's measurements are 350 x 350 x 5 mm. The mold's dirt surface was first cleaned with a scrapper, and then the mold surface was patched with a rag. Next, a silicon release agent was sprayed onto the mold's surfaces to make the laminate composite easier to remove. A mixture of EpoxyAmite 100 resin Part A and 103 slow hardener Part B was prepared using a weight ratio of 100A: 28.4B. They were combined and swirled until the mixture turned clear yellow instead of pale white. First the chopped strand mat placed in the mold. The mixture of mixed epoxy and bamboo fibers respectively for 355 μm & 500 μm is placed on the chopped strand mat. The mixture of epoxy and bamboo fibers is brushed in one direction with chopped strand mat. The mixture of epoxy and bamboo fibers that have been leveled throughout the surface layer of chopped strand mat. Then, chopped strand mat fiber layers are placed on a mixture of epoxy and bamboo fibers. The process has been repeated for four layers of mixed epoxy with bamboo fiber and five layers chopped strand mat. In accordance with ASTM D3039, ASTM D790, and ASTM D6110, the hybrid bamboo fiber (355 μm & 500 μm) is cut and ready for tensile, flexural, and impact testing. Scanning electron microscopy (SEM) observation is carried out at 10 to 30 kV utilizing a Philips XL 30 ESEM to examine the fracture surface.

Results and Discussion

Tensile Test. Table 2 presents the individual sample findings for the 355 μm and 500 μm bamboo hybrid composites, 100% chopped strand mat, laminated 100% epoxy, and 1–5% bamboo fiber. Additionally, the table displays the maximum tensile strength value; 118.4 MPa, were found for hybrid 500 μm bamboo fiber in 1%. The value had been the highest when compare with 355 μm and 500 μm bamboo hybrid composites 1- 5 % bamboo fiber. In the meantime, the greatest tensile modulus value of 3.0 GPa was also noted for the 500 μm bamboo fiber at 3%. Furthermore, Figs. 1 and 2 show the tensile strength and tensile modulus of the average ten samples from 1 to 5% bamboo fiber of 355 μm & 500 μm bamboo hybrid composites. In this case, the tensile strength recorded for the 355 μm & 500 μm bamboo hybrid composite with 1- 5 % bamboo fiber had been in the range between 94.8-118.4 MPa, 95.7-115.9 MPa, 78.3-124.8 MPa, 71.9-101.6 MPa and 87.2-114.7 MPa, whereas the values for 100% epoxy 61.3 MPa, and chopped strand mat composite 261.9 MPa, respectively. On top of that, Fig. 1 depicts that the addition of 1- 5 % bamboo fiber increased the tensile strength of 500 μm bamboo hybrid composites when compare with 355 μm. As a result, the 1% bamboo hybrid composite had the maximum tensile strength, measuring 118.4 MPa with 500 μm. However, with 355 μm bamboo hybrid composites for the 4% bamboo fiber, the lowest tensile strength was measured at 71.9 MPa, indicating a reduction in tensile strength of almost 64.7%. As a matter of fact, the tensile strength of 355 μm bamboo hybrid composites decreased by 59.3% upon the addition of 3% bamboo fiber, in comparison to that of 500 μm bamboo hybrid composites. Nevertheless, the addition of 1- 5 % bamboo fiber in 355 μm bamboo hybrid composite further reduced the tensile properties of the laminate hybrid composites compare to 500 μm bamboo hybrid composites. On the contrary, those that 500 μm bamboo hybrid composite had been stronger and stiffer. Generally, the tensile strength of 500 μm bamboo hybrid composite increased compare to 355 μm bamboo hybrid composites as the addition of 1- 5 % bamboo fiber. This is consistent with the idea presented by Lee et al. [11], according to which the interfacial properties between the natural fiber and the polymer composites have a significant impact on the tensile strength of laminated composites. Furthermore, the interlacing fibers found in directions determine the necessary tensile qualities [12]. Proceeding, it can be observed from the experimental findings shown in Fig. 2 that there is a definite trend of lowering tensile modulus when comparing the 500 μm bamboo hybrid composite to the 355 μm bamboo hybrid composite. The figure illustrates a drop in the tensile modulus with the addition of 355 μm bamboo hybrid composite. In fact, the highest tensile modulus of 3.0 GPa with 500 μm was obtained for the 3 % bamboo fiber. On the other hand, the lowest tensile modulus, which was 1.7 GPa with 4% bamboo fiber, was recorded from the 355 μm bamboo hybrid composite, which pointed towards a change by about 76.4% in tensile modulus. In precise, the addition of 1 % bamboo fiber from 355 μm to 500 μm reduced the tensile modulus to approximately 17.4%. Similarly, the tensile modulus for 1-5 % bamboo fiber also exhibited a decrease with the increment of bamboo in 355 μm and 500 μm. In short, a sample's tensile modulus indicates how well it resists deformation. In this investigation, samples with higher micron contents of bamboo showed greater resistance to deformation than those with lower micron contents. Consequently, it was established that the adhesion and compatibility of the chopped strand mat, matrix, and fewer bamboo micron size would reduce the strength of the composites. As a result, the strength was unaffected by the bamboo fibers that accumulated, indicating inadequate adhesion between the chopped strand mat and matrix. This supports the argument made by Azwa et al. [13] that void areas surrounding fibers were created by reduced adhesion between fibers and matrix.

