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Laboratory Analysis on the Mechanical Properties of Spiny (Kawayan Tinik) Bamboo Layers

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Abstract – *Bamboo has been introduced as a possible alternative to some construction materials nowadays. Its potential use in the field of engineering, however, is still not widely practiced due to insufficient engineering knowledge on the material's properties and characteristics. Although there are researches and studies proving its advantages, it is still not enough to say that bamboo can sustain and provide the strength and capacity required of common structures. In line with this, a more detailed analysis was made to observe the layered structure of the bamboo, particularly the species of Kawayan Tinik. It is the main intent of this research to provide the necessary experiments to determine the tensile strength of dried bamboo samples. The test includes tensile strength parallel to fibers with samples taken at internodes only. Throughout the experiment, methods suggested by the International Organization for Standardization (ISO) were followed. The specimens were tested using a universal testing machine, with a rate of loading set to 0.6 mm/min. It was then observed from the results of these experiments that dried bamboo samples recorded high layered tensile strengths, as high as 600 MPa. Likewise, along the culm's length and across its cross section, higher tensile strength was observed at the top part and at its outer layers. Overall, the top part recorded the highest tensile strength per layer, with its outer layers having tensile strength as high as 600 MPa. The recorded tensile strength of its middle and inner layers, on the other hand, were approximately 450 MPa and 180 MPa, respectively. From this variation in tensile strength across the cross section, it may be concluded that an increase in tensile strength may be observed towards the outer periphery of the bamboo. It is highly recommended to conduct experimental investigations on the layered compressive strength properties as well.*

Keywords—Lab Analysis, Mechanical Properties, Spinyt Bamboo Kawayan Tinik

I. INTRODUCTION

Bamboo requires only three to four years before they can be harvested and be ready for utilization and this characteristic makes them one of the best alternatives for other construction materials such as timber. Bamboo's lightweight and flexibility make it a good appealing alternative for residential construction in seismic regions like the Philippines. It is a renewable and versatile material, which is characterized by its high strength and low weight [1]. Because of its abundance in the country, growing almost everywhere, it became a staple construction material especially to those living in the rural areas. However, the use of bamboo as a construction material is not universally accepted. This is because of some limitations in durability, jointing techniques, flammability, and the lack of design guidelines and standardization for this type of material [1]. In order to have proper design guidelines and standardization for bamboos, it is best to understand first its material properties. Bamboo is often paralleled to wood or timber because of their similarities in chemical structure. The material properties as well as the physical structure are the characteristic that differentiates bamboo from wood. However, like timbers, bamboo also has some limitations such as the varying geometric and mechanical properties within and between different species of bamboo. With bamboo's pole-like structure, varying fiber distribution, along its length is also a challenge which affects the strength properties of the material.

Bamboos are known to have a high resistance to tensile forces. It has been said to have greater tensile strength than that of steel and could carry compression better than concrete. However, being hygroscopic in nature, its overall strength would significantly be affected, and thus, will lower its effectiveness.

Enough test methods are required for a material to be recognized in the field of engineering. In a study made by Harries and his colleagues [2], several methods for testing and determining the properties of bamboo are introduced which can be standardized to create proper design guidelines for using bamboo in the industry. These methods include those developed by the International Organization for Standardization (ISO) and International Network for Bamboo and Rattan (INBAR) for determining the mechanical properties of bamboo, such as its compressive, tensile, shear and flexural capacities.

One research investigated the tensile properties of bamboo laminae of species *Dendrocalamus strictus* [3]. In this research, it was found out that volume fraction of fibers in the outer regions of the bamboo is higher which were then responsible for the bamboo's variation in strength properties across its cross section. Low tensile strength was also recorded at the nodes of the bamboo. Also, tensile strength and Young’s modulus were found to increase from inner to outer layers across its cross section and from bottom to top along its length, due to the increase in the volume fraction of fibers.

In another study made by Naik [4], mechanical and physico - chemical characterization of nine different species of bamboo were evaluated. The tests conducted included the determination of tensile and compressive strength, shear and flexural strength, bending, hardness, and density of the bamboo. Results from the experiments showed that tensile strength is lower for the cases with nodes than the cases without the nodes. Also, higher compressive strength was observed on bamboos in dry condition than in green condition.

Li [5] evaluated the chemical, physical and mechanical properties of the bamboo species *Phyllostachys pubescens* for its possible use in manufacturing medium density fiberboard. His study also included investigations on the effects of plant age, horizontal layer, and vertical height location on the said properties. Experiments conducted in this study concluded that the physical and mechanical properties of bamboo vary with age and height of the bamboo culm. It was then found out that bamboo has its maximum strength properties at 3 to 6 years of age. His results also showed that compressive strength of bamboo increases with height, and from central to outer parts of the bamboo’s cross section.

Espiloy [6] made investigations on the physico-mechanical properties and anatomical characteristics of *Bambusa blumeana* and *Gigantochloa levis*. The physico-mechanical properties such as the relative density, shrinkage, moisture content, static bending and compression parallel to fibers were correlated to the bamboo's anatomical characteristics such as the fibrovascular bundle frequency and dimension of fiber and vessel. Results of the study showed that the two properties were dependent on each other. The study also showed comparison between the two bamboo species. It was found out that compact fiber tissues were present in the outer layer of the bamboo cross section, whereas the inner layer consists mostly of parenchyma cells. Results also showed that increasing compressive and bending strengths towards the top portions of the culm for both species may be observed. This general increase in compressive and bending strengths towards the top portion of the whole culm might be attributed to the significant increase in the bamboo’s anatomical and physical properties towards the same direction along the culm length.

From all over the world, there has been several researches on the mechanical properties of different species of bamboo [7-15]. Results from these researches show proof of how strong the material is, and with this, give assessments on its potential in the field of engineering.

