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Characterization of the Mechanical Properties of Ghanaian Bamboo for Structural Applications

Andoh P. Y., Tawiah, P. O., Agyei-Agyemang A.
Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

ABSTRACT

Construction industries make use of Bamboo because of its high strength, growth rate and abundance in most parts of the world. Bamboo is one of the oldest building materials used by man, (Abd.Latif et al., 1990). Unfortunately, local bamboo species in Ghana have not been used in such engineering applications even though bamboo is abundant in the country. The objective of this work is to study the mechanical properties of Ghanaian Bamboo and establish its suitability for structural engineering applications. Two types of bamboo, the *bambusae vitata* and the *bambusae vulgaris*, were used to perform tensile tests to determine the yield strength, ultimate strength and the modulus of elasticity; while bending tests were conducted to determine the modulus of elasticity and ultimate strength. The studies found a linear relationship between the applied loads and the corresponding extensions for tensile and bending tests. The yield and ultimate strength properties of the species improved as the number of days increased due to possible reduction in moisture content. Similar results were obtained for the bending tests. The results also showed that the properties obtained were well within the range of foreign bamboo species. It was concluded that the mechanical properties of the local bamboo have been characterized by determining their yield strength, ultimate strength and modulus of elasticity. It can therefore be established that, the two species under study can be used in engineering application.

Keywords: *Bamboo, Tensile Test, Characterization, Bending Test, Modulus of Elasticity*

1. INTRODUCTION

Bamboo is a common natural composite material composed of cellulose fibers imbedded in a lignin matrix. Bamboo is a relatively abundant and sustainable resource, (Dixon and Gibson, 2014). There are about 31.4 million hectares of bamboo worldwide, with 60% concentrated in China, India and Brazil, (FAO, 2010). Cellulose fibers are arranged along the length of bamboo ensuring higher tensile flexural strength and rigidity in that direction (Xiaobo Li, 2004). The column of bamboos is a cylindrical shell, which is divided by transversal diaphragms at the nodes. (Radin Mohd Ali, 2009). Tensile strength of bamboo culm depends upon the density of bamboo culms along and across fibers (Verna et al, 2004).

The bamboo culm comprises of about 50% parenchyma, 40% fiber and 10% of vessels and sieve tubes. Fibers contribute about 60% to 70% of the weight of the total culm tissue. (Xiabo Li, 2004). The fiber of a bamboo has an average length of 2 mm and an average diameter between 10 and 20 µm. The percentage of fiber is highest at the base of the culm and decreases from the bottom to the top. (Radin Mohd Ali, 2009)

Mechanical property of a material is the behavior of the material when subjected to different loads. Several factors affect the mechanical properties of bamboo. One major factor that hugely affects or has a direct impact on the mechanical properties of bamboo is the specific density property. Density of a material is the quantity of its mass divided the volume of the material. Specific density of bamboo is the density of bamboo compared to the density of water. Higher specific density of bamboo results in an increased mechanical strength properties. Ahmad (2000), reports that, the specific gravity of bamboo ranges from 0.5 to 0.79. Within a cum wall, the moisture content decreased from the interioir outwards (Anwar, 2005). That is, its relative density increased from the interioir outwards. It is reported that the density of bamboo increases from the base of the culm to the top. (Nordahlia A. S et al, 2012). They explained that the wall thickness decreases from the top of the culm without any change in the amount of fibers in the cross section of the culm. This makes the top section of the culm to possess higher amount of fibers contributing to an increased density. They also argued that the higher density at the top of the bamboo was as a result of the distribution of vascular bundles and silica content.

Tensile strength is the ability of a material to be stretched without breaking. A research by C.S Verma et al. (2012) about the tensile strength of bamboo reveals that the tensile strength of a bamboo culm depends upon the density of bamboo culms along and across fibers; while the density of the bamboo is influenced by the age and the portion of culm concerned, (Santhoshkumar and Bhat, 2014). Fiber strength of bamboo is not uniform when a section is considered . Fiber strength is higher at the outer regions of the bamboo. The density of bamboo varies from the centre to the perifery of the culm, due to difference in fibre concentration across its cross-section (Chand et al., 2010). According to them, tensile strength is proportional to the volume fraction of fibers and the fiber strength is about 600 MPa. This is about 12 times higher than the matrix strength. The volume fraction of fiber is higher (60 to 65%) at the outer regions and smaller at the inner regions (15 to 20%). This means the fibers are only present in small amounts and are often spread over a large area in the inner region of a culm section. The tensile strength of raw bamboo culms for various species is in the range of 111 to 219 MPa. The weakest portion of bamboo culm when it comes to tensile strength is the node. The reason for this is that, at the nodes the fibers are entangled in various directions. Matrix failure occurs before fiber failure. Tensile strength of bamboo increases from inner to outer region across any section of bamboo. Tensile strength also increases from the top to bottom of bamboo culms. This is due to an increase in volume fraction of fibers at the top of the bamboo. It also increases with height due to the increased specific density at the top of bamboo culm.

