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RESEARCH ARTICLE OPEN ACCESS

Comparative Mechanical Properties of Selectied Bamboo Species

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ABSTRACT
This study aimed to evaluate some basic mechanical properties of selected bamboo species that are applicable to structural applications. Seven bamboo species planted inside the Central Mindanao University Campus were tested, namely: *Dendrocalamus merrillanus*, Elmer; *Gigantochcloa atter*, Hassk; *Bambusa vulgaris* Var. Schrad; *Dendrocalamaus asper*, Schultes. F; *Dendrocalamus latiflorus*, Rehm.; *Bambusa vulgaris* Schrad.; and, *Bambusa blumeana*, Schultes were subjected to four-point bending test, compression parallel to grain test and shear strength parallel to grain test. Data were taken from bottom, middle and top portion of the bamboos. Result showed that *Dendrocalamaus asper*, Schultes. has the stronger compressive strength at an average of 104.02 MPa, *Dendrocalamus latiflorus*, Rehm. has the stronger shearing strength at an average value of 12.65 MPa, while *Dendrocalamus merrilanus*, Elmer has the stronger flexural strength with and average value of 188.39 MPa. All six bamboo species tested is 2-6 times stronger than 80% stress graded *Vitex parviflora* Juss. (Molave) in compressive strength, 1.7-4.4 times stronger in shearing strength and 1.4 – 7.85 times stronger in flexural strength.

Keywords: *bamboo culms, four-point load set-up, compression parallel to grain, shear strength parallel to grain, bamboo internodes*

I. INTRODUCTION

Bamboo is abundant natural resource and available everywhere. It has been a conventional constructional material since ancient times but currently overlooked due to the availability of other construction materials which requires large amount of energy for its production and is not renewable. In recent years, bamboo has come to be recognized as a very important non-wood resource. This is due to the rapid destruction of tropical rainforests and the unrelenting demand for raw materials by wood based industries. Bamboo has high strength, usually straight and lightweight, easy to propagate, grow rapidly and suitable for almost endless variety of purposes (Espiloy, et.al., 1999). However, there is no available data for mechanical properties of bamboo and most people do not know how one bamboo species is compared to another species or to a known structural timber material in terms of strength. Hence, this study is conducted.

Seven bamboo species available in Central Mindanao University that can be used for structural purposes were identified and subjected to common mechanical properties such as Flexural or Bending Strength, Compression Parallel to Grain and Shear Strength Parallel to grain. Bamboo species identified include: *Dendrocalamus asper*, Schult.F, commonly named as “giant bamboo”; *Dendrocalamus latiflorus*, Rehm. commonly named as “machiku”; *Gigantochloa atter*, Hassk commonly named as “sweet bamboo”; *Bambusa blumeana*, Schultes commonly named “kawayan tinik”; *Bambusa vulgaris*, Schrad. Commonly named as “kawayan kiling”; *Bambusa vulgaris* Var. Schrad. Commonly named “golden bamboo”; and, *Dendrocalamus merrilanus*, Elmer commonly named as “bayog”.

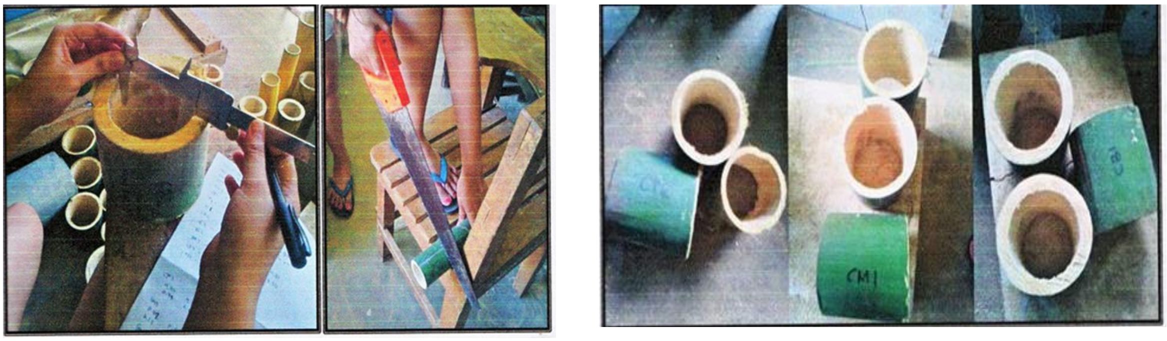
II. OBJECTIVE

The main objective of this study is to make a comparison of the basic mechanical properties of some selected bamboo species that are applicable to structural applications. Specifically, it aimed to: a) determine the flexural strength of the selected bamboo species using the modified four-point load test of the bamboo culm; b) to determine the compression parallel to grain along its culm internodes; c) to determine the shear strength parallel to grain along its culm internode; and, d) to make a comparative analysis of the mechanical properties among the bamboo species and with commercially available hardwood. Tests were conducted for the bottom, middle and top portion of the bamboo.

