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Utilization-oriented Technological Properties of Two Myanmar Bamboo species

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မြန်မာ့ဝါးနှစ်မျိုး၏အသုံးချမှုဆိုင်ရာနည်းပညာဂုဏ်သတ္တိများ

ချိုချိုမြင့်၊ သုတေသနလက်ထောက်-၂
သစ်တောသုတေသနဌာန၊ ရေဆင်း

ခင်မြင့်မြင့်၊ ပါမောက္ခ(ဌာနမှူး)
ရူပဗေဒဌာန၊ မိတ္ထီလာတက္ကသိုလ်

ခင်မောင်ဆင့်၊ လက်ထောက်မန်နေဂျာ
မြန်မာ့သစ်လုပ်ငန်း

စာတမ်းအကျဉ်း

ဝါး၏သုံးစွဲမှုအလားအလာကို စနစ်တကျသောနည်းဖြင့် မြှင့်တင်ပေးနိုင်ရန်နှင့် သစ်သားအစားထိုး သုံးစွဲနိုင်ရန် ဝါးနှစ်မျိုး၏ ရူပနှင့်အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကို စမ်းသပ်လေ့လာခဲ့ပါသည်။ ၎င်းဂုဏ်သတ္တိများသည် ဈေးကွက်တွင် လက်ခံလာမှုအတွက် အခြေခံအချက်အလက်များပင်ဖြစ်ပါသည်။ ၎င်းဂုဏ်သတ္တိများသည် အထူးသဖြင့် အင်အားအရေးပါသော အသုံးပြုမှုများအတွက် အရေးပါလှသည်။ စမ်းသပ်လေ့လာခဲ့သောဝါးမျိုးများမှာ ထီးရိုးဝါးနှင့်ဝါးနွယ်တို့ဖြစ်ပြီး စီးပွားရေးအရလည်းအရေးပါလှပါသည်။ဝါးတစ်မျိုးကိုခြောက်ရုံ၊တစ်ရုံကို ဝါးပင်ခြောက်ပင်နှုန်း ကျပန်းခုတ်ယူစမ်းသပ်ခဲ့ပါသည်။ ဝါးတစ်ပင်ကိုအောက်၊ အလယ်၊ အဖျားဟု ခွဲခြမ်းစမ်းသပ်ခဲ့ပါသည်။ အစိုဓာတ်ပါဝင်မှုသည် ထီးရိုးဝါးတွင် ၇၇.၇% ရှိပြီး ဝါးနွယ်ဝါးတွင် ၆၄.၈% ရှိသည်။၎င်းအစိုဓာတ်သည် ဆောက်လုပ်ရေးလုပ်ငန်းသုံး သစ်များထက် မြင့်မားနေပြီး ဝါးပင်အမြင့်သို့တက်လေ လျော့ကျသွားလေဖြစ်သည်ကိုတွေ့ရပါသည်။ အချင်း၊ အထု၊ အရှည်နှင့်ထုထည်ကျုံ့မှုပမာဏသည်လည်း သစ်မျိုးများထက်များနေသည်ကိုတွေ့ရပြီး ၎င်းမြင့်မားမှုသည် ရေချိန်သိပ်သည်းဆ မြင့်မားသောကြောင့်ဖြစ်သည်။ အဆိုပါဝါးမျိုးများ၏ ရုံးပြန်သတ္တိနှင့်အင်အားများသည်လည်း မြင့်မားသောကြောင့် ၎င်းတို့ကိုဆောက်လုပ်ရေးလုပ်ငန်းများတွင် ဘေးကင်းစွာသုံးစွဲနိုင်ပါသည်။ ဝါးနွယ်ဝါးသည် အုပ်စု(၁)တွင် စာရင်းဝင်သဖြင့် ဆောက်လုပ်ရေးအတွက် အကောင်းဆုံး ဖြစ်သည်ဟုဆိုရပါမည်။ ထီးရိုးဝါးကိုအုပ်စု(၂)တွင် စာရင်းသွင်းနိုင်သောကြောင့်ဆောက်လုပ်ရေးလုပ်ငန်းများတွင် သုံးစွဲနိုင်ကြောင်းလေ့လာတွေ့ရှိရပါသည်။

