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Research Article

Characterization and Analysis of Tension Parallel Properties in *Bambusa blumeana* A Study of Bamboo's Mechanical Strength for Structural Application

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ABSTRACT

The dissertation showcased the comprehensive exploration of a specific bamboo species, Bambusa blumeana, the mechanical properties specifically focusing on its tension parallel characteristics. The study employs a rigorous methodology, including one-way analysis of variance, t-test, and multiple linear regression as statistical treatment methods, to characterize tension parallel properties of Bambusa blumeana. By subjecting bamboo specimens, Bambusa blumeana, Bambusa vulgaris, and Dendrocalamus asper, to controlled tension forces, the research team meticulously analyzes a key mechanical parameter: tensile parallel strength to fiber. The findings enhanced understanding on its potential applications in various structural contexts. The results suggest that both Dendrocalamus asper and Bambusa vulgaris contain higher allowable tensile strength compared to Bambusa blumeana. This then indicates that Dendrocalamus asper and Bambusa vulgaris emerge as a material with their tensile parallel strength mechanical attributes as compared to Bambusa blumeana. The study outcomes presented herein aim to inform future research endeavors and inspire innovative bamboo applications in structural engineering.

Keywords: Bambusa blumeana Mechanical Properties, Structural Applications, Tension Parallel Properties, Tension Strength Parallel to the Grain

INTRODUCTION

The Philippines, rich in diverse natural resources, contributes significantly to both local consumption and international trade. These resources account for 19% of the country's total wealth, underscoring their critical role in national and global economies [5]. Bamboo, classified under the family of grasses, being one of the natural resources usually sighted on rural areas is known for its versatility composed mostly 39,000-53,000 ha of plantation which divided amongst the 62 living species in the country. With that the Philippines managed to be ranked as the 6th largest distributor of bamboo [1].

Amongst the 62 species *Bambusa blumeana*, commonly referred to as *Kawayang Tinik*, has been one of the species widely recognized and used for construction purposes as it is both economical and quite abundant in the country [2]. Inspired by the efforts of the *Hilti Foundation's* local initiative, *Base Bahay Foundation Inc.*, researchers are dedicated to optimizing the industrial potential of this specific species.

Base Bahay Foundation Inc.:

Base Bahay Foundation Inc., a non-government organization focused on creating sustainable, quality, and affordable housing, promotes the use of locally sourced, renewable materials to meet structural and community needs. Leveraging technological advancements and partnerships with research institutions, the foundation has developed numerous communities utilizing bamboo for sustainable construction [6]. A notable innovation is the *Cement-Bamboo Frame Technology*, accredited by AITECH (Accreditation of Innovative Technologies for Housing) for its resilience to earthquakes, pests, and other structural threats.

This study aims to concentrate on *Bambusa blumeana*, examining its tensile strength parallel to the fiber. Given its known versatility, researchers are committed to optimizing its properties and contributing additional data to PNS 22157 (Philippine National Standard 22157 - Mechanical Properties and Testing of Bamboo). The findings could support future applications and assist foundations like *Base Bahay* in enhancing their projects and benefiting the communities they serve.

Since material characterization is essential for identifying the properties of construction materials. Measuring the tensile strength parallel to the fibers reveals the limits of the material's capabilities under stress [4]. As researchers aim to determine the limits of *Bambusa blumeana*, they must consider existing studies on its properties. Accurate testing is crucial and requires appropriate equipment capable of measuring tensile load with near 1% precision. It must also be noted that the tensile load must be applied concentrically along the longitudinal axis of the test piece to prevent longitudinal twisting.

Tension Parallel Strength of *Bambusa blumeana:*

Despite *Bambusa blumeana's* versatility and economic potential in construction, comprehensive data on its tensile strength properties parallel to the grain remain scarce. Existing literature and research on this bamboo species are limited, and a thorough understanding of its mechanical behavior in tension strength remains lacking. This gap in knowledge restricts its potential use as an alternative building material in various applications. Although The Philippine National Standard 22157 (PNS22157) on Mechanical Properties and Testing of Bamboo outlines guidelines for evaluating bamboo's mechanical properties. This standard however may not fully capture the specific properties and behavior of *Bambusa blumeana*. Thus, the need for additional data on the tensile strength parallel to the grain for this species limits the standard's breadth and may impede its practical application in the industry.