III. METHODOLOGY

3.1 Gathering of Specimen

Selected bamboo species were at the mature age of three to five years and without any damage to the entire length. Felled bamboo poles were immediately dispatched for processing. All tests were conducted within seven days after felling to insure those test specimens are still green. Prepared specimen were stored in a shed and kept away from direct sunlight to avoid cracking. Specimen for compression and shear has its length equal to the outer diameter. Specimens for flexure have a minimum of eight nodes and maximum of eleven nodes or 30 times outside larger diameter. All test specimens were gathered for the bottom, middle and top part of the bamboo pole. Three specimens with three replications each were prepared for every bamboo species representing bottom, middle and top part. Specimens for compression parallel to grain and shear parallel to grain are prepared with the length equal to the diameter of the culm. Routine preparation of test specimen is shown in Fig. 1.



a) Measurement and cutting of bamboo b) Specimen for compression and shear tests
Fig. 1. Routine preparation of bamboo test specimen

3.2 Compression Test Parallel to Grain

Compression strength test was undertaken using the compression accessory of the universal testing machine (UTM) and following the specification of ISO/TC 165 /N314. Compression tests parallel to grain were on specimens without any node, and the length of the specimens were taken equal to the outer diameter, however for outer diameter less than 20 mm or less, the length was taken as twice the outer diameter. So that the bamboo will not crack prior to testing, all test specimens were soaked in fresh water. Test specimen are placed in between top and bottom paten of the UTM and compression load is applied gradually until failure is observed which is either deformation on the contact surface, buckling of the specimen or splitting of the specimen. Set-up is shown in Fig. 2.

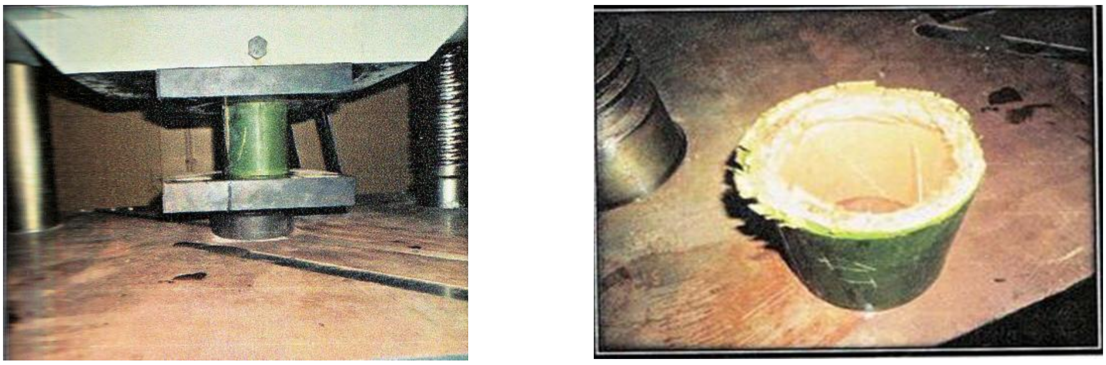


Fig. 2. Compression Test Set-up and typical appearance of specimen at failure

3.3 Shear Strength Test Parallel to Grain

Shear Strength Test Parallel to Grain was carried out using the ISO/TC 165 /N314 Specifications. A tetra-shear apparatus was fabricated as shown in Fig. 3. Specimen was set-up in the apparatus such that shear failure line was predetermined. The specimen was supported at the lower end over two quarters, opposite one another; and loaded at the upper end over two quarters which are not supported. The shear strength test parallel to grain is shown in Fig. 4.

Fig. 3. Tetra-shear apparatus for Shear Test

Fig. 4. Shear strength parallel to grain test set-up

3.4 Flexural Test

A modified four-point load set-up following the procedure of ISO/TC 165 /N314 Specifications. Test culms used are without visually apparent defects. In order to obtain failure in bending, the free span was at least 30 x D, in which D is the outside diameter. The full length of the culm was measured as the free length plus at each ends a half-internode- length. The usual length has a minimum of eight internodes and a maximum of eleven internodes. The test set-up is shown in Fig. 5. The load used are block with corresponding weights placed in a saddle such that the saddle will be able to deliver equal four-point load to the specimen. Actual loading of the set-up is shown in Fig. 6.

