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EXPERIMENTAL INVESTIGATION ON PHYSICAL AND COMPRESSIVE PROPERTIES OF UNTREATED AND TREATED DENDROCALAMUS ASPER AND GIGANTOCHLOA SCORTECHINII BAMBOO UNDER MONOTONIC LOADING

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ABSTRACT

Bamboo is a natural material having a fast reproduction and high mechanical strengths. However, when a bio-based material in general, and bamboo in particular are expected to be a construction material, their sensitivity to moisture and their durability are usually questionable. Indeed, it is well known that these materials do not possess the same performance in the long-term, when compared to industrial materials, especially for the treated bamboo. The present study explores the physical and compressive properties of the untreated and treated Dendrocalamus Asper and Gigantochloa Scortechinii bamboo species were investigated under applied monotonic loads. A six-meter length of both species of bamboo poles were undergoing post-harvesting conventional treatment i.e., using combination of borax and boric acid. The bamboo culms were soaked horizontally for duration of 2 weeks which are effective against borers, termites and fungi. The physical properties tests of 36 samples and compression strength tests of 48 culm samples (i.e., top, medium and bottom) were conducted using Universal Tensile Machine (UTM) were according to the ISO 22157-1:2004. In particular, the compression test of untreated and treated bamboo culm samples were tested at location of node and internode under monotonic increasing uniaxial load. Notably, the results showed that the treated Dendrocalamus Asper bamboo experienced significant increment of compressive (i.e., 20%) and physical properties (i.e., 14% - 16%) of the bottom part of culms compared to Gigantochloa Scortechinii bamboo. The study proved that the treatment process could increase the compressive properties of treated specimens, compared to untreated bamboo. The influence of node on bamboo in adjusting the compressive properties of untreated and treated bamboo is also included.

1. Introduction

Bamboo is a versatile plant that grows in many parts of the world, in particular, the tropical and subtropical areas where Handana M.A.P., *et al* [1] reported, 65% of the area is in Asia. While Tahir [2] mentioned, China and India are the two countries together have more than half the total bamboo resources globally. Aside from Asian countries, some African researchers namely Appiah-Kubi, E., *et al* [3] and Adedipe., *et al* [4] also conduct some studies to utilize their local bamboo species as construction material. In Malaysia, bamboos are distributed from sea level to 3000 m above and there are about 70 bamboo species in the country with 20 of the world's species found in the

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country's native forests, including Dendrocalamus asper (Betong bamboo), Gigantochloa levis (Beting bamboo), Gigantochloa scortechinii (Semantan bamboo), and Gigantochloa ligulata (Tumpat bamboo) as reported by INBAR 2021 [4]. Specifically, there are 50 species of bamboo in Peninsular Malaysia, 30 species in Sabah, and 20 species in Sarawak.

At this present time, developing environmentally friendly with low-cost construction materials is a challenging issue especially for the rural area. Conventional construction material such as concrete, steel and timber are usually associated with high-cost materials due to the production and processing method. Construction industry starts to move to green construction especially in the rural area in which timber is needed as there are limited facilities to transport other conventional material such as concrete and steel. Even though timber is known to have environmentally compatibility, reusability and simplicity in fabrication, the main problem with timber is availability and cost of the material as the source of timber is getting low. Timber possesses intermediate strength and less flexible due to its grains pattern and natural defect. Other than that, timber required longer period up to 10 years before can achieve the strength and be harvested compared with bamboo which needs less period, about 3 years to achieve required strength. Non matured timber usually will cause the reduction of strength properties. Consequently, replacing it with bamboo in areas where the strength is the primary consideration is a practical alternative.

Compared with all conventional construction material such as timber and steel, bamboo also exhibits excellent mechanical properties. As a natural and fibrous material, there is a just small number of Malaysian researchers includes Siam., *et al* [5][6], Bahrin., *et al* [7], Osman. S., *et al* [8], Adam., *et al* [9] and Awalluddin., *et al* [10] study on the anatomical and physical characteristic as well as mechanical properties of bamboo that cause the utilization of bamboo being neglected especially in Malaysia. As being used traditionally since the ancient time, bamboo is generally known to have flexible, lightweight, tough and low-cost material. As well as timber and other construction materials, bamboo also required extensive testing on specific age in order to determine the strength achieved by the bamboo itself. Furthermore, even though there is small research on the mechanical properties such as compressive, tensile, shear for various species of bamboo all over the world, there is no specific design data on mechanical properties and design rules of bamboo. So, there is need to conduct the research on bamboo and prove that the bamboo will offer great potential as an alternative to other conventional construction materials and practices.

in this study, the physical and compressive properties of untreated and treated dendrocalamus asper and gigantochloa scortechinii bamboo is experimentally investigated under monotonic loading. This research is a part of an experimental work which focuses on the possibility of utilizing bamboo as a construction material.

