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Investigation on Physical and Mechanical Properties of Some Myanmar Bamboo Species

Khin Maung Sint, Assistant Manager,
Myanmar Timber Enterprise
Cho Cho Myint, Research Assistant 2
Forest Research Institute

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မြန်မာ့ဝါးအချို့တို့၏ရူပနှင့်အင်အားဂုဏ်သတ္တိများကို လေ့လာခြင်း

ခင်မောင်ဆင့်၊ လက်ထောက်မန်နေဂျာ
မြန်မာ့သစ်လုပ်ငန်း
ချိုချိုမြင့်၊သုတေသနလက်ထောက်–၂
သစ်တောသုတေသနဌာန၊ရေဆင်း။

အကျဉ်းချုပ်

ဝါးအသုံးချခြင်းနှင့် ဝါးထွက်ပစ္စည်းပြုလုပ်သည့် နည်းစနစ်များသည် ဝါးမျိုးအလိုက်ကွဲပြားသော ဂုဏ်သတ္တိများပေါ်တွင် မူတည်ပါသည်။ အိုင်တီတီအိုဝါးစီမံကိန်းတွင် ဆောင်ရွက်ရမည့် လုပ်ငန်းများထဲမှ တစ်ခုအပါအဝင်ဖြစ်သော ရူပနှင့်အင်အားဂုဏ်သတ္တိများ စမ်းသပ်ခြင်းကို သစ်တောသုတေသနဌာန၊ ရေဆင်းရှိ သစ်ရူပနှင့်သစ်အင်အားဌာနစိပ်တွင် စမ်းသပ် လေ့လာခဲ့ပါသည်။ တပင်တိုင်ဝါး၊ ဝါးကြီး၊ ဝါးဘိုးမျက်ဆံကျယ်၊ ဝါးဘိုးကြီး၊ ဝါးနွယ်၊ ကရင်ဝါး၊ ဝါးယား၊ သနပ်ဝါးနှင့် ထီးရိုးဝါးတို့ကို စမ်းသပ်ခဲ့ခြင်းဖြစ်ပါသည်။ စမ်းသပ်ခဲ့သော ရူပနှင့်အင်အားဂုဏ်သတ္တိများအပေါ်မူတည်၍ သင့်တော်သော ဝါးအသုံးချနည်းများကို လေ့လာတင်ပြထားပါသည်။

Investigation on Physical and Mechanical Properties of Some Myanmar Bamboo Species

Khin Maung Sint, Assistant Manager,
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Cho Cho Myint, Research Assistant 2
Forest Research Institute, Yezin

Abstract

The utilization and processing of bamboo species depend on the properties of individual species. As a part of the work under the ITTO Bamboo Project, physical and mechanical properties of 9 bamboo species were investigated in Timber Physics and Mechanics Section, Forest Research Institute, Yezin. Tabindaing wa (*Bambusa longispiculata*), Wagyi (*Dendrocalamus calostachya*), Wabogyi (*Dendrocalamus giganteus*), Wabo myet san gye (*Dendrocalamus hamiltonii*), Wanwe (*Dinochloa maclellandii*), Kayin wa (*Melocanna baccifera*), Waya (*Gigantochloa nigrociliata*), Thana wa (*Thyrosostachys oliveri*) and Htiyo wa (*Thyrsostachys siamensis*) were investigated. Based on the results of the physical and mechanical properties, the appropriate end uses of the bamboos were briefly discussed.

Contents

1. Introduction

Bamboos are a group of woody grasses, which gives us a versatile material for different purposes. They belong to the subfamily Bambusoideae of the family Poaceae. There are more than 1250 species and 75 genera in the world. They are distributed in tropical, subtropical and temperate regions of the world, with a great abundance in the tropical Asia and America.

With the increase of the world population, the decline of timber supply and the improved technology in processing and the invention of high-tech machine, bamboos step into a more important role than in the past. Although they could be seen as minor forest produce in the past, they can today fetch more income than timber and its products in some countries.

In Myanmar, natural bamboo forest was estimated to be 2170000 ha, endowed with about 100 species under 17 genera. The rural people of Myanmar have been using bamboos as rafters and purlings, walling material, and flooring in building houses, in making agricultural implements, as clothlines, for fencing, and for making various kitchen utensils, and furniture. Immature bamboos are used for tying material, and bamboo shoots for food. Today, the demand for bamboo is not limited to such a small scale, but extended from the rural small industrial sector to the large industries.