Table 2. Tensile strength and modulus data for the 355 µm and 500 µm bamboo composite.

Mechanical Properties	100% Epoxy	Chopped Strand Mat	Hybrid Composite									
			1%		2%		3%		4%		5%	
			355 µm	500 µm	355 µm	500 µm	355 µm	500 µm	355 µm	500 µm	355 µm	500 µm
Tensile Strength (MPa)	61.3	261.9	94.8	118.4	95.7	115.9	78.3	124.8	71.9	101.6	87.2	114.7
Tensile Modulus (GPa)	4.5	8.5	2.3	2.7	2.3	2.9	2.2	3.0	1.7	2.5	2.2	2.6



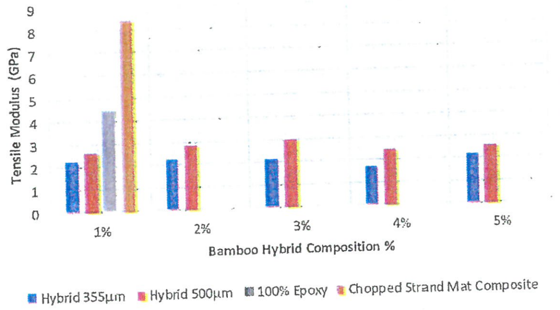


Figure 1. Chart of tensile strength against bamboo hybrid composition.

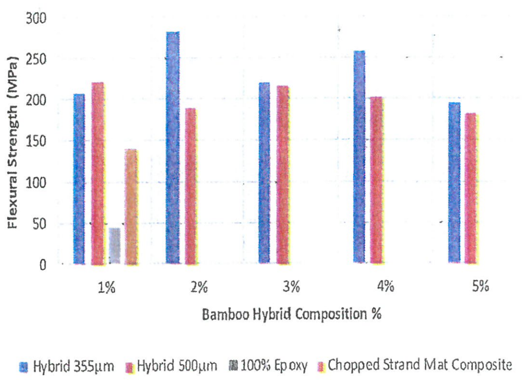
Figure 2. Chart of tensile modulus against bamboo hybrid composition.

Flexural Test. A flexural test was performed to find out how much bending a material could tolerate before breaking. Table 3 displays the specific sample results of the 100% epoxy, 100% chopped strand mat, 355 µm and 500 µm bamboo hybrid composites with respect to 1 - 5 % bamboo fiber. The table shows that the highest flexural strength; 282.9 MPa, had been recorded for hybrid 355 µm bamboo fiber in 2%. These values had been the highest, in comparison to 1 - 5 % bamboo fiber. Meanwhile, the highest flexural modulus value; 28.4 GPa, had been noted for the 2% bamboo fiber, instead of the 1 to 5%. Apart from that, the flexural strength and flexural modulus of the average ten samples from each 1- 5% bamboo fiber of the 355 µm and 500 µm bamboo hybrid composites are shown in Figs. 3 and 4. According to the results, the 500 µm bamboo hybrid composite showed the lowest flexural strength, ranging from 2 to 5%, while the 355 µm bamboo hybrid composite recorded the maximum flexural strength. The figure also clearly shows that the 355 µm bamboo hybrid composites demonstrated more rigidity, and strength, as compared to 500 µm with 2 - 5 % bamboo fiber. In addition, one can note that 355 µm bamboo hybrid composite possessed the highest flexural strength when compared to 500 µm bamboo hybrid composite. This could be the outcome of the samples' fiber-matrix adhesion strength, void content, and composition percentages. More specifically, flexural modulus represents the amount of resistance composites exert to bending deformation, while flexural strength is the mixture of tensile and compressive strengths that directly varies with interlaminar shear strength [14]. As proven, the flexural properties decreased for 500 µm as the percentage bamboo layers were added from 2 to 5 %. As such, the highest flexural strength value; 282.9 MPa with 2% was observed for the 355 µm bamboo hybrid composite. Meanwhile, the lowest flexural strength; 184.4 MPa with 5% was obtained for the 500 µm bamboo hybrid composite, this revealed a variation in flexural strength of almost 53.4%. Furthermore, the flexural strength of the hybrid composite was reduced by 48.0% with the addition of 500 µm bamboo in 2% as opposed to 355 µm. Furthermore, it was discovered that the flexural strength of the 355 μm with 4% bamboo hybrid composite was 258.6 MPa, whereas the flexural strength of the 500 μm bamboo composite was 203.9 MPa, indicating a 21.1% decrease in comparison to the 355 μm bamboo hybrid composite.