2. Methodology

2.1 Sample Preparation

There are two bamboo species namely Dendrocalamus Asper (Betong) and Gigantochloa Scortechinii (Semantan) supplied from Perak origin were used for the experimental investigation. The untreated bamboo samples were air-dried under the shed while treated bamboo had been soaked for 2 weeks using borax and boric acid preservation method by 1.5:1 ratio then dried under shed. Horizontal soaked method used for the treatment process.

2.1Experimental Investigation
2.1.1Mechanical Testing

All bamboo species were cut into small samples, in which the samples were taken from the node and internode of the bamboo culm. Three tests have been involved in this study including, compression, tensile, and moisture content, in accordance with ISO 22157 Part 1 [11]. Compression test was measured from two opposite points of the outer surface. The average diameter was recorded. Average wall thickness, t, of the bamboo culm was measured from four points, separated by a 90^0 angle around the diameter of the specimen. Compression test was carried out by using a Universal Testing Machine, where the specimens for two bamboo species were tested under uniaxial monotonic compression loading. The samples were loaded continuously with compression force increases over time until complete failure of the bamboo samples. Maximum load for each specimen was recorded by using a data logger.

2.1.2 Determination of Moisture Content

For the determination of moisture content, samples of each culm for both treated and untreated from bottom, middle, and top part with size 25 mm x 25 mm x wall thickness were taken as Figure 1. Each section of treated and untreated for two types of bamboo (top, middle, and bottom) were cut from each section. Every single culm labelled after cutting process. Then, weighed the initial weight of each samples before drying as Figure 2. After that, the samples were dried in an oven at a temperature of 103 ± 2°C and the mass after 24 hours of drying were recorded. Lastly, for each test samples, the moisture content MC were calculated by using the Eq. (1).

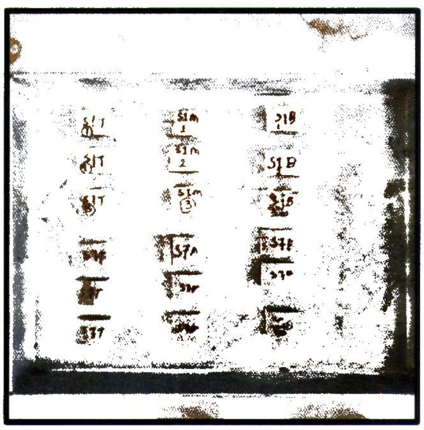

Fig. 1. Moisture content samples of 35 mm x 35 mm in size

Fig. 2. MC sample weighing before and after oven dried

$$MC\ (\%) = \left(m - \frac{m_0}{m_0}\right) x\ 100 \qquad (1)$$

Where m is mass before drying (gram) and m0 is mass after oven drying (gram)

3. Results
3.1 Physical Characteristic

The physical characteristic of the bamboo was determined prior to the mechanical testing and determination of samples moisture content. Table 2 shows the physical characterization of bamboo samples used for the experimental investigation.

Table 1
Physical characteristic of bamboo samples

Samples	Section	Outer Diameter (mm)	inner diameter	Thickness (mm)	Height (mm)
Semantan 1	Top	71	57	7	154
	Middle	71	57	7	160
	Bottom	78	56	11	158
Semantan 2	Top	75	61	7	157
	Middle	80	62	9	154
	Bottom	84	54	15	156
Betong 1	Top	94	72	11	160
	Middle	102	72	15	155
	Bottom	111	77	17	160
Betong 2	Top	103	79	12	160
	Middle	105	77	14	160
	Bottom	110	76	17	159
Semantan 7	Top	53	43	5	158
	Middle	54	41	7	161
	Bottom	55	40	7	160
Semantan 8	Top	90	81	7	157
	Middle	91	71	10	160
	Bottom	95	66	12	159
Betong 7	Top	99	81	9	158
	Middle	100	78	11	160
	Bottom	102	56	23	162
Betong 8	Top	100	78	11	158
	Middle	104	78	13	159
	Bottom	110	84	13	160