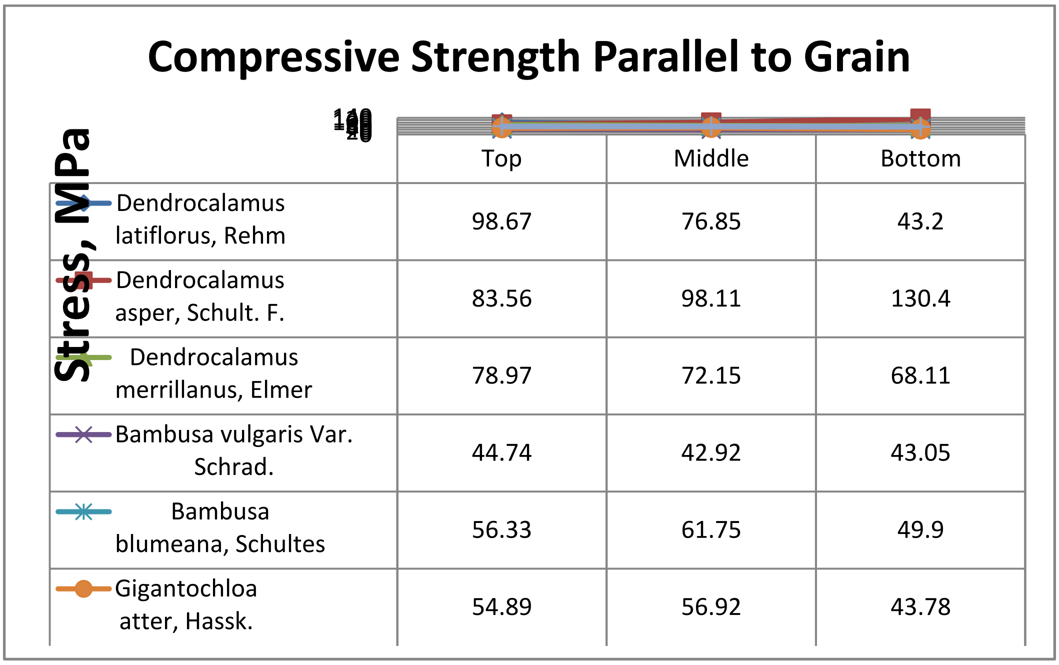
Fig. 5. Actual test set-up for flexural test

Fig. 6. Actual loading for the four-point flexure test

IV. RESULTS AND DISCUSSION

The conduct of the test was done in two stages. No data was taken for shear strength parallel to grain for golden bamboo; giant bamboo and sweet bamboo as the specimen were overtaken events that lead to aging of the specimen.

Compressive strength of bamboo was taken as the load when bamboo culm started to crumble divided by the average area of the bamboo culm to resist the load. The average of the three data was taken as the average compressive strength. Data was taken from the bottom, middle and top part of the bamboo. Fig. 7 shows the summary of the compressive strength of each species of bamboo tested and its comparison with each species.



	Top	Middle	Bottom
Dendrocalamus latiflorus, Rehm	98.67	76.85	43.2
Dendrocalamus asper, Schult. F.	83.56	98.11	130.4
Dendrocalamus merrillanus, Elmer	78.97	72.15	68.11
Bambusa vulgaris Var. Schrad.	44.74	42.92	43.05
Bambusa blumeana, Schultes	56.33	61.75	49.9
Gigantochloa atter, Hassk.	54.89	56.92	43.78

Fig. 7. Comparison of the result of the average Compressive stress in MPa of 6 bamboo species

Computation of compressive strength is taken from the equation

$$\sigma_{ultc} = F_{ult} / \{\pi/4[D^2 - (D-t)^2]\} \text{ --------- } (1)$$

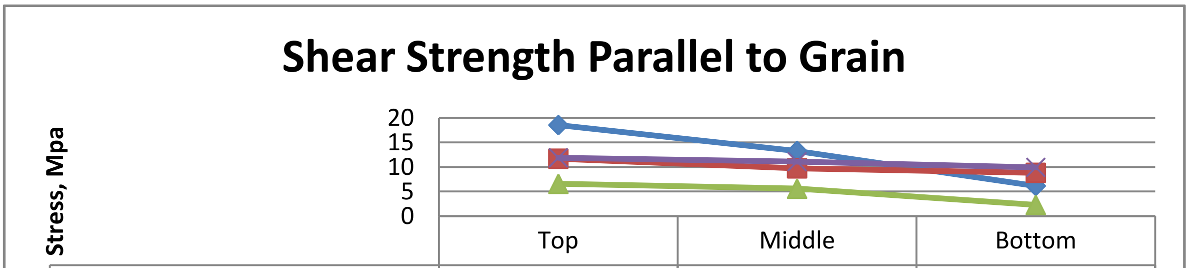
where σ_{ultc} is the compressive strength, F_{ult} is the load at failure, D is the outside diameter of bamboo and t is the thickness of the bamboo culm.

