Physical and Mechanical Properties of Six Myanmar Bamboo Species

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Abstract: *Bamboo has been a traditional construction material in many regions for centuries. The rural people of Myanmar have been using bamboos in building houses and in making agricultural implements. Moreover, the rapid growth and maturation rate of bamboo as well as its good strength properties and global accessibility make it a promising non-conventional building material resource. However, due to limited standardization and design criteria, bamboo has often been relegated to non-engineered and marginally-engineered construction. The main objective of my study is to identify the physical and mechanical properties of some bamboo species in Myanmar and these properties based on ISO 22571. This paper contains the six kinds of bamboo species in Myanmar namely Thyrsostachysregia Bennet (Htiyo-wa), Gigantochloarostrata Wong (Waya-wa), Bambusa tulda Roxbo. (Thaik-wa), D. hamiltonii Nees (Wabo-myetsangye), D. longispathus Kurz (Wanet-wa), Bambusapolymorpha Munro (Kyathaung-wa).The mean moisture content of tested bamboo species ranges varies from 35% to 110%. The crushing strength is range from 35 N/mm^2 to 70 N/mm^2. In addition the maximum shearing strength of bamboo is 320 N/mm^2 in D. hamiltonii Nees (Wabo-myetsangye) and Bambusapolymorpha Munro (Kyathaung-wa). Furthermore, the bending strength is highest at the bottom portion. However modulus of elasticity is peak at the top portion. The tensile strength on node and internode is not very different. The best mechanical performance was found in Bambusa tulda Roxbo (Thaik-wa).*

Key Words: *Bamboo Culm, Geometric Properties, Physical Properties, Mechanical Properties.*

1. INTRODUCTION:

*Ba*mboo is the fastest growing plant in the world having growth up to 60 cm or more in a day. Bamboo has social, economic and cultural significance and is used extensively for building materials along with thousands of uses [1]. In Myanmar, the area of bamboo forest is the third highest country among India, China, etc. The rural people of Myanmar have been using bamboos as rafters and purlins, walling material, and flooring in building houses, in making agricultural implements, as cloth lines, for fencing, and for making various kitchen utensils, and furniture. Moreover, bamboo has both advantages and disadvantages for construction material. The pros of bamboo material are lightweight, strong, versatile, good mechanical strength, environmentally friendly etc. In recent years, with the issue of sustainability the use of bamboo has gained a new value. This awareness is followed by many bamboo building built in recent years especially in most countries with plenty of indigenous bamboo species. Bamboo grows abundantly throughout the country either mixed with timber trees or in pure stands [5]. Myanmar is situated in the western-most part of south East Asia, between latitude 10’29.5” North and longitude 92’ 100.5”East.It is the largest country in the south East Asia with a total land area of 676,578 square kilometers and 50% is covered with forest. Moreover, Myanmar is the tropical region and it has 17 genera, about 100 species and 4 varieties of bamboo. Three main bamboo productive areas can be categorized as Bago(Pegu) region, Rakhine Yoma and Taninthayi Region[2].

Figure (1) Main Bamboo Productive Areas

2. SCOPE:

The scope of this paper is confined to study physical and mechanical properties of six species of bamboo in Myanmar under green condition.

3. MATERIALS:

There are six species of bamboo which approximately 3years old were taken from several places in Myanmar.

Geometric Properties of Bamboo

a. Wabomyetsangye wa (MSK)

Wabomyetsangye wa, large tufted bamboo, white when young, green-grey when old is a common bamboo of upper Myanmar and covers large areas of ground. It grows in upper and northern parts of Myanmar [7, 8]. It is normally 9-20 m in height, 100-150 cm in culm diameter and 8-15 mm in wall thickness. It can be used for building, building construction, handicrafts, shoots, fodder, weaving, etc.

b. Kyathaung wa (KY)

Kyathaung wa, a large bamboo of about 10-20 m in height, gregarious and tufted. Culms are 70-90 mm in diameter and usually 5-10 mm thick-walled. Internodes are 60-75 cm long and it is easily known by its ashy-white culms. It is very common in the Pegu Yoma and one of the most useful bamboos in Myanmar. It is in great demand for building materials, shoots, baskets, pulp& paper.

c. Wanet wa(WN)

The culms of Wanet wa are about 8-18m long, and 70-80 mm in diameter with long internodes are 35-45 cm. It grows mostly along the side of ravines on moist, fertile loamy soils. It can be used for building, baskets, shoots.