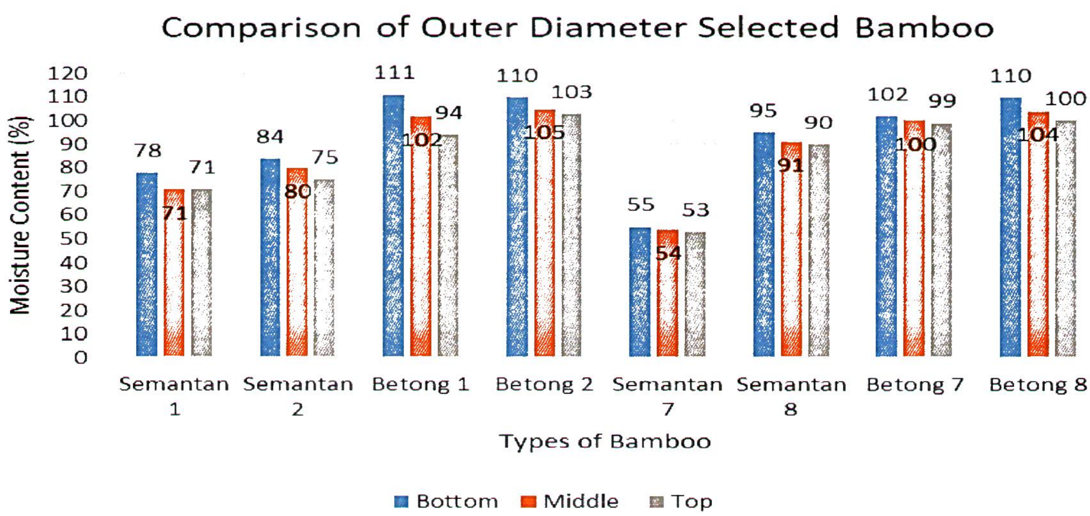

Fig. 3. Comparison of Outer Diameter Selected Bamboo

Table 1 shows the outer diameter, inner diameter, thickness and height of bamboo differ along the length and part or section. The bamboo culm outer diameter as well as the wall thickness of the bamboo as indicate in Figure 3, decreased in value from the bottom to the middle and top parts. Even the same types of bamboo species, the physical characterization also may vary as stated by Molari. L *et al.,* [12], Bahtiar *et al.,* [13], Drury. B *et al.,* [14] and Gauss. C *et al.,* [15]. Overall, the culm of Betong bamboo is largest than the Semantan bamboo in comparison of outer diameter, inner diameter, and thickness for all part top, middle, and bottom which in good agreement with study conducted by Hamdan. H *et al.,* [16] on physical characterization of Malaysian bamboo species.

The primary factors influencing the use of bamboo as a construction material are the characteristics of its culm. Among these characteristics, culm diameter is particularly crucial whether bamboo is employed in its cylindrical state or processed into various products. A substantial diameter in bamboo culms results in an abundance of fibers due to the thicker wall. According to Ma. R *et al.,* [17], the minimum external diameters bamboo culms use for construction industry are mainly distributed between 60 mm and 130 mm. Culms with a thickness ranging from 5mm to 20mm are well-suited for structural applications that require end-bearing loading, such as foundations, beams, columns, and bridges.

3.2 Moisture Content Test

The moisture content for Semantan and Betong bamboo was obtained using Eq 1 and the results shown in Table 2 and 3.

