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Establishing the Characteristic Shear Strength of a Local Bamboo Species: *Bambusa blumeana* (Kawayan Tinik)

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Abstract: The mechanical properties of a structural material such as flexure, shear, and compressive strengths are needed in the structural design process. Unfortunately, published studies of the shear strength of an important local species: *Bambusa blumeana* (Kawayan Tinik) are limited. The authors focused on this property since joint connections are possible points of failure when a bamboo structure is subjected to extreme loads. The latest ISO 22157-1 test protocol and ISO 12122-1 were used to establish the shear strengths from twelve bamboo samples from Laguna. The results show that the average shear and characteristic shear strengths of Kawayan Tinik are 12.2 MPa and 9.56 MPa, respectively. Since testing facilities are limited at the site, the authors also proposed a linear model to estimate the shear strength of bamboo using the physical properties derived from the tests.

Key Words: *Bambusa blumeana*; bamboo; shear parallel to fiber; mechanical properties; ISO 22157-1; ISO 12122-1;

1. INTRODUCTION

There is a need to look for sustainable construction materials that can address climate change impacts as well the demand for low-cost housing (Salzer et al., 2016). Bamboo can be part of the solution to these global challenges (International Bamboo and Rattan Organisation (INBAR), 2020). According to DOST-FPRDI (2020), the global bamboo industry is in 2006 was about US$ 7 billion and projected to increase to US$17 billion by 2020.

The Philippines ranks 6th in the world as an exporter of bamboo and rattan products (Aggangan, 2015). However, due to the backlog in producing housing units and for the repair or replacement of existing houses, demand for bamboo is rising (Department of Science and Technology, 2020). Since bamboo is a demand among rural households that uses bamboo or in combination with other low-cost construction materials, there is a need therefore to establish its mechanical properties to be able to fully utilize it as an alternative construction material. In this regard, physical and material properties must first be established.

In this paper, the authors considered *Bambusa blumeana* (Kawayan Tinik). It is considered one of the 12 most economically important bamboo species in the Philippines (Department of Science and Technology, 2020). Also, according to an article published in (Agrimag, 2019), the *Bambusa blumeana* species is one of the most important bamboo resources for the Philippine rural population. It was introduced in the Philippines during the early 1900s and since then has become naturalized and can be found throughout the settled areas at low and medium altitudes (Roxas, 2012). A study conducted by (Decipulo et al., 2003) where it compared 3 local bamboo species in Malaybalay, Bukidnon. *Bambusa blumeana* species emerged as the species with the highest clump productivity and sustainability with a mean yield and harvest of 2.87 culms/clump per year and 4.87 culm/clump per year, respectively. This is superior in comparison to the other 2 bamboo species

Bambusa vulgaris (local name: Kawayan Kiling) and *Bambusa blumeana* var Luzonensis (local name: Bayog). Kawayan Kiling species have a mean yield and harvest of 2.29 culms/clump per year and 3.25 culms/clump per year, respectively while Bayog species have a mean yield and harvest of 1.45 culms/clump per year and 1.93 culms/clump per year, respectively. *Bambusa blumeana* species can be found on the following plantations: (1) Rosario, La Union; (2) Magalang, Pampanga; (3) Dunarao, Capiz; (4) Minglanilla, Cebu; (5) Malaybalay, Bukidnon; and (6) Bislig, Surigao del Sur. Because of the abundance of *Bambusa blumeana* species, it is then imperative that it should be prioritized for harvest and production. However, for one to properly utilize this abundant resource, its physical and mechanical properties must be established first.

This study aims to focus on the shear strength of bamboo parallel to fiber for *Bambusa blumeana*. Due to a range of mechanical properties and bamboo species in the Philippines, a targeted approach of research is necessary to progressively establish an area that requires further investigation. In a study by (Mitch, 2019), the shear strength parallel to the fiber is the mechanical property of bamboo that has the highest variation. Thus, the result of this study will define a concrete value at least for this bamboo species. Moreover, shear is pointed out as one of the governing forces on joint failures on bamboo structures when subjected to extreme loading conditions (Janssen, 1981). Another important part of this research is to determine the correlation of physical properties such as density and moisture content to that of the shear strength parallel to fiber. Density is the most important mechanical property of bamboo because the greater the density (i.e., the more molecules are present per unit volume), the heavier the bamboo and this characteristic results in properties that are desirable in most situations (Janssen, 1981). A rule of thumb on dry bamboo wherein the ratio of the ultimate stress in $\frac{N}{mm^2}$ and the mass per volume in $\frac{kg}{m^3}$ is equal to 0.021 as established by (Janssen, 1981). This study aims to develop the same correlation for the *Bambusa blumeana* species.

