The Influence of Laminated Layer and Thickness Gigantochloa Scortechinii Bamboo Strips on Mechanical Performance of Unsaturated Polyester Composites

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Abstract: In this study, several types of Gigantochloa scortechinii bamboo strips were used as fillers in an unsaturated polyester matrix and characterized in term of their tensile and flexural properties. The strips were formed with the culm fiber composite with inner-to-outer layer thicknesses of 1.5 mm, 2.0 mm, and 2.5 mm. The laminated bamboo strips composites were developed using the hand lay-up technique. The analysis was carried out using a 2- factor, 3- level design of experiment (DOE) and an analysis of variance (ANOVA) to determine how the layer strip and the thickness of the bamboo affected the mechanical properties of the composites. It was proven that both the bamboo layer and the thickness demonstrated significantly different results in terms of the tensile and flexural performance. The overall results indicated that the middle layer of the laminated composite exhibited the highest tensile and flexural strength.

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1. Introduction

Driven by environmental awareness, natural fibers have gained increasing acceptance as reinforcing materials for fiber-reinforced composites due to their low density, high specific strength and stiffness, low-cost, renewability, and biodegradability. Natural fibers have also been proven to be a good and effective reinforcement in thermoset and thermoplastic matrices (Monteiroa et al., 2008; Abdel Hakim et al., 2012 and Abdel Salam Sabbah et al., 2011). Bamboo has very good mechanical properties and it is considered the most efficient material in nature in terms of strength and cost. Moreover it is an abundant natural resource available in many countries and one of the fastest growing grass plants. Okubo et al., (2004) noted that bamboo fibers are often called 'natural glass fibers' due to their high strength characteristics. For example, Amada et al., (1997) stated that the strength of bamboo fibers is approximately 600 MPa which was 12 times higher than the matrix strength. This strength of bamboo is closely related to the resistance to fracture value reported by (Amada and Untao 2001), and Liese (1998) stated that the fibers of bamboo are much longer than those of hardwood, but shorter than those of softwood. They also revealed that bamboos with 3.5 years of age are suitable for any purpose (Hisham et al., 2006). Meanwhile, Kamruzzaman et al., (2008) stated that the bottom portion of bamboo contained the highest proportion of water, while the top portion had the lowest. Yu et al., (2008) reported that longitudinal shrinkage decreased greatly from inner to outer layers. Moreover, according to Latif (1992), the use of bamboo for quality products should be limited to the basal and middle portions. However, Han et al., (2008) emphasized that the superior mechanical properties have not been well defined for polymer-based composites. They added that using bamboo fibers with various parameters can help reduce the demand for wood fibers and the environmental impacts associated with wood fiber harvesting.

Therefore, various dimensions of bamboos can be exploited as a type of rational structural material by widening the, applied range of bamboos, which allows for use of the abundant bamboo resources. Additionally, there are the striking features that the bamboo has due to its high specific tensile and flexural properties. Thus, this study was performed on 4-years-old bamboo using the basal to middle parts of the internodes along the bamboo culm between 0.3 m and 13.5 m above the ground level, with 30 culm and size 12.6 m. The objective of this work is to identify the factors that affect laminated bamboo strip/ unsaturated polyester composites using inner, middle and outer layers with 1.5 mm, 2.0 mm and 3.0 mm of thickness. The extraction of bamboos is shown in Figure 1.

Pure Bamboo

Bamboo Strip

Strip Dimension (12 mm)

Figure 1: The schematic extraction of bamboo parts

2. Experimental

2.1. Experimental Design

The focus of this work is on two parameters: the type of layer and its thicknesses. Because the levels of each factor used were determined referring to the manufacturing capability and its competency, three levels were chosen for the composition of the layer and its thickness. The 2- factor, 3-levels for the design of experiments (DOE) was then used based on outcomes of the Design-Expert software.