d. Htiyo Wa(HY)

Htiyo wa is grown in villages, schools and monasteries. It rarely grows in natural forests. It is graceful, tufted, straight and strong culmns, naked in lower parts and nodes are not prominent. The culms can be 7.5 m to 12 m long and has a diameter of 35-60 mm. The culms are usually straight and very strong. Its internode is 185-270 mm long. They can be used for all general purposes, decoration, framing, walling, concrete formwork and scaffolding. The average external diameter of Htiyo is 46 mm and its wall thickness 9 mm.

e. Waya wa(WY)

Waya wa, evergreen, densely tufted, gregarious attains a culm height of 9-15 m and a culm diameter of 40 - 60 mm with a wall thickness of 7 - 20 mm. Internodes are often solid and 40- 60 cm long. They are suited to uses as building, construction, handicrafts, basket, and walking sticks. It is found in Lower Myanmar and Taungu [7,8]. It is also planted in Yangon Division.

f. Thaik wa(TH)

The culms of Thaik wa are 7-15 meters high and attain 35-50 mm diameter with strong thick wall 7-25 mm or solids culms. Thaik wa is a strong, useful, thick-walled bamboo with dark-green colour, but the culms are not always straight. They are used for building material, shoots, pulp & paper, handicraft, implement, (fodder, furniture).

Table1: Averages values of geometric properties of bamboo

Average Value of Bamboo						
Name	MSK	KT	WN	HY	WY	TH
Length(mm)	7805	10073	7177	7552	9062	7285
No of nodes	18	15	20	34	17	13
Node to Node Spacing(mm)	482	709	396	224	539	558
Node Diameter(mm)	115	88	78	48	54	49
Diameter(mm)	110	87	76	46	49	42
Thickness(mm)	11	7	7	9	11	13

According to the dimension study, the species of studied bamboo can be categorized in two groups namely group 1 for large diameter and group 2 for small ones. The first group involves MSK, KT and WN and its diameter range from 70-150mm and the latter group involves HY, WY and TH and its diameter range from 35-60mm shown in table (1).

Table2: Grouping of tested bamboo species

Group-1	Large Diameter	MSK
		KT
		WN
Group-2	Small Diameter	HY
		WY
		TH

4. EXPERIMENTAL STUDY:

There are six species of bamboo which approximately 3years old were taken from several places in Myanmar. They were sound and free from any defects, and were representative of average dominant bamboo culms of the locality. The name of the species, the name of locality, and the age of the culms and date of cutting and felling and transportation were recorded. In testing physical and mechanical properties, the designations in ISO 22157 were followed. [3][4]

Physical Properties:

Each bamboo culm was divided into three equal parts: Bottom, Middle and Top.
From the base of each part, specimens for testing physical properties were cut and prepared. The tested physical properties are:
(i) Moisture content
(ii) Shrinkage
(iii) Density and
(iv)Water absorption

Mechanical Properties:

The mechanical properties of bamboos depend on the species itself, the age, moisture content, its origin(soil, altitude, climate conditions) , part of the stem (bottom, middle ,top) [6]. Additionally, the position of the nodes and the internodes themselves produce different characteristics; nodes are weaker in compression and bending [9].The mechanical properties of bamboo tested are static bending, compression parallel to grain, and tension parallel to grain and shear parallel to grain.

5. RESULTS AND DISCUSSION:

5.1 Physical Properties:

i. Moisture Content (MC)

The result of moisture content of the bamboo culm in green condition is shown in Figure (2). The percentage of moisture content is peak at HY among all six kinds of bamboo species. The percentage of moisture content is higher in bottom portion than the remaining two portions. For WN and HY, the percentage of moisture content in top portion is higher than in middle portion.

