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Analytical Behaviour in Mechanical Properties of *Dendrocalamus Asper* Bamboo as Construction Building Materials in the Philippines

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ABSTRACT

Objective – This paper focus on mechanical properties of all Giant Bamboo by which soaked specimens was influenced by traditional preservations; however, there is a variance in how they affect the compressive and bending strength.

Methodology/Technique – Three separate sets of specimen undergone natural preservation were subjected to compressive and bend testing following the ISO standards 22157-1:2004(E) and ASTM standards. Salt-treated specimen got the highest compressive strength reached up to 53.61 MPa, S=15.59 MPa ± 29.08% of the mean followed by fresh-water treated and untreated specimen with 45.16 MPa, S=12.46 MPa ± 26.93% of the mean and 34.12 MPa, S=5.00 MPa ± 14.65% of the mean respectively. On the other hand, using three-point bending test, treated specimens for salt-water preservation got the highest average bending strength which reached up to 218.35 MPa compared to the ones treated of fresh-water and untreated with 188.05 MPa and 71.75 MPa respectively. Two factors was being used to evaluate the significant effect of bamboo on bending strength using Two-way Analysis of Variance in terms of the position of the culm and natural treatment as untreated and soaking in salt and fresh water are significant: bending strength decreases from bottom to top while modulus of elasticity increases

Findings – It is shown that both treated and untreated are good constructional materials with excellent mechanical properties against compression and bending, which may address deforestation concern in the country.

Novelty – The study determined the influence of treatment, specifically conventional method of treatment to the mechanical properties of bamboo.

Type of Paper: Empirical

Keywords: Dendrocalamus Asper Bamboo, Deforestation, Mechanical Properties, Natural Treatment, Construction Materials

1. Introduction

In a developing country like the Philippines with majority of the population clinging on the poverty level, people would choose timber over concrete and steel since it's more affordable. However, the demand of timber

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could no longer balance with the consumption and thus would cause scarcity of the supply at some point. To prevent the depletion of timber supply, possible alternatives of timber has been taken into consideration and one is bamboo. Worldwide, there is a growing interest in the development of bamboo products as a sustainable, cost effective and ecologically responsible alternative construction material [1]. Bamboo is a renewable, sustainable material with a yield of biomass per hectare competitive with wood [2]. Recently, there has been increased interest in the design and application of Structural Bamboo Products (SBP) [3]. By bamboo preservation the preservative should be introduced into the culm structure as deeply and uniformly as possible. Soaking and seasoning involves immersing the culms in stagnant or running water for a few weeks to leach out the sugars. After this, the wet bamboos are air-dried under shade [4]. The low durability of bamboo in an exposed environment requires for long time use often preservation with chemicals [5 - 6]. The success is influenced by following factors: the treatability of the bamboo culm, its moisture content, the type of preservative and the treating process applied.

Bamboo is found in abundance in Asia and South America. In many Asian countries bamboo has not been explored fully to its extent although it is considered as natural engineering material [7]. Many investigations and results on the mechanical properties of bamboo are presented in literature [8 - 15]. However, those values have been calculated through scientific research tests and so the available data on the bamboo's properties have been obtained by different methods. Hence, bamboo preservation methods fall into two categories as explain by [4]: traditional and chemical preservation.

Traditional Preservation

In many places, traditional preservation methods – such as curing, smoking, soaking and seasoning, and lime-washing – are used. The real effect of these methods is not known. However, these methods are popular as they can be applied without any capital investment and with low skill levels. For curing, the harvested bamboo culms are left in the open, with branches and leaves intact. Transpiration process, which continues even after felling, causes the starch content to fall. Smoking, treatment of the culms over fire, is effective against fungi and insects. Soaking and seasoning involves immersing the culms in stagnant or running water for a few weeks to leach out the sugars. After this, the wet bamboos are air-dried under shade. Lime-washing – literally washing with lime water – is reported to protect against fungal attack.