Compressive strength of bamboo culms depends, mainly, on age and moisture content. Higher moisture content decreases the compressive strength of bamboo culms and vice versa. A research by Gutu reveals that, the compressive stress of bamboo perpendicular to the longitudinal direction increased with age. She further stated that one year old bamboo recorded the lowest value of 16.1 MPa compressive stress while a five year old one had the highest stress. The top part of the culm had the highest compressive stress and Young's modulus than the middle and bottom (Gutu, 2013). According to Juan Francisco and Juliana, maximum compressive strength for bamboo culms occurs in 3 year old culm but the difference between the compressive strength of 3 and 4 year old is 1 %. They again indicated that the compressive strength decreases at age 5 (Juan Francisco and Juliana, 2010). The compressive strength of bamboo is said to be twice that of concrete (Gutu, 2013).

Bamboo composite laminate has higher strength properties over other materials and composites. C. S. Verma et al (2012) investigated the advantages of bamboo composite laminate and came out with the following observations. They indicated that the properties of teak in literature such as tensile are 95 to 155 MPa, Young's modulus is 10 to 15.6 and density is is 0.62 g/cm^3. Properties obtained for LLBCs such as tensile strength is 120-251 MPa, Young`s modulus is 11.6-17.5 GPa and density is 0.9 g/cm^3. This clearly indicates that the tensile strength of bamboo composite laminate is far higher than teak. Laminates made from the outer region of the bamboo culm was stronger than those made from the inner region. Layered laminate bamboo composite has higher strength properties than single lamina. This makes it more usable in terms of building and general purpose material because, there is the possibility to increase the volume of bamboo composites in all direction by increasing number of layers. Figure 1 shows the process of bamboo lamination.

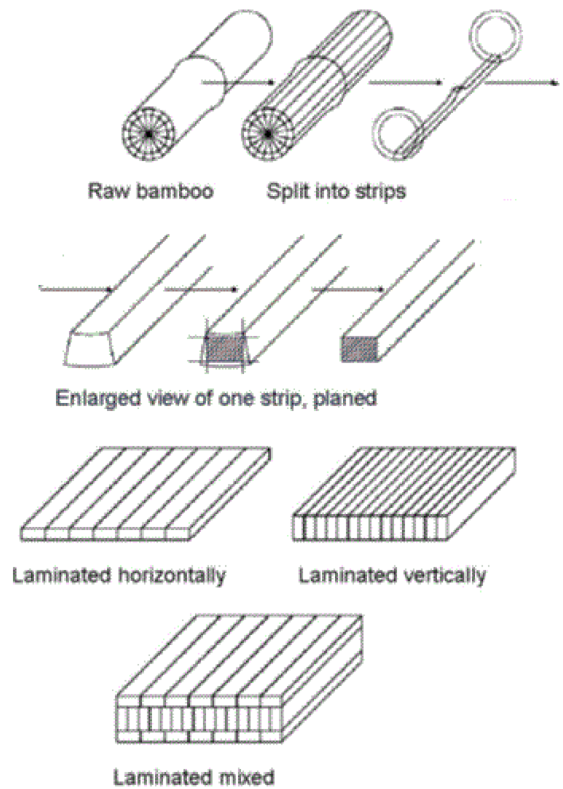

Figure 1 Manufacturing process of laminated bamboo lumber using bamboo strips (M. Mahdavi, 2011)

There is reduced tensile property (Average tensile strength is 210 MPa and modulus is 9.5 GPa) in unidirectional layered laminate bamboo composite. made from outer region laminas as compared to average tensile properties of outer regions laminas of bamboo Culm (Average tensile strength is 260 MPa and modulus is 16.9 GPa).This is due to the presence of adhesive in former materials which have low strength and modulus than bamboo laminas. Mechanical properties of bamboo are sensitive to changes in moisture content, with Compressive and shearing strength parallel to the grain being most sensitive followed by longitudinal tensile modulus and then bending modulus, (Jiang et al., 2012). Hence the focus of this work is to study the mechanical properties, yield strength, and ultimate strength using tensile and bending technique, of Ghanaian Bamboo and establish its structural engineering applications, knowing that the strength of bamboo is greater than many timber products, (Mahzuz et al., 2013).

2. MATERIALS AND METHODS

2.1. Materials

Two types of bamboo were considered for the experiments (the bambusae vitata and the bambusae vulgaris). The bambusae vitata is green in colour and bambusae vulgaris is the yellow in colour. These species were considered for the experiments because they are the most common type of the local bamboo in Ghana. The bamboo consists of two parts, the rhizome which is below the ground and the culm which is above the ground. The culm is the jointed stem of the bamboo. It can be either hollow or solid stem, but the bamboo species considered had hollow culms. The culm is divided into the segments by nodes. The culm mainly consists of strands of fibers and lignin matrix.