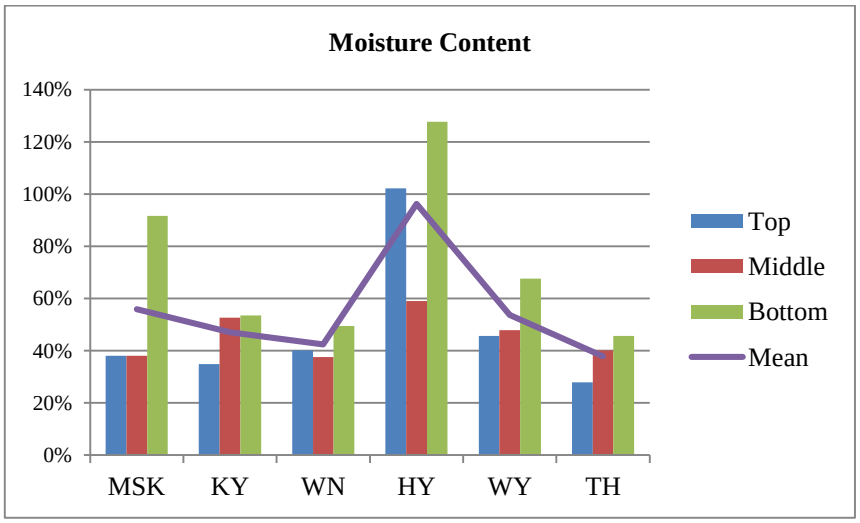

Figure (2) Percentage of moisture content for six bamboo species

For group 1, the average moisture content of MSK has the most superior and KT followed the second and WN come from third. As for the group 2, HY possess the largest moisture content in basal portion especially and the percentage of moisture content is 1.7 times higher for WY and 2.5 times for TH respectively. Generally, moisture content is highest in the bottom portion and lowest in the top portion and it is one the most important factor for determining strength properties of bamboo.

ii. Shrinkage

This figure illustrates the longitudinal shrinkage, diameter shrinkage and thickness shrinkage with three portions for each species. In this graph, the first part shows the percentage of thickness shrinkage of six bamboo species. The wall thickness shrinkage from green to oven-dry condition is not definitely increasing or decreasing. The highest wall thickness shrinkage is found in TH wa range from 4-14% and the least shrinkage in KY wa from 1-3%. Species and culm height have a significant effect on the wall-thickness shrinkage.

The middle part of the figure shows the diameter shrinkage. It can be found that the diameter shrinkage decrease with height in most bamboo species. It is the highest in WY wa (7.508%) and the least in WN wa (3.488%). So, there is a significant effect of species and culm height on the diameter shrinkage from green to oven-dry.

The longitudinal shrinkage of the tested bamboo species are shown in final part of the graph. It ranges from 0.225 % in TH wa to 1.326% in WY wa. The longitudinal shrinkage of bamboo is quite small as in wood. Compared to diameter shrinkage and wall-thickness shrinkage, it is negligible. It is quite clear that it decreases with height.