Chemical Preservation

If bamboo is to be used in modern industry or in large-scale projects for housing or other buildings, chemical methods of preservation are unavoidable. It is better to avoid preservatives with chemicals like arsenic as they pose a risk to the environment as well as to the health of those handling them. Effective and safe chemicals are based on the element boron, such as copper-chrome-boron (CCB). Chemicals like boric acid, borax and boron are cheap and effective. Good preservation has been obtained in Costa Rica with a boron-based fertilizer, disodium octoborate tetrahydrate (chemical formula $Na_2 B_8 O_{13}.4H_2 O$), with 66% active boron content. A big advantage of using this chemical is that there is no waste at all. Once it has been used in the preservation process for some time and is mixed with starch and sugar from the bamboo, it can be applied as a fertilizer! Two methods are available to introduce chemicals into the bamboo: modified Boucherie process for whole green culms and dip-diffusion for split culms.

While the potential of bamboo is promising, more widespread development and use of bamboo is hampered by the lack of engineering data for mechanical properties and appropriate building codes [16 - 17]. The applications of raw bamboo materials are limited in civil engineering due to its dimensional instability caused by the moisture. In addition, [16], provides an overview of existing standard test methods for bamboo, their use and practical utility in a field environment, and reports new test methods suitable for characterizing the longitudinal splitting behavior of full-culm bamboo. Mechanical properties parallel to the fibers including tension, compression and flexural (modulus of rupture) capacities have been widely studied [18 - 22].

However, many researchers have already began the journey to explore its utilization in structural engineering [23]. Bamboo has emerged as an ultimate green material [24] meeting the definition of a renewable and sustainable raw material with little harmful impact to the environment [25].
Despite the advantageous properties of bamboo, there are problems that prevent its “could-have been long lasting durability”. Bamboo’s starch is prone to insect and fungal attacks that consume the bamboo and makes it ineffective as a structural material. To divert this, analysts have proposed treatments such as chemical and natural treatments that could preserve bamboo culms. Treatments in bamboo basically aim to lessen the insect attacks and expand the lifespan of the material. However, the researchers of this study had a doubt whether the treatments have effects on the mechanical properties of the bamboo. Hence, a study about the influence of treatment, specifically conventional method of treatment to the mechanical properties of bamboo will be determined.

2. Materials and Methods

2.1 Preparation of Materials

Two year old Giant Bamboo *(Dendrocalamus asper),* collected from Mandaue City, Province of Cebu, were cut about 150 mm above the ground level. Portions cut up to 4.5 m from the basal portion were used for the evaluation of mechanical properties. The bamboo were manually cut into specified length of 300 mm for compressive testing of full culm and 220 mm for bending testing were split longitudinally [Fig. 1]. During the treatment of specimens, 5 for each bamboo were submerged in fresh-water, salt-water, and 5 specimen for untreated. After 7 days, the bamboo specimens were removed from the water and were stacked vertically in air-drying for 1 week. After 7 days of air-drying, compressive and bending strength of the specimens were determined using the 6 tonner Universal Testing Machine [Fig. 2].

Table 1. Dimensions of Giant Bamboo (Dendrocalamus Asper)

Bamboo Species	Diameter Range, mm	Length Internode, mm	Compression Cut	Bending Length, mm
Dendrocalamus Asper	90-120	120-400	300	220

Fig. 1 Selection and Machining of Bamboos

Fig. 2 Universal Testing Machine

2.2 Statistical Analysis for Mechanical Properties

Statistical analysis was carried out using SPSS 13. Two-way (ANOVA) was used to determine in terms of the position of the culm and natural treatment as untreated and soaking in salt and fresh water whether or not the differences in means were significant. Investigation of behaviour of the materials under different loading conditions, deformation behaviour, stress state and the failure behaviour of bamboo species in different culm position is an important requirement for the effective use of these bamboo specie for different engineering applications.

3. Results and Discussion

This paper analysis the treated and untreated bamboo species in salt and fresh-water within one week and air-dried for another one week on how mechanical properties influence the specimen specifically in compressive and bending strength following the ISO 22157-1:2004(E) International Organization of Standardization [26] and standard test method of ASTM designation requirements.