Most bamboo species have lower average compressive strength in the bottom part and most have higher compressive strength in the top part followed by the middle part. However, the data obtained was not true to *Dendrocalamus asper*, Schult.F, commonly named as “Giant bamboo” where the bottom part or the base has higher compressive strength as compared to the middle and top part. It is also apparent that *Dendrocalamus asper*, Schult.F is best material for compressive strength.

In obtaining the shear strength parallel to grain, the load when the bamboo culm was about to split up along where the tetra-shear apparatus was applied divided by the average thickness of the bamboo culm multiplied by length of bamboo culm. It should be noted that for a single loading, the bamboo culm will be split into 4 parts so that the total area computed was the equivalent to four surface areas. Shear strength parallel to grain is computed using the equation

$$\sigma_{ult} = F_{ult} / \Sigma\,(t \times L) \text{ in MPa ------- } (2)$$

where σ_{ult} is the shear strength parallel to grain, F_{ult} is the load when the bamboo starts to crack, t is the thickness of the bamboo culm and L is the length of the bamboo culm. Result of the test is given in Fig. 8 along with the comparison of strength of the four bamboo species.



	Top	Middle	Bottom
Dendrocalamus latiflorus, Rehm	18.54	13.275	6.143
Dendrocalamus merrillanus, Elmer	11.69	9.75	8.82
Bambusa blumeana, Schultes	6.58	5.58	2.28
Bambusa vulgaris, Schrad	11.88	11.08	9.92

Fig. 8. Comparison of the result of average shear strength parallel to grain of 4 bamboo species

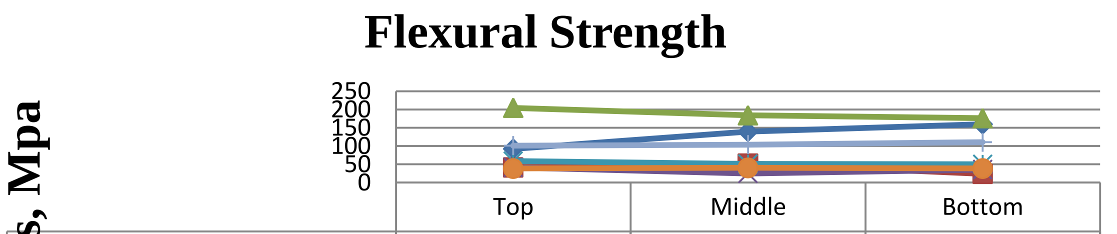
From the result of the shear test parallel to grain, all 4 bamboo species have the same trend, that is, the top part of the bamboo has higher shear strength and it decreases in the middle part and into the base part. The most probable reason is that the top part is more mature than the middle and bottom part. *Dendrocalamus latiflorus*, Rehm. commonly named as “Machiku”; has the higher shear strength parallel to grain, however, two other bamboo species, *Dendrocalamus merrilanus*, Elmer commonly named as “bayog” and *Bambusa vulgaris*, Schrad. Commonly named as “kawayan kiling” showed almost average shear strength parallel to grain. This bamboo species does not easily split up when subjected to either bending or compression load. *Dendrocalamus merrilanus*, Elmer commonly named as “bayog” does not usually grow bigger so that its structural use may be limited to flexural.

In obtaining the flexural strength of bamboo, the modified four-point set –up was used. The bamboo was loaded until a crack is heard during the loading. The cracking sound maybe due to splitting of the bamboo in the basal portion or ultimate bending where the central four-point load is attached. In order to take into consideration the taper effect of the bamboo, the following equation is integrated into the computation of flexural strength. Flexural strength was computed using the equation

$$f_{b\ ult} = P * L\,(D_m/2)/6I_x \text{ ---------- (ISO / TC165N314) ----- (3)}$$

$$I_x = \{\pi/64[(d_o + t_o x)^4 - (d_i + t_i x)^4]\} \text{ --------- (4)}$$

Where $f_{b\ ult}$ is the flexural strength of bamboo, D_m is the mean diameter of bamboo, I_x is the adjusted moment of inertia to consider taper effect, d_o is the outer diameter of bamboo at distance x, t_{ox} is the thickness of bamboo culm at distance x, d_i is the inner diameter of the stem at distance x.



