SPECTA Journal of Technology
E-ISSN : 2622-9099
P-ISSN : 2549-2713
Homepage jurnal: https://journal.itk.ac.id/index.php/sjt

Influence of Mango Polyphenol Treatment in Mechanical Properties of *Dendrocalamus Asper* Bamboo

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Abstract

This study investigated the effectiveness of mango polyphenol (MPP) powder in pH 7.4 seawater as a natural treatment on the mechanical properties of unidirectional full culm bamboo (*Dendrocalamus asper*). Our observations are explained through the changes in MPP percentage of 5, 10, and 20 of the raw material upon treatment. The 10% amount of MPP is dominant with 43.83 MPa at the top part (nodal), 10% amount of MPP in compressive strength with 47.13 MPa at the middle part (non-nodal), and 5% in flexural strength with 43.07 MPa at the top part. The treatment process combining seawater absorption plus mango polyphenol powder is more effective in improving mechanical properties with MPP variations than using them alone. Finally, materials identified as having favorable effects on full bamboo culm.

Keywords: Dendrocalamus asper bamboo, mango polyphenol, mechanical properties

Abstrak

Pada penelitian ini dilakukan efektifitas serbuk mangga polifenol (MPP) dalam air laut pH 7,4 sebagai perlakuan alami terhadap sifat mekanik bambu batang utuh searah (Dendrocalamus asper). Pengamatan kami dijelaskan melalui perubahan persentase MPP 5, 10, dan 20 bahan baku pada saat perlakuan dimana jumlah MPP 10% dominan pada kuat tekan sebesar 43,83 MPa pada bagian atas (nodal) sebesar 10%. MPP pada kuat tekan dengan 47,13 MPa pada bagian tengah (non nodal), dan 5% pada kuat lentur dengan 43,07 MPa pada bagian atas. Proses pengolahan gabungan dari penyerapan air laut ditambah bubuk polifenol mangga lebih efektif dalam meningkatkan sifat mekanik dengan variasi MPP dibandingkan dengan menggunakannya sendiri. Terakhir, material yang diidentifikasi memiliki efek menguntungkan pada batang bambu utuh.

Kata Kunci: Dendrocalamus asper bamboo, mangga polifenol, sifat mekanik

1. Introduction

Bamboo, a fast-growing plant that holds high mechanical properties similar to wood as materials, is being considered as an alternative for hard and softwood (Razak et al., 2010). Bamboo such as *Dendrocalamus asper* is qualified for laminated boards, composite materials, and ply bamboo due to its availability, fast-growing capacity, and personalized appearance (Anwar et al., 2004). A natural quality fiber-reinforced material (Ghavami et al., 2003), bamboo

Submitted April 2020, Revised May 2021, Accepted May 2021, Published August 2021

developed in nature is capable of producing desired results and remains strong in an environmental capacity. Mechanical properties of bamboo have been proved to be comparable to those of traditional building materials (Van der Lugt et al., 2006) and as an alternative building material due to its universal availability.

The weakness of bamboo materials is that they cannot be placed outside or exposed under high moisture content. Similar with other lignocellulosic material, bio-degradation agents of bamboo has a very low resistance. The big amount of starch makes it more capable of being affected by fungal and insect attacks; therefore, fresh felled bamboo must be treated. Treated bamboo culms prolong their service life. Hence, keeping bamboo in good condition falls into two (2) groups: chemical and traditional preservation (Janssen, 2000).

Chemical methods of preservation are inevitable once the bamboo is to be utilized in large-scale projects and modern industry for residential or other buildings. It is better to avoid chemicals like arsenic as they are dangerous to the environment and the well-being of those handling them. Copper-chrome-boron is effective, cheap, and safe compared to other chemicals like borax, boron, and boric acid. In Costa Rica, chemical treatment has been acquired with a boron-based fertilizer. Some other preservation process mixed with sugar can be useful as a fertilizer. Boucherie procedure and dip-diffusion of full green culms for split culms are the two processes available to introduce chemical treatment into the bamboo.

Traditional preservation methods – like seasoning, smoking, curing, washing with lime, and soaking - are performed. The existing effect of these procedures is not specified. However, these particular set-ups are favorable as they can be performed without any principal investment and with equatorial levels of skill. The bamboo culms harvested are left open for curing, with leaves intact with branches. After felling for the transpiration process continues, starch content starts to decline. Treatment of the bamboo culms over a fire, called smoking, is to prevent fungi and insect attacks. Seasoning and soaking are putting the bamboo culms in flowing or stagnant water for a week to remove the sugars. After soaking and seasoning, the wet bamboos are air-dried under shade. Lime-washing is to prevent fungal attacks.

