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ASSESSMENT OF TESTING PROTOCOLS FOR BAMBOO FOR TENSION PARALLEL TO FIBER

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ABSTRACT: To determine tension parallel to fiber properties of Bamboo, one can employ ISO 22157. However, several studies highlighted some challenges in using the method such as premature failure of testing due to force at clamping and slipping failure at the grips. Hence, this study aimed to look for a solution to address these challenges. This study investigated, both qualitatively and quantitatively, three testing protocols in determining bamboo's tensile strength parallel to fiber – (1) ISO 22157, (2) a modification of ASTM D143, and (3) Pittsburgh Method. The success rate, test duration, load rate and transmission, specimen preparation, equipment fabrication, and execution of the three protocols were compared. The physical properties of bamboos, such as moisture content, density, and shrinkage, were also measured in the study. The results of the study showed that the modified ASTM D143 test is the most viable method to use in testing the tensile strength parallel to fiber of bamboos. Modified ASTM D143 produced the highest tensile strength with value equal to 100.36 MPa, compared to specimens tested under ISO 22157 with tensile strength only reaching 94.11 MPa, while Pittsburgh Test produced the lowest tensile strength of 76.78 MPa. Modified ASTM D143 also yielded the lowest confidence interval which implied good consistency. Modified ASTM D143 is the recommended test protocol based on the results of this study as it gained the highest success rate during testing, lowest testing duration and the easiest to execute.

Keywords: Bamboo, Tensile strength parallel to fiber, ISO 22157, ASTM D143, Pittsburgh method

1. INTRODUCTION

Timber is getting scarce in the Philippines. The need for safe, sustainable, and low-cost housing is also on the rise. These factors urgently call for an alternative for timber used in construction. There are more than 62 species of bamboo growing in the Philippines [1]. The species of bamboo that are abundant in the country are *Bambusa blumeana* (locally referred to as "kawayang tinik"), *Dendrocalmus asper* ("giant bamboo"), *Bambusa sp. 1* ("bayog"), and *Schizostachyum lumampao* ("buho") [2]. The abundance of bamboo in the Philippines and its potential to be used as a construction material strengthen its value as alternative to timber. Bamboo is used as an alternative to wood and it has been considered as "poor man's timber" [3]. Its reputation changed in recent times with technological developments and researches [1,4] which led to different uses of bamboo for ceilings, floorings, cabinetry, furniture, and even as a base of a bicycle [1-2,4-7]. Construction application, such as scaffolding, was also one of the most notable uses of bamboo. Bamboo is a renewable material, being one of the fastest growing plants in the world. It can be harvested at an age as early as 3 years compared to timber which takes about 25 years to mature and be harvested [8]. Since bamboo is technically a grass, it regenerates faster. In 2004, ISO published ISO 22157-1 (Bamboo - Determination of physical and mechanical properties) with 2 parts: Requirements, and (2) Laboratory Manual. This test method provides guidelines and procedures in conducting the tests for determining the strength characteristics of bamboo, its important physical properties (like moisture content, shrinkage, and density) and the requirements for conducting all these tests.

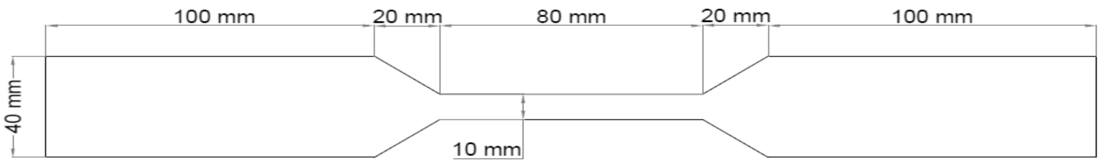

Fig.1 ISO 22157 Specimen (TP1)