Among many applications of bamboo, domestic housing predominates in rural areas of tropical countries. Other types of construction are farm and school buildings and bridges. Other applications of bamboo related to construction are its uses as scaffolding, water piping and as shuttering, and reinforcement for concrete.

Bamboo can be used to make all the components of small buildings. Bamboos used in a building are foundations, floors, walls, roofs, and doors and windows. Some common types of foundations in which bamboo is used are bamboo in direct ground contact, bamboo on rock or preformed concrete footings, bamboo incorporated into concrete footings, composite bamboo/concrete columns, and bamboo reinforced concrete (D L Jayanetti, et. al., 1998).

The floor of a building comprises structural bamboo elements like beams and joists, and floor decking. Round bamboos are normally used for structural elements. Bamboo floor decking can take small bamboo culms, split bamboos, flattened bamboos, bamboo mats or bamboo panels.

The uses of bamboos as walls and partition are very extensive. The major elements of a bamboo wall are posts and beams, which constitute part of the structural frame work. An infill between framing members is required to complete the wall.

The bamboo structure of a roof comprises purlings and rafters. Bamboo is also used in a variety of forms, as a roof covering and for ceiling. Bamboo can be used for making windows and doors, which comprise a bamboo framed with an infill of woven bamboo or small diameter culms.

Although the uses of a bamboo species is preliminary determined by its diameters, total length, usable length, straightness, internode length, wall thickness, etc., the utilization-oriented technological properties are of quite importance in defining the quality of a bamboo. Among these properties, physical and mechanical properties are the most important ones, especially in the uses of bamboos as structural elements in constructions and furniture where strength is required So, in order to utilize bamboos effectively, systematically and rationally under scientific and technological conditions, the first step is to study its properties. Each bamboo is characterized by properties peculiar to itself and thus, its uses will differ accordingly.

By investigating physical and mechanical properties, the useful data can be obtained:

- to establish characteristic strength functions,
- to arrive at the allowable stress,
- to select the suitable species for a specific purpose, and
- to establish the relationship between mechanical properties and factors such as moisture content, density, specific gravity, growth site, position along the culm, the presence of node and internode, etc.

The objective of this paper is to present the test results of physical and mechanical properties of nine bamboo species, which will be very useful for comparison of bamboos, for further processing and for selection of a species for specific purposes.

2. Literature review

To increase the self-sufficiency of developing countries, indigenous materials must be exploited to the full (Jules J.A. Janssen, 1998). Among them, bamboo is a familiar material with a long history of usefulness. The ever increasing demand for raw material due to the ever increasing population of the world, the increasing decline of productivity of forests, the imposing problems arising from destruction of forests, and the short production cycle and rapid growth of bamboos make a great interest in bamboo as a wood substitute.

The diminishing wood resource and restrictions imposed on felling in natural forests, particularly in the tropics, have focused world attention on the need to identify a substitute material which should be renewable, environmentally friendly and widely available. In view of its rapid growth, a ready adaptability to most climatic and edaphic conditions and properties superior to most juvenile fast growing wood, bamboo emerges as a very suitable alternative (D L Jayanetti, et. al., 1998).

A series of research on bamboo have been carried out in bamboo-growing countries and by some researchers in various fields. Studies on physical and mechanical properties of bamboos have been done as an important role in the utilization of bamboo as an engineering and construction material in many countries. In testing bamboos, it was found that the compressive stress increases with decreasing moisture content. The effect of the height of specimens and node was not significantly different. But the position along the culm was very significant. There were significant effect of moisture content, height of the specimens, node and position along the culm on shear stress. Shear strength decreases from bottom to top. (W. Liese, 1980). These variations in properties affect its uses. In China, the top part easily splitable due to weak shear strength and thin wall, is used for making skewers, chopsticks, toothpicks, etc.

The physical and mechanical properties vary not only along the culm of the same species but also in horizontal direction. The outer part of the culm has a far higher specific gravity than other inner part. Specific gravity increases along the culm from the bottom to the top. Mechanical properties are correlated with specific gravity (W. Liese, 1980). This increase is related to the increase of fibre at the top.

In fact, the properties of the bamboo are determined by its anatomical structure (W. Liese, 1980). The vascular bundles are not evenly distributed on the bamboo cross section. Although the total number of vascular bundles decreases with increasing height of a culm, the vascular bundle concentration is the highest on the top portion. The highest vascular bundle concentration was found on the top portion of three year old bamboo with 467 bundles/cm^2 (Xiaobo Li, 2004).