The design of this study is to assess the effects of mango polyphenol powder (MPP) as additional material for salt-water for traditional treatment to establish data from the mechanical properties of entire culm bamboo. The consumption and production of mango, loaded with various polyphenolic powder that has been cultured for 4,000 years, have step-by-step become larger as its quality has grown. During processing, by-products of mango, such as kernel and peel, constitute 17-22 percent of the fruit (Pitchaon, 2011) which have worldwide popularity (Kim et al., 2010). Since these wastes are a discarding problem, attempts have been done to utilize this by-product efficiently (Sogi et al., 2013). Production and consumption of mango are gradually increasing. Mango peel is rejected as waste and becoming a root of pollution, even though it was confirmed to be safe from pesticide residue, microbes, and heavy metals with other functional properties. The capacity of these mechanical properties parallel to the fibers including flexural (modulus of rupture), compression, and tension have been thoroughly studied (Amada et al., 1996, 1997; Amada & Untao, 2001; Amatosa Jr, E Loretero, et al., 2019; Ghavami et al., 2003; Laksono et al., 2020; Li & Shen, 2011; Lo et al., 2004; Sogi et al., 2013; Vaessen & Janssen, 1997). Less information on the material properties of tensile and longitudinal shear perpendicular to the fibers (Sharma et al., 2013). Species, age, and preservation technique are some parameters to consider for the durability of non-treated bamboo and calculated to have a setup life of 10–15 years, in good storage or conditions (Ghavami, 2008).

2. Materials and Methods

Two-year-old Native Bamboo (*Dendrocalamus asper*) was harvested from Calbayog City, Samar, Philippines. Parts were cut up to 3.0 m from the basal area that will be utilized for the experiment. The bamboo was manually cut into a specific length of 1200mm and 300 mm for the top, middle, and bottom portion of the bamboo. During the immersion of samples, 3 for each bamboo parts were immersed in salt-water with mango polyphenol powder with different variations of 0.5% (5 g powder per 1 Liter water), 1% (10 g powder per Liter water), and 2% (20 g per Liter water) for seven (7) days as a traditional treatment to keep bamboo against insect attack. Specimen were subjected to compression and bending test following the standards of ISO 22157-1:2004(E) and ASTM from wetting and relatively free from liquid; samples, taken from soaking, were stacked vertically in air-drying under shade for one (1) week (Amatosa Jr & Loretero, 2016).

Table 1: Macroscopic characteristics of Philippine Native bamboo (*Dendrocalamus Asper*)

Macroscopic Characteristics	Unit	Literature 1	Literature 2	Literature 3	Native Bamboo
Culm length	m	20-30	18-23	-	20-30
Internode length	cm	20-25	35	14-45	30-35
Internode Diameter	cm	8-20	9-13	1.2-9.3	8-18
Culm wall Thickness	mm	11-20	10-14	4-30	6-13

Literature: (Dransfield & Widjaja, 1995; Othman, 1995; Pakhkeree, 1997)

3. Result and discussion

This paper analyzes the treated Philippine Native bamboo (*Dendrocalamus asper*) species soaked in seawater with mango polyphenol compound that could affect the mechanical properties. The sample was soaked within one (1) week and air-dried for another one week specifically in compression and flexural strength following the International Organization of Standardization ISO 22157-1:2004(E) (Standardization, 2004) and ASTM designation requirements for the effectiveness of this material for different engineering bamboo applications.

3.1. Compressive Test Results

Table 2: Values of computed results for compressive strength of Dendrocalamus Asper (without Node)