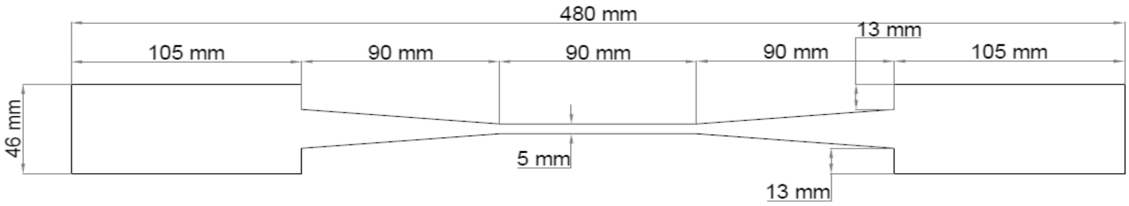

Fig.2 Modified ASTM D143 specimen (TP2)

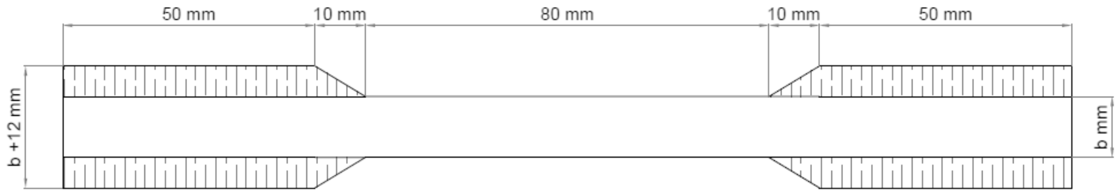

Fig.3 Pittsburgh method specimen (TP3)

Also, it has published ISO 22156 Bamboo - Structural Design. One of the properties that this test protocol determines, based on [9], is the tension parallel to the fiber. However, this test method exhibited some notable shortcomings: specimen clamped at the grips failed due to the force of gripping, and slipping at the grips [10,11]. The study of [12] also observed similar issues and additionally noticed that it has problems with specimen orientation noting that reduction should be made in the tangential direction of the specimen so as not to remove the extreme inner and outer culm wall fibers from the test coupon. Generally, testing for tension parallel to the grain is difficult to achieve, and the specimens generally fail in combined flexure and shear [10].

There are several inconsistencies observed in ISO 22157 during testing. The study of [10,11] noticed failure at the grips cause due to the force demanded by clamping for sufficient hold on the specimen. Additionally, slippage at the grips also occurs. According to [13], adjustments should be made to ISO 22157 in determining properties of bamboo to make sure that the cause of failure is tension and not failure due to compression because of the grip issues. The study of [14] recommended the adaptation of [15] ASTM D143 for testing tension parallel to fibers.

It is evident that there is a need for modifications in ISO 22157 to address concerns about testing of tension parallel to fiber. The study of [16] had attempted to address one of its issues by investigating the shear property of bamboo. Prior to making any recommendation to ISO 22157, verification of a new test protocol is needed, hence, this study assessed three testing protocols: (1) ISO 22157 itself, (2) a modification of ASTM D143, and (3) Pittsburgh Method - a test adapted from [11]; in determining bamboo's tensile strength parallel to fiber.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The material used in the study is a homegrown bamboo known as "kawayang tinik" (*Bambusa blumeana)* which was sourced from Tarlac, Philippines. The specimen came from several culms of the said species. Testing was done using a Shimadzu UH-1000kN universal testing machine equipped with finely-tuned control loading rate settings and is available locally. The number of specimens tested for each protocol was 25.

2.2 Testing Protocols (TP)

2.2.1 TP1: ISO 22157

For this protocol, the specimen had gauge area of 10 mm in width, and a length of 80mm (Fig.1). The ends of the test specimen were shaped to ensure failure at the gauge portion. The node of the bamboo was taken to be exactly at the middle of the gauge length. Notably, the whole specimen was slightly curved. The specimen was cut using a handsaw. The load was applied constantly at a rate of 2.0 mm/min.

2.2.2 TP2: Modified ASTM D143

The second testing protocol is a modification of ASTM D143 which, without modification, is for testing of tension parallel to grain for small clear specimens of timber. The modification of this standard test method, as adopted in this study, came in the form of special grips which was attached to the testing machine to lessen failures. The specimen was cut using a table saw because the specimen profile requires high precision (Fig.2). A load rate of 1 mm/min was constantly applied for this test.