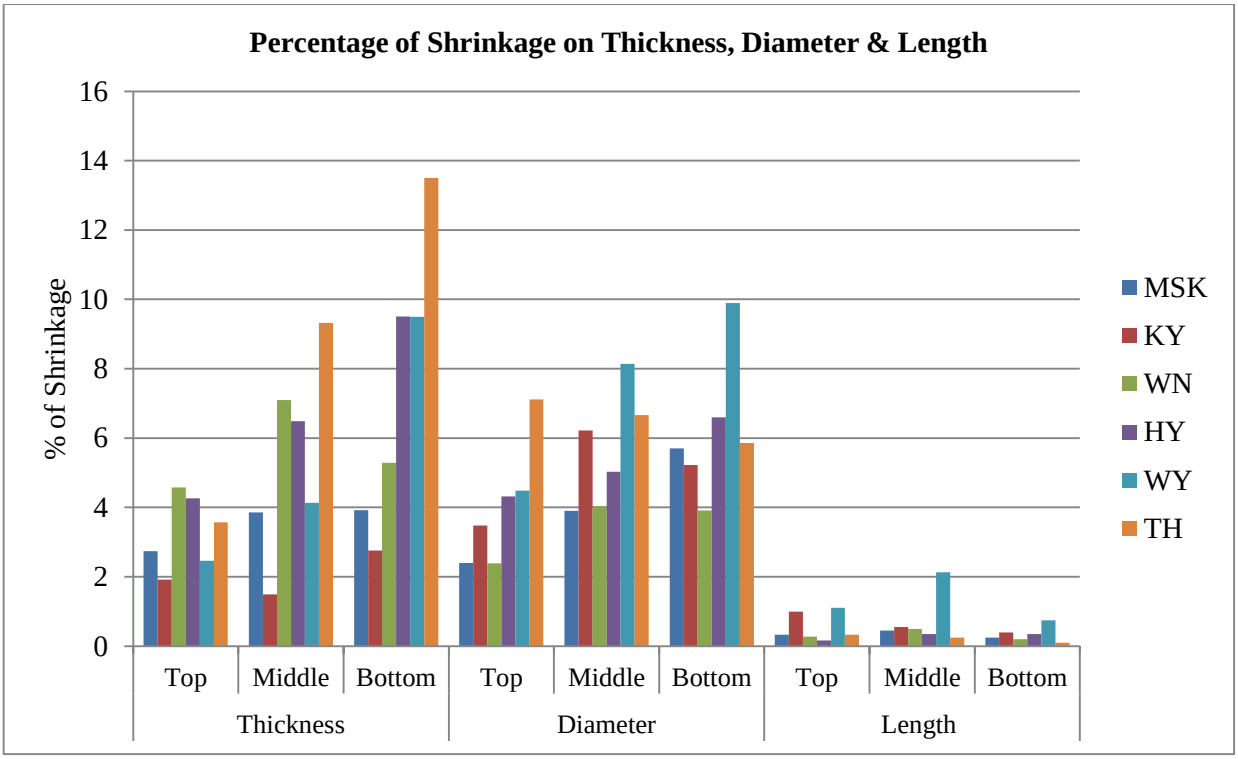

Figure (2) Percentage of Shrinkage on Thickness, Diameter & Length for six bamboo species

iii. Density

Table (3) Basic Density of bamboos

Basic Density (kg/m3)	MSK	KT	WN	HY	WY	TH
Top	618	615	1402.62	1043.12	641.90	702.58
Middle	614	714.42	745.62	1172.5	680.90	718.58
Bottom	511.42	683.71	647.25	450.75	584.72	668.58

The average basic density of the tested bamboo species ranges from 581 kg/m^3 in MSK wa to 932 kg/m^3 in WN wa shown in figure (4). This variation could be due different anatomical and chemical compositions and other factors such as climate, site, etc. There are significant effects of species and culm height on density. It is very clear that green density increases with height in almost all species (Table 2). This is due the increase in the concentration of vascular bundles and the higher amount of silica in the upper portion.

