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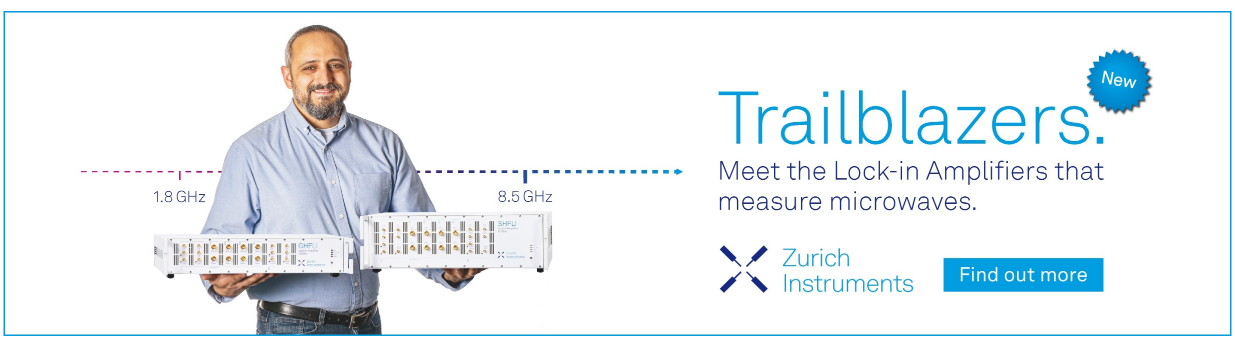

The Physical and Mechanical Properties of Treated and Untreated Gigantochloa Scortechinii Bamboo

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Abstract. Bamboo's advantages such as fast growing, renewable and easily available raw material meets the demand of sustainable material in construction. Bamboo act as reinforcement to enhance strength in structural members. This paper investigated on the properties of Gigantochloa Scortechinii bamboo (moisture content, density, compression, shear and bending) by referring to ISO 22157. Moisture content for both untreated and treated bamboo high at the bottom section while density is high at the top section. Compression strength for untreated bamboo were between 19.96 to 23.80 MPa and treated bamboo were between 31.74 to 36.60 MPa. High compression was at the top section which have the greatest wall thickness. Shear strength recorded between 4.28 to 5.69 MPa for untreated bamboo with node and 3.67 to 5.21 MPa for treated bamboo with node. The shear strength of samples with node recorded high strength compared to internode. Untreated bamboo recorded the MOR between 53.64 to 73.66 MPa and 58.23 to 62.86 MPa for treated bamboo. MOE of untreated bamboo were between 26.70 GPa to 36.31 GPa while treated bamboo were between 28.83 to 33.41 GPa. By replacing bamboo to the conventional building material, cost of materials will be reduced and sustainability will be enhanced.

INTRODUCTION

Bamboo has been widely known as sustainable building materials to replace the use of conventional materials such as wood, brick, concrete and steel. But, before bamboo is accepted as one of the construction material, its basic properties need to be studied. In Malaysia, most common bamboo species available and most widely utilized is Gigantochloa Scortechinii [1]. Bamboo is described as low cost, easy availability in local and high in strength as strong as steel. Besides, bamboo is known as environmental friendly, fast-growing and renewable resource material, it only takes within 3-5 years to be collected readily and matured [2-4].

Bamboo not only can prevent erosion, it even revitalize devastated rain and forest soil. Moreover, for the supply chain of bamboo, it will help to promote the local economy. With its high tensile strength, bamboo can replace steel in reinforced concrete [5]. Bamboo's engineering aspect being neglected and not used in modern construction. More engineering design, practical examples and dissemination of information using bamboo technology is required [6].

This study was aimed to determine the physical and mechanical properties of untreated and treated Gigantochloa Scortechinii (Buluh Semantan). The test includes the moisture content, density, compression strength, shear strength and flexural bending strength.

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METHODOLOGY

Preparation of Materials

The 3-4 years old Gigantochloa Scortechinii bamboo (Buluh Semantan) were used in this study because of this type of bamboo widely used in local bamboo industries in Malaysia. This bamboo species were collected from Hulu Langat, Selangor, Malaysia with diameters ranging from 45 to 60 mm. the height of the bamboo culm is about 3m approximately. The untreated bamboo was air dried under the shed and the treated bamboo was treated by using borax and boric acid then dried under shed.

