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ESTABLISHING THE STRENGTH PARAMETERS PARALLEL TO FIBER OF *DENDROCALAMUS ASPER* (GIANT BAMBOO)

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ABSTRACT: The supply of timber is becoming scarce in the Philippines. *Dendocalamus asper* (or giant bamboo) is a candidate for safe, sustainable, and low-cost alternative housing to timber. However, its mechanical properties are yet to be established. In this paper, the compressive strength, shear strength, and tensile strength parallel to fiber of *Dendrocalamus asper* are determined using ISO 22157 and ASTM D143 tests. For the latter, a slight modification of ASTM D143 was employed. The result yielded an improved tensile strength parallel to fiber. The tensile strength was also tested using a modified version of ASTM D143, wherein the length of the test piece was changed to ensure failure within the gauge length. Two hundred (200) samples of 2m-long *Dendrocalamus asper* (giant bamboo) poles were prepared and used for testing. Equipment was fabricated to the dimensions of the test sample. The obtained tensile strength parallel to fiber using the ISO 22157 method had an average strength of 312.78 MPa for specimens with attached hardwood tabs and 424.43 MPa for specimens with attached softwood tabs while with the Modified ASTM D143-94 method, the average strength was 269.86 MPa. The shear strength parallel to the fibers had an average strength of 10.64 MPa at the internode and 11.87 MPa at the node. Lastly, the compressive strength parallel to the fibers had an average strength of 63.42 MPa at the internode and 55.55 MPa at the node

Keywords: Dendrocalamus asper, Giant Bamboo, ISO 22157, ASTMD143

1. INTRODUCTION

Bamboo belongs to the grass family Poaceae and it is most abundant in tropical areas. Moreover, it belongs to the flowering perennial evergreen plants in the grass family. There are over 62 bamboo species that can be found in the Philippines [1]. It is commonly used for indigenous products and there has been a growth of popularity in structural design for the reason of its known mechanical property of flexibility and lightweight characteristic.

Demand for cheaper raw materials and sustainable resource materials in construction is increasing due to the decrease of the total forest cover in the Philippines, where over 9.1 million hectares of land were deforested within 78 years due to biophysical factors and logging as its major course [2]. The increase of popularity in bamboo as an alternative material in construction is because of its comparable properties to timber. Timber is known for its many applications to construction and engineering. However, while Bamboo would take 3-5 years to regrow, timber would take approximately 25 years [3]. The use of timber has fallen from 2011 through 2012 resulting in a total of 91% drop of its revenue while those of the non-timber forest products including bamboos gained 17% revenue for the same period [4]. The industrial deficit can be addressed by introducing bamboo into new forms of housing materials and other construction uses. The standardization of the bamboos in the Philippines can be done by including its properties to the National Structural Code of the Philippines. However, the mechanical properties of bamboo vary for each species, making it a problem for the bamboo industry.

One of many bamboo species that can be found in the Philippines is the *Dendrocalamus asper* or “Giant bamboo” in common name. The said species is an erect bamboo which can be found in India, Thailand, Vietnam, Malaysia, and the Philippines. It has a height of 20 – 30 meters tall, a diameter of 8 – 20 centimeters near the base and a wall thickness of 11 – 20 millimeters which becomes thinner with height. It is distinguishable by short brown hair in its culm internodes. In the country, it is the tallest and largest bamboo specie. It is considered as one of the most important bamboo species in the Philippines since it is used to build houses known as “bahay kubo” and make indigenous materials [5]. In a study by [6], the species flowered in parts of Samar, Leyte, and Bukidnon. Another location where *Dendrocalamus asper* can be found is in the province of Pampanga.

There is limited data regarding the mechanical properties of local Giant bamboo (Table 1) [7,8]. Also, with the location of the Giant bamboo source varies, its strength properties also vary. In this study, the mechanical properties of Giant Bamboo were determined by utilizing ISO 22157-1 [9] as the

Table 1. Available date for mechanical properties of local Giant Bamboo (*Dendrocalamus asper*)

Study	Location	Shear strength parallel to fiber (MPa)	Compression parallel to fiber (MPa)
Acma, L. (2017)	Central Mindanao University	-	104.02
Alipon et al (2011)	Malaybalay, Bukidnon	8.31 (internode) 8.33 (node)	47.9 (internode) 48.83 (node)
	Makiling, Laguna	3.18 (internode) 3.9 (node)	29.96 (internode) -

Note: Node indicates the presence of the node at the center of the specimen while internode specimens have no node at all.