Utilization-oriented Technological Properties of Two Myanmar Bamboo species

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Abstract

In order to enhance the utilization potential of bamboos in a systematic way and to apply them as a timber substitute, physical and mechanical properties of two bamboo species were studied, which serve as a basis for promoting their acceptance to markets, especially in uses where strength is essential. The tested bamboo species are *Thyrsostachys siamensis* and *Dinochloa maclellandii,* which are commercially important among many bamboo species occurring in Myanmar. Six clumps and six culms per clump were randomly harvested from natural bamboo forests and planted bamboo clumps, and the culms were divided into three portions (Base, Middle and Top). Physical and mechanical properties were tested according to DIS 22157. The moisture content is 77.7% in Htiyo wa and 64.8% Wanwe wa and decreases with height. Shrinkage in diameter, wall thickness, longitudinal direction and volume is high compared to common construction timbers, which decreases with height, and is closely associated with high specific gravity. Their elasto-mechanical properties are also high enough to use safely in constructions and many other applications such as furniture, and are found to significantly vary with height. Htiyo wa can be grouped into Group II, which is best suited to construction and Wanwe wa into Group I.

Key words: ***Thyrsostachys siamensis* , *Dinochloa maclellandi*, Physical and Mechanical Properties,Utilization**

Contents

1. Introduction

Bamboo is a woody grass producing a versatile material used for constructions, furniture, handicrafts, baskets, mats, rayon, paper, food, fodder and fuel wood (Nor 1995). Except Europe, it is widely distributed in tropical, subtropical and mild temperate zones of all continents (Lobovikov 2007). Varying in number of world bamboo genera and species, around 90 genera and 1200 species are reported in many publications (Lobovikov 2007; Maoyi 1995; Fu 2000). But, around 400 bamboo species and subspecies still occur in the world and are less well-known (Bystriakova et al. 2004). Thus, the world bamboo species can be up to 1500-1600 high, which is in agreement to the number of woody and herbaceous bamboo species (1575) given by Ohrnberger (1999). Among bamboo growing continents, Asia is the richest as it is endowed with 65% of the total world bamboo resources (Lobovikov 2007). It also stands first in terms of bamboo species, as 1012 species are found in the Asia-Pacific region (Bystriakova 2003).

There are 17 bamboo genera and around 97 species (75 - 100) in Myanmar (Lobovikov 2007; Htun 1998), which exercise a very important role in daily life of people, at least in the rural areas. Its utilization expands from construction to production of toothpick, and from economic purposes to environmental conservation. Bamboo culms and shoots can be used at any age. According to Adam (2009), the utilization potential of bamboo is as follows:

- <30 days it is good for eating
- 6-9 months for baskets
- 2-3 years for bamboo boards or laminations
- 3-6 years for construction
- >6 years bamboo gradually loses strength

2. Literature review

Bamboo is a renewable material, which consumes very much lower energy than other construction materials such as wood, concrete, steel, etc. It needs only half of energy as wood does, one-sixth as concrete and one-eight hundredth as steel. It is also very light, but can be compared to steel in tensile strength and much stronger and stiffer than wood. It is as efficient as steel in axial compression and stiffness (Janssen, 1981). But bamboo is more resistant to earthquakes and strong winds than any other construction materials due to its low weight which causes much less acceleration-induced inertia forces in direct proportion to its mass (Gutierrez 2004). In fact, the energy stored in bamboo and wood, which is the measure of toughness or sudden impact, is half of that of steel, but as it is very much lighter than steel, only 10% of bamboo building will be destroyed while 90% of steel building is destroyed in an earthquake (Gutierrez 2004; Janssen 1981). As bamboo has excellent mechanical properties, especially a superior tensile strength (Liese, 1987; Kumar et al. 1994), which must be present in a material to qualify for earthquake resistance (Gutierrez 2004), it can resist earthquakes and cyclones.

Mechanical properties vary not only between bamboo species, but also within species and culms. While modulus of rupture, moisture content and shrinkage are decreasing with height, modulus of elasticity, maximum crushing strength and densities are increasing in Melaysian bamboos *Melaocanna baccifera* and *Bambusa balcooa* (Sattar et al. 1991). The increasing trend can be explained by the increase of sclerenchyma tissues and decrease of parenchyma at the top (Liese and Weiner, 1995; Sattar et al, 1991). The mechanical and physical properties were found to be affected by age and height (Mohamad, 1995). The general agreement is that a bamboo culm matures at about two to three years and has reached its maximum strength (Liese and Weiner, 1995). As bamboo shrinks 10-16% in diameter and 15-17% in wall thickness, its shrinkage is appreciably higher than that of wood (Kumar et al. 1994). In fact, the shrinkage is totally dependent on the moisture content and starts at higher moisture contents above fiber saturation point.