Specimen	Area, A (sq.mm)	Immersion Condition (days)	Maximum Compressive Force, (kN)	Compressive Strength (psi)	Compressive Strength (MPa)	Mean	Standard Deviation, S (MPa)
1-5cb	3,556.48	7	106.2	4,330.98	29.86		
2-5cb	3,547.84	7	110.1	4,500.96	31.03	29.63	
3-5cb	3,189.70	7	89.3	4,060.54	28.00		
1-5cm	2,148.85	7	78.7	5,311.91	36.62		
2-5cm	2,099.57	7	99.1	6,584.83	47.20	40.85	35.09
3-5cm	2,523.48	7	97.7	5,615.34	38.72		(5.67 ± 16.16%)
1-5ct	1,860.80	7	65.8	5,128.70	35.36		
2-5ct	1,882.80	7	64.5	4,968.65	34.26	34.78	
3-5ct	2,373.28	7	82.4	5,035.71	34.72		
1-10cb	3,414.13	7	120.4	5,114.80	35.27		
2-10cb	3,562.57	7	134.4	5,471.65	37.73	34.82	
3-10cb	3,796.81	7	119.5	4,564.89	31.47		
1-10cm	1,759.29	7	85.7	7.065.20	48.71		
2-10cm	2,671.92	7	122.5	6,649.57	45.85	47.13	42.38
3-10cm	2,519.75	7	118.0	6,792.13	46.83		(6.27 ± 14.81%)
1-10ct	1,851.97	7	77.2	6,045.96	41.69		
2-10ct	1,625.77	7	79.9	7,128.01	49.15	45.19	
3-10ct	2,355.61	7	105.4	6,489.63	44.74		
1-20cb	3,547.84	7	110.0	4,496.87	31.00		
2-20cb	1,795.62	7	59.5	4,806.02	33.14	31.85	
3-20cb	3,466.55	7	108.9	4,556.30	31.41		
1-20cm	2,346.57	7	85.0	5,253.73	36.22		
2-20cm	1,795.62	7	59.5	4,806.02	33.14	34.81	33.18
3-20cm	1,859.82	7	65.2	5,084.61	35.06		(1.80 ± 5.43%)
1-20ct	1,460.84	7	48.4	4,805.34	33.13		

Submitted April 2020, Revised May 2021, Accepted May 2021, Published August 2021

2-20ct	1,225.22	7	38.2	4,522.00	31.18	32.88	
3-20ct	1,150.41	7	39.5	4,979.96	34.34		
1-wcu	3,785.81	0	115.8	4,579.27	31.66		
2-wcu	1,225.22	0	38.2	4,499.00	31.09	31.82	31.82
3-wcu	4,556.60	0	145.9	4,735.16	32.70		(0.82 ± 29.08%)

5cb - compression at 5% mixture, bottom part; 10cb - compression at 10% mixture, bottom part; 20cb - compression at 20% mixture, bottom part; 5cm - compression at 5% mixture, middle part; 10cm - compression at 10% mixture, middle part; 20cm - compression at 20% mixture, middle part; 5ct - compression at 5% mixture, top part; 10ct - compression at 10% mixture, top part; 20ct - compression at 20% mixture, top part; wcu – compression for untreated without-node

Table 3: Values of computed results for compressive strength of Dendrocalamus Asper (with Node)

Specimen	Area, A (sq.mm)	Immersion Condition (days)	Maximum Compressive Force, (kN)	Compressive Strength (psi)	Compressive Strength (MPa)	Mean	Standard Deviation, S (MPa)
1-5cb	3,925.42	7	111.8	4,130.83	28.48		
2-5cb	4,731.04	7	139.8	4,285.80	29.55	29.38	
3-5cb	2,984.51	7	89.9	4,368.86	30.12		
1-5cm	1,909.30	7	86.8	6,593.66	45.46		
2-5cm	3,122.74	7	89.3	4,147.60	28.60	37.77	36. 71
3-5cm	2,624.21	7	103.0	5,692.72	39.25		(7.56 ± 20.59%)
1-5ct	1,628.92	7	65.0	5,787.57	39.90		
2-5ct	1,896.15	7	79.3	6,065.73	41.82	41.82	
3-5ct	1,473.41	7	69.5	6,841.38	47.17		
1-10cb	4,572.59	7	149.6	4,745.16	32.72		
2-10cb	3,689.80	7	146.5	5,758.59	39.70	35.25	
3-10cb	4,391.36	7	146.3	4,832.00	33.32		
1-10cm	2,324.78	7	100.4	6,263.74	43.19		
2-10cm	2,298.08	7	94.5	5,964.16	41.12	43.02	40.70
3-10cm	1,872.39	7	83.8	6,491.27	44.76		(4.81 ± 11.82%)
1-10ct	1,309.46	7	53.6	5,936.85	40.93		
2-10ct	1,396.44	7	62.1	6,449.88	44.47	43.83	
3-10ct	2,482.45	7	114.4	6,683.87	46.08		
1-20cb	3,556.48	7	126.0	5,138.45	35.43		
2-20cb	3,796.81	7	120.4	4,599.27	31.71	33.89	
3-20cb	3,189.70	7	110.1	5,006.33	34.52		
1-20cm	2,302.20	7	89.9	5,657.38	39.01		
2-20cm	1,807.79	7	65.2	5,230.96	36.07	36.07	36.94
3-20cm	1,795.62	7	59.5	4,806.02	33.14		(4.22 ± 11.41%)
1-20ct	1,373.07	7	56.5	5,968.11	41.15		
2-20ct	1,184.38	7	42.9	5,253.49	36.22	40.87	
3-20ct	1,140.40	7	51.6	6,562.59	45.25		
1-cu	1,873.78	0	65.4	4,966.59	34.14		
2-cu	3,789.80	0	118.0	4,566.55	31.35	32.91	32.91
3-cu	1,488.00	0	49.1	4,822.34	33.23		(4.32 ± 29.08%)