Kawayan Tinik, *Bambusa blumeana* in scientific terms, is known to be widely distributed all over the Philippines. With this, it becomes the most accessible material for utilization in the country. However, its widespread use in the construction industry is still being hindered due to lack of engineering knowledge on the material. The use of bamboo in the industry is still being limited due to lack of standards or methods incorporating proper guidelines on the design of this type of material. In order to have the right design guidelines, mechanical properties of the material should be first investigated and understood.

Bamboo is orthotropic in nature. They have independent mechanical properties longitudinally (parallel to its fibers), radially (across its cross section) and tangentially (perpendicular to growth rings). In line with this, it is therefore important to evaluate the layered strength characteristics of the material.

Through the years, many studies and researches have been conducted proving the advantages and potential of bamboo in the field of engineering. However, the results of the researches incorporating the mechanical properties of bamboo were presented in average, which indicates that the experimental tests done did not fully consider the layered structure of the material. It is therefore the intent of this research to investigate the layered structure of the bamboo, specifically, the species of *Bambusa blumeana*, or Kawayan Tinik. It aims to investigate the layered mechanical properties of the material basing the division of the layers on the shape and distribution of fiber in its cross section.

II. METHODOLOGY

There are very few standards incorporating methods on testing the layered properties of bamboo and with the difficulty in the preparation of the samples, only the tensile strength tests, parallel to fibers at internodes, would be conducted in this study. The experiments done required the use of a universal testing machine and the standards that was followed throughout the experiments were based on the methods proposed by ISO – ISO 22517-1 (*Bamboo – Determination of Physical and Mechanical Properties Part 1: Requirements*) and methods done from previous studies.

Dried bamboo culms were tested in this study. Samples were placed inside an oven with temperature of 60ºC, for 24 hours. The effects of this treatment in the bamboo's properties, however, would not be discussed and considered in detail throughout the research.

The bamboo culms that were tested were mature enough to yield significant results. Since the age of the culms could not be determined exactly, the effects of bamboo age in the mechanical properties were not discussed.

2.1. Data Collection

The bamboo culms investigated in the study was procured from the province of Bagilawa, Batangas. The samples considered from these culms were taken from three parts: the top, middle, and bottom portions as shown in Figure 1. The layers included the outer, middle and inner layers, determined from the behavior of the fibers in the bamboo's cross section.

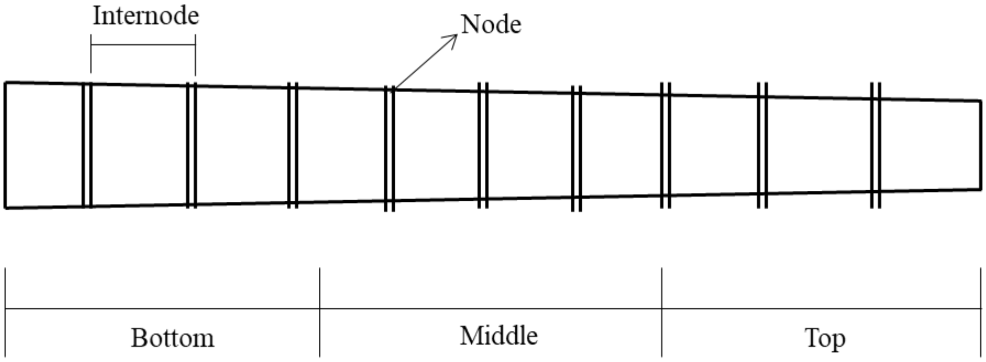


Figure 1. Parts of Bamboo Culm

Ten mature culms were randomly selected from a clump of bamboos. These culms were then cut 30 centimeters above the ground in order not to affect the growth of other culms in the clump. From the bottommost internode, internodes were then numbered in decreasing order, from 30 to 1. These internodes were divided into three parts, the top, middle and bottom part, consisting of ten internodes each. The 7th, 8th and 9th internode from each part, as shown in Figure 2, was then considered for the tests that were conducted.

2.2. Determination of Layer Thicknesses

From the ten culms procured, two culms were selected for determining the layer thicknesses. From these culms, 6 sample blocks per part (top, middle, and bottom part) were prepared from the internodes that were considered for the experimental tests. The dimension of the blocks is shown in Figure 3. Three blocks, per part, were then randomly chosen. A total of nine samples were then observed. Note that the thickness, *t*, is dependent on the part where the samples will be taken.

An optical microscope, with 10x magnification, was used in the determination of the thicknesses and boundaries of the layers. The layers were identified by the shape and distribution of fibers in the cross section, as shown in Figure 4. The determination of thickness was also guided by a study of Brea, et al. [16]. Note that the blocks were dried before it was observed under the optical microscope.