2.2. Materials

The internode between 0.3 m and 13.5 m above the ground level was cut according to the desired thicknesses of 1.5 mm, 2.0 mm, and 2.5 mm. All specimens were washed with water and dried in an oven at 60°C for 72 hours to reduce their moisture contents because the green bamboo fibers had a high moisture content (Kamruzzaman et al., 2008). The unsaturated polyester (UP) resin Reversol P-9509 with specific gravity of 25°C: 1.12; viscosity of 450-600 cps volumetric shrinkage of 8% and acid value of mg KOH/g solid resin 29-34 was mixed with the hardener methyl ethyl ketone peroxide (MEKP). The mixture was then used to prepare the laminated composite.

2.3. Fabrication of Composites

The above materials were subjected to the hand lay-up process to produce the mould of the sample with dimensions 120 mm x 120 mm x 3 mm (length, width and thickness, respectively). UP was mixed with the methyl ethyl ketone peroxide (MEKP), which acted as a catalyst, at a ratio of 100:2. The mixture was stirred until its physical color changed from light pink to pale yellow. The mixture was then poured inside the mould until it covered the whole bottom surface. Then, 10 bamboo strips were placed slowly on the top of the bottom surface to wet them. After that, the UP mixture was poured again on the top surface of the strips, and it was brushed in one direction to ensure that it fully covered the strips. The fabricated composites with three different layers are shown in Figure 2 to Figure 4.

2.4. Testing Standards

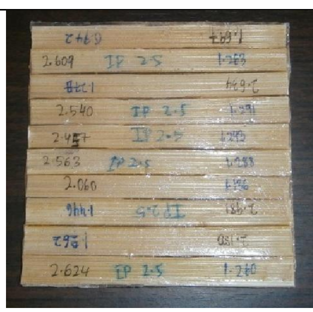

Figure 2: Inner Strip

Figure 3: Middle Strip

Figure 4 : Outer Strip

Figure 5: Tensile Testing

Figure 6: Flexural Testing

The tensile and flexural tests were performed according to ASTM D3039 and ASTM D790 using Instron 5569A (USA) with a capacity of 50 KN, and a cross head speed of 2 mm/min, and the specimen positioning and the operating conditions were 25 ± 2 ° C with 50% humidity (Figure 5 and Figure 6). The experimental results of each testing have been explained in detail in the earlier work (Rassiah et al., 2014).

3. Results and Discussion

Table 1 shows the factor and level of the layers and thickness variables, while Table 2 and Table 3 show the ANOVA results for the tensile and flexural strengths.

Table 1: Factor and Level

Factor	Level 1	Level 2	Level 3
Layer (strip)	Inner	Middle	Outer
Thickness (mm)	1.5	1.5	1.5
	2.0	2.0	2.0
	2.5	2.5	2.5

Table 2: ANOVA for Tensile Strength of different Bamboo Strips

Source	Sum of Squares		Degree of Freedom		Mean Square		F (Value)		P (Value)	
	Tensile Stress	Tensile Modulus	Tensile Stress	Tensile Modulus	Tensile Stress	Tensile Modulus	Tensile Stress	Tensile Modulus	Tensile Stress	Tensile Modulus
A= Layer	203.16	1.136E+006	2	2	101.58	5.697E+005	52.95	12.95	<0.0001	0.0003
B= Thickness	657.65	5.899E+006	2	2	328.83	2.949E+006	171.41	67.29	<0.0001	<0.0001
AB	26.06	2.003E+005	4	4	6.51	50065.38	3.40	1.14	<0.0309	0.3685
Error	34.53	7.890E+005	18	18	1.92					
Total	921.4	16.928E+022	26	26						