The method of sampling along the length of the bamboo culm is a limitation of this study. The strength of the node and internode may be influenced by the position where the sample is acquired, according to various literature (i.e., from the top, middle, and bottom of the bamboo culm). This was not considered in this study due to the small number of samples available during the testing. Nonetheless, the sampling was conducted in an unbiased, randomized manner. It must also be noted that the influence of the bamboo age has little significance on the shear strength of bamboo (Correal & Juliana Arbeláez, 2010). Hence, the age of the specimen was not considered in the study, as well.

2. METHODOLOGY

The shear strength property of one of the most economically viable bamboo species in the Philippines, *Bambusa blumeana* were properly characterized based on 12 shear test results. This study determined the average shear strength and characteristic shear strength of the said bamboo species. ISO 22157-1 (2017) test protocol for shear was the testing method used. suitable research requirements and instrumentations were followed based on this protocol. A sample test specimen is shown in Figure 1. Individual measurements of length, thickness, and diameter were done on each bamboo specimen. The ends of the bamboo specimens are ensured to be parallel to each other so that the load applied will be perfectly perpendicular to the plane of the specimen's ends. Proper due diligence is also carried out to check defects on the samples such as holes or cracks. Shimadzu AG-100 kN Xplus Universal Testing Machine (UTM) as sourced by Base Bahay Innovation Center (BIC) located in Makati, Philippines was used for all the tests. Based on trial tests, a loading rate of $0.15\,\frac{mm}{min}$ to $0.30\,\frac{mm}{min}$ is needed to achieve a testing time of $300 \pm 120\,s$. This is consistent with the recommendation of ISO 22157-1 (2017). A typical set-up showing the shear plates that were used in this study is also shown in Figure 2. The shear strength of bamboo parallel to fiber was computed through the failure load as shown on the Universal Testing Machine (UTM) and the total shear plane areas on the control points established. This is given by Equation 1 where f_v is shear strength in MPa, t is the average thickness of the specimen at the control points and L is the length of the specimen at the control points.

$$f_v = \frac{F_L}{\sum Lt} \qquad \text{(Eq. 1)}$$

Through ISO 22157-1 (2017), the other physical properties like the moisture content (ω), linear weight (q), and basic density (ρ) were also derived. Equation 2 shows the computation of moisture content using the oven-dry method where ω is the moisture content in %, m_i is the green weight of bamboo, and m_0 is the oven-dry weight of bamboo. Equation 3 likewise indicates the formula to determine the linear weight or the mass per unit length of the specimen where q is the linear weight in $\frac{kg}{m}$, m_e is the mass of the test piece at the green condition and L is the length of the test piece. Finally, the computation of the basic density (ρ) is in $\frac{kg}{m^3}$ is given by Equation 4 where m_0 is the oven-dry weight of the test piece and V is the volume of the green test piece.

$$\omega(\%) = \left[\frac{m_i - m_0}{m_0}\right] x\ 100 \qquad (\text{Eq. } 2)$$