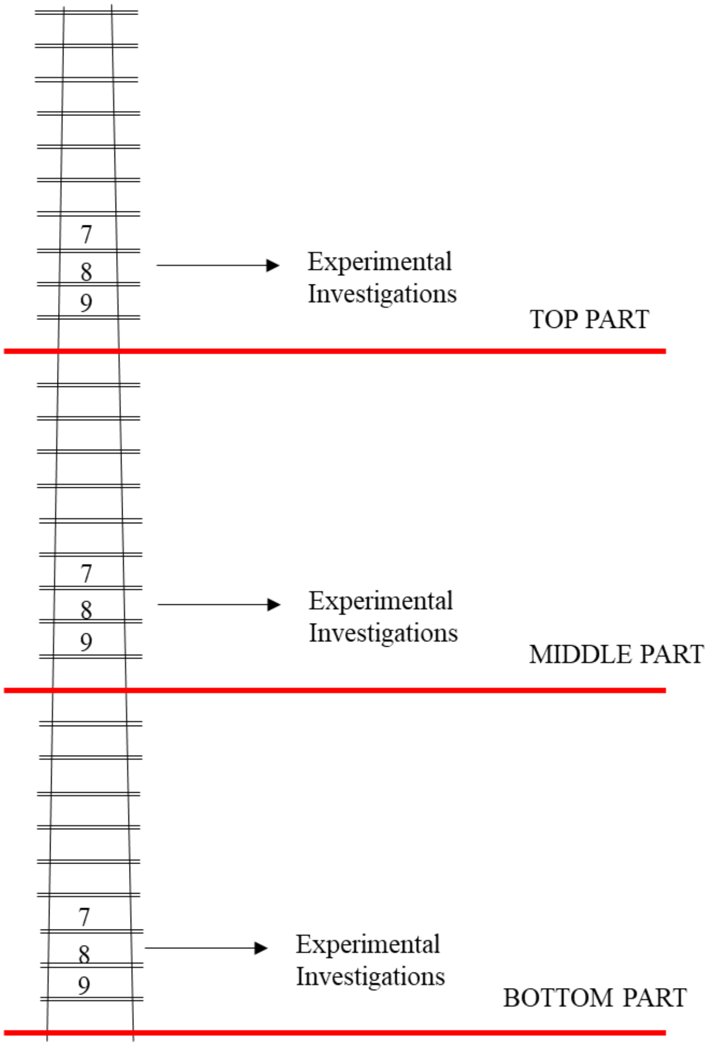


Figure 2. Culm Division and Internode Numbers

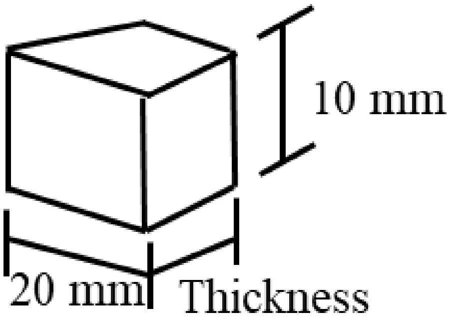


Figure 3. Sample blocks for the determination of layer thicknesses

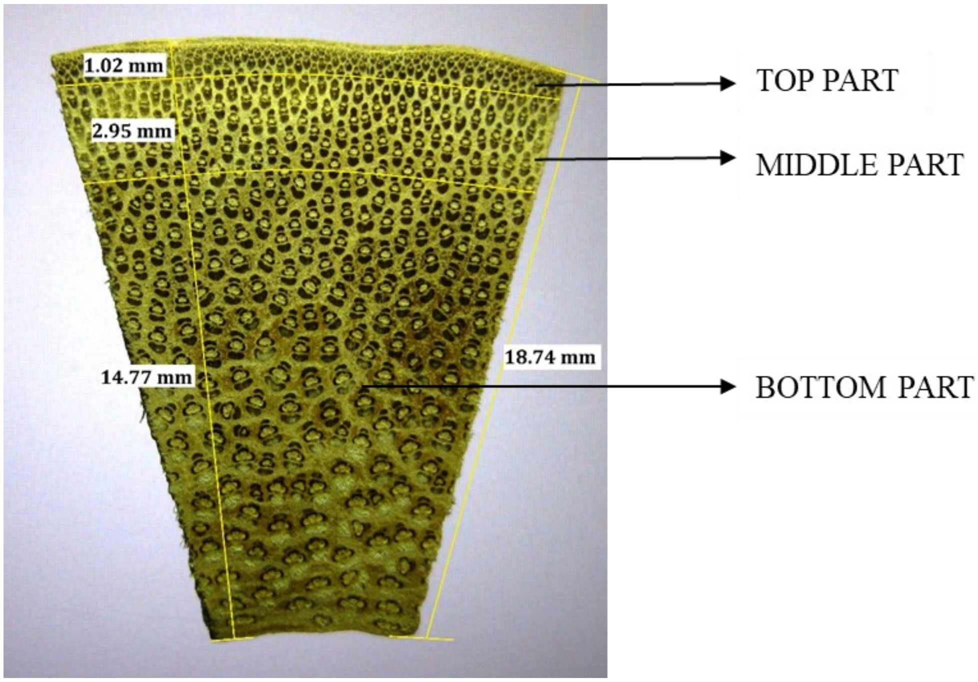
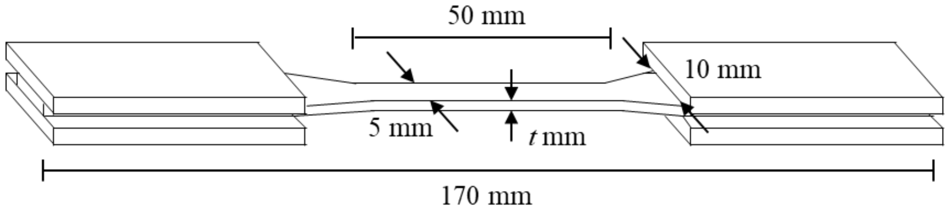


Figure 4. Shape and fiber distribution in the bamboo's cross section

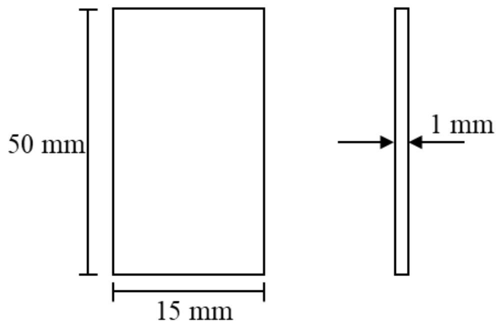
2.3. Preparation of Samples for Experimental Tests

After determining the thicknesses of each layer, samples were prepared following the guidelines proposed by ISO and some references.