In Indonesia, the interrelationship between the physico-mechanical properties of *Gigantochloa pseudoarundinacea* was determined and the results stated that the slope-inhabiting bamboo population have a higher specific gravity, modulus of elasticity and tensile strength than the one growing in the valley. Moreover, specific gravity increased from bottom to top, but modulus of rupture from the two habitats did not differ significantly (Tavip Soeprayitno, et. al., 1988). Physical and mechanical properties are found to vary within species.

A comparative study on moisture content and strength properties of six Indonesian species of green and air-dry bamboo shows that there is a general increase in bending, compression, tensile and shear strength from the green to air-dry condition (Soenardi Prawirohatnadjo, 1988).

The study on the abrassive resistance of *Bamboo vulgaris* var. *striata* and *Gigantochloa scortechinii* shows that the two species higher abrassive resistance than Kempas, the common flooring timber, and rubber wood, a light traffic flooring timber. So, they are suitable for flooring purpose under medium traffic condition (Abd. Latif Mohmod, et. al., 1988).

In India, some common bamboos for structural uses are listed, which are found to grow on ridges and warmer area. They have a greater wall thickness with close node. Depending on the availability and cost, the following species are selected for home construction (Harendra Nath Mishra, 1988).

1. *Dendrocalamus strictus* - Culms are solid and suited for structural uses.
2. *Bambusa tulda* - Strong culms are suitable for construction of roofing and scaffolding.
3. *Bambusa arundinacea* - The culms are used for rafters, house posts, tent pole, etc.
4. *Bambusa polymorpha* - It is the best for walls, floors, and roofs of houses.

In our country, research on bamboos has been conducted in various fields; Silviculture and Management, Market Potential, Processing Technologies and Utilization Properties. But a number of research work on bamboos still exist in various fields. Investigation on physical and mechanical properties of indigenous bamboos with a view to promoting systematic and efficient utilization is one of the fields.

A knowledge of physical and mechanical properties of bamboo is necessary in assessing its potential uses as building material for housing, furniture making and for general construction work and in converting it to a variety of finished products. Furthermore, the different properties of this resource will not only serve as a basis for promoting its acceptance but also for improving its market potential (Z.B. Espiloy, 1985).

In the past, great effort on research has been put on timber, which was rich in many countries. And testing standards for timber are available for them, but there was no agreed testing standards for bamboos. That would be one immediate problem with tests of bamboos. To give bamboo an equivalent place among other building material, one should promote both standardization of test methods and intensive investigation into mechanical properties of bamboos and physical and biological influences on these (Jules Janssen, 1980).

Today, INBAR has prepared a draft ISO standard for testing physical and mechanical properties of bamboos (INBAR, 2001). There fore, it is great value to test and present the physical and mechanical properties of some Myanmar well-known bamboo species.

3. Material and Methods

3.1 Material

The tested bamboo species were selected by the Director, The ITTO Bamboo Project, PD 146/02 Rev. 1 (I), titled “Promoting Sustainable Utilization of Bamboo through Community Participation in Sustainable Forest Management’. Normally, these selected species are the most abundant in Myanmar and well-known to people. Fifteen bamboo species were selected to test their physical and mechanical properties, among which the results of six bamboo species were published as a research paper in 2006.

In this paper, the results of the rest nine species were presented, but some properties of the first six species, which could not be presented in 2006, were mentioned for completeness. The tested nine species are:

(1) Htiyo wa (*Thyrsostachys siamensis*)
(2) Kayin wa (*Melocanna baccifera*)
(3) Tabindaing wa (*Bambusa longispiculata*)
(4) Thana wa (*Thyrsostachys oliveri*)
(5) Wabogyi wa (*Dendrocalamus gigantius*)
(6) Wabomyetsangye wa (*Dendrocalamus hamiltonii*)
(7) Wagyi wa (*Dendrocalamus calostachyas*)
(8) Wanwe wa (*Dinochloa maclellandii*)
(9) Waya wa (*Gigantochloa nigrociliata*)

Table 1: External diameter of tested bamboo species measured at green condition (mm)