Furthermore, accurately measuring the tensile strength parallel to the grain of *Bambusa blumeana* requires appropriate testing machines that can apply concentric loads along the test piece's longitudinal axis without inducing longitudinal twisting. There also exists a problem when it comes to the availability of precise and reliable testing methods and equipment which is essential for obtaining accurate data on the material's strength properties. Therefore, acknowledging the possibility that the lack of such resources may hinder a comprehensive analysis of *Bambusa blumeana's* tensile strength parallel to the grain.

Organizations such as *Base Bahay Foundation Inc*. are committed to offering sustainable, quality, and affordable housing solutions using locally sourced renewable materials. Bamboo, particularly *Bambusa blumeana*, has demonstrated various potential as a construction material for these projects. To enhance the structural integrity and performance of these sustainable housing models, a deeper understanding of *Bambusa blumeana's* tensile strength parallel to fiber and its potential for use in innovative construction technologies is necessary.

To assess such the researchers' objectives are (1) to characterize the tensile parallel strength of *Bambusa blumeana*, assessing its potential for structural applications where it becomes critical, (2) compliance with the Philippine National Standard 22157 on Mechanical Properties and Testing of Bamboo (PNS-ISO 22157:2020) by testing 41 samples. With each sample subdivided into three strips with a gauge length of 50 to 100 mm, utilizing a Universal Testing Machine (UTM), (3) to anticipate the tension parallel strength based on input parameters namely gross area, moisture content, and density, (4) integration of the tensile strength data from the 41 samples tested in this study with the existing data from 60 *Bambusa blumeana* samples provided by *Base Bahay Inc*, completing the 101 samples required to meet *ISO 12122 standards* for data integrity, (5) to conduct a comparative analysis of tensile strength parallel among two other bamboo species using a one-way ANOVA statistical test, multiple regression analysis to determine the relationship between input parameters and tensile strength, and use a t-test to identify which species possess higher allowable tensile strength and lastly, (6) aid in the enhancement of the latest edition of the NBCP (National Building Code of the Philippines).

RESEARCH METHOOLOGY

The methodology involves a systematic and thorough approach, it includes careful selection and preparation of bamboo samples, using suitable testing equipment and setups, conducting tests that would measure it tension parallel strength, and assessment of the accumulated data. To ensure reliability in the testing process, mature bamboo culms with consistent features in age, diameter, and growth conditions, are selected as the primary source of the samples. These culms undergo proper cleaning and moisture conditioning to eliminate external factors that may influence the test results. This helps the study to minimize variations, eliminate further points of error, and enhance the accuracy of the test outcomes.

A. Phase 1:

This phase requires a lot of time as it will demand time to carefully check possible resources and be able to find studies that do in fact relate to the paper. As illustrated on Figure. 1, during the first phase assessment of issues and factors that may cause variation in data is important to properly investigate the physical and mechanical factors that may arise. A comprehensive review of essential and relevant papers could set the tone of the paper and lead the researchers to the correct path. Next would be the gathering and analysis of papers that are aligned with the field subjected. Which then would also be essential for the next part which is solicitation of insights from professionals to better understand the whole concept and have enough knowledge about the subject matter to be able to properly implement appropriate practices and lastly evaluate the significance of the said influences. By committing to such the researchers would be able to retrieve honest data.