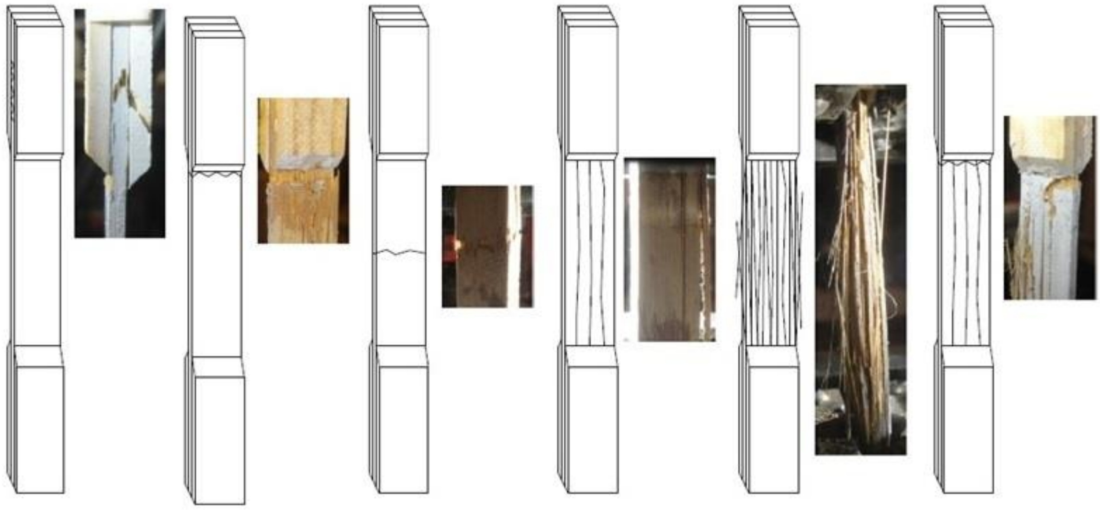

Fig.4 Failure mode of bamboo when tested in tension parallel to grain (Richard and Harries, 2015)

2.2.3 TP3: Pittsburgh method

The Pittsburgh method is a test protocol adapted from [10]. The specimen (Fig.3) had a rectangular cross-section dimension with breadth equal to the culm wall thickness (t), and width (b) equal to one-half the culm wall thickness or less. The specimen width did not exceed 20 mm and included one node in the gauge section. The gauge length was set at 80 mm. The gripped ends of radially oriented test pieces had softwood tabs laminated to the breadth dimension using coconut lumber with a thickness of 6mm. The load rate of the test was set at 5mm/min.

3. RESULTS AND DISCUSSION

Table 1 shows the tensile strength of each protocol and the average value of moisture content, density, and shrinkage of all specimens. As seen, the Pittsburgh Method (TP3) produced the least tensile strength average while modified ASTM (TP2) produced the highest tensile strength. Table 2 summarizes all tensile strength test results, characteristic value, allowable stress and confidence interval.

3.1 Modes of Failure

The study of [10] discussed three modes of failure for testing of bamboo in tension. The first is a fracture that occurs parallel to the grain. This failure mode, however, is considered to be difficult to analyze and difficult to achieve. The second mode of failure is a combination of flexural and shear failures while most of the experts and researchers have decided to discard the third mode.

Moreover, [12] noticed several types of failure in testing bamboo for tension parallel to grain using the Pittsburgh method (Fig.4) and these are: tab failure, failure at the interface of the grip and gauge, tensile rupture within the gauge, longitudinal splitting, splintering failure ('brooming'), and, combination of any type mentioned. Tension failure and the splintering tension are the preferred failure modes in bamboo tested for tension parallel to the grain.

Table 1 Tensile strength (parallel to fiber) summary of test results

Test Protocol	Average Tensile Strength, MPa	R_k, MPa	Moisture Content, %	Density ρ (kg/m^3)	Shrinkage, %
TP1	94.11	44.86	10.95	682.48	1.40
TP2	100.36	62.67	10.95	682.48	1.40
TP3	76.78	43.45	10.95	682.48	1.40

Table 2 Tensile strength (parallel to fiber) values for three (3) testing protocols

Test Protocol	Range (MPa)	Average (MPa)	Rk (MPa)	Allowable Stress (MPa)	Confidence Interval (MPa)	Confidence Interval Range@ 95% confidence level, MPa
TP1	51.72-145.18	94.11	44.86	9.97	12.89	81.22-106.99
TP2	49.65-131.84	100.36	62.67	13.93	10.09	90.27-110.45
TP3	42.71-102.36	76.78	43.45	9.66	13.59	66.22-93.40