The International Organization for Standardization (*ISO*) suggested the use of a so – called "dogbone" specimen for the tensile tests parallel to grains at internodes. This "dogbone" specimen includes a reduced area gage length which help enhance failure at the neck. This technique was done to minimize failure at the grip area. The schematic diagram for the test specimen is shown in Figure 5.



(a) Test Specimen



(b) Grip

Figure 5. Dogbone Style for Layered Tensile Strength Test

Because of the bamboo's pole – like structure, the specimens that would be prepared may have a relatively curved shape that may cause the specimens to crush or slip when loaded or clamped on the testing machine. Thus, grips, made of bamboo strips with dimension 15 mm by 50 mm by 1 mm, were attached to the specimens to minimize or prevent this possible mode of failure. Shelwood white glue was used to bond these grips and the layered specimens itself.

The thicknesses of the layers that were tested were based from the results of the observations made under an optical microscope. These results were then approximated into the thicknesses shown on Table 1 for simplicity in the preparations.

Table 1. Thicknesses, t_S, of test specimens

Location	Outer Layer	Middle Layer	Inner Layer
Top Part	0.50	1.00	3.00
Middle Part	0.75	1.00	3.00
Bottom Part	1.00	1.00	3.00

Four bamboo culms were randomly chosen for the testing of its layered tensile strength. Speed cutter was used to properly cut the desired internodes from the poles. From these internodes, strips were cut using a sharp knife. These strips were then cut into layers as described in the following sections.

2.3.1. Outer Layers

Test specimens for the outer layers of each part were prepared including the bamboo's exterior green skin as shown in Figure 6. Thus, the thicknesses of these specimens were measured from this external skin to a value, t_S, as presented in Table 1.

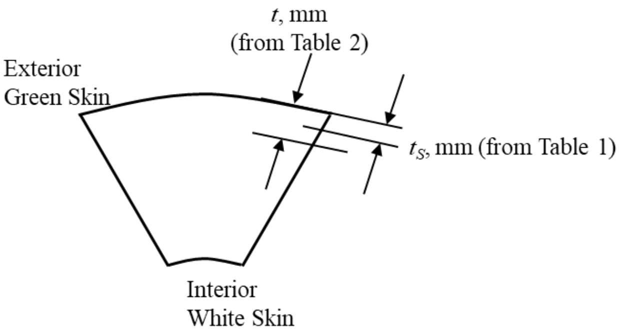


Figure 6. Outer Layer Specimens

2.3.2. Middle Layers

Middle layer specimens were measured from its inner boundary, as defined on the optical microscope observations, up to a thickness, t_S, given in Table 1. Figure 7 shows the manner that was described.

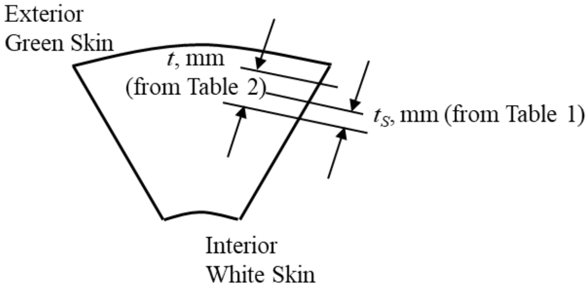


Figure 7. Middle Layer Specimens

2.3.3. Inner Layers

On the other hand, for the inner layers of each part, test specimens included the bamboo's interior white skin as shown in Figure 8. The value, t_S, set on Table 1, were then measured from this interior skin.

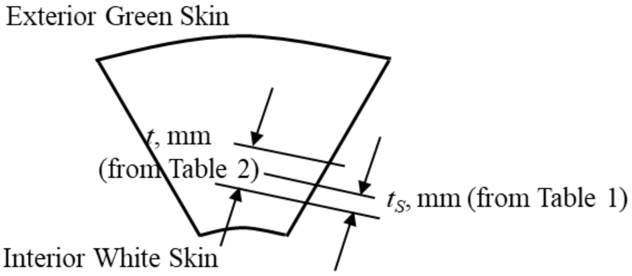


Figure 8. Inner Layer Specimens

2.4. Layered Tensile Strength Test

Throughout the experimental tests, the methods proposed by the ISO was implemented. As stated from the standards, tests shall incorporate the use of a Universal Testing Machine with the rate of loading set to 0.6 mm/min. From the maximum loads and extensions that were obtained from the tests, layered tensile stresses and strains were then determined from equations 1 and 2.

$$\sigma = \frac{F}{A} \tag{1}$$

where σ : Stress (MPa)
F: the load or force acted on the material (N)
A: the area where the force, F is applied (mm^2)

$$\varepsilon = \frac{\Delta}{L} \tag{2}$$

where ε : Strain (%)
Δ: the change in length (mm)
L: length of the material (mm)

2.4.1. Dried Bamboo Specimens

In order to reduce the moisture from fresh bamboo culms, specimens were dried in an oven for 24 hours at 60ºC temperature. Since bamboos are hygroscopic, specimens were then exposed to air for at least an hour, just to make sure that the moisture of the specimens equilibrate to the moisture of its surroundings. In this way, all three layers, the outer, middle and inner layers, would have approximately equal moisture after drying. Thus, moisture differences on each layer may then be regarded as a minor factor that could affect the experimental results and may be taken as negligible.

2.4.2. Moisture Content

Although set as to have negligible effect, moisture content was still noted in the experiments for further reference.

2.4.2.1. Fresh Culm Moisture Content

Moisture content of fresh bamboo culms were obtained by preparing blocks of dimension 25 mm by 25 mm by thickness, shown in Figure 9, as proposed by ISO. These blocks were taken from the internodes chosen for tensile strength investigations. Nine blocks were prepared from each part, the top, middle and bottom part.