Although bamboo is rich in silica content, the entire silica is located in the epidermis layers and its contribution to the resistance to the attacks by fungi and insects is limited to only these layers.But it contains a very much large amount of starch, which makes it very susceptible to attacks by fungi and insects (Kumar et al. 1994). Bamboo is more susceptible to white rot fungi than brown rot, which is due to the fact that white rot fungi can utilize both carbohydrate and lignin (Hamid et al. 2003). In fact, durability is also dependent on the age of the culm as well.

In Myanmar, it has been a long tradition of utilizing bamboo culms in building houses and bridges, scaffoldings, ladders, furniture, etc, where strength is essential. As the culms available vary in species and size, their applications differ accordingly. There are also extensive bamboo forest areas in Myanmar, which amount to 27,853,000 ha in 2005 with value of bamboo wood removal being estimated to be about 229 billion kyats in 2004-05 (FAO, 2006). Despite their such significant importance to the country's economy and daily life of people, information on their utilization-oriented technological properties such as physical and mechanical properties are still scare, which serve actually as basis to the promotion of their systematic utilization. Thus, the objective of this study is to investigate physical and mechanical properties of two economically important and abundantly available Myanmar bamboo species in order to promote their utilization in a systematic way.

3. Material and Methodology

In selecting bamboo species for this study, the following criteria were bone in mind:

(i) They should have a diameter of at least 25 mm, so that they can be practically put into uses where strength is required.
(ii) They should be of economically importance in Myanmar.

Depending on these criteria, Htiyo wa and Wanwe wa were selected for this study. These both species are readily available near Yezin. Htiyo wa is grown in almost every monastery and village in Pyinmana Township. Wanwe wa grows wild abundantly in the forests near Yezin.

These two species are also economically important species (Htun, 1998). Although their production data are not available, they can be convinced that they are economically important at least to the rural population.

According to the measurement data of tested sample culms, they attain a diameter of about 35 mm. They are so long that culms can bend over others. The two species were collected from Pyinmana Township.

3.1 Htiyo wa (*Thyrsostachys siamensis*)

Htiyo wa is grown in villages, schools and monasteries. It rarely grows in natural forests. It can be found in almost every monastery in Pyinma Township. It is called Kyaung wa in some parts of Myanmar.

The culms can be 7.5 m to 12 m long and have a diameter of 38-75 mm. They are usually straight and very strong. Their internodes are 150-300 mm long. They can be used for all general purposes, framing, walling, concrete framework and scaffolding (Jayanetti and Follet 1998). The tested sample culms are found to attain an average height of 10 m. The average external diameter of Htiyo is 42 mm and its wall thickness 7.92 mm.

The culm can be up to 13 m high and the culm diameter is 3-6 cm. The internodes are 15 – 19 cm long. The culms are densely packed and slightly out-arched at the upper part. The culm sheath is persistent, closely covering the internode. It is light green and white waxy when young. The distinguishing characteristics of the bamboo are its closely dense growth with branching absent in the basal part (Moe et. al., 2006).

3.2 Wanwe (*Dinochloa maclellandii*)

There are four bamboo species of genus Dinochloa in Myanmar according to the Checklist of the trees, shrubs, and climbers of Myanmar prepared in 2003. They are *Dinochloa andamanica* (Poaceae), *Dinochloa compactiflora* (M*elocalamus compactiflorus*) (Poaceae), *Dinochloa maclellandii* (Poaceae) and *Dinochloa marginata* (*Bambusa marginata*) (Poaceae).

Wanwe wa is an evergreen, lofty, often scandent bamboo. Culms are up to 30 m long, and 25-50 mm in diameter. Internodes are 15-20 cm long. It grows mainly in tropical lowland rain forests. It is found in Bago, hill forests and Taninthary Division (Hundley, 1987). The tested sample culms attain an average height of about 12 m, an average diameter of 31.43 mm, and an average wall thickness of 7.82 mm.

3.3 Methodology

Bamboo culms are selected from various clumps in the standing condition. Six clumps per species were randomly chosen, and six culms were randomly selected from each clump. They were sound and free from any defect, and were representative of average dominant bamboo culms of the locality. They were at least 3 years old.