Table 3 Qualitative comparison of three (3) testing protocols

Testing Protocol	Success Rate	Test duration < 5 min?	Specimen Preparation Difficulty	Needs accessory?	Test Difficulty
TP1	68%	Yes	Mid	No	Mid
TP2	76%	No	High	Yes	Easy
TP3	48%	Yes	Mid to High	No	Mid

3.1.1 TP1: ISO 22157

For the ISO 22157 test (TP1), there were five modes of failures observed during testing: bearing, shear, premature cracking or cracking in grips, tension (parallel to fiber) failure on a node or brittle tension, and splintering tension failure (parallel to fiber). Out of 25 specimens, 17 (68%) failed in tension (parallel to fiber) while 8 (32%) failed in non-tension mode. These different failure patterns observed during the study reinforced the shortcomings of ISO 22157 as highlighted in various studies [10,11]. Non-tension failure was observed notably in many of the specimens (32%) demanding similar attention to the need for ISO 22157 to be studied further.

3.1.2 TP2: Modified ASTM D143

There were three modes of failures observed in this test protocol: tension brittle, splintering tension parallel, and shear failure. Out of 25 specimens, a total of 19 (76%), failed in tension (parallel to fiber), 6 specimens (24%) failed in shear. This test protocol obtained the highest percentage of failures in tension compared to the other test protocols. Tension failures observed in this test were the preferred tension failure modes i.e. tension brittle and splintering tension).

3.1.3 TP3: Pittsburgh method

There were two failures observed: tension (parallel to fiber) failure on a node, and bearing failure. Out of 25 specimens, 12 (48%) failed in tension (parallel to fiber), 13 specimens (52%) did not fail in tension (parallel to the fiber) but instead, failed in bearing failure mode. It is to be noted that non-tension failure for this test protocol (52%) was even higher than tension failure (48%). This significantly high non-tension failure mode called for similar attention as that of TP1 with respect to studying and improving the method further to ensure tension failures during tensile test.

3.2 Qualitative Analysis

Table 3 shows the success rate of the testing protocols. The most successful testing protocol was the modified ASTM D143 (TP2) with 76% (19 out of 25 tests). The least successful method was TP3 with 48% (12 out of 25 tests). The success rate is taken as the ratio between the number of tests exhibiting tension failure and the total number of tests. This criterion, in this study, is considered important in deciding which testing protocol can be best suited for testing bamboo specimens.

It is observed that TP2 had the fastest average testing time with 258 seconds as the grip accessory made the setup simpler. TP1 and TP3 took 534 and 682 seconds, respectively, to complete the test.

This was attributed to the difference in load rates between test protocols. Both TP1 and TP3 demanded careful attention during setup to ensure that the specimen is oriented parallel to the direction of loading in the testing machine. Additionally, for TP1 and TP3, it was observed that the load-displayed values were fluctuating due to the clamping at the grips. During test, the grips compressed the specimens and when the specimen got thin as a result of compression, slipping at the grips happen, thus, the fluctuation of values. At the beginning of the tests for TP1 and TP3, it took time for the load to increase, as the clamps needed to grip the specimen firmly. Qualitative observations for all test protocols were summarized in Table 3.

The preparation of a specimen is very important to obtain the expected failure. For TP1, the preparation of the specimen was simple since its specimen's width was larger compared to that of the other testing protocols. The specimens for

TP2 were the most difficult to prepare since it needs precise and careful preparations as it demands that the part where the grip accessory and the specimen comes into contact must be parallel to make sure the load distribution is equal. For TP3, preparation was rated between medium and high. It is easier than TP2 test since it is much easier to cut but tedious due to the addition of tabs.

TP1 and TP3 did not require additional grips as the testing machine's grip is sufficient to conduct the tests. For TP2, however, extra grips (i.e. grip accessory) were fabricated for better clamping. TP2 is the easiest test to execute as the additional grips made the clamping setup easy. TP1 and TP3 made the setup for clamping extra difficult as the testing machine's grip requires manual adjustment for the specimen to be perfectly aligned with the load direction.