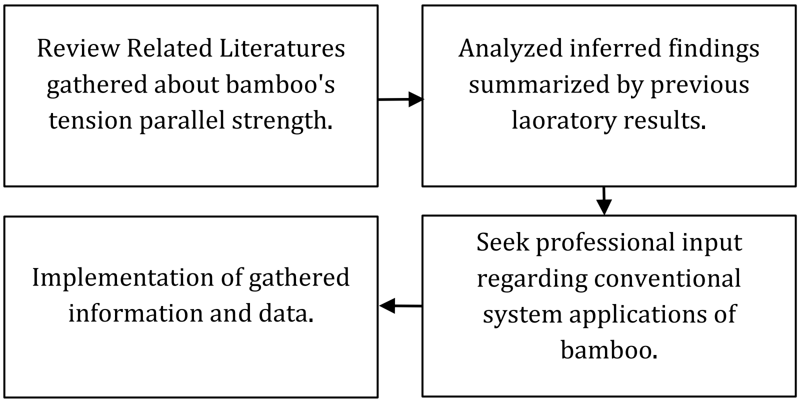


Figure 1. Phase 1 of the study

B. Phase 2:

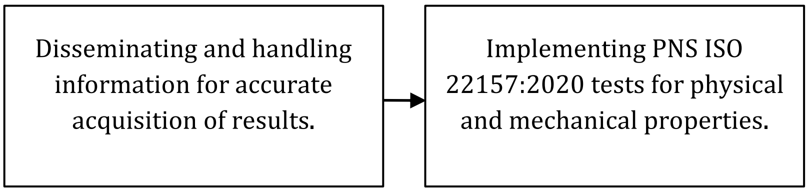


Figure 2. Phase 2 of the study

After gathering the needed information, necessary sorting of data would be practiced by verifying and conducting tests that will expound the understanding regards the initial findings. The species, *Bambusa blumeana*, would be carefully processed and analyzed. The data would be deduced from the samples gathered mainly focusing the tension strength of *Bambusa blumeana*. To follow the said process as seen on Figure 2, it must be noted that the dissemination and handling of information acquired must be in accordance with guidelines and standards being followed such as the *ISO 12122*. In that matter upon application of the researchers gathered data, substantial information about the species must be collected and concluded. Following that conducting the PNS ISO 22157:2020 tests to assess both the physical and mechanical characteristics of bamboo culms would be necessary as it would help on deciding whether it is suitable for construction and engineering applications.

C. Phase 3:

Following the application would be the comparison of the gathered data with the existing data, in this phase keen observations would be enlisted along with identification of patterns, trends, and unique attributes of the bamboo's mechanical properties. This would then give a clearer insight into the potential of *Bambusa blumeana*. With that, the existing data collected from the 60 samples would be merged with the tested 41 samples. Additionally, data from the other two species, *Dendrocalamus asper* and *Bambusa vulgaris* would be compared with the acquired data moving forth with the comprehensive analysis that can be done after such. To get a more objective result from it the researchers would execute One-way ANOVA statistical test to observe the relationship of the species of bamboo with its tension parallel strength along with the difference of interaction amongst the different species. Figure 3 exhibits the flow that will be followed.

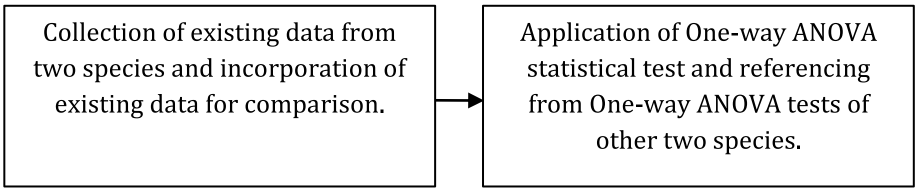


Figure 3. Phase 3 of the study

D. Phase 4:

After the data gathering process, as well as the analyzation of the required data the researchers would then be able to conduct complete examination and interpretation of the findings. This would be done by going over the last two steps, as shown in Figure 4, the coefficient of the Tension Parallel Strength of Bambusa blumeana would be evaluated from the data acquired from the One-way ANOVA tests. Following the creation of findings, other statistical treatments can then be performed such as T-test and Multiple Regression, which were also conducted to observe relation of the factors along with its strength and species.

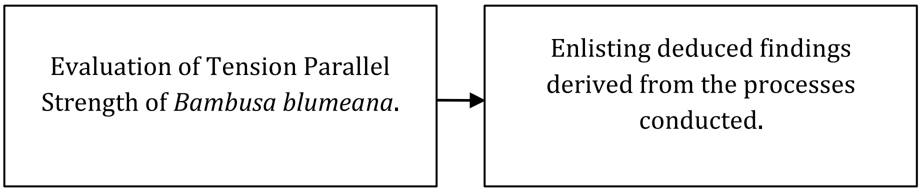


Figure 4. Phase 4 of the study

Research Instrument:

The statistical treatments used were One-way ANOVA, Multiple Regression and T-test. Before utilizing the said statistical treatment, it was recognized that the independent variable used would be the maximum load (F_{ult}) or the Mean Cross-sectional Area of the Culm (A_g) this is contrasted by the dependent variable which would be the tension strength of the strips parallel to fiber. As for the One-way ANOVA, it was realized that by performing such statistical treatment the researchers would be able to pinpoint whether or not a certain correlation between the tension strength attributed to each independent variable separately. To have a clearer understanding between the interaction of the independent variables and collectively impact the mechanical properties of bamboo, multiple regression analysis is to be utilized.