The name of the species, the name of locality, the age of the culms and date of felling and transportation were recorded. The sample culms bear the name of the species, the clump number, and the culm number. Physical and mechanical properties were tested in accordance with DIS 22157.

3.4 Data analysis

In this research, the influence of two factors on physical and elasto-mechanical properties has been analyzed for a single clump: culms with 6 levels (1-6) and culm height with 3 levels (bottom, middle and top) with one repetition per section for each property.

The experimental design was a completely randomized two-factorial model:

$$Yijk = \mu + Ai + Bj + (AB)ij + \varepsilon ijk \quad \text{------ (I)}$$

However, for a bamboo species, the influence of three factors as sources of variation of properties has been analyzed: clumps, culms and culm heights. The third factor C (clumps) was added to the above model.

The experimental design was a completely randomized three-factorial model.

$$Yijkl = \mu + Ai + Bj + Ck + (AB)ij + (AC)ik + (BC)jk + (ABC)ijk + \varepsilon ijkl \quad \text{-----(II)}$$

where,

Yijkl = Value of variable Y due to the effect of the i^{th} level of culms, j^{th} level of culm heights and k^{th} level of clumps at l^{th} repetition

μ = Mean value of expectation of variable Y

Ai = Influence of i^{th} level of culms

Bj = Influence of j^{th} level of culm height

Ck = Influence of k^{th} clump

(AB)ij = Influence of interaction between i^{th} level of culms and j^{th} level of culm height

(AC)ik = Influence of interaction between i^{th} level of culms and k^{th} level of clumps

(BC)jk = Influence of interaction between j^{th} level of culm height and k^{th} level of clump

(ABC)ijk = Influence of interaction among i^{th} level of culms, j^{th} level of culm height, and k^{th} level of clumps.

If the influence of mentioned factors and their interactions was significant, the test of significant difference was conducted according to Tukey's test. But the effects of clump, culms, and sections and their interactions all could not be analysed at one and the same time due to one specimen per section for some properties. More than one specimen was required for parallel testing.

4. Results and discussion

4.1 Moisture content

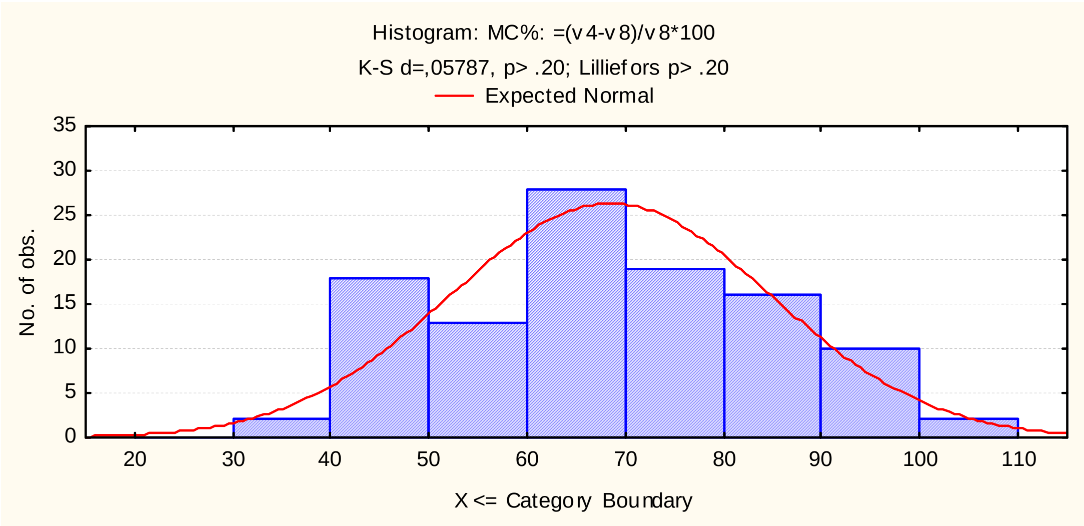

Figure 1: Distribution of moisture content of Wanwe wa following normal one

Moisture content is an important factor governing physical and mechanical properties of bamboo. Bending and compression strength of green bamboo significantly differ from those of the same air-dried bamboo (Li, 2004).The moisture content ranges from 64.5% to 85.3% in Htiyo wa and from 65.4% to 71.6% in Wanwe wa at 95% probability level, and decreases with height in every culm of both species .This trend is due to increasing fibers and decreasing parenchyma with height (Liese, 1980) as the decrease of parenchyma decreases the water holding capacity (Kumar et al. 1994). The two species are found to be significantly different in moisture content, which is the result of differences in anatomical characteristics and inherent factors.