Table 2. Number of specimens tested (total 107)

Strength Property	Testing Method (ISO 22157-1)	No. of specimens
Tension parallel to the fiber	ISO 22157-1	23
	Modified ASTM D 143-94	30
Shear parallel to the fiber	ISO 22157-1 (without node)	12
	ISO 22157-1 (with node)	12
Compression parallel to the fiber	ISO 22157-1 (without node)	15
	ISO 22157-1 (with node)	15

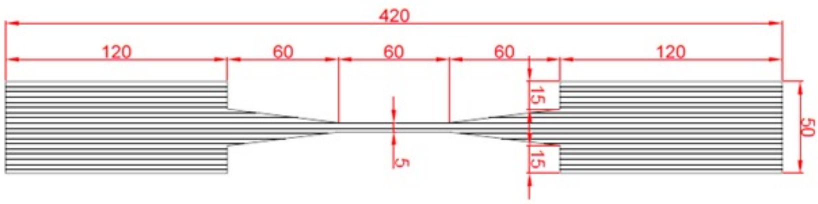

Fig 1. Specimen for Modified ASTM D143-94

standard method of determining the mechanical properties of bamboo. Moreover, the Modified Colombian Test [10] and the Modified ASTM D143-94 [11] are used as test methods. Through testing the tensile, compressive, and shear strength of *Dendrocalamus Asper*, standard specification of its mechanical properties can be provided. With this, it would be a basis for the capability of the said bamboo in different structural engineering applications.

2. TESTING METHODS

2.1 Preparation of specimens

The detailed methods from [11] and [9] were followed for the determination of the strength properties of *Dendrocalamus asper*. A total of 107 cured specimens were tested for all the mechanical properties (Table 2). The curing process was done for about 3 weeks at that involved a specialized water treatment pump, drying racks, and a chemical solution to prevent termites and powder post beetle attack. The selection of the sample was based upon a testing authority to identify the species and to determine any defects for which may affect the properties of the bamboo. Bamboo poles that were broken, damaged, and discolored were discarded. The test samples were fabricated according to the specifications for each method. Physical properties of the specimen were measured prior to testing. Universal Testing Machine (UTM) was used for testing the bamboo to determine its strength properties. The weight and dimensions of the portion from each specimen were obtained after testing for the determination of moisture content and density.

2.2 Tension Parallel to Fiber

The Modified ASTM D143-94 [11] is an alteration of the method of testing for the tensile strength parallel to the fibers of timber discussed in [12]. As the dimension of the specimen indicated in [12] is not suitable for a bamboo specimen, a modification to the dimension of the specimen was introduced in [11]. The length of the specimen used was increased in width to avoid failure due to shear and had the following dimensions as shown in Fig. 1. A fabricated special grip made, shown in Fig. 2, of steel materials was introduced into the machine to prevent failures due to compression. This fabricated special grip was then attached to a testing machine with constant load application. Tension parallel to fiber was also tested using the test standard ISO 22157-1. The test specimen was cut from the test culm with a width of half of the average thickness of the culm as shown in Fig. 3. Wooden tabs were attached at both ends and both sides of the bamboo using Palochina and Mahogany, softwood and hardwood, respectively. The dimension of the test specimen is shown in Fig. 4.

The tensile strength parallel to fiber is computed using the following equation

$$\boldsymbol{\sigma_P = F_P/(b * t)} \quad (1)$$

where σ_P (in MPa) is the ultimate tensile strength parallel to the fiber, b is the gauge length and t is the wall thickness (specimen thickness).