Research Materials:

Since the test would be following certain standards, the researchers made sure that the enlisted materials are in accordance with the guidelines. The materials that will be utilized are Culm Section (Figure 5), cut into Bamboo Strips (Figure 6) attached with equally cut Tabs (Figure 7) on its end and then a Universal Testing Machine (UTM) Clamp will be used to secure (Figure 8) onto the Universal Testing Machine (Figure 9). Culm sections of the bamboo will be meticulously chosen as the main test specimens. These sections will be further subdivided into three strips with exact dimensions to ensure uniform testing conditions. To prevent breakage and ensure precise data collection during the experiments, tabs will be affixed to both ends of each strip.

A Universal Testing Machine (UTM) will be crucial for this study, applying tensile forces to bamboo strips to measure their resistance and tension strength parallel to the fiber. Wood glue will securely bond the tabs to the bamboo strips, ensuring stability during testing. For it to be stable and uniform, the clamps with a weight of 20kg each would ensure that the strips are in place during testing minimizing the potential of errors. The integration of these research materials will enable a comprehensive investigation into the tensile strength parallel to the fibers of Bambusa blumeana, providing valuable insights into its mechanical properties and potential use as an alternative construction material.

Figure 5. Bamboo Culm Section [2]

Figure 6. Bamboo Strip

Figure 7. Tabs

Figure 8. 20kg UTM Clamp

Figure 9. Universal Testing Machine

DATA GATHERING PROCEDURE

The process for testing the tensile strength parallel to the fibers of *Bambusa blumeana* involves a detailed step-by-step procedure. Initially, the cross-sectional dimensions (width and thickness) of the test piece are measured with a precision of 0.1 mm at three locations along the length of the gauge portion, as shown in Figure 10. The mean cross-sectional area is then calculated using these measurements and Equation 1.

The procedure strictly follows Section 5.2 of the Philippine National Standard ISO 22157 during load application. The maximum load (F_{ult}) reached during the test is recorded, along with the failure mode. Specimens that fail outside the gauge portion, the designated region for analysis, are excluded from subsequent strength analysis. Following that the tension strength parallel to the fibers, shall be calculated from Equation 2. Moreover, since gross area is also recognized it must be calculated by multiplying the length, height and thickness of the strip, as seen on Equation 3. Additionally, the weight of the strip over volume would then determine the density, featured at Equation 4, and as for the moisture content, as described by Equation 5, the post-oven weight subtracted from post-test weight and would be divided altogether by the post-test weight multiplied by 100 for its percentage form.

$$A_g = d \times b$$

Equation 1. Mean Cross-sectional Area of the gauge portion

Where:

δ wall thickness
b width of specimen (b < (δ / 2) < 20 mm)

1 culm section

2-gauge length = 50 mm to 100 mm

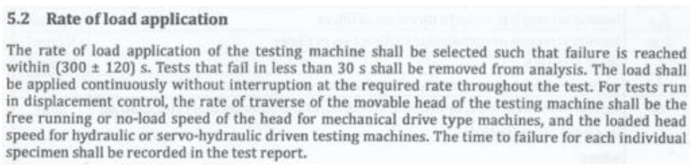
$$f_t, 0 = \frac{F_{ult}}{A_g}$$

Equation 2. Tension strength parallel to fiber

Where:

F_{ult} is the maximum load at which the specimen fails, in Newtons (N)
A_g is the mean cross-sectional area of the gauge portion in square millimeters (mm^2)

For each culm tested, out of the three tested specimens, only the lowest tensile strength parallel to the fibres, **f_t,0**, shall be reported.


5.2 Rate of load application

The rate of load application of the testing machine shall be selected such that failure is reached within (300 ± 120) s. Tests that fail in less than 30 s shall be removed from analysis. The load shall be applied continuously without interruption at the required rate throughout the test. For tests run in displacement control, the rate of traverse of the movable head of the testing machine shall be the free running or no-load speed of the head for mechanical drive type machines, and the loaded head speed for hydraulic or servo-hydraulic driven testing machines. The time to failure for each individual specimen shall be recorded in the test report.