2.2. Preparation of Samples

The green and the yellow bamboos were harvested from a bamboo farm with a rip saw. They were then split into eight equal strips along the grains by passing it through a planning machine. The material/specimen was prepared to a thickness of 5 mm, and width of 20 mm. With the rip saw, the specimen was cut between the nodes to a length of 250 mm. The sample is as shown in Figure 2.

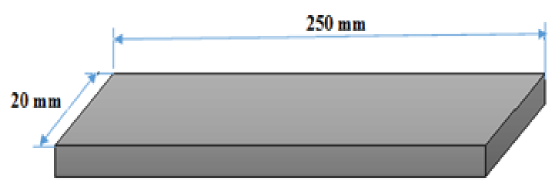

Figure 2 Bamboo sample

2.3. TENSILE TEST

The objective of this experiment was to obtain the mechanical properties of local bamboo species bambusae vitata (a green bamboo) and bambusae vulgaris (yellow bamboo). A tensile test machine, as shown in Figure 3a, was used for this test. Figure 3b, however, was used for the bending test. Five samples were used for each of the species in the tensile test. A length of 25 mm was marked out away from both ends of the sample specimen. This was done to allow for better grip by the Tensile Test Machine (TTM). The sample specimen was clamped at the ends of the 25 mm mark. Each sample was griped firmly in two vises attached to the machine. The wheel of the testing machine was then turned to drive the rack and pinion system to allow the gripping part get closer to accommodate the specimen. The sample was then strained to an extension of 2.54 mm and the corresponding force was then determined by a balance system attached to the machine. The extension and its corresponding force were then recorded. The specimen was given successive further extensions of 2.54 mm each time and the corresponding force recorded until the material failed. This procedure was repeated for the remaining samples for the two species and the results were recorded. This process was repeated each day, for the next four days and the results were recorded.

Figure 3 Testing Machines:-

(a) Tensile test; (b) Bend test

A plot of the load versus displacement was used to determine the modulus of elasticity (E), the yield strength (y_t) and the ultimate strength (u_t). The modulus of elasticity (E) was determined) using (Equation. 3).

For the plot of load versus extension,

$$e = \frac{Pl}{AE} \quad \text{.........................} \ 1$$

Using load (P) versus extension (e), the slope, S is given by

$$s = \frac{l}{AE} \quad \text{..........................} \ 2$$

Hence

$$E = \frac{Sl}{A} \quad \text{.............................} \ 3$$

Where l is the length of the sample and A is the cross sectional area of the sample.

2.4. Bending Test

The objective of this experiment was to obtain the mechanical properties of local bamboo species bambusae vitata (green bamboo) and bambusae vulgaris (yellow bamboo). A bending test machine as shown in Figure 3b was used for this test. Twenty-five (25) samples each, of green and yellow bamboos were prepared for the tests. On the first day, five (5) samples were used for each of the species. The sample specimen was passed through the eye of the load holder and then placed on the support. A dial gauge was set on top of the load holder on the sample specimen. A load of 2.25 kg was hanged on the specimen and the corresponding reading of the dial gauge recorded. The specimen was loaded successively with additional 2.25 kg at a time, until failure. The total loads with corresponding deflections were recorded accordingly. This was repeated for the four other samples of green bamboo and five yellow bamboos. Similar tests were performed each day, using other sample specimen, for four consecutive days. In all 25 samples each, of green and yellow bamboos were tested; that is, five (5) samples of each on each day.

The plot of the load versus deflection was used to determine the modulus of elasticity (E), and the ultimate strength (u_t). The modulus of elasticity (E) was determined by using Equation 9. Considering the simply supported bamboo sample AB of the length l, carrying a point load w at the centre of beam c as illustrated in Figure 4,

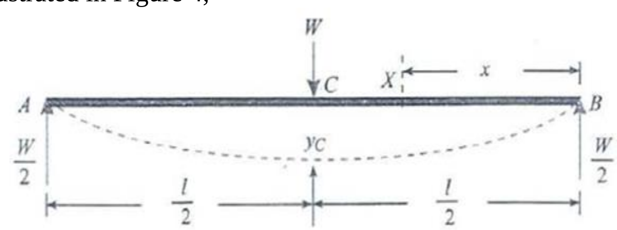

Figure 4: A simply supported and centrally loaded beam

Reactions at the supports,

$$R_A = R_B = \frac{W}{2} \quad \text{...................................} 4$$

Considering a section X at a distance x from B. The bending moment at this section was,

$M_x = RB(x) = \frac{W}{2}x$ 5

From bending moment equation,

$M = EI\frac{d^2y}{dx^2}$ ……………………………………6

Substituting Equation (6) into Equation (5) and integrating twice, the equation of deflection is

$EIy = \frac{Wx^3}{12} + C_1x + C_2$ ………………………7

Solving for C_1 and C_2, and substituting these values in Equation (7), we obtain

$EIy = \frac{Wx^3}{12} - \frac{Wl^2x}{16}$ …………………………....8

Maximum deflection occurs at midpoint c, where, $x = \frac{l}{2}$, substituting this into Equation (8) gives a maximum defection of

$$W = \frac{48EI}{l^3}y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .9$$

Where I is the second moment of area

$I = \frac{bt^3}{12}$

Where b is the width and t is the thickness of the specimen.