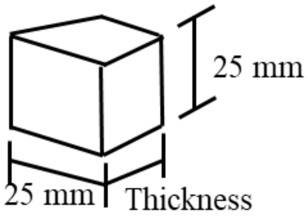


Figure 9. Sample blocks for the determination of Moisture Content

Masses of these blocks were taken before placing it inside an oven at 103°C. After 24 hours, masses of these blocks were recorded at regular intervals of 2 hours until the differences of successive measurements of masses did not exceed 0.01 grams.

2.4.2.1. Test Specimens Moisture Content

Immediately after the specimens were tested, specimens were weighed and placed inside an oven at 103°C temperature. Following the guidelines stated in the ISO for the determination of moisture content, masses of the tested specimens after drying for 24 hours were recorded at regular intervals until these masses does not vary much from the successive measurements done.

2.4.3. 3366 INSTRON Universal Testing Machine

Throughout the experiments, 3366 INSTRON Universal Testing Machine, shown in Figure 10, was used. This machine has a maximum load capacity of up to 10 kN. The attachment used by the instrument to properly hold the specimens are flat and made of rough rubber in order to reduce possible slippage of the specimens that will be tested. The instrument is connected to a computer, which uses the program Bluehill 2, to measure and calculate the needed stress – strain curves.

Figure 10. 3366 INSTRON Universal Testing Machine

III. RESULTS AND DISCUSSIONS

3.1. Bamboo Layer Thicknesses

Table 2 shows the bamboo layer thickness. Under the microscope, it was observed that inner layers had the largest range in the bamboo's cross section. On the other hand, outer layers were noted to have the least.

Table 2. Bamboo Layer Thickness

Location	Outer	Middle	Inner	Total Length
Top Part 1	0.59	1.19	3.06	4.84
Top Part 2	0.63	1.21	3.6	5.44
Top Part 3	0.65	1.29	3.37	5.31
Average	**0.62**	**1.23**	**3.34**	**5.20**
Middle Part 1	0.72	1.94	4.12	6.78
Middle Part 2	0.75	1.97	6.53	9.25
Middle Part 3	0.78	2.09	6.44	9.31
Average	**0.75**	**2.00**	**5.70**	**8.45**
Bottom Part 1	0.94	2.81	14.22	17.97
Bottom Part 2	0.97	2.84	16.22	20.03
Bottom Part 3	1.02	2.95	14.77	18.74
Average	**0.98**	**2.87**	**15.07**	**18.91**

The fibers at the outer periphery may be seen to be almost circular in shape. This shape gradually changes into elliptical towards the inner periphery until it resembles the shape of a clover. Fibers in this "clover" like shape may be seen to be separated and divided from each other. This variation in shape and distribution of fibers, according to Ray (2005), might be the cause of the differences in the tensile strength of the bamboo across its cross section.

3.2. Fresh Bamboo Culm Moisture Content

Fresh culms were observed to have moisture content of approximately 34%. From Table 3, highest moisture content, of approximately equal to 36%, were observed at the bottom part, while the top and middle parts were seen to have almost the same moisture of about 33%.

Table 3. Moisture Content of Fresh Bamboo Culms

PART	MEAN MOISTURE CONTENT
Top	32%
Middle	33%
Bottom	36%

The moisture contents recorded in the bamboo may be associated to its fiber distribution. Since the bottom part had the largest area among the three parts, it may have the highest ability to hold moisture. Also, as seen under the microscope, the fibers were seen to be more dispersed, as compared to the top and middle parts, which may be one of the factors affecting its moisture content.

3.3. Layered Tensile Strength of Bamboo

The mechanical properties of bamboo depend on the density of the fibers along the culm. Fiber density is not uniform along the culm; it is higher in the outer region of the bamboo [3, 17] and the tensile strength of the bamboo is proportional to the volume fraction of fibers. Therefore, in sections where the fibers are dense, it is expected to have higher tensile strength. Moreover, fibers, which makes up the sclerenchymatous tissue, act as caps of vascular bundles but also as isolated strands in some species. They have a polylamellate wall structure, especially the outer skin, which leads to very high tensile strength. This does not exist in other cell walls of fibers, which makes bamboo very strong against tensile srtress in the direction of the fibers. Moreover, the fibers are axially aligned along the bamboo culm. Tensile strength of bamboo is much stronger in this direction than in the direction perpendicular to the fibers. On the other hand, some studies have shown that tensile strength of the bamboo decreases in the nodes of the bamboo [3, 11, 18].

The maximum load and extension of each specimen tested were noted for the calculation of its stresses and strains. These stresses and strains were then plotted to obtain their relationship and were analyzed with the use of ANOVA (*Analysis of Variance*).

At least ten specimens per layer, of each part, taken from 4 different bamboo culms were tested for its layered tensile strength. In the tests, the specimens were assumed to be rectangular in shape and with other controls set as shown in Table 4.

Table 5 shows the summary of the results of the tensile strength test for different layers of the bamboo. Figures 11, 12, and 13 show the stress-strain diagram for the different layers along the length of the bamboo culm.

Table 4. Test Controls in the Experiments

Length	50 mm
Rate of Loading	0.6 mm/min
Sensitivity	40% of Rate of Loading

Table 5. Layered Tensile Strength of the Bamboo

Location	Maximum Load	Tensile Stress at Maximum Load (MPa)	Tensile Strain at Maximum Load (MPa)	Elastic Modulus (GPa)	Toughness Modulus (MPa)
Top Outer	1541.51	616.604	3.47	20.313	6.234
Top Middle	2208.26	441.651	4.00	12.200	8.428
Top Inner	2801.10	186.742	4.56	5.441	5.772
Middle Outer	1887.81	503.414	4.35	14.264	8.433
Middle Middle	2161.64	432.328	4.13	12.349	7.671
Middle Inner	2440.87	162.726	4.29	4.883	5.654
Bottom Outer	2096.71	419.342	4.71	11.133	15.194
Bottom Middle	1888.71	377.741	4.57	10.111	8.536
Bottom Inner	978.03	65.202	2.76	2.721	0.295

3.3.1. Top Part

From the experiments conducted, the outer layers of the top part recorded the highest tensile strength of approximately 600 MPa, whereas the inner layers recorded the lowest. It may be seen from the values gathered that the tensile strength of the outer layers was almost twice that of the average tensile strength of the three layers.