Table 3: ANOVA for Flexural Strength of different Bamboo Strips

Source	Sum of Squares		Degree of Freedom		Mean Square		F (Value)		P (Value)	
	Flexural Stress	Flexural Modulus	Flexural Stress	Flexural Modulus	Flexural Stress	Flexural Modulus	Flexural Stress	Flexural Modulus	Flexural Stress	Flexural Modulus
A= Layer	203.16	3.838E+006	2	2	101.58	1.919E+006	19.74	35.17	<0.0001	<0.0001
B= Thickness	2757.75	2.314E+006	2	2	1378.87	1.157E+006	268.01	21.21	<0.0001	<0.0001
AB	140.81	1.736E+005	4	4	35.20	43404.86	6.84	0.80	<0.0016	0.5435
Error	92.61	9.821E+005	18	18	5.14	54559.67				
Total	3194.33	17.709E+022	26	26						

3.1. Tensile properties

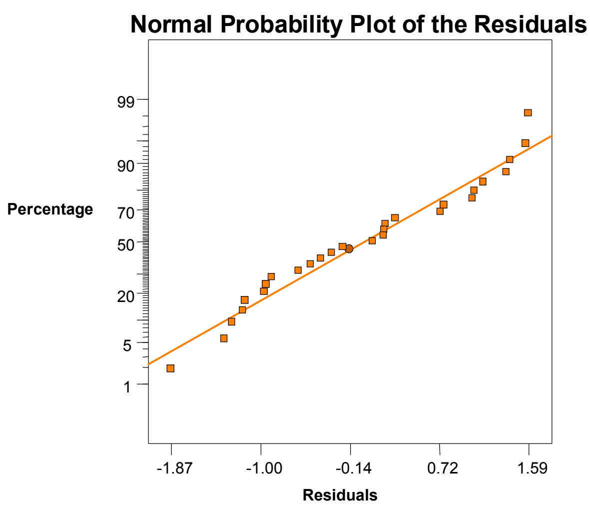

Figure 7: Normal plot of residuals for Tensile Stress

In the normal probability plots shown in Figure 7 and Figure 8, the residuals tensile stress and modulus demonstrated a stable variability for the tensile test samples, with R^2 values of 0.9625 and 0.9017. Based on analysis of variance (Table 2), all mean values for each group are significantly different (P-value<0.05). Thus, each variable has a significant effect on the tensile strength performance of the composites.

The results of the interaction plot for tensile stress and modulus on the different layers and thicknesses are presented in Figure 9 and Figure 10. As shown in these graphs, layered composites with 2.5 mm middle layer are outperformed as a layered composite. The tensile stress value of the inner and outer layers is lower than that of the middle layers for each thickness. The highest values for tensile stress and modulus are 48.767 MPa and 3897.21 MPa, which were found for middle layers. The results for layer types in this research show dissimilarities with the tensile strength performance for the thickness. Figure 11 shows the samples that failed in the mechanical testing. Meanwhile, Figure 12 shows scanning electron microscopy (SEM) images indicating poor interfacial bonding of the bamboo strip/ unsaturated polyester interfaces on the (a) inner and (c) outer laminated layers. These images demonstrate that the inner and outer laminated layers had a weak, adhesion. This is likely the main reason for the poor mechanical properties of the bamboo strip laminated composites. In contrast, the (b) middle layer shows a good bonding of the laminated layer.