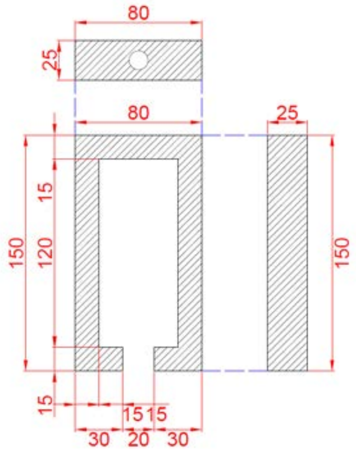

Fig. 2 Fabricated Grip for the Modified ASTM D143-93

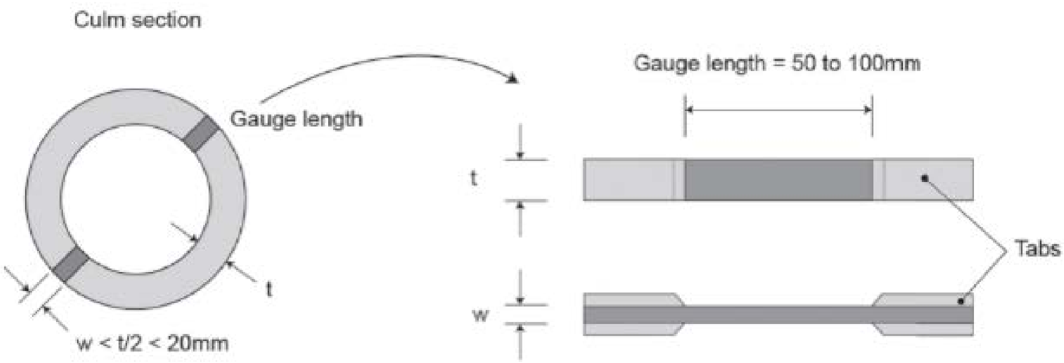

Fig. 3 Specimen for testing tension parallel to fiber based on ISO22157-1

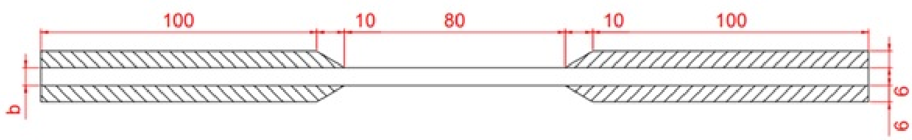

Fig. 4 Dimensions (in mm) of specimen for testing tension parallel to fiber based on ISO22157-1

2.2 Shear Parallel to Fiber

This was conducted in accordance with [9]. The test specimens considered for this test had a height equal to its diameter. Half of the samples tested were node samples and while the rest were internode samples. Node samples are specimens that have nodes in both ends while internode samples had no node at all. The specimen also had ends that were flat and in right angles to the length of the specimen. The wall thickness and the height were measured in the four areas of shear. The bamboo specimen was supported at the lower end over two quarters on opposite sides while the load was applied at the upper end of the specimen over the two quarters that were not supported (Fig. 5). The shear parallel to fiber is as shown below

$$\boldsymbol{\tau_{ult} = F_{ult}/(\Sigma(L * t))} \quad (2)$$

where τ_{ult} is the ultimate shear strength parallel to the fiber (MPa), F_{ult} is the maximum load at failure, t is the wall thickness and L is the length of test piece, and the Σ (L* t) is the sum of the four products of t and L.

2.3 Compression Parallel to Fiber

The compressive strength parallel to fiber as per [9] includes the use of a full culm specimen and a gadget, consisting of 2 plates and 2 sets of wedges that chrome-plated (see Fig. 6). The length of the specimen is the least value of the average diameter or ten times the average pole thickness. The wedges were used as an intermediate layer to minimize friction and radial restraint at the specimen ends. The wedges were also trimmed at the edges to allow movement against each other. The diameter and thickness of the plates are 250 mm and 40 mm, respectively. The compressive strength parallel to fiber is computed using the following equation:

$$\boldsymbol{f_{c,o}} = \boldsymbol{F_{ult}}/A \tag{3}$$

where $f_{c,o}$ is the compressive strength parallel to the fiber (MPa), F_{ult} is the maximum load at failure, and A is the cross-sectional area.