This trend of the strengths may be due to the behavior of the fibers present in the cross section. As seen from Figure 4, higher density of fibers may be seen at the outer regions of the bamboo which makes it very strong against tensile stress because there are more fibers to support the load. The fibers at this area may also be observed to have a more solid shape than that of the other layers.

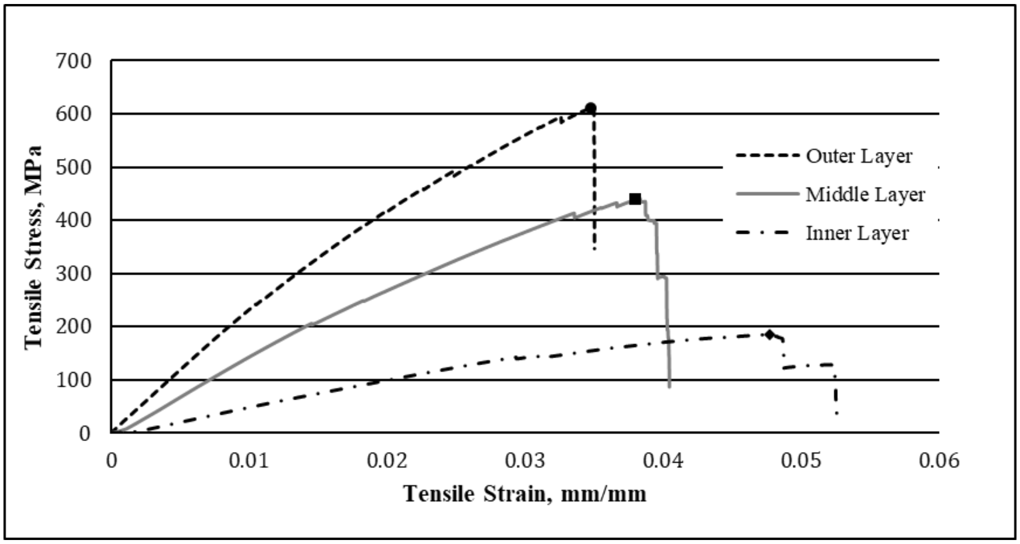


Figure 11. Stress-Strain Diagram of the Top Part of the Bamboo

3.3.2. Middle Part

Like for the top part, the outer layers of the middle part of the bamboo recorded the highest tensile strength of approximately 500 MPa. The inner layers also have the weakest tensile strength of about 160 MPa.

Comparing the results to that of the top part, the strengths recorded at the middle parts of the bamboo are lower. This behavior may be associated to the differences in the shape and distribution of the fibers at the top and middle parts, or in general, along the culm's length. From Figure 4, it may be observed that the outer layers of the middle parts are relatively apart from each other, unlike that of the outer layers of the top part. It may be considered to have the same shape of fibers, but its distribution across the cross section may significantly affect the strength.

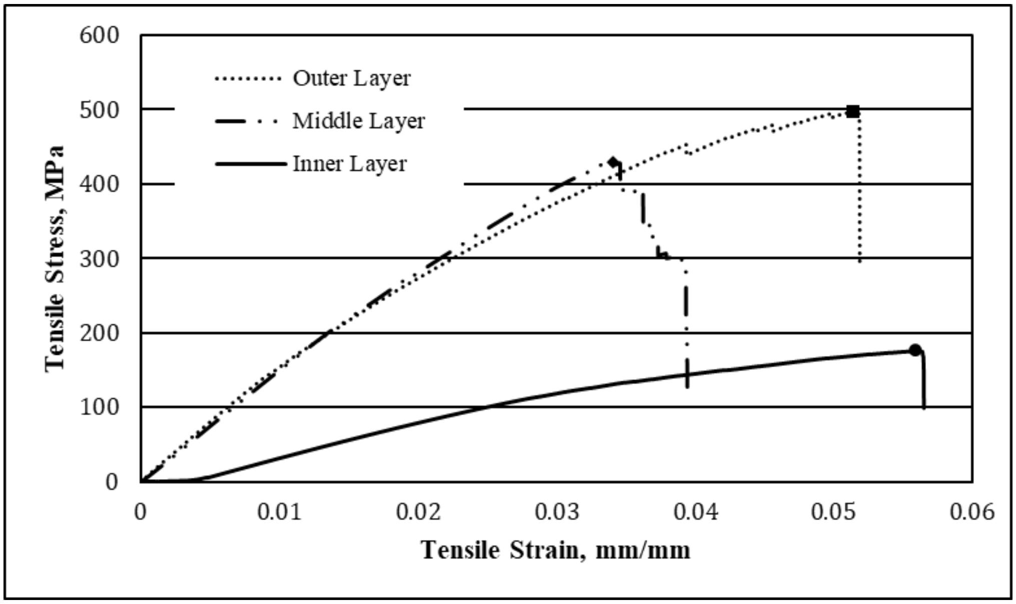


Figure 12. Layered Tensile Strength of the Middle Part of the Bamboo

3.3.3. Bottom Part

The outer layers of the bottom part recorded the highest tensile strength as compared to that of its middle and inner layers. The tensile strength of the outer layers was observed to be approximately equal to 400 MPa, while its inner layers recorded the lowest, roughly around 60 MPa.