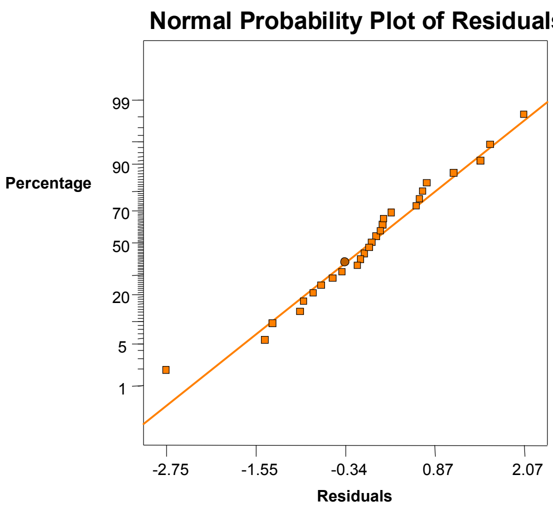

Figure 8: Normal plot of residuals for Tensile Modulus

Previous investigations on the relationship between the physical, anatomical and strength properties of 3-year-old cultivated tropical bamboos (Gigantochloa scortechinii) performed by Wahab et al., (2012) found that the mechanical properties are affected by the magnitude of the vascular bundles length, vascular bundles width, fiber length, fiber diameter, fiber lumens diameter, fiber wall thickness and the fiber Runkle's ratio. The results showed that the tensile strength increases with higher content of vascular bundles and cellulose which can lead to a higher density and a decreasing micro-fibril angle. The thickness of the bamboo strip was suggested to increase the tensile strength, thereby improving the laminated composite. Moreover, another study conducted by Wang et al., (2010) using different micro-fibril angles and densities, showed that a higher outer layer content than inner layer content leads to a higher density. The results indicated that using more outer layers compared to inner layers gives better mechanical properties. Yu et al., (2008) compared the mechanical properties of moso bamboo at different horizontal and vertical sampling positions of the culms. They found that the relative density, tangential shrinkage, tensile modulus of elasticity and tensile strength of the bamboo increased greatly from the inner layer to the outer layer. Therefore, laminating the middle layer bamboo strip with unsaturated polyester was expected to increase the tensile properties.