Physical and Mechanical Properties

Procedures and method used for the determination of physical and mechanical properties of bamboo were referring to International Standard ISO 22157-1 and ISO 22157-2 [7-8].

Determination of Moisture Content

Samples of 25 mm x 25 mm x wall thickness for both untreated and treated bamboo were taken near to the failure place for the determination of moisture content and density. The untreated and treated bamboo were cut from the each section of culm (bottom, middle, top). Initial weight before drying was weighed. Then, the samples were dried in an oven at a temperature of 103 ± 2°C. After 24 hours, the mass was recorded. For each test piece, the moisture content MC were calculated by using the Equation (1)

$$MC\ (\%) = (m - m_0 / m_0) \times 100 \quad (1)$$

where m: mass before drying (g) and m_0: mass after oven drying (g)

Determination of Density

The samples used in the determination of moisture content were the same used for density determination. The oven-dry density of each sample were calculated using Equation (2)

$$\text{Density}\ (kg / m^3) = (\text{mass} / V) \times 10^6 \quad (2)$$

where m: mass after oven dying (g) and V: volume of the sample (mm^3)

Compression Strength

The Gigantochloa Scortechinii bamboo were cut into three sections of each culm for both untreated and treated from the bottom, middle and top part. The height of each test specimen was cut into twice of the external diameter of the bamboo culms. Compression strength were tested by using digital compression test machine as shown in Fig. 1. The maximum compressive stress then were calculated by using the Equation (3).

FIGURE 1. Setup for compression test

$$\sigma_{ult} = F_{ult} / A \quad (3)$$

where σ_{ult}: compressive stress (MPa), F_{ult}: maximum load (N) and A: bamboo wall cross-sectional area (mm²).

Shear Strength

Internodes and nodes were cut from each sections of untreated and treated bamboo culm (bottom, middle, top). The length of the specimen were twice from the external diameter. The test were carried out by using the Digital Compression Test Machine with the specimen were supported at the lower end over two quarters. Load were at the upper end over the two quarters which are not supported. Figure 2 shows the general set-up of the shear test. The ultimate shear strength were calculated by using the Equation (4).

FIGURE 2. Setup for shear test

$$\tau_{ult} = Fult / As \quad (4)$$

where τ_{ult}: shear strength (MPa), F_{ult}: maximum load (N) and As: four products t and L.

Flexural Bending Test

The bending capacity of the bamboo culms were tested using a four-point bending test until failure as shown in Fig. 3. The samples with 3m length were tested by using the Magnus frame machine. Deflections were measured at mid-span with every 20mm load increment. Load-deflection diagram were plotted. The Modulus of Rupture (MOR) were calculated by using Equation (5). Then, the modulus of elasticity were calculated by using the Equation (6).

$$MOR = (F \times L / 6) (D / 2) / IB \quad (5)$$

where F: maximum load (N), L: free span (mm), D: outer diameter (mm) and IB: second moment of area (mm^4).

$$MOE = (23 \times F \times L^3) /(1296 \times \delta \times IB) \tag{6}$$

where δ: deflection mid-span (mm).

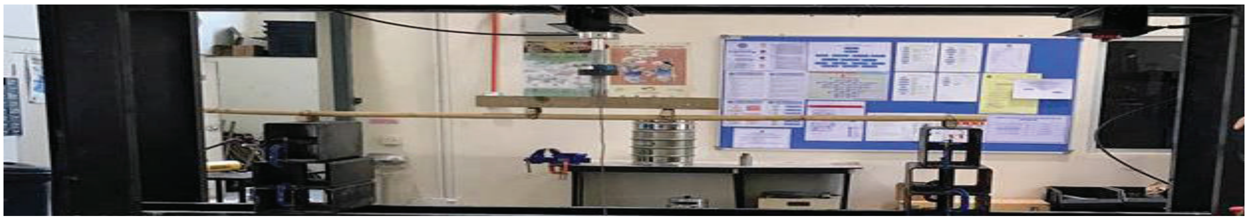


FIGURE 3. Setup for flexural bending test

RESULTS AND DISCUSSION

Air Dried Moisture Content and Density

The results of moisture content and density of air-dried untreated and treated Gigantochloa Scortechinii bamboo are shown in Table 1. Results were classified into three section which include bottom, middle and top. From the results obtained, moisture content at the bottom section for both untreated and treated bamboo were slightly greater compared to the middle and top section of the bamboo culm. Moisture content of the top section was recorded as the lowest. The moisture content listed decreased along the bamboo culm from bottom section to the top section. The treated bamboo recording the highest (25.93%) moisture content while the lowest was recorded from untreated bamboo (11.11%).