3.1 Compressive Test Results

Table 2. Values of computed results for compressive strength of *Dendrocalamus Asper*

Specimen	Area, A (sq.mm)	Immersion Condition (days)	Maximum Compressive Force, (kN)	Compressive Strength (psi)	(MPa)	Mean	Standard Deviation, S (MPa)
1-fc	7,775.19	7	280.80	4,454.11	30.71		
2-fc	6,082.12	7	293.20	6,992.27	48.21		
3-fc	4,901.67	7	218.70	6,470.13	44.61	45.16	12.16
4-fc	4,417.86	7	280.20	9,198.29	63.42		± 26.93%
5-fc	5,026.55	7	195.30	5,634.71	38.85		
1-sc	5,808.80	7	297.30	7,430.28	51.23		
2-sc	3,959.19	7	280.80	10,286.08	70.92		
3-sc	9,852.03	7	291.30	4,288.77	32.57	53.61	15.59
4-sc	5,741.46	7	361.80	9,140.28	60.02		± 29.08%
5-sc	6,361.73	7	339.00	7,729.06	53.29		
1-uc	4,756.70	0	125.96	3,842.05	26.49		
2-uc	5,223.50	0	196.26	5,449.07	37.57		
3-uc	6,030.70	0	190.34	4,577.39	33.56	34.12	5.00
4-uc	5,985.80	0	220.89	5,350.44	34.89		± 14.65%
5-uc	5,082.40	0	193.73	5,524.49	38.09		

fc – fresh-water compression; sc – salt-water compression; uc – untreated compression

As shown in table 2, Compressive strength properties have been evaluated using the internode specimens made parallel to the grains. Since, the specimen width available was only up to a few millimetres, ASTM D 695 – 96 [27] test technique has been used for the evaluation of compressive strength properties. the specimens submerged in salt-water got the highest average compressive strength which reached up to 53.61 MPa, S=15.59 MPa ± 29.08% of the mean, followed by the specimens submerged in fresh-water and untreated with average compressive strength of 45.16 MPa, S=12.46 MPa ± 26.93% of the mean and 34.12 MPa, S=5.00 MPa ± 14.65% of the mean respectively. It shows that the Giant Bamboo specimens which are treated in salt-water have increased its strength by 62.98% and fresh-water increased by 32.36% from untreated specimens. As the results prove, treated specimens under fresh-water and salt-water has greater capacity to withstand given test loads unlike the untreated specimens. The loading speed was 1.5 up to 2.2 KN/s or about 0.9 N/mm^2: as the deformation was found to be linear up to at least 50 percent of the failure load, this measured loading speed agrees with a calculated speed deformation of 0.02 mm/s. This speed is higher than ASTM D143-14 [28] requires for wood, but due to the small cross-section of the bamboo (2000 mm^2) it was difficult to run the press at a lower speed. However, it has been proved that the wood this rather high speed has little influence on the strength. Therefore, aside from prolonged lifespan or durability, salt and fresh-water treatment affects the compressive strength of the given specimen. Generally speaking, data from ACI 214 [29], 7 days result is comparable to certain 28 days allowable concrete compressive strength requirements used for residential purposes which is around 2,500 psi (17 MPa), 4,000 psi (28 MPa) for commercial uses, and as high as 10,000 psi (70 MPa) for other specified certain applications.

3.2 Bending Test Results

Bending strength has a direct influence on the behaviour of a structure, it is necessary to predict the deflection using the three-point bending test of each element of a structure before it is build. The test specimens are rectangular in cross-section and the length of the specimens is parallel to grains. Load applied at mid-span of the specimen and resulting deflection are measured. Standard test method to cover the determination of flexural properties of wood based structural panels is as per ASTM D 3043 - 95 [30].