4. CONCLUSION

Among three testing protocols investigated, modified ASTM D143 Test (TP2) produced the highest tensile stress reading at 100.36 MPa compared to ISO 22157 (TP1) with 94.11 MPa, and Pittsburgh method (TP3) with 76.78 MPa. It is concluded from this result that to maximize the strength property of bamboo specimens, particularly in tension parallel to fiber, TP2 must be employed in testing compared to the other two testing protocols (i.e. TP1 and TP3). TP2 also produced the most consistent results with the lowest confidence interval reinforcing further the conclusion made earlier.

From the results summarized above, it was concluded that the Modified ASTM D143 test (TP2) is the most recommended method to use. It had the highest success rate, lowest test duration, and the easiest to execute. The only downside for this test protocol is the demand for careful attention during the preparation of the specimen.

The second recommended test protocol is the ISO 22157 (TP1) based on the success rate, test duration, and specimen preparation. And the least recommended method is the Pittsburgh method (TP3) because of the lowest success rate, with non-tension failures even higher than tension failures. Additionally, TP3 also demanded long test duration and tedious specimen preparation.

5. REFERENCES

[1] Marquez C., Improving and maintaining productivity of Bambusa blumeana for quality shoots and timber in Iloilo and Capiz, the Philippines, Australian Centre for International Agricultural Research, 2006.

[2] Malab S., and Zafaralla J., Engineered kawayan technology promotion and investment options for commercialization, Monograph, Mariano Marcos State University, 2006, p.11.

[3] Janssen J, Bamboo in building structures. Doctorate thesis, Eindhoven University of Technology, Netherlands, 1981. Retrieved March 3, 2017, from http://alexandria.tue.nl/extra3/proefschrift/PRF3B/8104676.pdf.

[4] Razal R., Bantayan R., Delgado T., and Elec J., Bamboo Poles for Engineered-Bamboo Products Through Improved Clump Management and Harvesting: Lessons for the Philippines, Ecosystems & Development Journal, Vol. 4, Issue 1, 2013, pp.39-49.

[5] Schau E., Chang Y., Scheumann R., and Finkbeiner M., Manufactured products - how can their life cycle sustainability be measured? A case study of bamboo bicycle, Conference proceedings, in 10th Global Conference on Sustainable Manufacturing, 2012.

[6] Mitch D., Splitting capacity characterization of bamboo culms, Master's thesis, University of Pittsburgh Honors College, Pennsylvania, USA, 2009.

[7] Alipon M., Bauza E., and Sapin G., Development of Floor Tiles from Philippine Bamboos. Philippine Journal of Science Vol. 140, Issue 1, 2011, pp.33-39.

[8] Gutu T., A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization, International Journal of Innovative Technology and Exploring Engineering Vol. 2, Issue 5, 2013, pp.314-319.

[9] ISO 22157, Bamboo – Determination of physical and mechanical properties, Geneva, Switzerland: ISO/IEC, 2004.

[10] Atanda J., Environmental Impacts of bamboo as substitute construction material in Nigeria. Case Studies in Construction Materials 3, 2015, pp.33-39.

[11] Bartoli G., ISO Standards of Bamboo, Paper presented at Performance of Joints in Bamboo Structures Conference, Italy, 2005.

[12] Richard M., and Harries K., On inherent bending in tension tests of bamboo, Wood Science and Technology, 49, 2015, pp.99-119.

[13] Valdes D., and Zapata D., Test procedures for determining the physical and mechanical properties of bamboo, National University of Colombia, Bogota, 2004.

[14] Trujillo D., and Lopez L., Bamboo material characterization, Nonconventional & Vernacular Construction Materials Vol. 1, 2016, pp.365-392.

[15] ASTM D143, Standard Test Methods for Small Clear Specimens of Timber. ASTM International, West Conshohocken, PA, 2007.

[16] Cantos G. L., Lopez L., De Jesus R., Salzer C., and Garciano L., Investigation of an

[17] alternative testing protocol to determine the shear strength of bamboo parallel to grain, Maderas Ciencia Y Tecnologia, 21(4), 2019, pp.559-564.