Figure 10. Rate of Load Application
(Retrieved from *PNS22157*)

$$\text{Gross Area} = \text{Length x Height x Thickness}$$

Equation 3. Gross Area

$$\text{Density} = (\text{Weight(g)})/(\text{Volume}(cm^3))$$

Equation 4. Density

$$\text{Moisture Content} = ((\text{Post-test - Post-oven}))/(\text{Post-test}) \times 100$$

Equation 5. Moisture Content

RESULTS AND DISCUSSION

Figure 11. Different Breaking points of strips

As the researchers try to grasp the significance of the research within the broader engineering framework, the researchers also are trying to bridge the understanding of bamboo's mechanical advantages and its potential applications in construction. To enhance data analysis, the researchers will compare *Bambusa blumeana's* tensile strength parallel to the fiber with that of *Bambusa vulgaris* and *Dendrocalamus asper*. It is important to note that the comparison will focus solely on the tensile strength parallel to the fiber, incorporating considerations of gross area, density, and moisture content. This chapter presents the results, which encompass data collected through testing and analysis using a variety of tools, methodologies, software applications, and techniques. Using One-way ANOVA and T-tests, the mechanical properties were evaluated. The findings will then foreseeably contribute to an improved bamboo standard based on their tensile strength parallel.

Since data integrity is given much importance, the researchers reiterate the importance of following the PNS ISO 22157 as the standard and by using the Universal Testing Machine (UTM); the testing would ensure that the process practiced committed fully to the methodology and material processing prescribed. Which then showed on the 41 *Bambusa blumeana* samples, as it featured varying failure points which are breaking on tabs, splitting and crushing. As shown on Figure 11, each strips have its own failure points that could be analyzed as heavily influenced by gross area, moisture content, and density. Based on the data, sample B-B2A began to break within the gauge length at *28.53Mpa* being the strip that broke at the lowest tension, on the latter at *112.11 Mpa* B-B40A had shown to carry on the highest tension amongst the samples. By taking note of these factors, we will be able to determine which species exhibited the highest tension parallel strength. Additionally, we can assess whether the differences in tensile strength are statistically significant by applying a significance level of α=0.05 or 5%.

One-way ANOVA:

With the said considerations, One-way ANOVA was used to determine whether (A) *the null hypothesis*, which suggest that the *species does not have much of a difference* which can be seen at *p-value greater than* 0.05 or 5% and (B) resulting to the *alternative hypothesis*, which suggests that there is a *significant difference* where *p-value is less than* 0.05 or 5%. As referred to in Table 1 the p-value resulted in *0.000622042* which means that there is a *significant difference* between the three species compared.

Multiple Regression Analysis:

Multiple regression Analysis is used to determine whether the independent variable would be greatly affected by the dependent variable. In this case, the density (as Variable 1), Moisture Content (as Variable 2), and Gross Area (as Variable 3) were all taken into account and therefore had found that the density and gross area had a significant influence on the tension parallel strength property of *Bambusa blumeana* whilst the remaining factor which was Moisture Content had none as it exhibited a p-value more than 0.05. Results were shown on Table 2.

T-test:

The T-test provided a detailed understanding by identifying specific pairings among the bamboo species that exhibited significant differences. This was crucial for identifying the unique characteristics of each bamboo species concerning their tensile strength. As a result, a more detailed and comprehensive assessment of these natural materials was achieved which gave thorough conclusions and insights into the mechanical properties of these bamboos, enhancing their potential applications. A series of comparisons were made mainly against the capacity of *Bambusa blumeana*. Table 3.a. showed the capacity of *Bambusa blumeana* against *Bambusa vulgaris* while Table 3.b. showed that with *Dendrocalamus asper*. The results had shown that both *Bambusa vulgaris* and *Dendrocalamus asper supersedes the tension parallel strength* of *Bambusa blumeana*.

Anova: Single Factor
TSP
SUMMARY

Groups	Count	Sum	Average	Variance
TPS BB	60	4781.235672	79.6873	801.4246846
TPS BV	60	6038.190523	100.637	1080.296247
TPS DA	60	5469.684776	91.1614	691.1735385

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit		
Between Groups	13206.0914	2	6603.05	7.699164238	0.000622042	3.047012139	< 0.05 REJECT	NULL HYPOTHESIS
Within Groups	151800.7737	177	857.631				THEREFORE	THERE IS DIFFERENCE
Total	165006.8651	179						

Table 1. One-way ANOVA results

Regression Statistics	
Multiple R	0.5861916
R Square	0.3436206
Adjusted R Square	0.2904006
Standard Error	16.918541
Observations	41