Table 3. Values of computed results for bending strength of *Dendrocalamus Asper*

Specimen	% of change Related to Untreated Condition	Immersion Condition (Days)	Modulus of Elasticity $\mathcal{E}$, (GPa)	Applied Load (MOE) at Maximum P_{max} (N)	Modulus of Rupture (MOR) at Maximum $\sigma_{max,}$ (MPa)
1-fb		7	9.97	9,310	232.75
2-fb		7	7.46	10,670	266.75
3-fm	- 61.84 %	7	22.68	9,660	241.50
4-fm		7	16.12	4,640	116.00
5-ft		7	32.06	3,330	83.25
1-sb		7	19.96	10,030	250.75
2-sb		7	10.16	9,620	240.50
3-sm	- 67.14 %	7	16.90	7,970	199.25
4-sm		7	26.14	8,500	212.50
5-st		7	44.73	7,550	188.75
1-ub		0	6.44	2,960	74.00
2-ub		0	6.03	3,100	77.50
3-um		0	7.07	3,070	76.75
4-um		0	9.02	2,820	70.50
5-ut		0	9.48	2,440	60.00

fb – fresh-bottom; fm – fresh-middle; ft – fresh-top; sb – salt-bottom; sm – salt-middle; st – salt-top; ub – untreated

Data shown in Table 3, specimens with rectangular cross-section made from the culms between two nodes were used for the study. Since, the span length available between two nodes was not sufficient to have the required thickness-to-span ratio, thickness-to-span ratio of 1:16 was used for the present study (ASTM D 790 - 99) [31]. Treated specimens for salt-water preservation got the highest average bending strength which reached up to 218.35 MPa compared to the ones treated of fresh-water and untreated with 188.05 MPa and 71.75 MPa respectively. The *DA* untreated specimen decreased its strength by 67.14% from the salt-water specimens while untreated to fresh-water decreased its strength by 61.84%. Two factors was being used to evaluate the significant effect of bamboo on bending strength using Two-way Analysis of Variance in terms of the position of the culm and natural treatment as untreated and soaking in salt and fresh water. The position of the culm from bottom to top does have a significant effect on bending strength considering that $F(1,6) = 6.45$, $\rho<0.05$, with a critical value $F = 5.99$: Natural treatment has a significant effect on bending strength with a computed value of $F(2,6) = 15.24$, $\rho<0.05$, and with a critical value $F = 5.14$ and the position of the culm and natural treatment interaction has a significant effect on bending strength having a design value of $F(2,6) = 5.41$, $\rho<0.05$, with a critical value $F = 5.14$. The cross-head motion was calculated as per ASTM D 3043 - 95 [30]. As bending strength decreases from bottom to top, modulus of elasticity increases. Moreover, the results show that treating the specimen with fresh-water and salt-water increased the strength of the material.

3.3 Behaviour of Dendrocalamus Asper bamboo naturally treated specimen in compressive and bending strength.

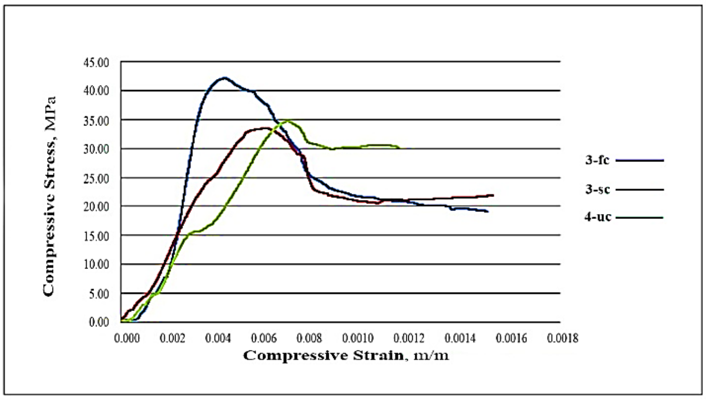

Fig. 3 Compressive Behaviour of specimen

In this graphical presentation in fig. 3, it shows that the sample *3-fc* has the least strain value because it suddenly reached its maximum stress, then it failed gradually that makes it ductile. As Sample *3-sc* slowly reached its maximum stress makes the strain value higher than sample3*2-fc* but it also fails gradually. In Sample *4-uc*, there is some point that as it reaches its maximum stress, there was a part that almost the value of stress becomes constant. The *3-sc* attained its highest strain among two samples and also fails gradually. It also shows that there is a relation between strain and the failure mode of specimens because strain determines the elasticity of the materials. The higher the value of strain that the materials can obtain before it reached its failure mode, shows elasticity of the materials.