Table 2
Semantan bamboo moisture content

Bamboo Types		Specimen	Weight Before,w (g)		Weight After,w (g)		Moisture Content, Mc (%)	Average MC
				Average		Average		
Semantan Treated	Top	T1	3.571	3.532	3.142	3.111	13.53	13.71
		T2	3.525		3.105			
		T3	3.499		3.086			
	Middle	M1	3.365	3.672	3.003	3.237	13.68	
		M2	3.871		3.394			
		M3	3.782		3.315			
	Bottom	B1	5.061	5.053	4.443	4.462	13.92	
		B2	5.199		4.566			
		B3	4.889		4.376			
Semantan Untreated	Top	T1	2.490	2.777	2.198	2.362	13.34	13.82
		T2	2.735		2.408			
		T3	2.805		2.480			
	Middle	M1	3.143	2.951	2.783	2.598	13.59	
		M2	2.566		2.250			
		M3	3.144		2.761			
	Bottom	B1	3.208	3.387	2.731	2.957	14.54	
		B2	3.757		3.316			
		B3	3.196		2.825			

Table 3
Betong bamboo moisture content

Bamboo Types		Specimen	Weight Before,w (g)		Weight After,w (g)		Moisture Content, Mc (%)	Average MC
				Average		Average		
Betong Treated	Top	T1	7.142	7.902	6.230	6.902	14.49	24.65
		T2	9.058		7.925			
		T3	7.506		6.552			
	Middle	M1	10.545	10.551	8.140	8.201	28.66	
		M2	10.190		8.055			
		M3	10.917		8.433			
	Bottom	B1	15.181	12.292	11.404	9.397	30.81	
		B2	10.696		8.478			
		B3	10.998		8.310			
Betong Untreated	Top	T1	6.122	6.054	4.829	4.715	28.39	31.48
		T2	5.800		4.470			
		T3	6.241		4.847			
	Middle	M1	7.975	8.066	6.250	6.208	29.23	
		M2	8.582		6.633			
		M3	7.641		5.741			
	Bottom	B1	11.010	10.887	8.331	7.957	36.82	
		B2	9.756		7.181			
		B3	11.900		8.360			

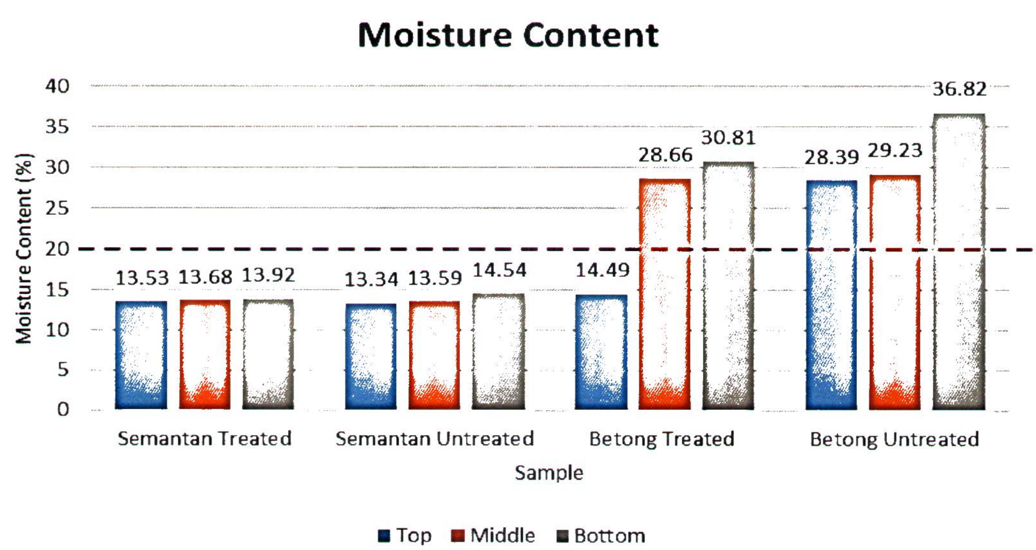

Fig. 4. Moisture content of different types of bamboo

The moisture content is a critical factor that has an impact on the mechanical properties of wooden materials. When using wood and lumber as building materials, it is necessary to maintain a specific moisture content level. For interior use, the recommended moisture content range is between 6% and 8%, while for exterior wood or components within constructed assemblies, it should be between 9% and 14% as stated by Simpson. W, [18]. However, for bamboo to be utilized in structural applications, ISO 22157-2 specifies a preferred moisture content of 20% maximum.