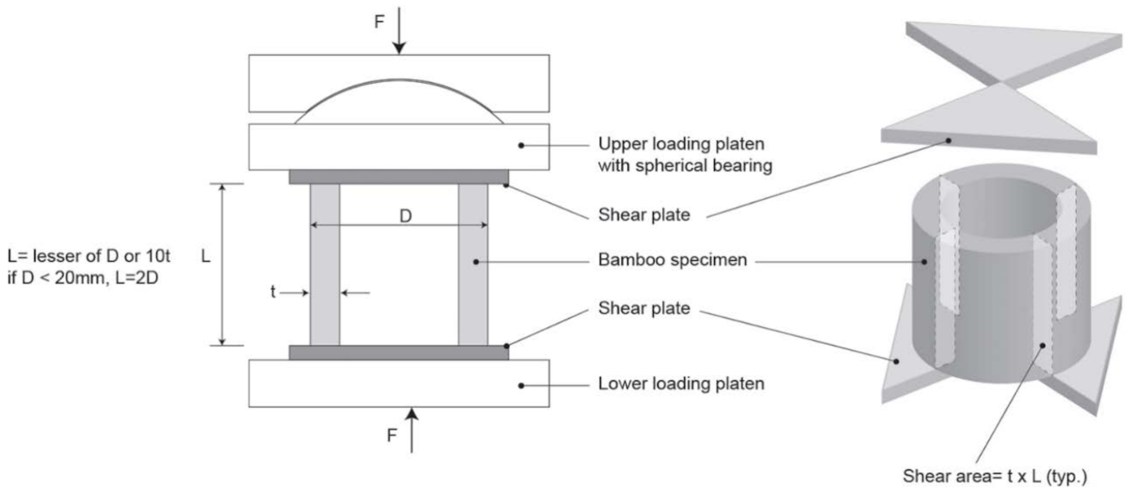

Fig. 5 Test apparatus and loading setup for testing shear parallel to fiber based on ISO22157-1

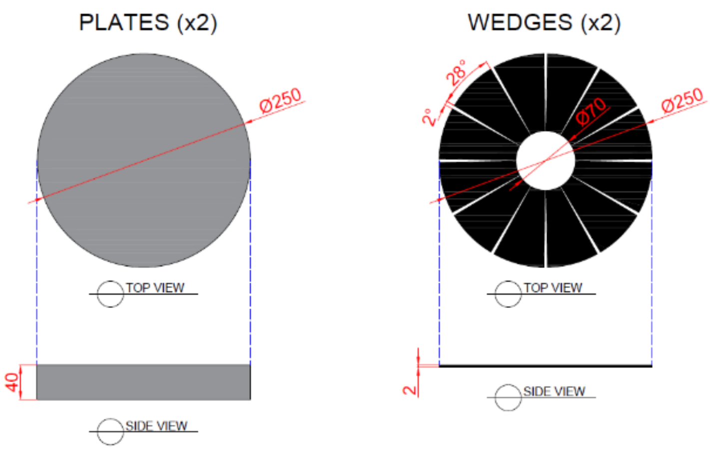

Fig. 6 Loading platen with special bearing (left) and intermediate layer (right) (dimensions in mm)

3. RESULTS AND DISCUSSION

3.1 Tension Parallel to Fiber

For the 30 specimens tested using Modified ASTM D143-94, there were 3 recorded failure modes. These were tension parallel failure on a node, shear failure, and bending failure. There were 10 (33%) specimens that failed in tension parallel on a node, 7 (23%) specimens in shear failure, 5 (17%) specimens in a combined failure of tension parallel on node and shear, 4 (13%) specimens in a combined failure of tension parallel on a node and bending, and 4 (13%) specimens in a combined failure of shear and bending. The dominant mode of failure is tension parallel failure on a node. However, the occurrence of other failure modes was not avoided due to the tendency of the gadget and specimen to slip. From the recorded failure modes and outlier test, only 18 specimens were included in the strength analysis accounting specimens that failed in tension. The obtained tensile strength ranged from 168.86 MPa to 356.93 MPa with an average strength of 269.86 MPa. The characteristic value, *Rk*, is 195.15 MPa producing an allowable strength of 61.20 MPa. The summary of results for the test is shown in Table 3.