Among the three layers of the bamboo, inner layer exhibited the lowest tensile strength. This may be due to the presence of voids in this area. These voids might serve as stress concentrators making this layer of the bamboo more susceptible to tensile stress. In addition, among the three parts of the bamboo considered, the bottom part gave the weakest tensile strength. This trend may be due to the variation of the fibers present in the cross section. The fibers at the bottom parts are more dispersed and spread, compared to that of the top and middle parts. The shape of the fibers, as well, may be observed to be relatively more elliptical and divided from each other. Although the bottom part had the thickest wall, the inner layers at this part are more enhanced, compared to the top and middle parts, which may also be one factor as to why it recorded the lowest tensile strength.

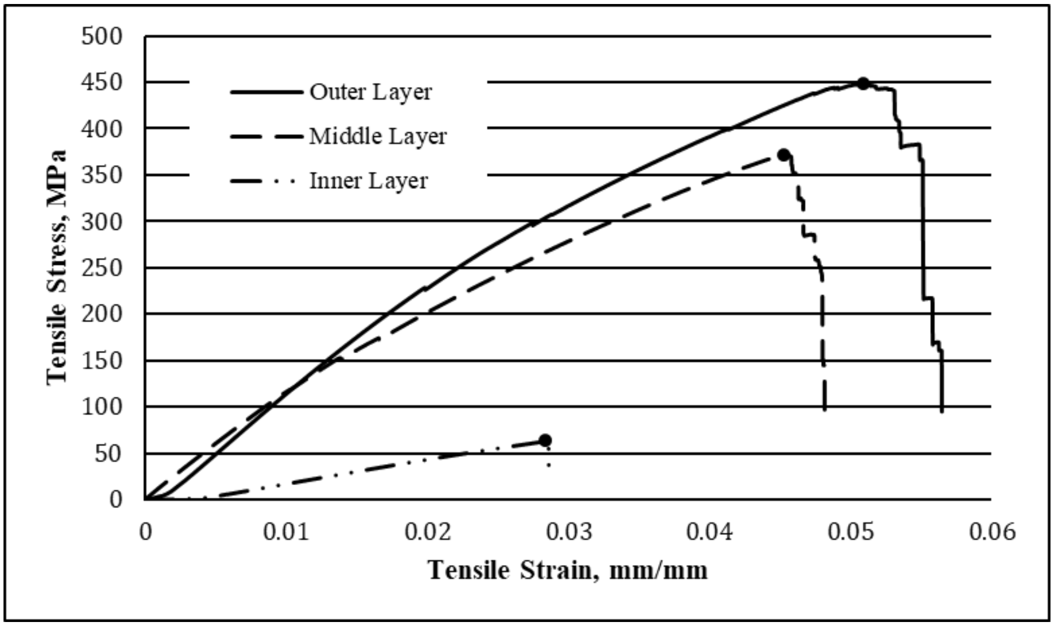


Figure 13. Layered Tensile Strength of the Bottom Part of the Bamboo

Figures 14 and 15 show the failure mechanism of the specimens after being subjected to tensile strength tests. From the specimens tested, usual failure was seen to be within, or at the center of the reduced area gauge length. Some failure occurred at the region where the cross-section tapers from the grip to the neck of the dogbone. Other specimens failed first at tip of the reduced area gauge length and continue to break at other location from both ends until total failure was achieved. In cases where failure at the grip occurred, additional specimens were tested until 10 specimens failed within the gauge length.

3.4. Elastic and Toughness Moduli

Modulus of elasticity and toughness were also studied for additional data references. The modulus of elasticity was directly collected form the instrument (INSTRON) used for tensile strength tests while the modulus of toughness was determined from the area under the stress-strain curves. The modulus of elasticity exhibited the same pattern as that of the tensile strength. For all layers, the values of both the tensile strength and the modulus of elasticity decreased from the outer layer to the inner layer. Along the culm of the bamboo, both properties also exhibit a pattern. Both values decreased from the top part to the bottom part. The highest average elastic modulus was recorded for the top part, outer layer with a value equal to 20.313 GPa and the lowest was for the bottom part, inner layer equal to 2.721 GPa. As for the modulus of toughness, its values did not exhibit a pattern along the parts of the culm. However, along the layers of the bamboo, the modulus of toughness decreased from outer to inner layer. The highest average toughness modulus recorded was found in bottom part, outer layer of the bamboo with a value equal to 15.194 MPa while the lowest at bottom part, inner layer equal to 0.295 MPa.