3. RESULTS AND DISCUSSION

3.1. Tensile Test Properties

Figure 5 (a) and Figure 5 (b) show plots of load versus extensions for green and yellow bamboo samples respectively for day 1. The plots show that the tensile behavior is characterized by a linear deformation followed by yielding before failure. In other words the plot has two parts, a linear part and a curved part. The linear part represents the yield region and the curved part of the plot represents the ultimate region. The yield region shows the character of the bamboo under stress before it begins to fail.

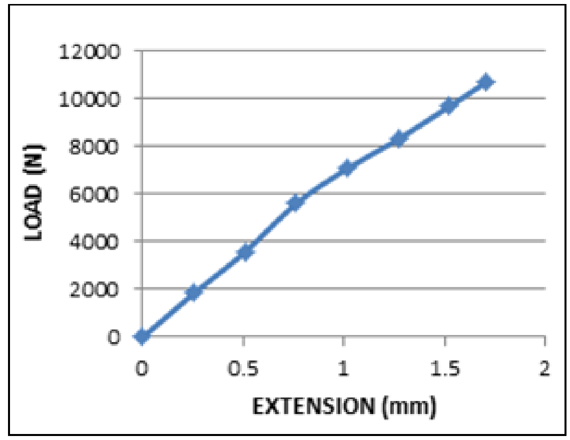

Figure 5a Plot of load versus extension for Green Bamboo

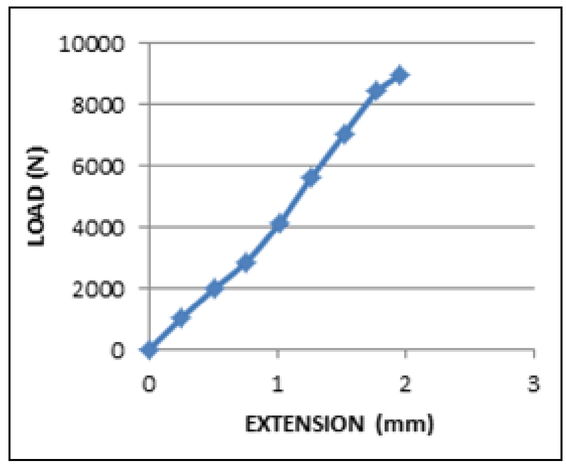

Figure 5b Plot of load versus extension for Yellow Bamboo

The yield region increases continuously to the top signifying the maximum load (Ultimate load) the bamboo can resist or endure before it begins to fail. It was observed that the load increases with increasing extension until it reaches a point where the plot begins to curve (the yield point). From Figure 5 (a) the yield force F_{yt} was 7788 N and the ultimate load F_{ut} was 8971N. The cross sectional area of the bamboo samples, bt, was 100 mm^2, therefore yield strength ($\boldsymbol{\sigma_{yt}}$) and the ultimate strength ($\boldsymbol{\sigma_{ut}}$) for green bamboo were obtained as 77.88 Nmm^{-2}.and 89.71 Nmm^{-2} respectively. This was repeated for four other samples and the results were tabulated and presented in Tables 1.

Table 1: Yield and Ultimate Strengths for Green Bamboo

	SAMPLE	DAY1	DAY2	DAY3	DAY4	DAY5
YIELD STRENGTH (Nmm^{-2})	1	77.88	57.85	75.65	79.43	70.58
	2	71.29	70.76	66.75	80.06	62.75
	3	69.15	66.75	71.20	62.30	58.87
	4	75.07	66.31	66.75	75.65	64.87
	5	92.74	72.09	44.50	66.75	62.21
ULTIMATE STRENGTH (Nmm^{-2})	1	89.71	89.40	104.75	99.55	92.87
	2	90.87	86.95	103.11	111.43	90.42
	3	107.20	109.29	98.57	93.67	79.06
	4	95.85	113.70	94.07	106.44	100.04
	5	109.95	102.13	106.18	101.91	99.28

The process was also repeated for yellow bamboo and using Figure 5 (b), the results obtained for the yield strength ($\boldsymbol{\sigma_{yt}}$) and the ultimate strength ($\boldsymbol{\sigma_{ut}}$) for the five samples during the five days are tabulated and presented in Table 2.