Besides, the 355 μm with 5% bamboo hybrid composite demonstrated 5.6% strength of the 500 μm. This most likely occurred because the hand lay-up laminate hybrid composite was patterned, exhibiting superior flexural characteristics mainly because of improved fiber interlacing in both directions [14]. However, the results for flexural modulus, as shown in Fig. 4, showed that the hybrid composite made of 355 μm bamboo had the highest stiffness when bent at 28.4 GPa with 2% bamboo fiber. The graph also showed that along the 1-5% bamboo fiber, the flexural modulus of hybrid bamboo measuring 355 μm and 500 μm increased and decreased. In fact, the highest flexural modulus value; 28.4 GPa with 2% bamboo fiber, was observed for the 355 μm bamboo hybrid composite. Conversely, the 500 μm bamboo hybrid composite showed a variation in flexural modulus of around 56.9%, with the lowest result for flexural modulus-18.1 GPa with 2% bamboo fiber. Moreover, the flexural modulus dropped by about 16.4% with an increase in 500 μm bamboo fiber from 3 to 5%. Moreover, the flexural modulus of the hybrid composites with a thickness of 355 μm and 500 μm demonstrates variations for every percentage of composition.

Table 3. Flexural strength and modulus data for the 355 μm and 500 μm bamboo composite.

Mechanical Properties	100% Epoxy	Chopped Strand Mat	Hybrid Composite 1%		2%		3%		4%		5%	
			355 μm	500 μm	355 μm	500 μm	355 μm	500 μm	355 μm	500 μm	355 μm	500 μm
Flexural Strength (MPa)	44.5	142.9	208.7	224.3	282.9	191.1	220.5	218.5	258.6	203.9	195.3	184.4
Flexural Modulus (GPa)	2.7	14.1	19.6	22.1	28.4	18.1	21.3	22.7	26.8	20.5	19.4	19.5



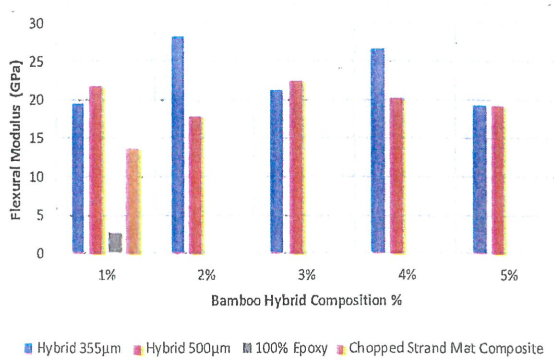


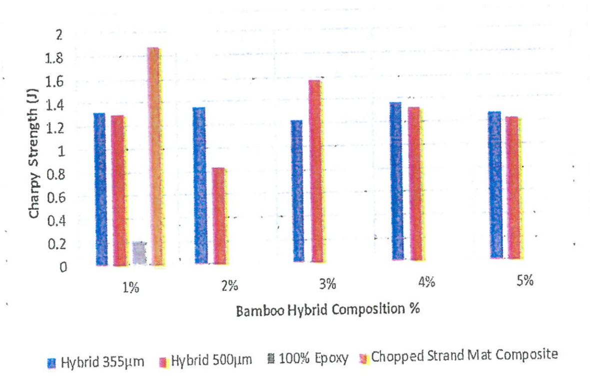
Figure 3. Chart of flexural strength against bamboo hybrid composition.

Figure 4. Chart of flexural modulus against bamboo hybrid composition.