Therefore, all the specimens are ductile because as it reached the maximum stress its fail mode has smooth transition as the failure becomes constant which result to small intervals of strain. But all the specimens' shows different yielding point where *4-uc* does not yield easily, thus it is more elastic among the two samples.

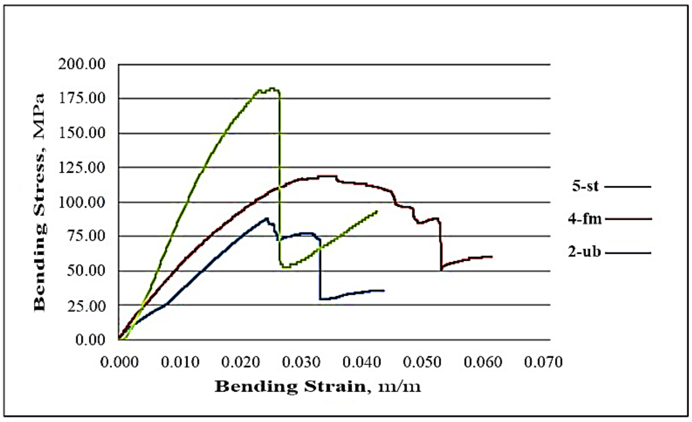

Fig. 4 Bending Behaviour of specimen

In this graphical presentation shown in fig. 4, Sample *2-ub* shows brittleness because as it reached its maximum stress it eventually fails, while Sample *4-fm* shows ductility since it fails gradually as it attained its maximum stress. The Sample *5-st* at first shows ductility as it obtained its maximum stress since it fail gradually but at some point while having its failure mode it shows brittleness because it eventually fails to its least failure mode. Therefore *4-fm* is more ductile among the two specimens while *2-ub* is more brittle along with all the specimens. The higher the value of strain that materials can obtain before it reached its failure mode, shows elasticity of the materials, thus *4-fm* is more elastic than the two specimens.

4. Conclusion

The threat of resource extinction of timber due to high demand for construction led to study of alternatives, specifically bamboo. Bamboo is a non-timber product with similar properties of timber. However, unlike timber its durability is sufficient for long term structural application. Still there are treatments in bamboo basically aiming to lessen the insect attacks and expand the lifespan of the materials. The result of the experiment shows that the treatment has significantly affected the strength of Giant Bamboo *(Dendrocalamus Asper)* specimen. Treated specimen increased its compressive and bending strength but other shows lower compressive and bending strength than the untreated specimens.

This paper focus on mechanical properties of all *Giant Bamboo* by which soaked specimens was influenced by traditional preservations; however, there is a variance in how they affect the compressive and bending strength. Bamboo is one of the versatile and strongest natural resource building materials. Hence, it is subjected to greater variability due to various conditions, such as years of growth, season, soil and environmental conditions, natural and chemical treatment and the location of bamboo culm within the bamboo. The *Giant Bamboo* specimens were influenced by natural preservation for just a week by increasing their compressive strengths. The average value of treated specimens in salt-water obtained the highest compressive strength compared in fresh water preservation and treated in Salt-water specimens obtained their highest bending strength. In bending, the position of the culm is significant: bending strength decreases from bottom to top, modulus of elasticity increases. Position of the culm does have a significant effect on bending strength $F(1,6) = 6.45$, $\rho<0.05$ wherein critical value $F = 5.99$. Natural treatment has a significant effect on bending strength $F(2,6) = 15.24$, $\rho<0.05$; critical value $F = 5.14$ Position of the culm and Natural treatment interaction has a significant effect on bending strength $F(2,6) = 5.41$, $p<0.05$; critical value $F = 5.14$. Moreover, the results show that treating the specimen with fresh-water and salt-water increased the strength of the material.

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