Bamboo, being a hygroscopic material, has the ability to absorb or release water in order to reach a moisture equilibrium with its surroundings. In this study, the moisture content (MC) of the bamboo species was measured by oven-drying the samples for 24 hours at a temperature of 103±2°C. Referring to Figure 4, the top part of the untreated is the lowest MC at 13.34% while the bottom part of the untreated is the highest with 14.54% for Semantan bamboo. However, for Betong bamboo, the top part of the treated samples has the lowest MC with 14.49%, while the bottom part of the untreated samples has the highest with 36.82%. The moisture content of Betong bamboo is higher than that of Semantan bamboo, with the highest for Betong bamboo being 36.82% and 14.54% for Semantan bamboo. These two highest MCs for both types of bamboo are obtained from the same part that is bottom-untreated. Moreover, the moisture content for both types of bamboo and treatment shows the same pattern that is increasing, with the top part showing the minimum MC and the bottom part showing the maximum MC. The bottom part has relatively high MC because the lower part of the bamboo is near the ground to absorb more water. Study by Wakchaure, M. R., [19] on Dendrocalamus strictus bamboo species also found that the moisture content decreased from the lower to the upper section of bamboo while the specific gravity increased.

Overall, the MC of the treated samples is lower than untreated samples for both Semantan and Betong Bamboo. The observed phenomenon can be attributed to the notable distinctions in chemical composition during the treatment affecting the microstructure of the samples. These differences play a significant role in influencing the characteristics and behavior of the bamboo, including its moisture content as mentioned by Kitti Chowana, [20].

Based on the result obtained, both Semantan treated and Semantan untreated samples has average MC 13.71% and 13.82% that is compatible for the requirement structural applications. The average moisture content of Betong-treated and untreated specimens is 24.65% and 31.48%, respectively, which is 4.65% and 11.48% extra from the desired maximum moisture content of 20%. This is because bamboo has vascular voids that can absorb water, and a thicker bamboo will have more vascular voids and a higher moisture content.

3.2 Compressive Strength

As reported in Table 4, the average compressive strength of both treated and untreated bamboo at node and internode section was observed to be high at the bottom part of all bamboo species, followed by middle, and lastly, top part. The different values signify the different specimen locations where the specimens were cut. Specimens taken far from the culm's base were slightly weak than the specimens that were taken near the culm's base. The difference in this property is attributed as the bottom part of the bamboo culm is responsible for bearing the weight of the entire plant. The bottom portion needs to withstand significant compressive forces from the weight of the stem, leaves, and sometimes even additional loads such as wind or other environmental factors. As a result, bamboo has evolved to have a denser, thicker structure in the lower part of the culm to support these compressive stresses.

Table 4

Compressive Strength of Bamboo Samples

Treated node	Section		Outer Diameter (mm)	Cross Sectional Area (mm2	Compressive Strength (N/mm2)	Average Compression Strength (N/mm2)
Semantan	Top	1	71	1407.616	51.08	56.79
		2	75	1495.592	62.50	
	Middle	1	71	1407.616	61.73	64.82
		2	80	2007.738	67.90	
	Bottom	1	78	2315.654	71.14	74.08
		2	84	3251.97	77.01	
Betong	Top	1	94	2868.646	54.38	68.64
		2	103	3431.064	82.90	
	Middle	1	102	4100.31	71.47	79.53
		2	105	4002.908	87.59	
	Bottom	1	111	5020.916	89.69	90.30
		2	110	4967.502	90.91	
Treated internode	Section		Outer Diameter (mm)	Cross Sectional Area (mm2	Compressive Strength (N/mm2)	Average Compression Strength (N/mm2)
Semantan	Top	1	79	1376.196	61.50	64.41
		2	95	1935.472	67.32	
	Middle	1	77	1539.58	62.01	70.19
		2	91	2545.02	78.36	
	Bottom	1	70	2039.158	85.04	83.40
		2	90	2940.912	81.76	
Betong	Top	1	95	2431.908	63.86	67.87
		2	97	2972.332	71.88	
	Middle	1	98	3006.894	65.31	83.70
		2	100	3553.602	102.09	
	Bottom	1	130	3179.704	102.34	103.15
		2	105	3757.832	103.96	
Untreated node	Section		Outer Diameter (mm)	Cross Sectional Area (mm2	Compressive Strength (N/mm2)	Average Compression Strength (N/mm2)
Semantan	Top	7	53	754.08	48.58	50.20
		8	95	1935..472	51.82	
	Middle	7	55	1055.712	52.54	52.95
		8	91	2545.02	53.36	
	Bottom	7	54	1033.718	61.34	59.65
		8	90	2940.912	57.96	
Betong	Top	7	99	2545.02	62.36	64.29
		8	100	3076.018	66.21	
	Middle	7	100	3076.018	66.36	68.22
		8	104	3716.986	70.07	
	Bottom	7	102	4709.014	80.90	84.70
		8	110	3962.062	88.50	
Untreated internode	Section		Outer Diameter (mm)	Cross Sectional Area (mm2	Compressive Strength (N/mm2)	Average Compression Strength (N/mm2)
Semantan	Top	7	55	785.5	53.01	52.13
		8	95	2186.832	51.24	
	Middle	7	57	961.452	57.70	54.47
		8	93	2186.832	51.24	
	Bottom	7	55	923.748	68.64	66.23
		8	95	2670.7	63.82	
		7	95	1935.472	68.91	