Results of untreated and treated bamboo showed the density at the top section was the highest. Bottom section of the bamboo culm showed the lowest density among the other section. Both untreated and treated bamboo listed the results of density increased from the bottom to the top section along the bamboo culm. Based on the results, it can be observed that higher portion of the bamboo culm have high density compared to the lower portion. This is because of the anatomical structure along the bamboo culm [1].

TABLE 1. Results of moisture content and density

Section	Moisture Content (%)		Density (kg/m³)	
	Untreated	Treated	Untreated	Treated
Bottom	15.79	25.93	608.00	785.45
Middle	12.50	23.08	610.98	832.00
Top	11.11	16.00	716.42	869.57
Mean	13.13	21.67	645.13	829.01

Compression Strength

The results for compression strength of the untreated and treated Gigantochloa Scortechinii bamboo are shown in Table 2 and 3. Top section for both untreated and treated bamboo indicated the highest compression strength. This is due to the large thickness of bamboo wall and high cross-sectional area compared to the middle and bottom section.

For untreated bamboo, the compressive strength is recorded to be 19.96 MPa at the bottom section and increased slightly to 23.80 MPa at the top. The compressive strength of the treated bamboo is found to be at its largest at the top section about 36.60 MPa which is slightly reduced to 31.74 MPa at the bottom.

Fig. 4 showed the two failure mode called End bearing and Splitting. From the crack pattern, top section with high thickness of wall only failed in end bearing. As the wall thickness decreased, it caused splitting (bottom and middle section).

TABLE 2. Results of compression strength for untreated bamboo

Section	Untreated Bamboo		
	Wall Thickness (mm)	Cross-Sectional Area (mm²)	Compression Strength (MPa)
Bottom	11.10	1583.38	19.96
Middle	17.40	2000.95	23.24
Top	27.30	2290.24	23.80
	Mean		22.33

TABLE 3. Results of compression strength for treated bamboo

Section	Treated Bamboo		
	Wall Thickness (mm)	Cross-Sectional Area (mm²)	Compression Strength (MPa)
Bottom	10.09	1439.86	31.74
Middle	12.96	1630.44	34.71
Top	19.25	1893.55	36.60
	Mean		34.35

(a)

(b)

FIGURE 4. Compression strength test (a) End bearing failure mode (b) Splitting failure mode

Shear Strength

Table 4 and 5 are the results for shear strength for untreated and treated bamboo. Highest shear strength at the top section for both node and internode. Bamboo with node showed the high shear strength compared to internode. The highest shear strength recorded was at top section of the node part which is 5.69 MPa and slightly reduced to 4.28 MPa at the bottom section for the untreated bamboo. Treated bamboo showed the same pattern, which high shear strength at the top for the bamboo with node (5.21 MPa) and bottom section are the lowest (3.67 MPa). The shear strength of samples with node was higher than internode. Figure 5 presents the failure mode of shear strength conducted on bamboo with node and internode. Bamboo with node showed the high strength and did not split as the internode.

TABLE 4. Results of shear strength for untreated bamboo

Section	Wall thickness (mm)	Height (mm)	Shear Strength (MPa)	
			Node	Internode
Bottom	7.30	92.80	4.28	4.10
Middle	8.20	91.00	4.56	4.25
Top	9.40	87.40	5.69	5.45

TABLE 5. Results of shear strength for treated bamboo

Section	Wall thickness (mm)	Height (mm)	Shear Strength (MPa)	
			Node	Internode
Bottom	10.54	126.08	3.67	3.54
Middle	11.18	123.12	4.61	3.94
Top	12.52	113.02	5.21	4.98