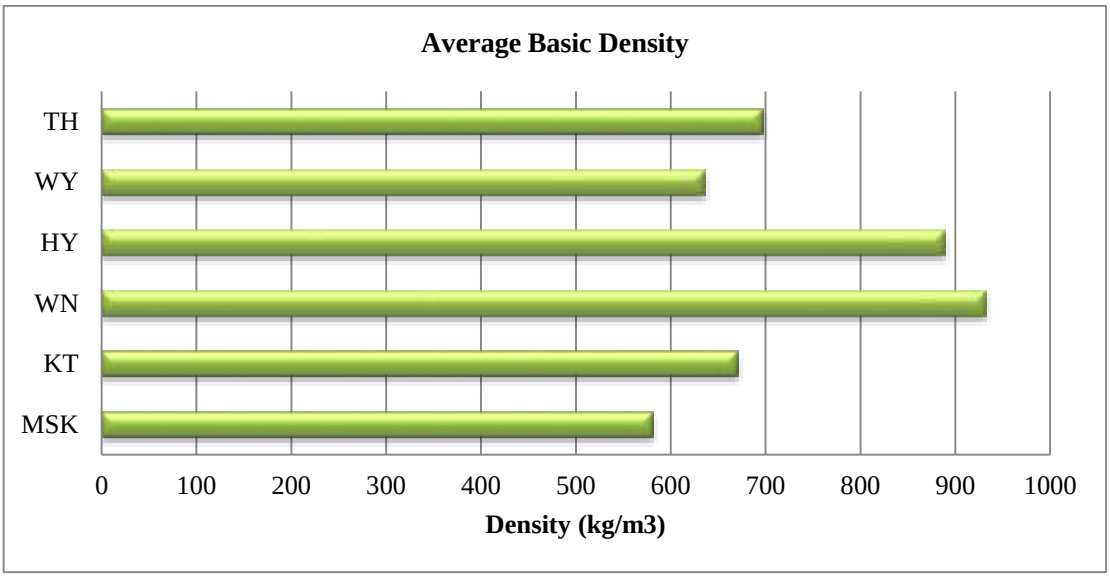

Figure (4) Average Basic Density for six bamboo species

iv. Water Absorption

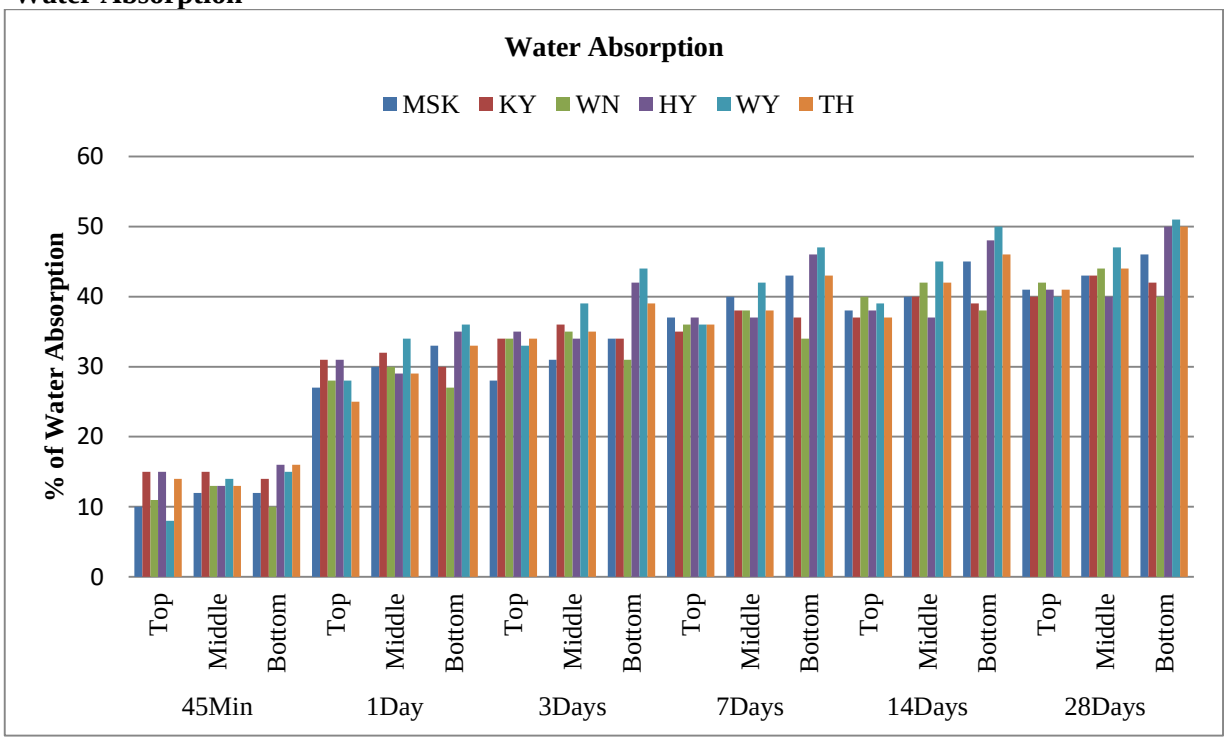

Figure (5) Percentage of water absorption for six bamboo species

Water absorption is used to determine the amount of water absorbed under specified condition. There are some factors such as type of plastic, additives used; temperature and length of exposure affect the water absorption. The figure (5) shows the result of water absorption test. Water absorption by bamboo sample when soaked is at faster rate from 45 min to 7days range from (22-30%) thereafter it declines for all species range from (2-3%). Generally, the rate water absorption is decreased from bottom to top portions. According to the results, for initial setting time of concrete KY and HY has the highest rate, for 7 days strength of concrete the rate of water absorption is upsurge at WY. At 28 days, the accretion of water absorption is WY.

5.2 Mechanical properties:

i. Ultimate bending strength

For flexural test, the test specimens are limited because of limitation of machine size. The length of specimens is 500 mm. The maximum stress of bamboos ranges from 3.8771 N/mm2 in KY to 48.0368 N/mm2 in TH in green condition with random nodes shown in (Table 4) and from 4.1657 N/mm2 in KY wa to 114.366 N/mm2 in TH for center node specimen shown in (Table 5).

Table (4) Ultimate Bending Strength (N/mm^2) (Ordinary Node)

Name	Ultimate Bending Strength (N/mm^2)					
Portion	MSK	KY	WN	HY	WY	TH
Top	5.0850	4.9161	12.4686	23.8278	28.3951	55.4916
Middle	2.4196	2.9352	10.7281	22.5070	30.2257	42.2279
Bottom	17.4428	3.7799	20.4568	30.3397	63.2667	46.3909

For small diameter group, TH is almost solid or with a very small hollow. So, it is quite good for construction uses. For the next group, WN (14.5512 N/mm2) has the highest ultimate bending strength and is suitable for construction purposes. Generally, the rate of bending stress is increased in bottom portion and decreased in top portion in most species. But in some species show the middle portion with least values.