Table 2: Yield and Ultimate Strengths for Yellow Bamboo

	SAMPLE	DAY1	DAY2	DAY3	DAY4	DAY5
YIELD STRENGTH (Nmm^{-2})	1	57.405	71.2	75.65	71.2	62.3
	2	53.3555	66.75	66.75	66.75	66.75
	3	55.335	72.179	71.2	72.179	62.3445
	4	56.782	62.3	71.2	62.3	75.65
	5	53.5335	64.525	57.85	64.525	67.64
ULTIMATE STRENGTH (Nmm^{-2})	1	104.397	106.845	100.125	106.845	98.523
	2	104.575	93.8505	97.9	93.8505	93.361
	3	107.245	93.45	100.125	93.45	95.1188
	4	100.882	89.801	102.35	89.801	102.381
	5	97.989	93.6725	100.125	93.6725	92.471

The modulus of elasticity of the bamboo was calculated from the slopes of the plots. The slope was calculated from the linear region of the graph. Using Equation 3 and for bamboo sample with length 200 mm and the cross sectional area of 100 mm^2, the moduli of elasticity were obtained for both green bamboo and yellow bamboo for the five days and were tabulated and presented in Table 3.

Table 3 Modulus of Elasticity of Green and Yellow Bamboo Samples for Tensile Test

		MODULUS OF ELASTICITY E (N/mm^2)				
	SAMPLE	DAY1	DAY2	DAY3	DAY4	DAY5
GREEN BAMBOO	1	909.20	891.20	1322.80	1582.60	1182.40
	2	871.60	1098.40	1246.60	1575.80	1235.20
	3	1187.00	1070.40	1145.00	1623.40	1140.60
	4	1071.40	1160.60	1222.00	1482.00	1276.40
	5	1129.20	1141.40	1293.00	1546.60	1224.00
YELLOW BAMBOO	1	1241.00	1392.00	1263.20	1392.00	1226.40
	2	1121.30	1382.00	1234.20	1382.00	1314.00
	3	1190.00	1420.80	1234.20	1420.80	1226.00
	4	1244.00	1349.80	1189.80	1349.80	1489.20
	5	1168.00	714.00	1244.80	714.00	1051.20

3.1. Bending Properties

Figure 6 (a) and Figure 6 (b) show plots of load versus extension for green and yellow bamboo samples on day 1.

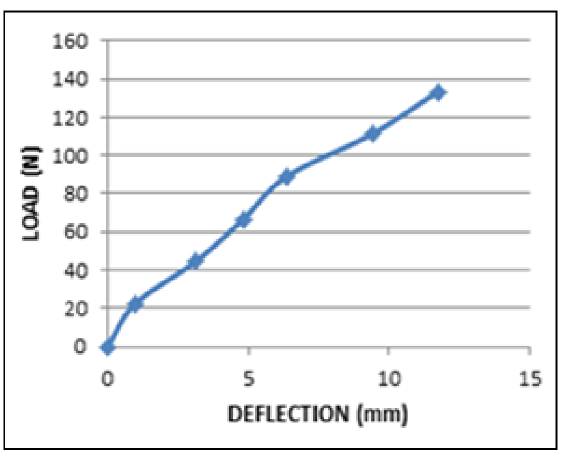

Figure 6a Graph of load against deflection:-Green bamboo

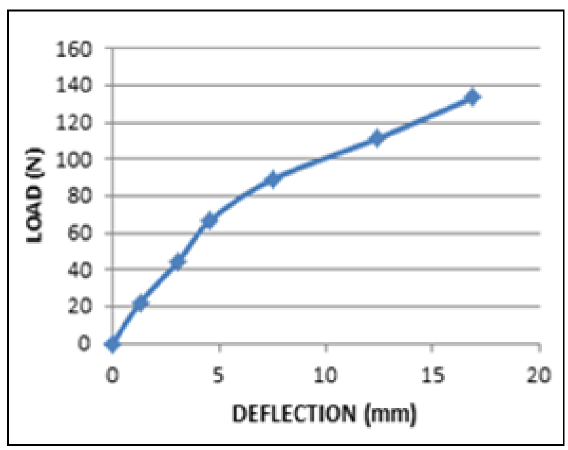

Figure 6b Graph of load against deflection:- Yellow bamboo

The plot shows that bamboo subjected to bend is characterized by a curved deformation. Using Figure 6, the ultimate strength for both the green bamboo and yellow bamboo were obtained. This was repeated for the remaining four samples for day 1. Five samples of each bamboo species per day were tested in a similar way for the next four consecutive days. The results were tabulated and presented in Table 4.

Table 4: Ultimate Stren length for Bent Test

		ULTIMATE STRENGTH (N/mm^2)				
	SAMPLE	DAY1	DAY2	DAY3	DAY4	DAY5
GREEN BAMBOO	1	80.10	93.45	106.80	93.45	66.75
	2	93.45	93.45	135.50	93.45	80.10
	3	80.10	80.10	120.15	80.10	66.75
	4	93.45	80.10	146.85	80.10	80.10
	5	93.45	93.45	120.15	93.45	80.10
YELLOW BAMBOO	1	80.10	80.10	120.15	80.10	66.75
	2	80.10	66.75	106.80	80.10	66.75
	3	93.45	66.75	106.80	53.40	53.40
	4	93.45	66.75	106.80	93.45	106.80
	5	80.10	66.75	106.80	93.45	80.10

The modulus of elasticity for the bamboo samples was calculated from the slope of the graphs and the results were tabulated and presented in Table 5.