4.2 Shrinkage

Shrinkage and swelling result from loss or gain of water in the cell wall below fiber saturation point in wood, which causes warping, checking, splitting, loosening of tool handles, gaps in strip flooring, etc. (Forest Products Laboratory 1999). As bamboo start to shrink right from the beginning of drying (Sattar, et al. 1991), its shrinkage appears to be higher those of most timber species, and the problems arising from shrinkage will be larger accordingly.

Htiyo wa shrinks from 6.7% to 9.1% in diameter, 7.6% to 8.0% in wall thickness, from 0.08% to 0.11% in axial direction and from 19.0% to 20.5% in volume while Wanwe wa does 7.8% to 8.3% in diameter, from 9.9% to 10.5% in wall thickness, from 0.22% to 0.27% in axial direction and from 19.6% to 21.5% in volume from green to oven-dry condition.

Wanwe wa shrinks more than Htiyo wa although they possess virtually almost the same moisture content. The higher moisture content normally contributes to the higher shrinkage (Sattar et al. 1991). There may be other factors governing shrinkage such as anatomical characteristics and dimensions of bamboo such culm diameter and wall thickness. Wanwe wa is thicker in wall than Htiyo wa, which might result in higher shrinkage of Wanwe wa, but this difference is not statistically different.

Volumetric shrinkage was determined by two different methods: water displacement method and direct measurement of dimensions, which result in significantly different shrinkage values in both species, with the direct measurement method giving the lower values.

Table 1: Comparison of average volumetric shrinkage values by two sample t-test

Species	Mean by water displacement method	Mean by direct measurement	t-value	df	p
Htiyo wa	19.8	14.1	12.4	214	0.00
Wanwe wa	20.5	17.1	5.9	214	0.00

4.3 Density and Specific gravity

Density is the mass contained in a unit volume of a material, and specific gravity is the ratio of the density of the material to the density of water. Specific gravity is also called relative density (Tsoumis 1991). As they are the indices of the amount of wood fibers in a given volume, they are directly related to strength, elasticity, pulp yield, shrinking and swelling, and heat transmission. The difference between the two parameters is that density is based on weight measured at any moisture content while specific gravity is determined on oven-dry weight.

The basic specific gravity ranges from 0.626 to 0.656 (water displacement method) and from 0.612 to 0.642 (direct measurement method) in Htiyo wa while it is from 0.626 to 0.654 (water displacement method) and from 0.617 to 0.647 (direct measurement method) in Wanwe wa at a 95% probability level. The specific gravities determined by two different methods are not significantly different from each other in both species. The specific gravity at 12% moisture content lies between 0.672 and 0.706 by water displacement method and between 0.655 and 0.690 by direct measurement method in Htiyo wa at a 95% probability level. It varies between 0.671 and 0.704 based on water displacement method and between 0.661 and 0.695 based on direct measurement method in Wanwe wa at a 95% probability level. The two means are not significantly different between the two different methods in both species.

The oven-dry specific gravity of Htiyo wa is from 0.782 to 0.816 by water displacement method and from 0.713 to 0.747 by direct measurement method while that of Wanwe wa ranges from 0.789 to 0.824 when based on volume by water displacement method, and from 0.746 to 0.780 when based on volume by direct measurement method. The means obtained from two different methods are found significantly different in both species. Although these two different methods result in similar values of basic specific gravity, oven-dry specific gravities were significantly different. This is due to the fact that at green condition, the volumes are the same by which method it is measured, but after oven-drying, the specimens underwent shrinking, which was not regular, and thus direct measurement could not give the accurate volume (normally over-estimated), resulting in lower oven-dry specific gravity, there by the two value being significantly different.