Table (5) Ultimate Bending Strength (N/mm^2) (Centre Node)

Name	Ultimate Bending Strength (N/mm^2)(Centre Node)					
Portion	MSK	KY	WN	HY	WY	TH
Top	9.489594	5.216137	15.23932	55.70861	52.16221	93.10339
Middle	4.238641	4.42267	16.59614	30.84912	71.84107	125.9946
Bottom	4.188287	4.046343	20.87365	37.50866	74.90843	123.9998

Figure (5) shows the comparison of bending stress with centre node and random nodes. According to the result, the center node specimens are higher bending stress than the ordinary node ones while there is no significant change in MSK and KY. Additionally, the node different result for small diameter group is more significantly increased than large diameter group. The strength different is about 2.5 times for TH and nearly 1.5 times higher for WN.

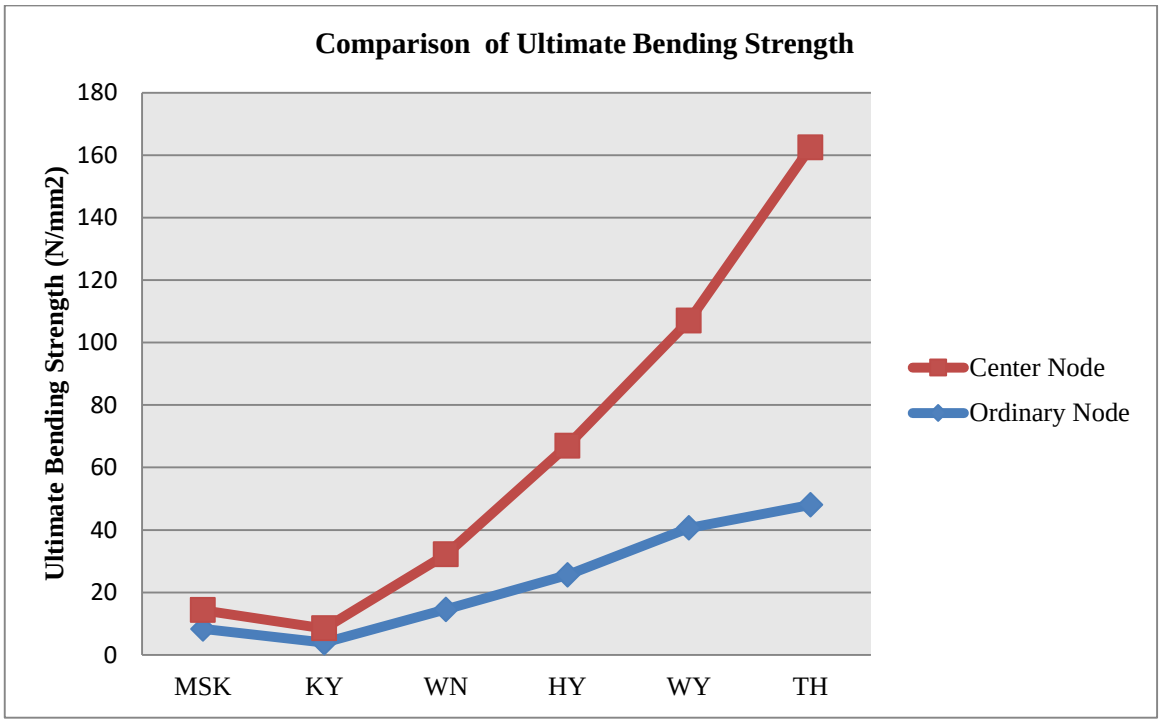

Figure (6) Comparison of Ultimate Bending Strength

Figure (6) shows the comparison of bending stress with center node and random nodes. According to the result, the center node specimens are higher bending stress than the ordinary node ones while there is no significant change in MSK and KY. Additionally, the node different result for small diameter group is more significantly increased than large diameter group. The strength different is about 2.5 times for TH and nearly 1.5 times higher for WN.

ii. Modulus of Elasticity

The modulus elasticity of tested bamboos at is given in Table 6 .In general, modulus of elasticity is varied with the height of the culm. The maximum modulus of elasticity is found in TH wa while the least modulus of elasticity was observed in KT wa. It shows that TH wa has a higher resistance to deformation than KT. For the large diameter group, WN wa has peak modulus of elasticity. Similarly, for small diameter group TH has the topmost species of the tested bamboo.