Table 5 Modulus of Elasticity for Bend Test

		MODULUS OF ELASTICITY E(N/mm^2)				
	SAMPLE	DAY1	DAY2	DAY3	DAY4	DAY5
GREEN BAMBOO	1	8546.13	8705.38	12678.28	9673.51	7490.63
	2	8984.39	9470.04	15009.38	9828.00	8918.61
	3	7114.54	11979.19	12403.10	9009.00	6962.57
	4	8392.61	7576.03	16494.84	8830.02	8908.68
	5	8814.88	7918.45	11111.11	10958.90	11204.48
YELLOW BAMBOO	1	6938.44	9343.77	13071.89	7655.50	6884.68
	2	6429.20	9281.89	10695.19	8583.69	6745.36
	3	8984.39	8196.29	12288.78	5141.38	5138.08
	4	9599.76	8651.64	10582.01	9876.54	12558.86
	5	6836.90	8101.54	10416.66	10296.01	8849.55

3.2. Modulus of Elasticity

From Table 1, it can be noticed that the values of the modulus of elasticity varied and therefore the range can be used to represent its modulus. Hence mean and standard deviation were determined using Equations 10 and 11 respectively.

$$E_{average} = \frac{\sum Ei}{n} \quad \text{....} \quad 10$$

$$\sigma = \sqrt{\sum \frac{(E - E_{av.})^2}{n}} \quad \text{....} \quad 11$$

Where n is the number of samples which is equal to five (5)

The results obtained from the average and standard deviation for the green bamboo on day 1 were 1034.48 and 123.40 respectively. Since the samples were less than thirty (30), the t distribution was used to calculate the range of the modulus of elasticity, E_R, values using Equation 12.

$$E_R = E_{ave} \pm \frac{t_{\alpha,\nu}\sigma}{\sqrt{N}} \quad \text{....} \quad 12$$

where $t_{\alpha v}$ is read from the t-distribution table, σ is the standard deviation and N is (n−1), but n is the number of samples, therefore, N is 4.

For this work a 95% confidence was chosen and using the t distribution table, $t_{0.95,4} = 2.13$

Hence, the range of the modulus of elasticity for green bamboo on day 1 was 1034.48 $\pm$ 131.42 N/mm^2. In other words the modulus of elasticity for green bamboo on day 1 ranged from 903.10 N/mm^2 to 1165.9 N/mm^2. This was repeated for 4 days and the results obtained were tabulated and presented in the Table 6

Table 6: Range of the Modulus of Elasticity for Tensile Test

DAY	Modulus of Elasticity E(N/mm^2)	
	Green Bamboo	Yellow Bamboo
1	1034.48 ±131.42	1192.04 ± 49.22
2	1072.40 ± 102.21	1354.04 ± 72.05
3	1245.00 ±65.45	1233.28 ± 25.76
4	1546.08 ± 64.99	1251.72 ± 287.35
5	1211.64 ± 47.86	1261.00 ±151.61

The Table shows the range of modulus of elasticity values from day 1 to day 5. The analysis shows that there is a significant variation in the modulus of elasticity values for green bamboo as the days increased. The least value was recorded on day 1 with a range of 1034.48 $\pm$ 131.42N/mm^2. This value increased on the second day to a range of 1072.4$\pm$ 102.210 N/mm^2. It increased again on the third day to 1245$\pm$ 65.452N/mm^2. The maximum range of the modulus of elasticity values occurred on day 4 with a range of 1546.08$\pm$ 64.99 N/mm^2 and it reduced slightly on day five. Generally, modulus of elasticity of the green bamboo for tensile test increased significantly from day 1 to day 4 but reduced slightly on the fifth day.

This process was repeated for yellow bamboo samples and the range of values for modulus of elasticity for tensile test were tabulated and presented in Table 6. The analysis shows that there is a significant difference between the modulus of elasticity values. The least value was recorded on day one with a range of 1192.86$\pm$ 49.22 N/mm^2. This value increased on the second day with a range1233.28 $\pm$ 25.76 N/mm^2. It decreased on the third day to1233.28 $\pm$ 25.76 N/mm^2. There was a further increase in the modulus if elasticity values on the fourth and fifth days with values of 1251.72 $\pm$ 287.35 N/mm^2 and 1261 $\pm$ 151.61 N/mm^2 respectively. The maximum range of the modulus of elasticity value occurred on day two with a range of 1354.04 $\pm$ 72.05N/mm^2. Generally, the modulus of elasticity of the yellow bamboo for tensile test increased significantly from day 1 to day 5.

Similarly, from Table 5, it can be observed that the values of the modulus of elasticity varied and therefore a range can be used to represent its modulus. Hence mean and standard deviation were determined using equations 10 and 11 respectively. The mean and standard deviation obtained for green bamboo on day 1 were 8370.52 N/$mm^2$and 660.77 N/mm^2 respectively. The range of values of modulus of elasticity for green bamboo on day 1 using equation 12 was 8370.52$\pm$703.721 N/mm^2. The process was repeated for the other days the range of values of green bamboo were tabulated and presented in Table 7.