For tension parallel to fiber using ISO 22157-1, there were two distinct modes of failure, bearing failure and tension parallel failure on a node. The node part of the bamboo, which is the weakest part, was chosen to be included in the specimen. However, bearing failure occurred, specifically in the laminated wooden tabs. In total, there were 14 (61%) out of 23 specimens that failed in bearing. Thus, only 9 (39%) specimens that failed in tension parallel on node were included in the outlier test. From the outlier test, there were only 4 and 3 accepted specimens for hardwood and softwood that is valid for strength analysis, respectively. For the hardwood specimens, the tensile strength ranged from 242.75 to 470.06 MPa with an average strength of 312.78 MPa. Whereas, for softwood, the tensile strength ranged from 373.03 to 456.93 MPa with an average strength of 424.43 MPa. The characteristic value, *Rk*, for the hardwood is 157.57 MPa and 167.57 MPa for softwood. Moreover, the computed allowable stress is 46.44 MPa and 112.78 MPa for hardwood and softwood, respectively. From the data gathered, it can be seen that the tensile strength obtained from specimens with softwood is relatively higher than that of specimens with hardwood shown earlier in Table 3.

Table 3 Summary of Mechanical properties of *Dendrocalamus Asper* (Giant Bamboo)

	Modulus of Rupture (MPa)		Ave. (MPa)	R_k (MPa)	Allowable Stress (MPa)
Tensile strength parallel to the fiber ISO 22157-1					
with Hardwood	242.75	470.06	312.78	130.61	46.44
with Softwood	373.03	456.93	424.43	317.20	112.78
Modified ASTM D143-94	168.86	356.93	269.86	172.14	61.20
Compressive strength parallel to the fiber (ISO 22157-1)					
with Node	44.83	55.73	55.55	26.76	9.52
without Node	49.67	62.27	63.42	30.26	10.76
Shear strength parallel to the fiber ISO 22157-1					
With Node	8.83	14.25	11.87	5.59	1.99
Without Node	5.88	15.33	10.64	3.66	1.30

3.2 Shear Parallel to Fiber

For the shear test, it was expected that the samples would not shear at all four planes based on the study done by [13]. All samples failed in shear, and 24 samples sheared in 2 planes, 3 samples sheared in 1 plane, 1 sample sheared in 3 planes, and 2 samples sheared in 4 planes. The shear strength for samples without node ranged from 5.88 MPa to 15.33 MPa while the shear strength for samples with node ranged from 8.83 MPa to 14.25 MPa. Samples without node resulted in an average shear strength of 10.64 MPa with allowable stress of 1.30 MPa while samples with node resulted in an average shear strength of 11.87 MPa with allowable stress of 1.99 MPa. The values obtained from the study are close to the strength values obtained by [14] with 8.31 MPa and 8.83 MPa for samples without and with nodes, respectively. In their study, the same species, *Dendrocalamus asper*, was used except for its locality which is in Malaybalay, Bukidnon. Comparing these data, yields a percentage difference of 24.59% for specimens without node and 29.37% for specimens with node.

3.3 Compression Parallel to Fiber

A combination of end bearing failure and a splitting failure occurred in the compression test. The resulting compressive strength of the samples without node ranged from 43.00 MPa to 69.60 MPa with an average strength of 63.42 MPa. On the other hand, the compressive strength of the samples with node ranged from 44.83 MPa to 63.21 MPa with an average strength of 55.55 MPa. The average compressive strength for samples without node had a higher value than those samples with node. In contrast, the allowable stress of samples without node was smaller than the allowable stress of samples with node. Moreover, comparing the obtained strength values to existing studies, the obtained values are closest to [14] having a compressive strength of 47.90 MPa for samples without node with percentage difference of 27.88% and 48.83 MPa for samples with node with percentage difference of 12.88%.

4. CONCLUSION

Among the mechanical properties tested, the Giant bamboo is considered strongest in tension parallel to the fiber, while it is weakest in shear strength parallel to the fiber. Table 3 shows a summary of the strength values obtained for each mechanical property and test. Comparing the obtained average shear strength parallel to the fiber from [14] yields a percentage difference of 24.59% and 29.37% for specimens without node and with node, respectively. Likewise, for compressive strength parallel to the fiber the percentage difference is 27.88% and 12.88% for specimens without node and with node, respectively.

The ISO 22157-1 method of testing the tension parallel to the fiber needs more development since the method and specimen were prone to slippage and bearing failure. Only a few samples failed in the expected mode of failure which is tension parallel failure. However, the shear testing method was considered to be effective and produced ideal failure modes. Most of the shear specimens failed in 2 planes (80%) instead of the expected four planes.

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