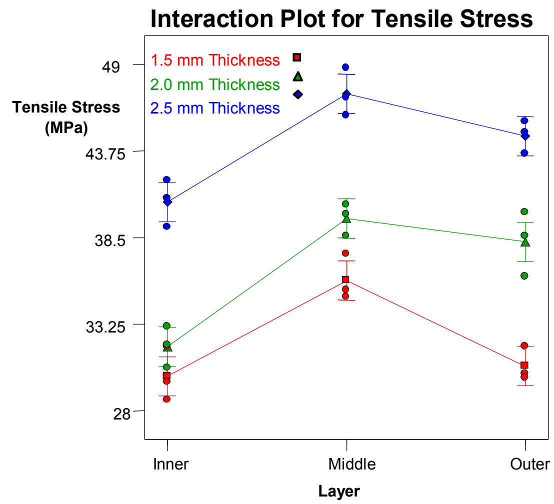

Figure 9: Interaction plot for Tensile Stress

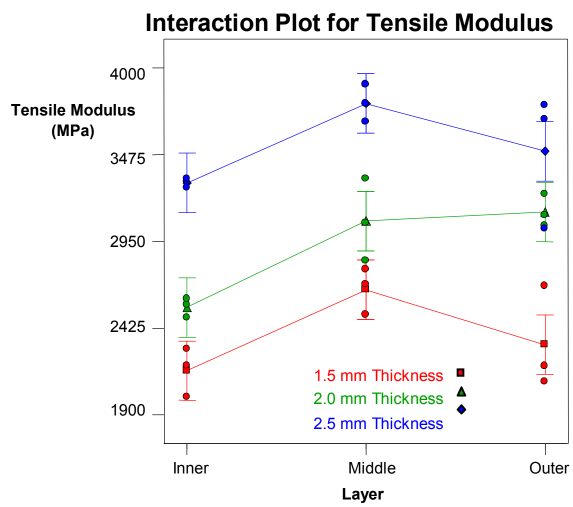

Figure 10: Interaction plot for Tensile Modulus

Figure 11: Composite Failure

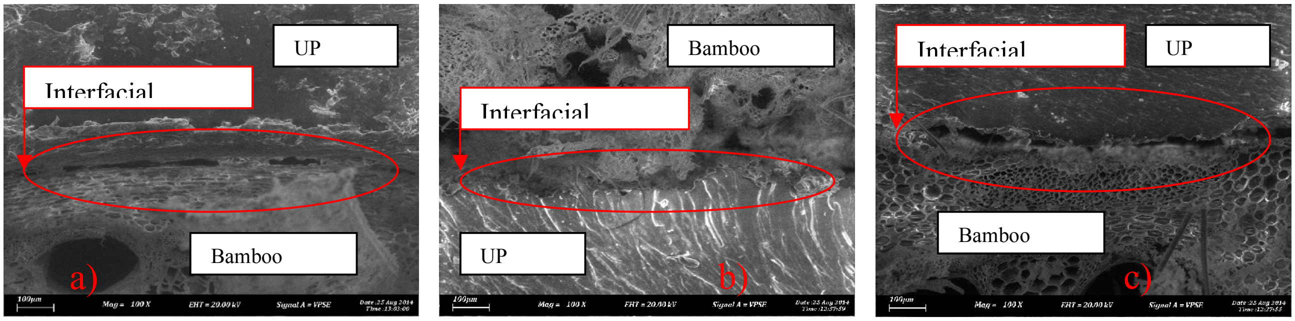

Figure 12: SEM images of the fractured surfaces of the a) inner, b) middle and c) outer layers with Magnification 100 x

3.2. Flexural Properties

In the normal probability plots shown in Figures 13 and 14, the residual flexural stress and modulus demonstrated a stable variability for flexural test samples, with R^2 values of 0.9710 and 0.8656. Based on analysis of variance (Table 3), all mean values for each group are significantly different (P-value<0.05). Thus, each variable layer and thickness has a significant effect on the flexural strength performance of the composites.

Meanwhile, Figures 15 and 16 show the interaction plots for flexural stress and modulus results of layers with different thicknesses. In this graph, the 2.5 mm middle layer composites are outperformed as a layered composite. The flexural value of the inner and outer layers is lower than that of the middle layer. The highest values of the flexural stress and the flexural modulus, (85.623 MPa and 5235.38 MPa, respectively) occurred in the middle layer. The significant differences in these two, values indicate that the thickness of the bamboo strip will increase the flexural strength when laminated with unsaturated polyester. In addition smaller thicknesses cannot withstand flexural force, especially for the inner and outer layers. Figure 17 shows the samples that failed in the mechanical testing.

During the flexural test, composites underwent compressive and tensile fracture. The high weight content of bamboo fibers increases their strength. According to Rao et al., (2010), the flexural strength and modulus increase linearly with the volume fraction of fibers. In addition the mixture of the matrix and fibers increases the flexural strength due to the bamboo culm geometry. This means that a particular part in the inner and the outer region of the bamboo strip needs to be removed before mixing with the matrix. Meanwhile, Wong et al., (2010) reported that the fracture resistance of all types of composites is higher compared to that of pure polyester. The cellulose content with higher density exhibited a good flexural strength for all layer and thickness conditions.