Table 7 Range of the Modulus of Elasticity for Bend Test

DAY	Modulus of Elasticity E(N/mm^2)	
	Green Bamboo	Yellow Bamboo
1	8370.52 ± 703.72	7757.75 ± 1362.36
2	9129.82 ± 1670.15	8715.03 ± 556.68
3	13539.35 ± 2066.47	11410.91 ± 1138.84
4	9659.89 ± 800.98	8310.63 ± 1960.39
5	8697.00 ± 1568.48	8035.31 ± 2715.53

The analysis shows that there is a significant difference in the modulus of elasticity values. The least value was recorded on day 1 and value obtained with a range of 8370.52$\pm$ 703.72 N/mm^2. This value increased on the second day to a range 9129.82$\pm$ 1670.15N/mm^2. It further increased on the third day to 13539.35$\pm$ 2066.47N/mm^2. There was a decrease in the modulus of elasticity values on the fourth and fifth days. The values were 9659.89$\pm$ 800.98N/mm^2 and 8696.99$\pm$ 1568.48N/mm^2 respectively. The maximum range of the modulus of elasticity value occurred on day three with a range of 13539.34532$\pm$ 2066.472N/mm^2. Generally, the modulus of elasticity of the yellow bamboo for bending test increased significantly from day one to day five. The modulus of elasticity of the green bamboo for bending test increased significantly from day 1 to day 3 but reduced from day 4 to day 5.

The process was repeated for yellow bamboo and the range of modulus of elasticity for bending test tabulated and presented in Table 7.

Table 7 shows the range of modulus of elasticity values of yellow bamboo from day 2 to day 5. The analysis shows that there is a significant difference in the modulus of elasticity values. The least value was recorded on day 1 with a range of 7757.75 $\pm$ 1362.36N/mm^2. This value increased on the second day with a range 8715.029 $\pm$ 556.68 N/mm^2. It further increased on the third day to 11410.91 $\pm$ 1138.84 N/mm^2. There was a decrease in the modulus of elasticity values on the fourth and fifth day. The values were 8310.63 $\pm$ 1960.39N/mm^2 and 8035.311 $\pm$ 2715.53N/mm^2 respectively. The maximum range of the modulus of elasticity value occurred on day three with a range of 11410.91 $\pm$ 1138.84 N/mm^2. Generally, the modulus of elasticity of the yellow bamboo for bending test increased significantly from day 1 to day 3 but reduced from day 4 to day 5.

3.3. Yield Strength

From Table 1, it can be noticed that the values of the yield strength of the green bamboo varied and therefore the range can be used to represent its yield. Hence the mean and the standard deviation were determined using Equations 13 and 14 respectively.

$$\sigma_{yt_{ave}} = \frac{\sigma i}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 13$$

$$\sigma = \sqrt{\frac{\sum (\sigma yt - \sigma av)2}{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 14$$

The mean and standard deviation obtained for day 1 were 77.23 N/mm^2 and 8.33 N/mm^2 respectively. The range of the yield strength values for day one was calculated for green bamboo on day 1. Since the samples were less than thirty (30), the t-distribution was used to calculate the range of the yield strength values with 95% confidence level using Equation 15

$$\sigma_{yt} = \sigma_{yt_{ave}} \pm \frac{t\sigma}{\sqrt{n}} \quad \ldots\ldots\ldots\ldots\ldots 15$$

The range obtained for green bamboo on day 1 was 77.23 $\pm$ 8.86 N/mm^2. The process was repeated for the four other days and the values obtained were tabulated in Table 8

Table 8: The Range of Yield strength for the Tensile Test

DAY	Yield strength (N/mm^2)	
	Green Bamboo	Yellow Bamboo
1	77.23 ± 8.86	55.29 ± 1.75
2	66.75 ± 5.3	67.39 ± 4.05
3	66.06 ± 11.52	68.53 ± 6.43
4	72.84 ± 7.55	67.19 ± 3.83
5	63.854 ± 4.13	66.94 ± 5.2

The analysis shows that there is a significant difference in the yield strength values. The least value was recorded on day five with a range of 63.854$\pm$4.13N/mm^2. The maximum range of the yield strength value occurred on day two with a range of 66.06$\pm$11.52N/mm^2. Generally, the yield strength for tensile test of the green bamboo increased from day one to day five.

The process was repeated for yellow bamboo and the range of yield strength values were calculated using Equation 15 and the values were also tabulated and presented in Table 8

The analysis shows that there is a slight difference in the yield strength values. The least value was recorded on day five with a range of 66.94$\pm$5.20N/mm^2. The maximum range of the yield strength value occurred on day 2 with a range of 67.39$\pm$4.05N/mm^2. Generally, the yield strength for tensile test of the yellow bamboo increased from day one to day five.