$$q = \frac{m_e}{L} \qquad (\text{Eq. } 3)$$

$$\rho = \frac{m_o}{V} \qquad (\text{Eq. } 4)$$

Fig. 1. Bamboo Specimen

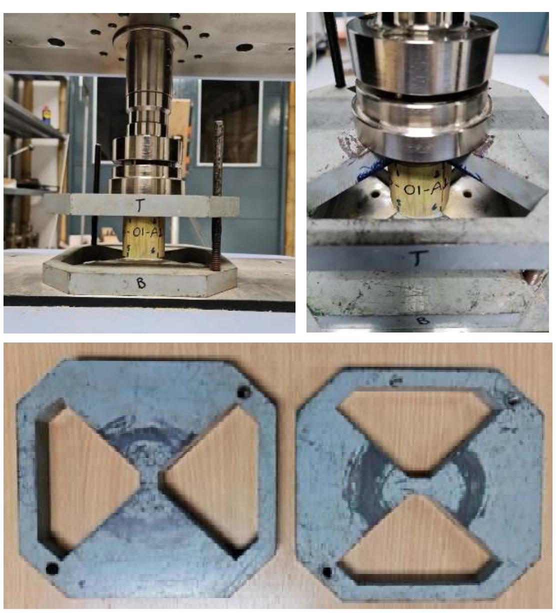

Fig. 2. Test Set-up and Shearing Plates

To evaluate the characteristic strength value of the test results, ISO 12122-1 (2014) was used based on (International Organization for Standardization (ISO), 2014). The 5th percentile evaluation should be used as the basis for the characteristic shear strength value according to the said standard. The method of non-parametric data analyzed using AS/NZS 4063.2 is used as the evaluation method to determine the characteristic value based on the 5th percentile value with 75% confidence. This was performed by ranking the raw test data results and determining the 5th percentile of the ranked data. Equation 5 shows the 5th percentile value with 75% confidence. In this formula $X_{0.05,0.75}$ is referred to as the characteristic value in $\frac{N}{mm^2}$, $X_{0.05}$ is the 5th percentile value of the sample in $\frac{N}{mm^2}$, V is the coefficient of variation of the test data calculated by dividing the standard deviation of the sample and the mean value of the sample, n is the size of the sample, and $k_{0.05,0.75}$ is a multiplier to give the 5th percentile value with 75% confidence. This multiplier $k_{0.05,0.75}$ is computed to be equal to 1.270 for n = 12.

$$X_{0.05,0.75} = X_{0.05}\left(1 - \frac{k_{0.05,0.75}V}{\sqrt{n}}\right) \qquad (\text{Eq. } 5)$$

Linear regression analysis was performed to further assess the correlation between the bamboo culm geometry and physical properties to the mechanical property used in this study.

3. RESULTS AND DISCUSSION

A typical shear failure pattern that is observed in this study is shown in Figure 3. Most of the specimens failed on either 1 or 2 shear failure planes.

Fig. 3. Typical Shear Failure Patterns

A digital vernier caliper with 0.5% precision was utilized to measure the geometric properties. Using the length and thickness measured on the specimen, the shear failure areas are likewise computed. A summary of the geometric characteristics of the bamboo specimens used is given in Table 1 while the other physical properties are shown in Table 2. It can be observed that the coefficient of variation (COV) is highest on linear weight (q) at COV = 0.21 while the COV of moisture content (w) and basic density (ρ) are 0.05 and 0.06, respectively. Generally, the measure of the level of variation from the mean for these physical properties is quite low.

Table 1. Summary of Geometric Characteristics

Species	All specimens (Average)				
Scientific Name	n	Length mm	Dia. mm	Thick mm	Area mm^2
B. blumeana	12	54.94	55.8	3.80	830

Table 2. Summary of Other Physical Properties

Species	All specimens			Internode Specimens
	n	w (%)	q (kg/m)	ρ (kg/m^3)
B. blumeana	12	10.31 (0.05)	0.54 (0.21)	731.85 (0.06)

Table 3 summarizes the average shear strength (f_v) and characteristic shear strength ($f_{v,c}$) using ISO 12122-1. The computed average shear strength of *B. blumeana* is 12.20 MPa (StDev = 1.424 and COV = 0.117). COV is low so we expect a low standard of deviation, as well. The characteristic shear strength is 9.56 MPa. As expected, we yielded a lower value as characteristic values concentrate on the lower limit (5^{th} percentile) of all the data values. Table 4 shows the computation for the characteristic shear strength. The 5^{th} percentile computed is 9.98 MPa and the multiplier $k_{0.05,0.75}$ is 1.270. It must be noted that the KS parameter obtained is 0.1108 while the Critical Value is 0.3754 therefore, we cannot reject the null hypothesis that the data fit the distribution. Thus, the distribution satisfies the goodness of fit test.