5nb - compression with node at 5% mixture, bottom part; 10nb - compression with node at 10% mixture, bottom part; 20nb - compression with node at 20% mixture, bottom part; 5nm - compression with node at 5% mixture, middle part; 10nm - compression with node at 10% mixture, middle part; 20nm - compression with node at 20% mixture, middle part; 5nt - compression with node at 5% mixture, top part; 10nt - compression with node at 10% mixture, top part; 20nt - compression with node at 20% mixture, top part; cu – compression for untreated with-node

Data display in Table 2, using the internode section from a full culm bamboo parallel to the grains, shows the mechanical properties of the *Dendrocalamus asper*. ASTM D 695 – 96 (International, 2010) test procedure has been used for the assessment of compressive strength (Amatosa Jr, Loretero, et al., 2019). Specimens soaked in salt-water with 10 grams mango polyphenol powder reached up to 42.38 MPa, S=6.27 MPa ± 14.81% of the mean, superseded by the samples in 5, 20 grams powder per 1-liter saltwater and non-treated with an average compressive strength of 35.09 MPa, S=5.67 MPa ± 16.16% of the mean; 33.18 MPa, S=1.80 MPa ± 5.33% and 31.82 MPa, S=0.82 ± 2.57% of the mean, respectively. It shows that the naturally treated native bamboo samples increased their strength by

29.75% for 10 grams powder per 1-liter saltwater; 24.63% for 5 grams powder per 1-liter saltwater; and 23.29% for 20 grams powder per 1-liter saltwater from non-treated samples. To show the results, naturally treated samples under 10 grams powder per 1-liter saltwater have a greater ability to resist the loads applied, unlike the non-treated ones.

As shown in Table 3, using the nodal section for compressive strength properties has been analyzed. The same ASTM standards were utilized to evaluate the mechanical properties for a nodal section in which salt-water with 10 grams mango polyphenol powder reached up to 40.70 MPa, S=4.81 MPa ± 141.82% of the mean, followed by the specimens in 20, 5 grams powder per 1-liter salt-water and untreated with an average compressive strength of 36.94 MPa, S=4.22 MPa ± 11.41% of the mean; 36.71 MPa, S=7.56 MPa ± 20.59% and 32.91 MPa, S=1.42 ± 4.32% of the mean respectively. The loading speed was 1.5 up to 2.2 KN/s or about 0.9 N/mm2: this speed is higher than ASTM D143-14 (ASTM, 2009) requires for wood. It was hard to run and at less speed due to the small cross-section of the bamboo (2,000 mm2). Therefore, saltwater treatment plus mango polyphenol powder affects the compressive strength of the given samples aside from longer lifespan or durability. Traditionally speaking, ACI 214 (Malhotra et al., 1976) allowable compressive strength for concrete in 7 days result of treated bamboo is comparable to certain 28 days requirements used for residential purposes which are around 17 MPa (2,500 psi), 28 MPa (4,000 psi) for commercial uses, but not as high as 70 MPA (10,00 psi) for other prescribed certain applications.

3.2. Bending Test Results

Flexural (Bending) strength has an immediate influence on the behavior of a structure. Using the three-point bending test, it is important to declare the deflection of each element before it is built. The test samples are in full culm, which is parallel to grains. The load is applied at the mid-point of a sample, and the resulting deflection is measured. The standard procedure for testing flexural properties as per ASTM D 3043 – 95 (ASTM, 2011).