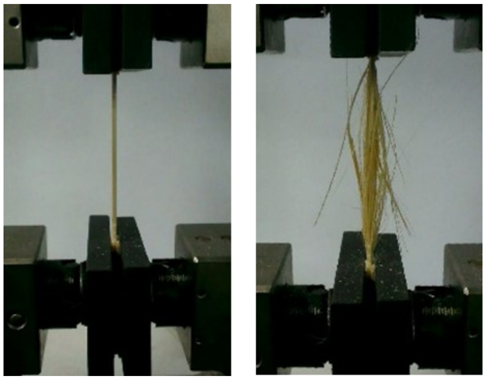


Figure 14. Specimen before and after applying forces

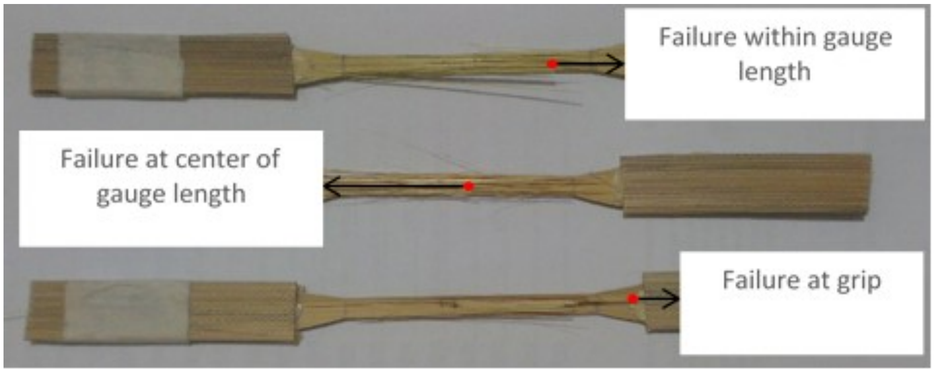


Figure 15. Different Mode of Failure of the specimens

3.5. ANOVA Model for finding the Bamboo Section with the Highest Tensile Strength

In conducting the analysis, there has been a need to take the logarithmic values of the tensile stresses for the assumptions of ANOVA to hold. These requirements and assumptions were then verified and statistically tested.

Duncan test was done to obtain which part and layer recorded the highest tensile strength.

Table 8. Duncan Test on the Highest Layered Tensile Strength

Means with the same letter are not significantly different.					
Duncan Grouping		**Average LOG (Tensile Strength)**	**Average Tensile Strength**	**# of Specimen**	**Layer - Part Combination**
	A	6.42174	616.604	10	Top Part Outer Layer
	B	6.20750	503.414	10	Middle Part Outer Layer
C	B	6.08246	441.651	10	Top Part Middle Layer
C	D	6.05957	432.328	10	Middle Part Middle Layer
C	D	6.03170	419.342	10	Bottom Part Outer Layer
	D	5.92913	377.741	10	Bottom Part Middle Layer
	E	5.22537	186.742	10	Top Part Inner Layer
	F	5.07302	162.726	10	Middle Part Inner Layer
	G	4.16365	65.202	10	Bottom Part Inner Layer

From Table 8, results of Duncan test concluded that the outer layers of the top part had the highest recorded tensile strength, whereas inner layers of the bottom part had the lowest. As for the order it generated, it may be observed that tensile strength increases from the bottom to top part of the culm length. This trend may be visibly observed from the shape and distribution of fibers from each part. It may be seen, for instance, that the bottom part had the thickest cross-sectional area, and at the same time, the thickest inner layer. In line with this, it may be seen that most of the fibers present in its cross section are elliptical, or clover – like, in shape, which may indicate that fibers are more scattered, separated and divided from each other, and thus, influences its low tensile strength. This behavior of the fibers may also explain the increase in tensile strength observed from inner to outer layers of the bamboo.

Additional Duncan test was done to determine the ranges and estimations as to how much the tensile strengths will increase if taken from different parts of the bamboo.

From the results of Table 9, bamboo sections taken from the outer layers of the top part are expected to have twice as much tensile strength of the average. On the other hand, bamboo sections taken from the inner layers, regardless of what part, are expected to have a tensile strength that is only a fraction (21% to 62%) of the average.

Table 9. Duncan Test on the Ranges of Layered Tensile Strength

EFFECTS OF PART OF BAMBOO				
Duncan Grouping (Groups with the same letter do not have a significantly different treatment effect)		**Additive Effect on the LOG (Tensile Strength)**	**Multiplicative Effect on the Tensile Strength**	**Layer - Part Combination**
	A	0.733503	2.08236153	Top Part Outer Layer
	B	0.519263	1.68078778	Middle Part Outer Layer
C	B	0.394223	1.48323068	Top Part Middle Layer
C	D	0.371333	1.44966515	Middle Part Middle Layer
C	D	0.343463	1.40982079	Bottom Part Outer Layer
	D	0.240893	1.27238437	Bottom Part Middle Layer
	E	-0.462867	0.6294761	Top Part Inner Layer
	F	-0.615217	0.54052337	Middle Part Inner Layer
	G	-1.524587	0.21771087	Bottom Part Inner Layer

IV. CONCLUSION AND RECOMMENDATION

In this research, it has been proven that layering the bamboo had a significant effect in the tensile strengths that will be obtained. It may be observed that tensile strength of bamboo is highly dependent on the behavior of the fibers consisting it. From the experimental results obtained, and statistical analysis conducted, an increase in tensile strength may be observed from the bottom to top part. It may be concluded that the top part of the bamboo could resist the highest tensile strength. Overall, the top part recorded the highest tensile strength per layer, with its outer layers having tensile strength as high as 600 MPa. The recorded tensile strength of its middle and inner layers, on the other hand, were approximately 450 MPa and 180 MPa, respectively. From this variation in tensile strength across the cross section, it may be concluded that an increase in tensile strength may be observed towards the outer periphery of the bamboo.

With the results of this research, additional verification on the properties of the bamboo may be provided, and thus, further engineering analysis may be made. From here, the potential of bamboo in the field of engineering may then be properly assessed and evaluated. Once the bamboo's potential in the industry is proven, it may be of big help in providing solutions in the aspect of sustainable development. For instance, in our country, bamboos may be used to provide shelter to most of the population, which, in the long run, may help improve the country's stability.

With these results of investigations, bamboo has proven its potential in the field of engineering. Having strengths as high, or even higher, than that of other materials used in construction, bamboo may obviously be utilized as an alternative. However, further evaluations and investigations shall still be conducted to properly approximate its overall capacity.

Since there are very few researches on the bamboo's strength perpendicular to fibers at both internodes and nodes, evaluation of its layered tensile strength in this manner is highly recommended. Moreover, investigations on its layered compressive strength parallel and perpendicular to fibers at both internodes and nodes are also suggested.

Microstructural analysis on the specimens before and after testing is also recommended in order to verify the outcomes of the experiments. With this, characterization on the bamboo's fibers and composition may be obtained which may further provide evaluation on the material's strength.

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