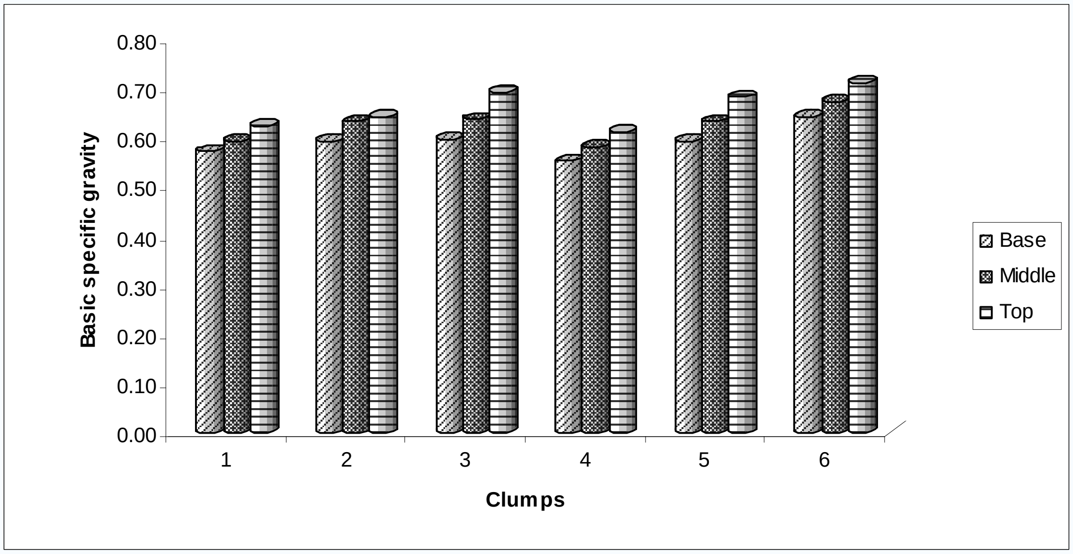

Figure 2: Graph showing basic specific gravity of Htiyo wa increasing with height

In both species, the specific gravity increases with height. This is due to the presence of higher proportion of sclerenchyma tissue/fibrovascular bundle at the top of the culm (Sattar et. al. 1991). In the vertical direction the amount of fibres increases from bottom to top and that of parenchyma decreases. Walter Liese (1985) also found that the specific gravity increases along the culm from the bottom to the top . In wood, the increase of fibres increases specific gravity and other mechanical properties (USDA, 1999). Bamboo follows the same trend.

4.4 Modulus of rupture (MOR)

The mean maximum stress that Htiyo wa can offer as a beam ranges from 62.30 to 74.27 N/mm^2 at green condition of 54.46% moisture content, and from 86.35 to 99.50 N/mm^2 at 16.1% moisture content, while that of Wanwe wa lies between 93.81 and 107.52 N/mm^2 at green condition of 52.37% moisture content, and between 114.51 and 126.47 N/mm^2 at 13.78% moisture content.

If the fiber saturation point of this bamboo is assumed to be 20% (W. Liese, 1980), the change of maximum stress due to 1% moisture change is about 4.26% in Htiyo wa and about 3.17% in Wanwe wa. Along the culm, modulus of rupture seems to decrease with height in both species, which is in agreement to the finding by Sattar et al. (1991).

4.5 Modulus of elasticity (MOE)

The modulus of elasticity of Htiyo wa ranges from 25310 to 28340 N/mm^2 at green and 30065 to 33820 N/mm^2 at air dry condition of 17.94% MC. The modulus of elasticity of Wanwe wa ranges from 39538 to 43975 N/mm^2 at green condition and 40598 to 45224 N/mm^2 at air-dry condition. The higher the modulus of elasticity, the stiffer the material is.

Along the culm, the modulus of elasticity increases with height at both green and air-dry conditons. In case of *Dendrocalamus strictus* tested by Limaye (1952), MOE is increasing with height. Sekhar, et. al., (1962) found that the MOE at the top is higher than those at the other parts.

4.6 Maximum crushing strength (MCS)

The maximum crushing strength of Htiyo wa lies between 37.20 and 41.52 N/mm^2 at green and between 49.80 and 56.51 N/mm^2 at air-dry condition while that of Wanwe wa ranges from 35.03 to 38.90 N/mm^2 at green condition and from 44.20 to 51.45 N/mm^2 at a 95% probability level.

Along the culm, the maximum stress is increasing with height at both conditions. Analysis of data by two sample t-test shows that there is a significant difference between sections. The Turkey's test shows that significant difference is restricted to base and top at both conditions. This increasing trend is due to the increase of fibers at the top.