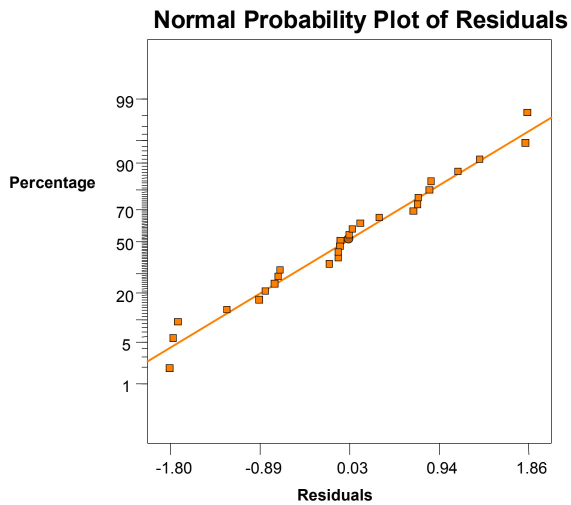

Figure 13: Normal plot of residuals for Flexural Stress

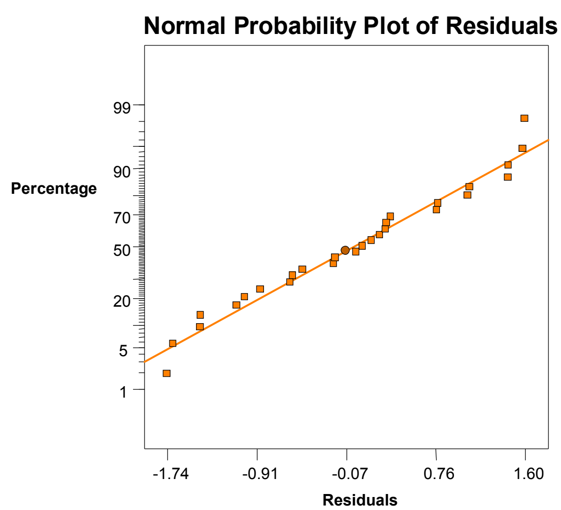

Figure 14: Normal plot of residuals for Flexural Modulus

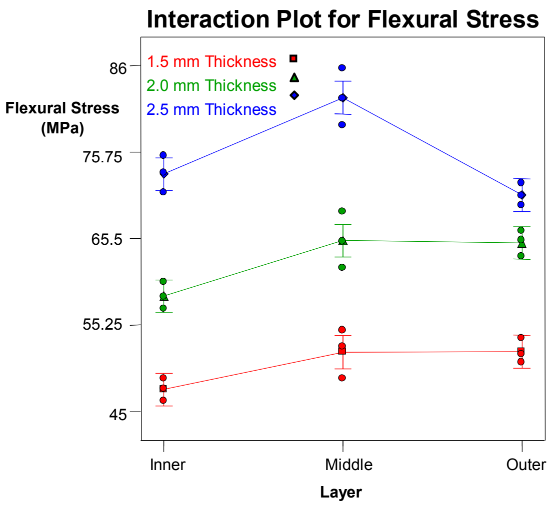

Figure 15: Interaction plot for Flexural Stress

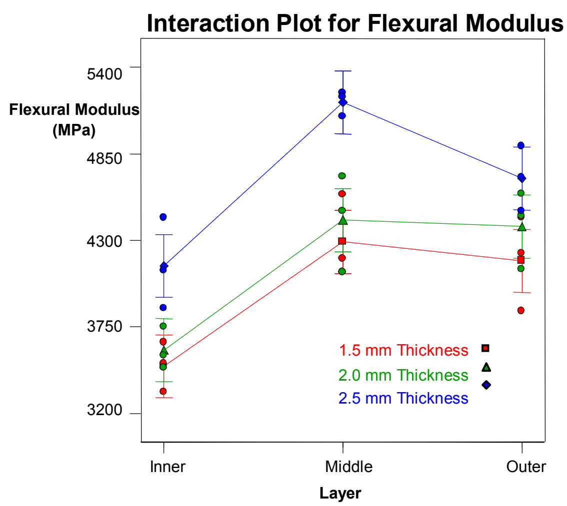

Figure 16: Interaction plot for Flexural Modulus

Figure 17: Composite Failure

Conclusions

In these studies, the layer and thickness are identified as the factors that are important in the development of new natural fiber composites. The analysis, which used a design of experiments (DOE) and analysis of variance (ANOVA), shows that the optimum results were achieved when the middle layer of 2.5 mm was used. Thus, the ANOVA analysis outcome had established correctly that the layer types and thicknesses used have significant effects on the tensile and flexural properties. The middle layer laminate was shown to have better tensile and flexural strengths. The measurement of composite characteristics indicated that thicker layers of laminated unsaturated polyester and bamboo strips displayed greater tensile and flexural strength performance compared to a thin layer, especially for middle layers. In addition, a larger impact on the tensile and flexural properties was observed with thinner inner and outer layers.

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