3.4. Ultimate Strength

From Table 1, it can be noticed that the values of the ultimate strength of the green bamboo varied and therefore the range can be used to represent its ultimate strength. Hence mean and standard deviation were determined using Equations 16 and 17 respectively

$$\sigma_{ut_{ave}} = \frac{\sigma i}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 16$$

$$\sigma = \sqrt{\frac{\sum (\sigma ut - \sigma av)2}{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 17$$

The mean and standard deviation obtained for green bamboo on day 1 was 98.86 N/mm^2 and 8.38 N/mm^2 respectively.

The range of the ultimate strength for green bamboo on day 1 was calculated using equation 4.9.

$$\sigma_{ut} = \sigma_{ut_{ave}} \pm \frac{t\sigma}{\sqrt{n}} \quad \ldots\ldots\ldots\ldots\ldots 18$$

The range obtained was 98.86 $\pm$ 8.92 N/mm^2 for green bamboo on day 1. The process was repeated for the other four days and the values obtained were tabulated and presented in Table 9

Table 9: Range of Ultimate Strength for Tensile Test

DAY	Ultimate strength (N/mm^2)	
	Green Bamboo	**Yellow Bamboo**
1	98.86 ± 8.92	103.03 ± 3.43
2	100.3 ± 11.28	95.54 ± 6.23
3	101.362 ± 4.73	100.14 ± 1.52
4	102.61 ± 6.42	95.55 ± 6.30
5	92.33 ± 8.07	96.73 ± 3.91

The analysis shows that there is a difference in the ultimate strength values for the various days. The least value was recorded on day 5 with a range of 92.332$\pm$ 8.07 N/mm^2. The maximum range of the ultimate strength value occurred on day 4 with a range of $102.61 \pm 6.42\ mm^2$. Generally, the ultimate strength for tensile test of the green bamboo increased slightly from day 1 to day 4 but decreased significantly on day 5. The process was repeated for yellow bamboo and the ultimate strength values obtained for tensile test for day 1 to day 5 were also tabulated and presented in Table 9.

The analysis shows that there is a difference in the ultimate strength values. The least value was recorded on day 2 with a range of 95.54$\pm$6.23 N/mm^2. The maximum range of the ultimate strength value occurred on day 1 with a range of 103.03$\pm$3.43 N/mm^2. Generally, the ultimate strength for tensile test of the yellow bamboo changed slightly from day 1 to day 5.

From Table 4, it can be noticed that the values of the ultimate strength varied and therefore the range can be used to represent its ultimate strength. Hence a similar procedure was used to determine the range of the ultimate strength. The results for both the yellow and green bamboo as presented in table 10.

Table 10: The Range of Ultimate Strength for Bend Test

DAY	Ultimate strength (N/mm^2)	
	Green Bamboo	**Yellow Bamboo**
1	88.11 ± 6.97	85.44 ± 6.97
2	88.11 ± 6.97	88.11 + 5.69
3	125.85 ±14.74	109.23 ± 5.69
4	88.11 ± 5.83	88.11 ± 6.96
5	88.11 ± 5.83	85.11 ±6.97

For green bamboo the ultimate strength was the same for all the days except day 3. However for the yellow bamboo it increased from day 1, peaked on day 3 and decreased on day 5

.The modulus of elasticity and yield stress of the two species of bamboo were found to show a linear correlation with extension for tensile test. The bending strength did not show a strong linear relation between modulus of elasticity and strain. The variation between the strength properties for both tensile and bending was significant for all days. The increase in the modulus of elasticity, yield strength and ultimate strength for both tensile and bending properties was appreciable for both species as the number of days increased. Conclusively, the mechanical properties of local bamboo have been characterized. In a bid to know how strong or weak the strength of local bamboo species were, their strength properties were compared with other foreign species. For example, maximum ultimate strength of giant timber bamboo (phyllostachys bamboo) was 120.06 N/mm^2 and yield strength of 99.87N/mm^2. This can be compared to the local bamboo which had 102.61 to 109.02 N/mm^2 and 68.37 to 86.09N/mm^2 for tensile. The ultimate value for calculta bamboo from India for bending was 192.78 to 180.80 $N/mm^2$and that of Puerto Rico was 111.96 to 147.95N/mm^2. The local bamboo had a range of 81.15 to 95.07 N/mm^2 to 111.11 to 140.59N/mm^2. Modulus of elasticity for these foreign species above was 11,764 to 13,333 N/mm^2 and 9265 to 10833 N/mm^2 respectively for bending. The local species ranged from 7459.67 to 10799.79 N/mm^2 to 11472.87 to 15605.81N/mm^2.

4. CONCLUSION

This study evaluated the tensile and bending properties of local green and yellow bamboos to find out how their characters vary with days. It can be concluded that the mechanical properties of the local bamboo has been characterized by determining their yield strength, ultimate strength and modulus of elasticity and their strength compares well with those of foreign species. The local bamboo, as per the determined mechanical properties can be used for structural engineering applications just like the foreign species.

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