Species	Part of culm	Means	N	Std.Dev.	Std.Error	CV%
Htiyo wa	b	47.23	70	4.659	0.378	10
	m	45.09	70	4.235	0.344	9
	t	33.69	68	2.906	0.239	9
	All Grps	**42.08**	**208**	**7.147**	**0.334**	**17**
Kayin wa	b	40.13	44	6.29	0.646	16
	m	41.28	30	9.33	1.160	23
	t	36.10	32	6.47	0.779	18
	All Grps	**39.24**	**106**	**7.56**	**0.498**	**19**
Wabomyetsangye wa	b	69.63	46	10.45	1.049	15
	m	62.40	38	10.13	1.119	16
	t	56.30	38	8.36	0.924	15
	All Grps	**63.22**	**122**	**11.15**	**0.685**	**18**
Tabindaing wa	b	17.00	48	3.10	0.305	18
	m	16.68	48	3.37	0.332	20
	t	15.65	48	3.17	0.312	20
	All Grps	**16.44**	**144**	**3.25**	**0.184**	**20**
Thana wa	b	49.93	84	4.22	0.313	8
	m	47.30	84	4.09	0.303	9
	t	42.38	84	4.63	0.343	11
	All Grps	**46.54**	**252**	**5.32**	**0.226**	**11**
Wabogyi wa	b	124.42	70	12.24	0.993	10
	m	102.42	66	8.20	0.685	8
	t	87.21	66	7.49	0.626	9
	All Grps	**105.07**	**202**	**18.13**	**0.860**	**17**
Wagyi wa	b	125.95	54	9.26	0.856	7
	m	107.40	56	11.52	1.046	11
	t	87.34	54	11.38	1.051	13
	All Grps	**106.90**	**164**	**19.02**	**1.001**	**18**
Wanwe wa	b	32.74	72	3.46	0.277	11
	m	32.11	72	3.89	0.311	12
	t	29.44	72	3.39	0.271	12
	All Grps	**31.43**	**216**	**3.85**	**0.176**	**12**
Waya wa	b	56.00	72	8.35	0.668	15
	m	46.25	68	5.42	0.446	12
	t	39.89	70	5.66	0.459	14
	All Grps	**47.47**	**210**	**9.40**	**0.437**	**20**

Tabindaing wa, Wabogyi wa and Waya wa were collected from Kawhmu Township, Yangon Division. Wanwe wa and Htiyo wa were collected from Pyinmana Township, Nay Pyi Taw Division. Kayin wa was collected from Kayin State, Wagi wa from Shan State and the rest from Mandalay Division.

Table 2:Wall thickness of tested bamboo species measured at green condition (mm)

Species	Part of Culm	Means	N	Std.Dev.	Std.Error	CV%
Htiyo wa	b	11.528	140	1.760	0.100	15
	m	6.507	140	0.754	0.043	12
	t	5.650	136	0.627	0.036	11
	All Grps	7.916	416	2.848	0.094	36
Kayin wa	b	7.487	88	2.91	0.209	39
	m	4.230	60	0.50	0.044	12
	t	3.452	64	0.40	0.034	12
	All Grps	**5.347**	**212**	**2.64**	**0.122**	**49**
Wabomyetsangye wa	b	16.872	92	4.89	0.344	29
	m	10.640	76	1.94	0.150	18
	t	7.142	76	1.11	0.086	16
	All Grps	**11.900**	**244**	**5.24**	**0.226**	**44**
Tabindaing wa	b	3.555	96	0.89	0.061	25
	m	2.534	96	0.59	0.040	23
	t	2.015	96	0.30	0.020	15
	All Grps	**2.702**	**288**	**0.90**	**0.036**	**33**
Thana wa	b	8.045	168	1.58	0.082	20
	m	5.791	168	0.78	0.040	13
	t	4.856	168	0.63	0.033	13
	All Grps	**6.231**	**504**	**1.72**	**0.052**	**28**
Wabogyi wa	b	17.404	140	2.92	0.166	17
	m	9.006	132	1.14	0.067	13
	t	6.616	132	0.87	0.051	13
	All Grps	**11.135**	**404**	**5.04**	**0.169**	**45**
Wagyi wa	b	20.975	108	3.86	0.250	18
	m	10.339	112	1.36	0.087	13
	t	7.860	108	0.92	0.060	12
	All Grps	**13.025**	**328**	**6.16**	**0.229**	**47**
Wanwe wa	b	9.786	144	3.34	0.188	34
	m	7.597	144	1.91	0.107	25
	t	6.071	144	1.04	0.059	17
	All Grps	**7.818**	**432**	**2.76**	**0.089**	**35**
Waya wa	b	22.862	144	2.28	0.128	10
	m	14.352	136	1.87	0.108	13
	t	10.219	140	1.33	0.075	13
	All Grps	**15.892**	**420**	**5.63**	**0.185**	**35**