Table 4: Values of computed results for bending strength of Dendrocalamus Asper

Specimen	% of change Related to Untreated Condition	Immersion Condition (Days)	Modulus of Elasticity (MOE) $\mathcal{E}$, (GPa)	Applied Load at Maximum P_{max} (N)	Modulus of Rupture (MOR) at Maximum $\sigma_{max,}$ (MPa)
1-5fb		7	5.02	10,100	41.84
2-5fb		7	4.20	7,300	29.14
3-5fb		7	6.92	14,000	43.45
1-5fm	- 16.20 %	7	13.65	5,500	39.82
2-5fm		7	7.23	5,000	34.75
3-5fm		7	5.79	7,100	37.35
1-5ft		7	7.89	3,300	58.91
2-5ft		7	15.81	2,900	45.63
3-5ft	________	7	10.38	4,100	55.22
1-10fb		7	5.23	8,000	37.36
2-10fb		7	4.53	12,400	37.94
3-10fb		7	3.47	8,900	33.85
1-10fm	- 13.71 %	7	13.96	5,200	43.18
2-10fm		7	8.35	6,000	37.63
3-10fm		7	5.64	5,600	37.94
1-10ft		7	18.72	5,400	60.04
2-10ft		7	16.06	4,700	48.05
3-10ft	________	7	3.12	5,400	37.20
1-20fb		7	3.32	5,200	26.95
2-20fb		7	4.08	6,200	28.56
3-20fb		7	5.47	9,500	36.15
1-20fm	- 10.65 %	7	5.64	5,600	37.94
2-20fm		7	4.00	3,800	32.35
3-20fm		7	5.99	6,200	41.89
1-20ft		7	14.65	4,000	58.06
2-20ft		7	9.21	3,300	47.52

3-20ft	7	7.73	3,500	52.57
1-untreated	0	6.34	2,800	38.76
2-untreated	0	10.28	9,200	34.10
3-untreated	0	8.30	6,900	35.00

5fb - flexural at 5% mixture, bottom part; 10fb - flexural with node at 10% mixture, bottom part; 20fb - flexural with node at 20% mixture, bottom part; 5fm - flexural with node at 5% mixture, middle part; 10fm - flexural with node at 10% mixture, middle part; 20fm - flexural with node at 20% mixture, middle part; 5ft - flexural with node at 5% mixture, top part; 10ft - flexural with node at 10% mixture, top part; 20ft - flexural with node at 20% mixture, top part.

Presenting in Table 4, treated specimens from saltwater preservation with 5 grams of mango polyphenol powder per 1-liter water reached up to 42.91 MPa compared to those treated with (10 and 20) grams of powder and untreated with 41.47 MPa, 40.24 MPa, respectively. The non-treated native bamboo samples decreased their strength by 16.20% from the samples with 5 grams of mango polyphenol powder while untreated to (10 and 20) grams of polyphenol powder decreased its strength by 13.29% and 10.65%, respectively.

4. Conclusion

The native bamboo samples were influenced by natural treatment for a week to increase their compressive strengths. 10% amount of MPP is dominant in compressive strength with 43.83 MPa at the top part (nodal), 10% amount of MPP with 47.13 MPa at the middle part (inter-nodal), and 5% in flexural strength with 43.07 MPa at the top part. The highest average compressive values, compared to the untreated specimen, are 42.38 MPa with SD 6.27 MPa ± 14.81% and 40.70 MPa with SD 4.81 MPa ± 11.82% for inter-nodal and nodal section, respectively. Flexural strength is on 5% amount of MPP with 42.91 MPa and about 16.20% higher than the untreated specimen. Therefore, the treatment process combining seawater absorption and mango polyphenol powder (MPP) is more effective in improving mechanical properties with Total Phenolic Content (TPC): 77-127 mg Gallic acid equivalence per gram of powder and the Antioxidant Activity through DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay: 86740 to 217700 µmol Trolox 100 per gram of powder. Hence, the average result of treated specimens in saltwater with mango polyphenol powder obtained the highest flexural and compressive strength compared to untreated and comparable to the ACI 214 standards.

Acknowledgments

This study was conceptualized by the author/s and sponsored by Engineering Research and Development for Technology under the Department of Science and Technology, the Philippines, and all experiments were carried out in the Department of Engineering and Technology – Materials Testing Laboratory, Northwest Samar State University of Science and Technology, Calbayog City, Samar, and the Department of Chemical Engineering Laboratory, University of San Carlos, Cebu City, Philippines.

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Submitted April 2020, Revised May 2021, Accepted May 2021, Published August 2021