Table 6: Modulus of elasticity of tested bamboo

MOE(N/mm^2)	MSK	KT	WN	HY	WY	TH
TOP	612.29	459.02	1930.65	5413.15	5779.47	13168.14
MIDDLE	201.96	273.74	780.23	4225.84	4558.83	6850.93
BOTTOM	863.90	289.27	2386.51	3169.27	5791.42	8871.28

iii. Maximum crushing strength

As reported in Figure(7) , the average compressive strength of bamboo was observed to be high at the top part of some bamboo species such as KY, WN, HY whereas the middle part of some species such as MSK, WY,TH. The rate of compressive strength ranges from 42 N/mm2 in HY wa to 60 N/mm2 in TH wa at green condition. Normally the strength increases with height.

Visual inspection on the specimens after compression test also revealed multiple cracks, which eventually led to splits as individual specimens' sections buckled. These vertical cracks are shown in Figure 7. From this figure, it is the evident that bamboos with air-dried culms experienced brittle failure

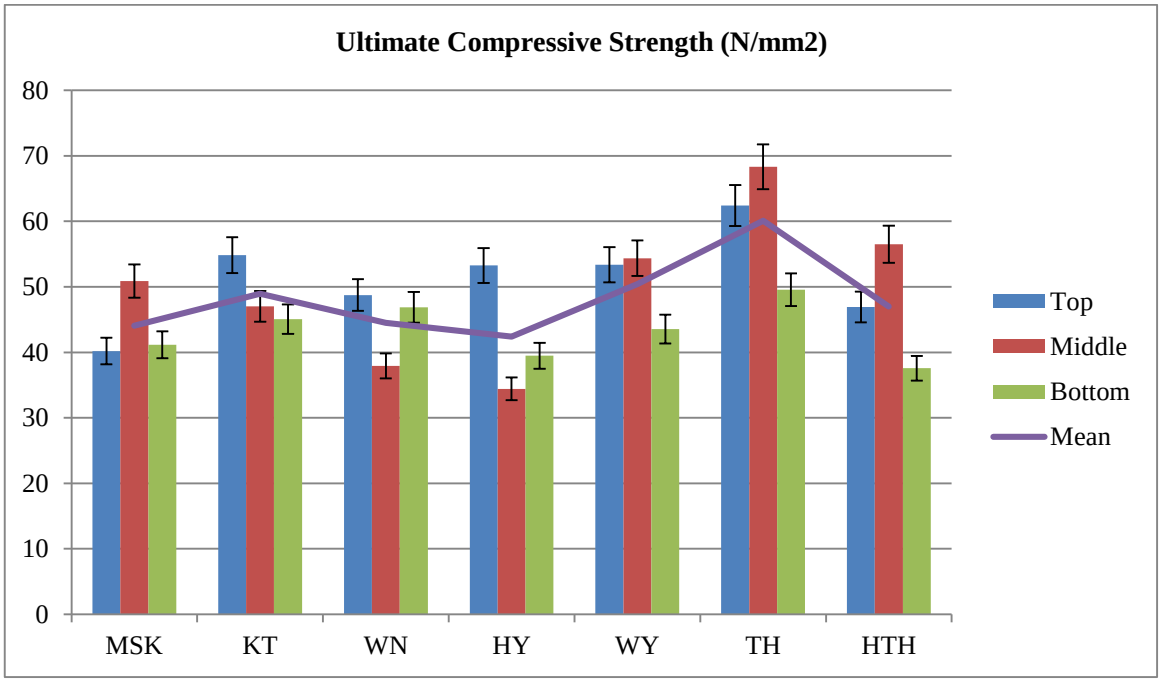

Figure (7) Ultimate Compressive Strength

iv. Tensile strength

Table7: Ultimate Tensile Strength of tested bamboo

Ultimate Tensile Strength (N/mm^2)						
Portions	MSK	KY	WN	HY	WY	TH
Top	215.084	292.02	157.1	220.2486	223.24	265.346
Middle	316.96	320.36	226.26	194.234	257.08	209.088
Bottom	251.826	243.02	182.84	175.822	200.08	142.438
Average	261.29	285.134	188.73	196.7682	226.7938	205.624

Tensile strength test parallel to bamboo's grain was carried out in the same condition as compressive strength test. The result of the tensile test is shown in Table 7. Table 7 shows the tensile strength of six kinds of bamboo species.

The average strength of MSK, KY,WN and WY are slightly higher at the middle part of the bamboo, while the strength at the top and bottom parts of WY are nearly equal, with recorded readings of over 200 N/mm2. The remaining species such as HY and TH have greatest tensile strength at top portion and middle followed the second and the strength of bottom portion is lowest.