Among the collected species, Wagyi wa is the largest bamboo in term of external diameter, which ranges from 106 mm to 108 mm at a 95 % probability level. The smallest bamboo is Tabindaing wa, which external diameter is from 1.63 mm to 16.6 mm at a 95% probability level (Table 1). Wall thickness is the largest in Waya wa and the least in Tabindaing wa. The wall thickness of Waya wa ranges from 15.71 mm to 16.08 mm at a 95% probability level. The wall thickness of Tabindaing wa is from 1.99 mm to 2.04 mm (Table 2). As we know, the thicker the wall thickness, the bamboo will be the more suitable for construction uses. Most bamboos are found to taper at the top. Thana wa and Tabindaing wa are the least tapering bamboos.

Htiyo wa is grown in villages, schools and monasteries. It rarely grows in natural forests. It can be found in almost every monasteries 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 has a diameter of 38-75 mm. The culms are usually straight and very strong. Its internode is 150-300 mm long. They can be used for all general purposes, framing, walling, concrete formwork and scaffolding (D L Jayanetti et. al., 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 (Table 1, 2).

The culm can be up to 13 m high and the culm diameter is 3-6 cm. The internode is 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 wand white waxy when young. The distinguishing characteristics of the bamboo are its closely dense growth with branching absent in the basal part (U Aung Zaw Moe et. al., 2006).

Kayin wa grows gregariously over large areas in the Rakhine Yomas, western Chin Hills and Upper Chindwin (Alex. Rodger, 1963). It grows in the Rakhine State, Upper Chindwin and Tanintharyi Division (H.G. Hundley, 1987). It grows on fertile loams of hill slopes and abandoned clearings by shifting cultivation. It prefers moist areas (ICFRE, 1993).

The culm can be 15-21 m high and has a diameter of 38 – 75 mm. The culm is straight, strong and durable (D L Jayanetti et. al., 1998). The culm is 9 – 18 m high and has a diameter of 25 mm to 76 mm and thin-walled (Alex. Rodger, 1963). The culm is 10-20 m high and a diameter of 30-70 mm. The culm is green when young and straw-coloured when old. (K.N. Subramaiam, 1998). The culm has an average external diameter of 39.24 mm and average wall thickness of 5.35 mm. The bamboo has thin tapering culms (Table 1 & 2).

It can be used for general purposes, framing, walling, flooring (strips), sheathing, matting, troughs and pipes (D L Jayanetti et. al., 1998). Slender culms are used in Myanmar for making the handles of Myanmar umbrellas.

Wabomyetsangye wa is a common bamboo of upper Myanmar and covers large areas of ground (Alex. Rodger, 1963). It grows in upper and northern parts of Myanmar (H.G. Hundley, 1987). It is normally 20-25 m in height, 150-250 cm in culm diameter and 12 mm in wall thickness (U Aung Zaw Moe, et. al., 2006). The culm diameter is 56.30 ±0.92 mm and the wall thickness 7.14±0.09 mm at 95% probability level (Table 1&2). It can be used for building, mats and basket making.

Tabindaing wa grows in Yangon Division. It attains a height of about 5-10 m, a diameter of 16.44±0.18 mm and a wall thickness of 2.70±0.04 mm (Table 1&2). The culms are so small that they are suited to uses as fishing rods and to making toys.

Thana wa is found to grow naturally in Bamaw, Katha and Shan State and Northern Myanmar (H.G. Hundley, 1987). It is found chiefly in Upper Myanmar in

Bamaw, Shwebo, Katha, Maymyo, Northern Shan States, etc. Walls are comparatively thin. (Alex. Rodger, 1963).

The tested sample culms are found to have an average diameter of 46.54±0.23 mm and an average wall thickness of 6.23±0.05 mm (Table 1&2). Culms are 15-21 m high, and attain an external diameter of 37-76 mm (Alex. Rodger, 1963). Culms are straight, 15-25 m high and about 50 mm in diameter. They are bright green when young and dull green or yellowish on maturity. Internodes are 40-60 cm long, and thin-walled (K.N. Subramaniam, 1998).