	Top	Middle	Bottom
Dendrocalamus latiflorus, Rehm	92.63	139.52	159.95
Dendrocalamus asper, Schult. F.	41.24	52	24.07
Dendrocalamus merrillanus, Elmer	204.8	184.13	176.23
Bambusa vulgaris Var. Schrad.	41.95	25.354	35.98
Bambusa blumeana, Schultes	59.02	51.37	50.25
Gigantochloa atter, Hassk.	38.64	40.33	38.77
Bambusa vulgaris, Schrad	101.46	104.21	110.53

Fig. 9. Comparison of average flexural strengths of 6 bamboo species

From the result of the test, the *Dendrocalamus merrillanus*, Elmer known as "bayog" produced the highest flexural strength followed by *Dendrocalamus latiflorus*, Rehm. commonly named as "Machiku". It is to be noted however that *Bambusa vulgaris*, Schrad. Commonly named as "kawayan kiling" showed almost average flexural strength, meaning, the strength from the top portion is almost the same as the middle and basal portion of the bamboo. For flexural uses, the *Dendrocalamus merrillanus*, Elmer or "bayog" is best material. *Dendrocalamus latiflorus*, Rehm. commonly named as "Machiku" is rarely available as its shoot is the sweetest so that the "kawayan killing" or *Bambusa vulgaris*, Schrad may come in second.

A comparison is made with the mechanical properties of the selected bamboo species with known timber. The comparison is shown in Table 1.

Table 1. Comparison of average values of stresses selected bamboo species with known timber species

Material	Compression Parallel to Grain, MPa	Shear Parallel to Grain, MPa	Flexural Stress, MPa
Dendrocalamus latiflorus, Rehm.	72.91	12.65	130.7
Bambusa vulgaris, Schrad.	66.08	10.96	105.40
Dendrocalamus merrilanus, Elmer	73.07	10.09	188.39
Bambusa blumeana, Schultes	55.98	8.65	53.55
Dendrocalamus asper, Schult. F.	104.02		39.1
Gigantochcloa atter, Hassk	51.86		39.24
Bambusa vulgaris Var. Schrad	43.57		34.43
Yemane @ 80% stress grade	7.87	1.96	12.6
Agoho @ 80% stress grade	14.5	2.95	26.3
Molave (*Vitex parviflora* Juss.) @ 80% stress grade	15.4	2.88	24.0

From the result of the test and the physical properties of the identified timber species as provided in the National Structural Code of the Philippines, it can be seen that the physical properties of the identified bamboo species are far superior than wood. There is so much potential for the utilization of bamboo into a development of Engineered Bamboo lumber products that can have far superior physical attributes than the available wood. Bamboo is easy to grow, can reach maturity in 3-5 years and more suitable in Tropical areas like the Philippines. Furthermore, bamboo can be used to replenish the denuded forest and help in the mitigation of barren areas into a more productive area.

V. CONCLUSION

From the result of the tests, the following conclusions are considered:

- The top portion of most bamboo species gives the higher mechanical properties than the middle portion and the basal portion is the weakest;
- All seven bamboo species produced high values of Compression Stress Parallel to Grain, Shear Stress Parallel to Grain and Flexural Stress;
- *Dendrocalamaus asper*, Schultes. has the stronger compressive strength at an average of 104.02 MPa;
- *Dendrocalamus latiflorus*, Rehm. has the stronger shearing strength at an average value of 12.65 MPa;
- *Dendrocalamus latiflorus*, Rehm. has the stronger flexural strength with and average value of 188.39 MPa; and,
- All seven bamboo species tested is 2-6 times stronger than 80% stress graded *Vitex parviflora* Juss. (Molave) in compressive strength, 1.7-4.4 times stronger in shearing strength and 1.4 – 7.85 times stronger in flexural strength.

VI. RECOMMENDATION

From the result of the research, it is apparent that there are still additional studies to be conducted, among them:

- To conduct other tests to determine other mechanical properties of bamboo to enhance its diversification and utilization such as: Tensile strength test; Density; Hardness; Elastic Modulus; Coefficient of Shrinkage and Impact;
- To conduct characterization study of the identified bamboo species;
- To conduct tests to determine the chemical properties of bamboo such as moisture content, silica content, lingo-cellulosic content and starch content; and,
- To conduct research on the development of engineered bamboo using the identified bamboo species.

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