4.7 Maximum shearing stress parallel to grain

The maximum shearing stress of Htiyo wa ranges from 10.9 to 12.2 N/mm^2 at green condition and from 15.4 to 17.2 N/mm^2 at air-dry condition. The maximum shearing stress of Wanwe wa ranges from 11.7 to 13.1 N/mm^2 at green condition and from 15.7 to 17.7 N/mm^2 at air-dry condition. Along the culm, the significant differences are observed among sections at both green and air-dry conditions. But the effect of node is not significant on maximum shearing stress. The pieces with node, however, have a higher value than those without ones.

Table 2: Physical Properties of Two Myanmar Bamboo Species (Htiyo and Wanwe)

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage: Diameter	Shrinkage: Wall Thickness	Shrinkage: Longitu-dinal	Shrinkage: Volumetric
			%	-	kg/m^3	%	%	%	%
Htiyo	Bottom	Green	90.6	0.603	1137	-	-	-	-
		Air-dried	12.0	0.645	923	4.249	4.303	0.057	8.11
		Oven-dried	0.0	0.757	757	7.081	7.171	0.095	20.27
	Middle	Green	78.3	0.640	1111	-	-	-	-
		Air-dried	12.0	0.688	985	4.252	4.891	0.062	8.12
		Oven-dried	0.0	0.804	804	7.087	8.152	0.104	20.30
	Top	Green	64.1	0.680	1108	-	-	-	-
		Air-dried	12.0	0.734	1029	3.929	4.852	0.051	7.47
		Oven-dried	0.0	0.837	837	6.548	8.087	0.084	18.69
	Average	Green	77.7	0.641	1119	-	-	-	-
		Air-dried	12.0	0.689	979	4.143	4.682	0.057	7.90
		Oven-dried	0.0	0.799	799	6.906	7.803	0.094	19.75
Wanwe	Bottom	Green	78.5	0.608	1076	-	-	-	-
		Air-dried	12.0	0.650	780	4.928	5.379	0.178	7.63
		Oven-dried	0.0	0.753	753	8.213	8.965	0.296	19.08
	Middle	Green	66.2	0.658	1083	-	-	-	-
		Air-dried	12.0	0.708	850	5.041	6.528	0.160	8.85
		Oven-dried	0.0	0.844	844	8.402	10.880	0.266	22.11
	Top	Green	60.8	0.655	1045	-	-	-	-
		Air-dried	12.0	0.704	845	4.575	6.491	0.101	8.17
		Oven-dried	0.0	0.823	823	7.625	10.819	0.168	20.42
	Average	Green	68.5	0.640	1068	-	-	-	-
		Air-dried	12.0	0.687	825	4.848	6.133	0.146	8.21
		Oven-dried	0.0	0.807	807	8.079	10.222	0.243	20.54

Note: 108 replications (six clumps x 6 culms/clump x 3 replications per culm) were tested for each property. M.C means "moisture content".

Table 3:Mechanical Properties of Two Myanmar Bamboo Species (Htiyo and Wanwe)

Species	Part of Culm	Seasoning	M.C	Static Bending		Compression parallel to grain		Shear	
				MOR	MOE	MCS	MOE	MS (WN)	MS (N)
			%	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
Htiyo	Bottom	Green	90.9	70.14	24210	35.82	1815	9.85	10.33
		Air-dried	16.1	90.93	29197	45.69	2063	13.35	13.63
		Adjusted	12.0	121.94	29219	74.51	2077	50.52	47.05
	Middle	Green	74.4	61.60	26038	40.11	2209	10.88	11.92
		Air-dried	14.5	88.48	31538	53.99	2690	15.62	16.71
		Adjusted	12.0	108.08	31548	69.54	2700	35.19	34.76
	Top	Green	64.5	73.11	30228	42.16	2367	12.64	13.73
		Air-dried	13.6	99.34	35093	59.78	2843	18.60	20.00
		Adjusted	12.0	117.01	35097	70.47	2848	30.67	31.69
	Average	Green	76.6	68.28	26825	39.36	2130	11.12	11.99
		Air-dried	14.6	92.92	31943	53.16	2532	15.86	16.78
		Adjusted	12.0	110.69	31952	70.43	2541	36.85	36.46
Wanwe	Bottom	Green	76.5	107.62	42885	35.62	1680	8.17	9.73
		Air-dried	14.8	133.49	42712	47.14	2183	12.81	13.17
		Adjusted	12.0	146.43	42712	64.55	2199	43.39	32.21
	Middle	Green	66.1	99.47	43931	37.32	1603	12.52	14.08
		Air-dried	13.6	110.99	41455	48.16	2417	19.29	17.90
		Adjusted	12.0	113.93	41454	55.54	2430	33.02	24.79
	Top	Green	57.9	94.91	38453	37.95	1749	14.68	15.10
		Air-dried	13.2	117.00	44567	48.16	2113	19.09	17.72
		Adjusted	12.0	120.91	44570	52.68	2116	24.13	20.63
	Average	Green	66.8	100.66	41757	36.97	1677	11.79	12.97
		Air-dried	13.9	120.49	42911	47.82	2238	17.07	16.27
		Adjusted	12.0	126.46	42912	56.71	2248	30.64	23.98