FIGURE 5. Shear strength test: Internode and node

Flexural Bending Strength

Figure 6 and 7 illustrated the load-displacement of the untreated and treated bamboo. The average ultimate load of flexural bending test for untreated bamboo is 1.31 kN, while treated bamboo is 1.23 kN. The bending failure mode shown in Fig. 8. Failure mode of longitudinal splitting is identified on the bamboo sample. The splitting crack is because of the weak lignin bonding between the bamboo fibers together. But, when load is removed, the bamboo specimen turns into its original straight form. This is an advantages as structural construction material in case of an earthquake or a hurricane [9]. The result computed for the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) for untreated and treated bamboo are shown in Table 6 and Table 7. For untreated bamboo, the MOR obtained is between 53.64 to 73.66 MPa and MOE were 26.70 to 36.31 GPa respectively. While the treated bamboo showed the result of MOR between 58.23 to 62.86 MPa and MOE were between 28.83 to 33.41 GPa.

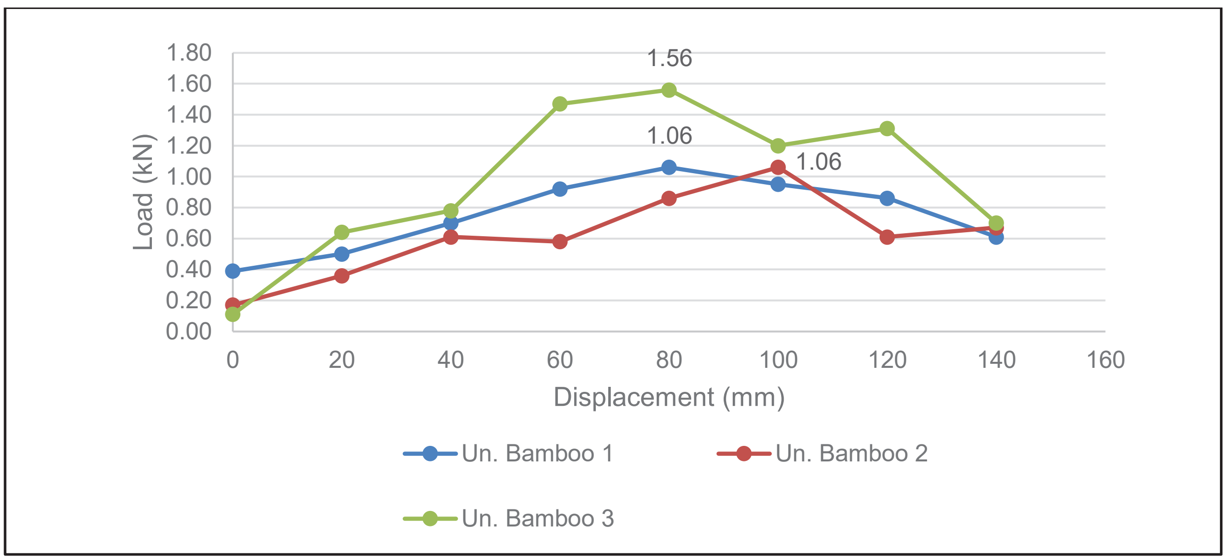


FIGURE 6. Flexural bending test on untreated bamboo

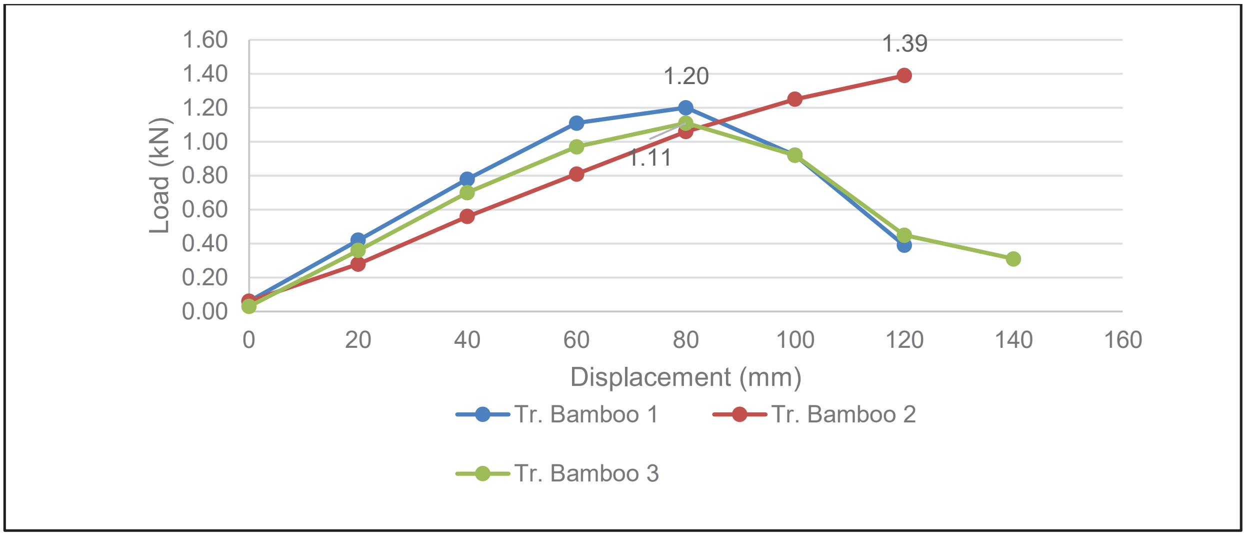


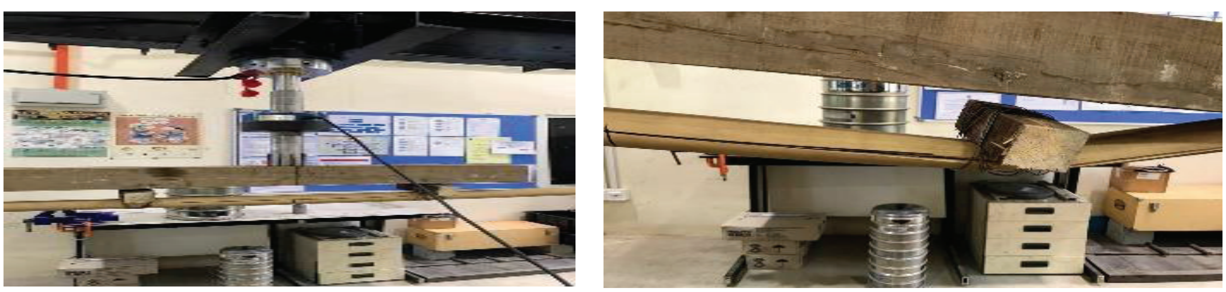
FIGURE 7. Flexural bending test on treated bamboo

TABLE 6. Results of MOR and MOE for untreated bamboo

Bamboo	D (mm)	T (mm)	F (N)	MOR (MPa)	MOE (GPa)
Bamboo 1	48.12	11.58	1060	53.64	26.70
Bamboo 2	49.00	9.54	1060	49.68	19.43
Bamboo 3	48.61	14.24	1560	73.66	36.31
	Mean			58.99	27.48