Wabogyi wa is a very large bamboo. It is rare in Myanmar except in cultivation (Alex. Rodger, 1963). It is found in Shwegyin, Thaungyin, Mawlamyine, and Upper Chindwin (H.G. Hundley, 1987). It is a native of Myanmar and is frequently cultivated in India.

It is called Giant Bamboo in English. Culms are 24-30 m high, 200-300 mm in diameter and usually 20-25 mm thick-walled. Internodes are 35-40 cm long and lower nodes have root scars (K.N. Subramaniam, 1998). Culms are found to have an average external diameter of 105.07±0.86 mm and an average wall thickness of 11.14±0.17 mm (Table 1&2).

Wagyi wa is a large bamboo and much like Wabo wa. Culms attain a height of 24 m and a diameter of 130-180 mm (Alex. Rodger, 1963). It is a tufted large bamboo with a culm height of 20-25 m. Internodes are 30-40 cm long (K.N. Subramaniam, 1998). The sample culms are found to have an average diameter of 106.90±1.00 mm and an average thickness of 13.03±0.23 mm (Table 1&2).

It is a native of Myanmar and occurs up to 1000 m elevation. It occurs in wild Meghalaya and Nagaaland in India (K.N. Subramaniam, 1998). It forms elegant clumps and is very commonly grown in Maymyo and the Northern Shan States for domestic uses. It is big enough to make house-posts for temporary structure and sections of the stem are used as containers for food and water (Alex. Rodger, 1963). It is found in Upper Myanmar, Upper Chindwin, Myitkyina, Bamaw, and Maymyo (H.G. Hundley 1987).

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 (K.N. Subramaniam, 1998). It is found in Bago, hill forests and Taninthary Division (H.G. Hundley, 1987). The tested sample culms attain an average height of about 12 m, an average diameter of 31.43±0.18 mm, and an average wall thickness of 7.82±0.09 mm (Table 1&2).

Waya wa attains a culm height of 10-15 m and a culm diameter of 56 - 90 mm with a wall thickness of 20 - 30 mm. Internodes are often solid and 15 - 30 cm long (U Aung Zaw Moe, et. al., 2006). The tested culms attain an average height of 12 m, an average diameter of 47.47 ± 0.44 mm and an average wall thickness of 15.89 ± 0.19 mm (Table 1& 2). It is found in Lower Myanmar and Taungu (H.G. Hundley, 1987). It is also planted in Yangon Division.

3.2 Methodology

Bamboo culms are selected from various clumps in the standing condition. Seven clumps per each species were randomly chosen, and six culms were randomly selected from each clump. They were sound and free from any defects, 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.

In testing physical and mechanical properties, the designations in ISO 22156 were followed.

3.2.1 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) Diameter shrinkage
(iii) Wall Thickness shrinkage
(iv) Longitudinal shrinkage
(v) Volumetric shrinkage
(vi) Density and
(vii) Specific gravity

The tested specimens for the physical properties were prepared from the full bamboo culms of internode sections, and were 100 mm high (long). They were free from any initial cracks.

3.2.1.1 Moisture content

The specimens were sanded so that any loose material can be removed from them. They were weighed to accuracy of 0.01 g while green and after drying in an oven. The drying was complete when the weight was constant. The moisture content of each test specimen was determined as the loss in weight, expressed as a percentage of the oven-dry weight.

$$MC\% = (W1 - W2) / W2 \times 100$$

where MC% is the moisture content
W1 is the weight of a specimen at green condition and
W2 is its weight after drying in an oven.

Moisture content is an important physical property, which affects other physical properties and mechanical properties. Normally, the more moisture content in material, the more it weighs and the more it cost for shifting and handling. Moreover, the green bamboo will take longer time to dry to the required moisture content. In addition, the selection of drying schedule is different for the same species depending on the initial moisture content. Moreover, it also effects the movement of bamboo. Swelling will occurs when the bamboo adsorbs moisture from the atmosphere and shrinking occurs when it desorbs its moisture to the atmosphere. Green bamboo is easily attacked by fungi.

3.2.1.2 Shrinkage

Shrinkage of bamboo was observed in the outer diameter, in the wall thickness and in the length of the test specimens. Moreover, volumetric shrinkage was also determined based on green and oven dry volume. Marking were done on the specimens to facilitate taking observations every time at the same place. On each specimen, 2 diameters, 4 wall-thickness and 2 lengths were measured while green and after oven-drying. The shrinkage was calculated as:

$$S_0 = (L1 - L2) / L1 \times 100$$

where S_0 is the shrinkage of a specimen from green to oven dry condition
L1 is the green (initial) dimension of the specimen and
L2 is the dimension of the specimen after oven-drying.