Betong	Top	8	94	1658.976	66.59	67.75
	Middle	7	99	3280.248	72.88	76.70
		8	98	3006.894	80.52	
	Bottom	7	100	4564.482	75.37	83.09
		8	99	4964.36	90.80	

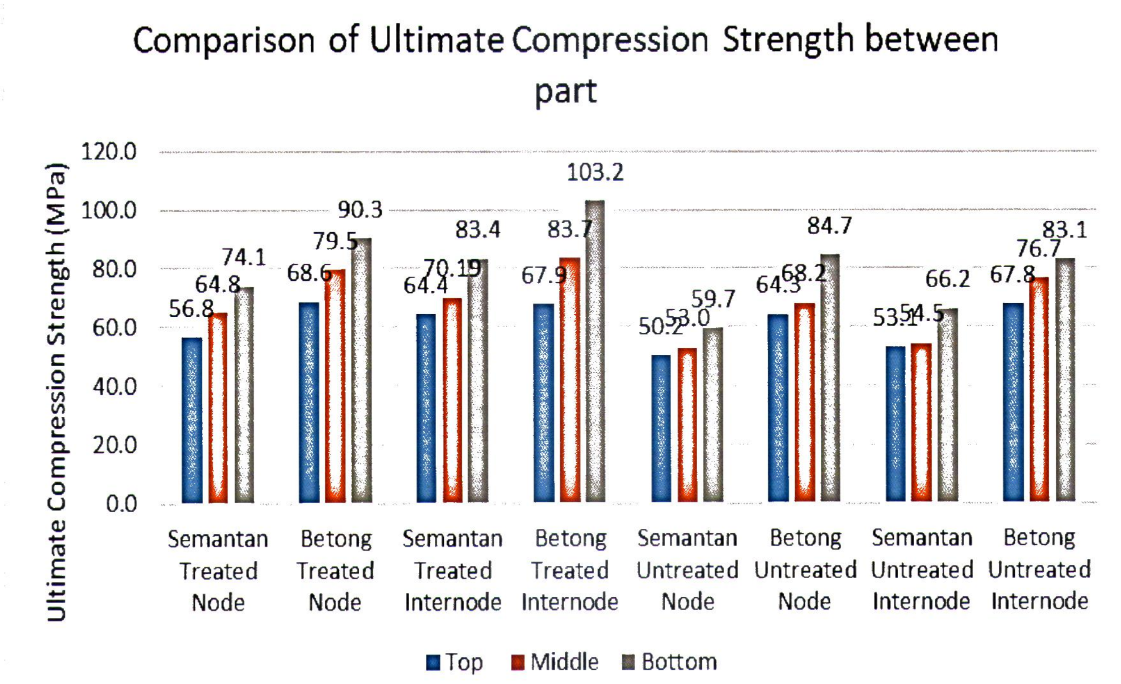

Fig. 5. Moisture content of different types of bamboo

Based on the findings of this research, it appears that there is significant difference in ultimate compressive strength among the different sections (top, middle, and bottom) of the two types of bamboos studied. As per Figure 5, the findings indicate a progressive rise in compressive strength, observed from the top section to the middle and bottom sections for all types of samples node and internode. The bottom specimens of Betong Treated Internode Samples demonstrated the highest compressive strength at 103.2 MPa, whereas the Semantan Untreated Node samples exhibited the lowest compressive strength at 59.7 MPa. When comparing the bottom part, it is observed that Betong treated internode shows the highest compressive strength at 67.9 MPa, whereas Semantan Untreated Node exhibits the lowest compressive strength at 50.2 MPa. There is a substantial disparity of approximately 25% between the compressive strength results obtained from the bottom and top part samples for all types of bamboo in this study. The compressive strength of the samples is influenced by various factors, and one of these factors is the wall thickness. Based on the physical characterization discussed, it was found that the bottom part of the bamboo has a higher culm thickness compared to the top part. Consequently, the bottom part exhibits a larger cross-sectional area, which contributes to its increased strength and ability to withstand higher load pressures.

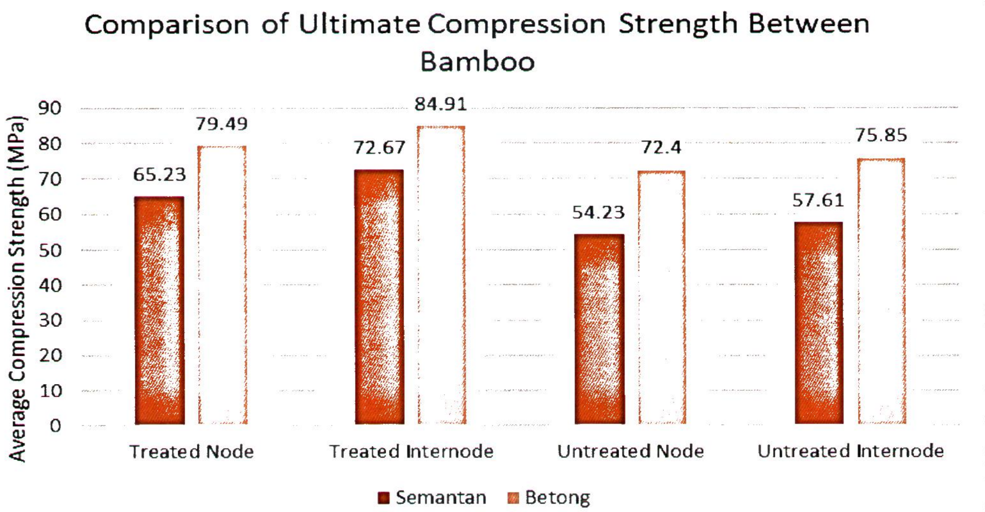

Fig.6. Moisture content of different types of bamboo