The average highest strength of the bamboo specie (KY) recorded a reading of 285.134N/mm2, while the lowest strength recorded a reading of 188.73 N/mm2 in WN.

Figure (8) Failure pattern under tensile test

Figure(8) shows failures of specimens taken from tensile test. Most of the specimens experienced similar mode of failure whereas the specimen with node is weaker than internode specimen.

v. **Maximum shearing strength**

Table 8: Ultimate shear strength of tested bamboo

Ultimate Shear Strength(N/mm2)		Bamboo Species					
		MSK	KT	WN	HY	WY	TH
Bottom	WN	42.9	53.05	39.8	41.97	51.72	37.13
	CN	35.91	53.93	35.03	54.76	59.75	36.86
Middle	WN	43.42	51.33	45.2	35.52	51.36	26.29
	CN	37.56	48.14	39.5	40.83	52.81	35.05
Top	WN	34.35	50.57	47.52	37.92	40.66	22.08
	CN	27.53	47.86	48.92	36.19	43.72	22.9

The maximum shearing strengths of bamboo are shown in Table 8. It ranges from 27 N/mm^2 to 60 N/mm^2 in tested bamboo species. For the large diameter group, the rate of strength is highest is KT. However, for small diameter group, the bottom portion has the peak ultimate shear strength. According to the result species and sections have significant effects on the maximum shearing strength in most species, but the effect of node/internode is not significant. In most cases, the shearing strength of the node portion is found slightly higher than that of the internode portion as shown in figure (8).Figure (9) shows failures of specimens taken from shear test.

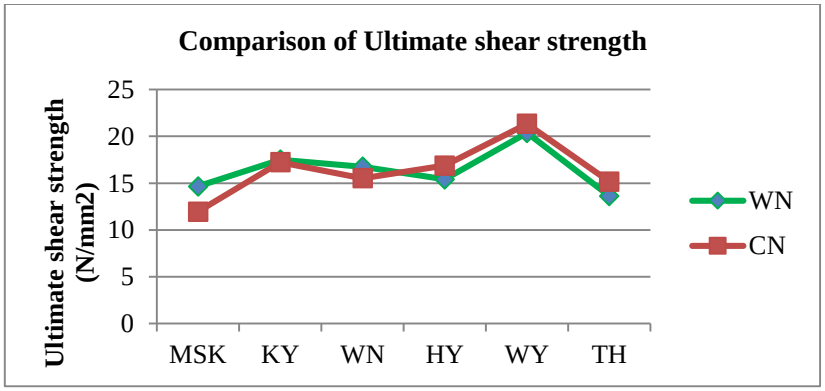

Figure (8) Comparison of Ultimate shear strength

Figure (9) Shear strength

6. CONCLUSION :

Species	Ultimate bending strength (N/mm^2) (CN)	Ultimate bending strength (N/mm^2) (WN)	Modulus of elasticity (N/mm^2)	Ultimate compressive strength (N/mm^2)	Ultimate tensile strength (N/mm^2)	Ultimate shear strength (N/mm^2) (CN)	Ultimate shear strength (N/mm^2) (WN)
MSK	6	8	560	44	260	34	40
KT	5	4	340	49	286	50	52
WN	18	15	1700	45	190	41	44
HY	41	26	4270	42	200	44	38
WY	66	41	5400	50	230	52	48
TH	114	48	9700	60	206	32	29

The present study indicates that bamboo has a promising potential to be used as a construction material. In the study, compression, tensile, and moisture content tests were conducted to test six bamboo species' ability and capability. From the overall result of mechanical testing, for group 1, both Wanet-wa and Kyathaung-wa have no significant difference in ultimate rate of compressive and shear strength. As for the ultimate bending test Wanet-wa is 4.5 times higher than Kyathaung-wa. On the other hand, Kyathaung-wa possesses upsurge ultimate tensile strength among six species. For group 2, Thaik-wa specie endured the highest compression and possesses the highest bending strength, followed by Htiyo-wa, Waya-wa species. Thus, the experimental results revealed that bamboo has a good performance in strength properties. Thus, the experimental results revealed both Wanet-wa and Kyathaung-wa have a good performance in strength properties for large diameter group and for small diameter group, the best mechanical performance was found in Thaik-wa. The findings of this study will indicate that the applying of bamboo should be used widely.

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