ANOVA

	df	SS	MS	F	Significance F
Regression	3	5544.364476	1848.12	6.45661	0.001259
Residual	37	10590.77002	286.237		
Total	40	16135.1345			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	11.781348	39.99221654	0.29459	0.76995	-69.25058	92.8132754	-69.25058	92.8132754
X Variable 1 - Density	22.170892	9.244212773	2.39835	0.02163	3.4403377	40.9014462	3.4403377	40.9014462
X Variable 2 - Moisture Content	7.3683841	4.772120528	1.54405	0.13109	-2.300851	17.0376188	-2.3008505	17.0376188
X Variable 3 - Gross Area	-0.432649	0.132850591	-3.2567	0.00242	-0.70183	-0.16346813	-0.7018299	-0.16346813

Table 2. Regression Analysis for Parameter's Significance

t-Test: Paired Two Sample for Means

	Bambusa Blumeana Tension Parallel Strength	Bambusa Vulgaris Tension Parallel Strength
Mean	79.6872612	100.6365087
Variance	801.4246846	1080.296247
Observations	60	60
Pearson Correlation	0.275762665	
Hypothesized Mean D	0	
df	59	
t Stat	-4.386467162	
P(T<=t) one-tail	2.41208E-05	
t Critical one-tail	1.671093032	
P(T<=t) two-tail	4.82416E-05	
t Critical two-tail	2.000995378	

Table 3.a. *Bambusa blumeana* vs *Bambusa vulgaris*

t-Test: Paired Two Sample for Means

	Tension Parallel Strength Dendrocalamus Asper	Tension Parallel Strength Bambusa Blumeana
Mean	91.16141293	79.6872612
Variance	691.1735385	801.4246846
Observations	60	60
Pearson Correlation	-0.163014407	
Hypothesized Mean Difference	0	
df	59	
t Stat	2.133611618	
P(T<=t) one-tail	0.018521392	
t Critical one-tail	1.671093032	
P(T<=t) two-tail	0.037042783	
t Critical two-tail	2.000995378	

Table 3.b. *Bambusa blumeana* vs *Dendrocalamus asper*

CONCLUSION

The testing procedures were meticulously executed in compliance with the *PNS ISO 22157* standard, ensuring the acquisition of accurate and reliable data. Our results highlighted several failure modes in *Bambusa blumeana*, which were characterized by breaking on tabs, splitting, and crushing. These failure modes prompted further investigation into the influence of factors such as gross area, moisture content, and density on the observed inconsistencies in tension parallel strength. One-way ANOVA revealed *significant variations* in tension parallel strength among *Bambusa blumeana, Bambusa vulgaris*, and *Dendrocalamus asper*, prompting further in-depth examinations. Multiple Regression Analysis highlighted that two of the factors (gross area, and moisture content) indeed poses an impact on the dependent variable, tension parallel strength. Lastly, T-test gave an understanding of having the boundaries *Bambusa blumeana* could only reach and how the two other contains far more capabilities in terms of tension parallel strength.

RECOMMENDATION

After thorough research and analyzation of the results obtained the researchers had come up with a series of suggestion, first to obtain much brevity of the relationship about the subject a more in-depth study about the microstructure of *Bambusa blumeana* could be done. Tackling more on the alignment of the fibers and considering the impact of environmental factors that may affect its growth. It would also be ideal to have explored more about the bamboo's etymology especially the habitat it transpired in and whether or not different lands, climates and such could make or break the tension parallel strength of the bamboo. Going forth, some advice was also given with regards to the prevention of damaging the strips and ensuring a more precise tension reading. This is to be done by having to use quite smaller tabs. On that case, the clamp would be able to grasp and put the tension more on the strip of the bamboo. Moreover, ensuring that the samples are equally cut but not too small on both sides, as the researchers have encountered some difficulties upon testing it due to the size of the samples. To expound more on the subject, the researchers would also like to point out that it would also be effective if an improved Universal Testing Machine (UTM) will be used, specifically one that can recognize the upon which point did the breakage occur. This is to automate the process of having to start all over again due to errors in testing. Lastly, a comprehensive analysis which includes all other bamboo species would also be commendable to have an insight of what could possibly be the correct species to be used in terms on construction aspect.

ACKNOWLEDGEMENTS

Upon the completion of the study, the group would like to extend their heartfelt gratitude to those who have contributed to its success. Their efforts enabled us to effectively acquire and analyze the data, making this achievement possible. To the BASE Bahay team, a HILTI Foundation, their dedication to the community development had inspired us to finish this study and gave us a lot of optimism to see the dissertation to pave the way for sustainable innovation and for the well-being of the people who lived in small communities. We hope that more people would have the same objectives as you do. Moreover, for the guidance and blessing of our lord, thank you.

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