According to Figure 6, In general, Betong bamboo demonstrates higher compressive strength when compared to Semantan bamboo for all types of samples. Among the Betong bamboo samples, the highest compressive strength was observed in the treated samples with nodes, measuring at 84.91 MPa. On the other hand, the lowest compressive strength was found in the untreated samples with nodes, measuring at 72.4 MPa. When comparing the compressive strength of the Betong untreated node in the current study with the results from a previous study, it is evident that the current test yielded significantly lower values. The compressive strength obtained in the current study was measured at 72.4 MPa, while the previous study reported by Awalluddin *et al.,* [21], is 78.03 MPa. In the case of Semantan bamboo, the highest compressive strength was recorded in the treated internode samples, measuring at 72.67 MPa. Conversely, the lowest compressive strength was observed in the untreated node samples, with a value of 54.23 MPa.

Indeed, one reason for the similarity in compressive strength between bamboo and hardwood tropical timber species could be attributed to the notable difference in thickness. Thickness is a crucial factor that influences compressive strength. Therefore, despite the inherent structural disparities between bamboo and hardwood, their comparable compressive strength may be attributed to other factors such as fiber arrangement and density as well.

Visual observation after samples undergo the uniaxial monotonic compression loading test demonstrated multiple fractures, which finally led to splits as specimen sections buckled as in Figure 7. Untreated Betong with node section shows end-bearing crack pattern occurs where bamboo compressive shows failure at the top of the sample due to the wall thickness of the sample. This also happens because the top surface of the bamboo is uneven, causing one side sample to receive more pressure during the test. Internode section samples for untreated Betong, as shown in Figure 8, revealed splitting failure where, as the bamboo receives maximum compression pressure, the load is transferred, causing the samples to split from top to bottom.