Table 3. Comparison of f_v and $f_{v,c}$ (MPa)

Species	All specimens		
	n	f_v, mean	$f_{v,c}$
B. blumeana	12	12.20	9.56

To find the correlation between the bamboo culm geometry (length, diameter, and thickness), shear area (A), basic density (ρ), moisture content (ω), and shear strength (f_v), the Pearson's correlation coefficients (r) were calculated for each regression analysis. Three levels of correlation were defined based on r values (i.e., strong for $r > 0.5$; moderately strong for $0.3 < r < 0.5$; and weak for $r < 0.3$). This regression coefficient characterizes the mean change in the dependent variable for each unit change in an independent variable if all other independent variables are kept constant. Also, linear regression analysis was done to assess the relationships between the bamboo culm geometry and physical properties to the shear strength of bamboo. The resulting r^2 the value indicates the performance of the model. The r^2 parameter is the percentage of the variations that are described by the independent variable (f_v). Values of r^2 that are nearer to 1 suggests that the model achieved represents more of the data points obtained in the study. Results of linear regression analyses as shown in Table 5, show that shear strength (f_v) has a relatively strong correlation with most parameters considered in this study. This can be attributed to r values which are greater than 0.30. However, model significance values are all greater than 0.05. The lowest p-value is 0.063 from the parameter moisture content (w). Further, this parameter has the highest r^2 value of 0.30. Hence, the linear regression model with the moisture content (w) as a parameter is suggested for usage.

Table 4. Evaluation of 5th percentile value with 75% confidence - Evaluation by fitting data to a distribution

Species	5th Percentile $X_{0.05}$ (MPa)	Multiplier $k_{0.05, 0.75}$	Characteristic Value $X_{0.05, 0.75}$ (MPa)
B. blumeana	9.98	1.270	9.56

Notes:
1. Method of evaluation is based on Section A.2.3 of ISO 12122-1:2014
2. Kolmogorov-Smirnov Parameter = 0.1108, Critical Value (Significance Level = 0.05) = 0.3754

To have a comparison between timber and bamboo, the characteristic shear strength is compared to the reference values for structural timber of Philippine woods considering the High Strength Group with 80% Stress Grade (NSCP 2015). Table 6 shows that the average shear strength of bamboo is far larger than the reference design capacity of most wood species in the Philippines.

Table 5. Linear regression models for shear strength parallel to the fiber of *B. blumeana*

Para meter	r	r^2	p-value	Coef.	Cons.
l	0.43	0.18	0.17	-0.10	17.83
d	0.48	0.23	0.12	-0.13	19.71
t	0.25	0.06	0.43	0.88	8.86
A	0.18	0.03	0.57	0.00	15.19
w	0.55	0.30	0.06	1.49	-3.19
q	0.37	0.14	0.23	4.76	9.62
ρ	0.39	0.15	0.44	-0.01	16.69

Table 6. Comparison of Characteristic Shear Strength $f_{v,c}$ (MPa) with Structural Timber of Philippine Woods

Source	Species	f_v MPa
This study Characteristic Strength		
	B. blumeana	9.56
Reference values for structural timber of Philippine woods (High Strength Group - 80% Stress Grade)		
	Agoho	2.95
	Molave	2.88
	Yakal	2.49
	Mahogany	2.71
	Narra	1.91

4. CONCLUSIONS

A total of 12 shear tests using ISO 22157-1 test protocol for shear was used to establish the shear strength of *B. blumeana*. The average shear strength obtained was 12.20 MPa while the characteristic shear strength obtained using ISO 12122-1 was 9.56 MPa. Using linear regression analysis, a general model is established to estimate the shear strength value of bamboo using physical properties that are easily obtained at the site. The correlation model $f_v = 1.49w - 5.19$ is suggested for approximation purposes. This capability to estimate the mechanical properties of bamboo is mainly useful in the perspective of nurseries and in forests where there is limited access to testing facilities. Results also showed that the shear strength parallel to the fiber of bamboo is comparable to some timber species in the Philippines thereby strengthening bamboo's position as an alternative material to wood.

For future studies, the authors suggest determining the other mechanical properties such as bending, tensile and compressive strengths. These important properties are crucial in the design of bamboo structures. It is also recommended to test the other economically important bamboo species in the Philippines.

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