Note: 108 replications (six clumps x 6 culms/clump x 3 replications per culm) were tested for each property. M.C means "moisture content", MOR "modulus of rupture", MOE "modulus of elasticity", MCS "maximum crushing strength", MS "maximum stress", WN "without node" and N "with node".

5. Conclusion

The classification of timber species for structural use in building is done on the basis of modulus of rupture and modulus of elasticity. Similarly, bamboos can be classified on the basis of modulus of rupture (MOR), modulus of elasticity (MOE), and maximum crushing strength (MCS) in green condition (Anon, 1993). The limits of these properties of the three groups are as follows.

Table 4: Limits of Modulus of rupture, Modulus of elasticity and Maximum crushing strength.

Group	MOR (Modulus of rupture in bending test)	MOE (Modulus of elasticity in bending test)	MCS (Maximum crushing strength in compression)
	(N/mm^2)	(N/mm^2)	(N/mm^2)
Group I	>70	>9000	>35
Group II	50-70	>6000	>30
Group III	30-50	>3000	>25

As the testing method is different in bending testing, Modulus of Elasticity is excluded in classification of Htiyo and Wanwe for their suitability as structural bamboos.

According to this classification, Wanwe wa (MOR = 100.66, MCS = 37) will be in Group I, which will be the best for construction uses. Htiyo wa (MOR = 68.28, MCS 39.36) will be in Group II. Even though Htiyo wa is in Group II, it can be in Group I according to its maximum crushing strength.

The basic specific gravity of the above tested bamboo species is 0.640 on average (on basis of volume determined by water displacement method. In India, the average basic specific gravity of 20 species is 0.639, ranging from 0.515 to 0.817.

Basic specific gravity, compression strength, shearing strength and modulus of rupture are found to be comparable to those of some Myanmar construction timbers such as Binga, Chinyok, Dwabok, Dwani, Hnaw, Kokko, Lein, Leza, Kyetyo, Leza, Myaukchaw, Myaukngo, Nabe, Sit, Taukkyan, Tawthayet, Taungthayet, etc. Their strengths are good enough to use in building as flooring, walling, roofing, in round bamboo furniture making and plybamboo furniture making, in many other purposes. Moreover, the rapid growth of bamboo is superior to that of any other plant. Therefore, it is the best substitute of timber at the present and in the future.

But, bamboos contain a substantial amount of initial moisture contents (Htiyo contains about 78% and Wanwe 68%), which is higher than those of most wood species. Serious decay occurs only when the moisture content of the wood is above the fiber saturation point (average 30%) (USDA, 1999). And thus, the bamboos can be easily be attacked by various fungi.

Moreover, bamboos shrink more than most timbers do (Htiyo shrinks 6.96% in diameter, 7.80% in wall thickness and 19.75% in volume; Wanwe shrinks 8.08% in diameter, 10.22% in wall thickness and 20.57% in volume). Unlike wood, bamboo shrinks right from the beginning of drying (Sattar, et.al., 1991). Bamboo starts shrinking from green condition even when the moisture content is in the order of 100-150% (Gnanaharan, 1993). Thus, high moisture content is related to high shrinkage and the possibility of the attacks by fungus. So, bamboos should be put into service at least after air-drying so that the problems arising from shrinking of bamboos in service could be minimized, if not eliminated. The younger bamboos contain higher moisture contents, and thus, the use of mature bamboos is also recommended. Another drawback of bamboos is its low natural durability compared to wood. Thus, it requires preservation treatment.

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