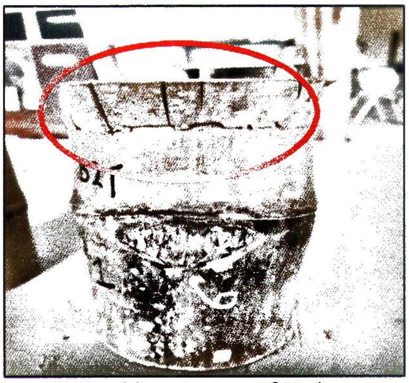
Fig. 7. Buckling Types of Failure

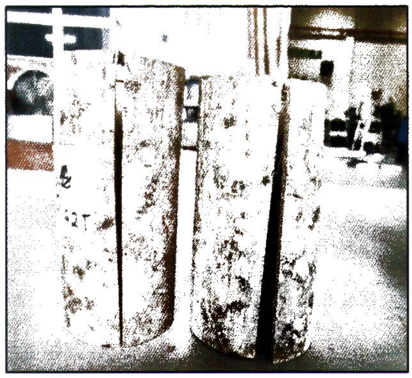
Fig. 8. Splitting Types of Failure

4. Conclusions

Bamboo is a cylindrical plant that grows upright. The diameter of the bamboo culm gradually decreases from the bottom part to the top part. In contrast, the thickness of the culm decreases as well, going from the bottom to the top. Furthermore, each type of bamboo possesses distinct physical characterization concerning length, outer diameter, and thickness. In this study, Dendrocalamus Asper (Betong) exhibits more pronounced physical characteristics compared to Gigantochloa Scortechinii (Semantan). Assessing the physical characterization holds significant importance as it directly influences the strength and mechanical properties of bamboo.

Based on the Moisture Content Test conducted on bamboo, all parts of Semantan Treated and Semantan Untreated meet the criteria outlined in ISO 22157-01-2004, with an average moisture content below 20%. However, for Betong bamboo, only the top part of Betong Treated meets the requirement, with a moisture content of 14.49%. The middle part (28.66%, 30.81%) and the bottom part (29.23%, 36.82%) of both Treated and Untreated Betong bamboo fail to meet the requirement. This can be attributed to the thicker thickness and higher presence of nodes in the middle section, as well as the proximity of the lower bamboo sticks to the ground. Achieving the ideal moisture content is of utmost importance in ensuring the long-term sustainability of bamboo as a structural material, as it directly impacts the mechanical properties of bamboo.

In general, a clear pattern is observed in the ultimate compressive strength of all bamboo samples. The bottom part of the bamboo exhibits higher compressive strength compared to the middle and top parts. This can be attributed to the larger outer diameter and thickness of the bottom part, relative to the other sections. Due to the fact that the weight of the entire bamboo is supported by the lower portion of the bamboo culm, occasionally extra stresses from the wind or other environmental elements, must be supported by the lower portion, which must withstand significant compressive forces. In order to withstand these compressive stresses, bamboo has evolved a denser, thicker structure in the lower portion of the culm. Regarding the treated and untreated bamboo samples, the compressive strength of treated bamboo samples is 18% higher than that of untreated samples for both bamboo types. This is because the borac and boric acid treatment or preservation method is aimed to protect the bamboo from damage caused by pests, thereby preserving the structural integrity of the bamboo surface, which in turn affects its strength. When comparing node and internode parts, it is observed that internode samples exhibit a 10% higher compressive strength compared to node samples for both types of bamboo. The presence of a node results in lower compressive strength due to the presence of a diaphragm that disrupts the shape and diameter of the bamboo culm.

In conclusion, conducting a thorough experimental investigation into the physical and mechanical properties of bamboo is crucial for establishing bamboo standards for structural applications. This significance arises from the fact that different types of bamboo possess distinct physical and mechanical characteristics. By comprehensively studying these properties, we gain a deeper understanding of bamboo's behavior under various conditions, thereby facilitating the establishment of standardized guidelines for its structural utilization. This research successfully achieved all its objectives, encompassing the comprehensive study of bamboo's physical and mechanical properties.

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