TABLE 7. Results of MOR and MOE for treated bamboo

Bamboo	D (mm)	T (mm)	F (N)	MOR (MPa)	MOE (GPa)
Bamboo 1	48.39	11.58	1200	58.23	28.83
Bamboo 2	49.58	9.64	1390	67.49	21.74
Bamboo 3	45.08	14.24	1110	62.86	33.41
	Mean			62.86	27.99



(a) (b)

FIGURE 8. Flexural bending test (a) Flexural bending set up (b) Failure mode

CONCLUSION

The physical and mechanical properties test was carried out on Gigantochloa Scortechinii bamboo with diameter ranging 45-60 mm. From the results obtained, the moisture content of bamboo was high at the bottom section. The density is increases from the bottom to the top section of the bamboo culm. It was found that the thickness of wall of the bamboo culm affected the strength. The more the thickness of the wall, the more strengthen the bamboo. Nodes presents along the bamboo culm generally have higher strength compared to the internodes. Flexural bending test showed that bamboo can turn into its original form after the load removal. This is a good information to suit bamboo as one of the structural construction material. It can prevent a huge damage to structural member in case of natural disaster, earthquake and hurricane happened. Bamboo is recognized as the alternative to replace the conventional building materials. By popularizing the bamboo for building materials, we will able to answer the call of contributing toward sustainability and reducing cost in construction because of using readily available raw material.

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