Charpy Impact Test. To ascertain the capacity of energy absorption in the different samples, an impact test experiment was conducted. The entire energy needed to shatter a specimen is referred to as the absorbed impact of energy. Because of this, the impact strength was determined by dividing the sample's cross-section area by the impact energy that was observed to be absorbed. Table 4 tabulates the results of individual samples for the 100% epoxy, 100% chopped strand mat, 355 μm and 500 μm bamboo hybrid composites with respect to 1-5 % bamboo fiber. The table further portrays that the highest impact strength values, which were 1.587 J , had been identified at the 3% of 500 μm bamboo hybrid composite. When compared to the results obtained for 1 to 5% composition 355 μm & 500 μm bamboo hybrid composites, these values were the highest. On top of that, Fig. 5 illustrates the average impact strength of each bamboo hybrid composition 355 μm and 500 µm for the 1 to 5 % fiber composition. The values suggested that the energy absorbed by the 355 µm bamboo hybrid composite had been lower than that of the 500 µm with 3% bamboo fiber composition. Moreover, the highest impact strength value; 1.587 J with 3%, had been noted for the 500 µm. On the contrary, the lowest impact strength was 1.233 J with 3 % for 355 µm bamboo hybrid composite, It revealed a variation in impact strength of almost 33.3%. Furthermore, the impact strength of the composite was reduced by 1.1% with the inclusion of bamboo fiber in the 355 µm and 500 µm sizes, primarily in comparison to the 1% composition. Nevertheless, the impact strength was decreased by about 28.7% because to the 3% composition increase between 355 µm and 500 µm. At actuality, the impact strength of the hybrid composite was reduced by the added 1 to 5% composition of bamboo fiber at 355 µm and 500 µm. As a result, the 500 µm bamboo fiber with a 3% composition demonstrated exceptional impact strength, mostly because of its capacity to absorb and disperse energy. Moreover, the interlacing feature of the fibers in both directions is necessary for these improved impact qualities [14]. Furthermore, Figs. 6 further illustrate the SEM micrograph of varied failure modes. The figures specifically portrayed the fractured specimens of 500 µm and 355 µm bamboo fiber 3 and 5 %. In addition, one can observe that the bamboo fiber in 500 µm and 355 µm (3 and 5 %) portrayed a different break with shattered fibers. Thus, many parameters, such as the presence of voids, interfacial binding strength, matrix, and fiber, had a significant impact on the impact properties of the fiber composites [15]. Consequently, the failure mode-which includes fiber pull-out, fiber fracture, fiber breakage, and matrix cracking-could be responsible for this behavior.

Table 4. Charpy strength data for the 355 µm and 500 µm bamboo composite.

Mechanical Properties	100% Epoxy	Chopped Strand Mat	Hybrid Composite									
			1%		2%		3%		4%		5%	
			355 µm	500 µm	355 µm	500 µm	355 µm	500 µm	355 µm	500 µm	355 µm	500 µm
Impact Strength (J)	0.213	1.900	1.327	1.312	1.360	0.847	1.233	1.587	1.380	1.333	1.280	1.240



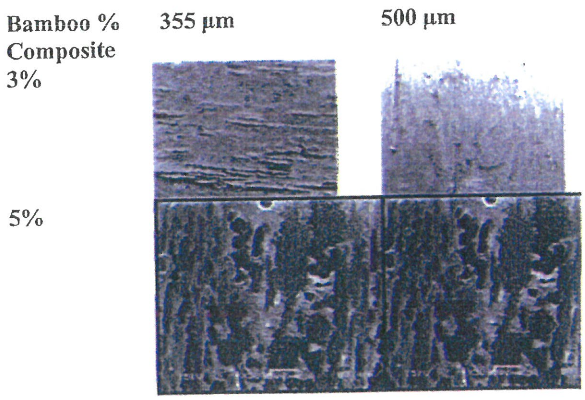


Figure 5. Chart of impact strength against bamboo hybrid composition.

Figure 6. Scanning electron microscope observation of bamboo composite.

Conclusions

The mechanical properties of 355 µm & 500 µm bamboo hybrid composite with various loading 1 to 5% of bamboo fiber have been studied. The tensile strength, tensile modulus, and impact strength were improved for 500 µm bamboo fiber in 3% of bamboo hybrid composition but opposite for flexural strength, and flexural modulus 355 µm bamboo fiber in 2%. The study shows that the 500 μm bamboo fiber with 3% bamboo hybrid composition has superior properties when compared with 355 μm. Incorporation and increase of percentages of bamboo fiber composition in epoxy, and chopped strand mat hybrid composites differentiate the mechanical properties of hybrid composites. It is clearly observed that the mechanical properties of 355 μm and 500 μm bamboo fiber give a comparision in various loading of bamboo. Incorporation and increase of micro bamboo fiber in chopped strand mat and epoxy can be attributed to the hybrid composite. Adding micro bamboo fiber to chopped strand mat and epoxy creates a hybrid composite that's strong, lightweight, and environmentally friendly. It improves strength, reduces weight, and enhances sustainability compared to traditional materials. This composite also offers better thermal and mechanical properties, while being cost-effective to produce.

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