The shrinkage of a specimen from green to 12% moisture content is adjusted as

$$S_{12\%} = S_0 \times (FSP - 12) / FSP$$

where $S_{12\%}$ is the shrinkage of a specimen from green to 12 % MC.
FSP is Fiber saturation point of bamboo species, which is assumed to be 20% (W. Liese, 1980).

Shrinkage or swelling is another important physical property, which can occur when losing or gaining moisture below fiber saturation point of the specimen or material in service. This shrinking and swelling can result in warping, checking, splitting, and loosening of tool handles, gaps in strip flooring, or performance problems that detract from the usefulness of bamboo products. That is why, it is important that these phenomena be understood and considered when they can affect a product in which bamboo is used.

3.2.1.3 Density and Specific gravity

The density of a bamboo test specimen is a ratio of its weight to its volume. The specimens were weighed while green, and its green volume was determined by water displacement method. Then, they were oven-dried in an oven at a temperature of 103±2ºC. After attaining a constant weight under oven-drying, the volume was measured again. Three different kinds of density were calculated on basis of measured volumes and weights. They are:

(1) Density based on green weight and green volume

(2) Density based on oven-dry weight and oven-dry volume, and
(3) Density based on oven-dry weight and green volume, which is known as basic density.

Moreover, air-dry density was determined as follows:

$$P_{12} = 1000 \times Q_{12} \times (1+12/100)$$

where P_{12} is density at 12% moisture content.
Q_{12} is specific gravity at 12% moisture content.

In mentioning specific gravity, the oven-dry weight of the test specimen is always used. It is the ratio of the density of bamboo to the density of water. Three different kinds of specific gravity are mentioned in this paper. They are:

(1) Specific gravity based on oven-dry weight and green volume, which is known as basic specific gravity,
(2) Specific gravity at 12% moisture content and
(3) Specific gravity based on oven-dry weight and oven-dry volume.

Specific gravity at 12% moisture content was determined as:

$$Q_{12} = Q_b / \{ 1-0.265 \times (FSP- 12) /FSP \times Q_b \}$$

where Q_{12} is specific gravity at 12% moisture content.
Q_b is basic specific gravity.
FSP is fiber saturation point of bamboo.

Density is sufficiently accurate to permit proper utilization of bamboo products where weight is important. Such applications range from the estimation of structural loads to the calculation of approximate shipping weights.

Specific gravity is an index of the amount of bamboo fibers in a specific volume. It is also important for comparison of species or products and estimations of product weight.

3.2.2 Mechanical Properties

The mechanical properties of bamboo depend on :

- the botanical species itself,
- the age at which the bamboo has been cut,
- the moisture content,
- the position along the culm and
- the position of the nodes and the internodes themselves produce different characteristics; nodes are weaker in compression and bending (Dr. Jules J.A. Janssen, 1995).

The sample bamboo culms are at least three years old and so are mature enough for uses as construction material. Green and air-dry test were done for each mechanical properties of every test species so that the effect of moisture content on the properties were analyzed. Each culm was divided into three equal parts and the effect of the position along the culm was analyzed.

The mechanical properties of bamboo tested are bending, shear and compression parallel to grain, following designations in ISO/DIS 22157. All mechanical tests were carried out on an Autograph Universal Timber Testing Machine.

3.2.2.1 Bending test

The test was a four-point loading test. The test culms were with visually apparent defects, The test specimen is the rest portion of bottom, middle, and top parts, from which specimens for shear and compression test were cut. In order to obtain a failure in bending, the free span was 30 x D , in which D is the outside diameter. The full length of the test culms were at least this free length plus at each a half internode length.

The loading of the culm was carried out uniformly at a constant speed. The speed of testing at constant rate of movement of the loading head of the machine was 0.5 mm/s. The maximum load was determined.

The ultimate strength in static bending was given by the formula:

$$MS_{max} = F \times L \times (ED /2) / (6 \times I)$$

where MS_{max} is the ultimate strength (maximum stress)
F is the applied maximum load
L is the free span
ED is the outside diameter
I is the moment of inertia, which was calculated with $I = (3.142/64) \times (ED^4 – ID^4)$, where ID is the internal diameter.

The modulus of elasticity was calculated with the formula:

$$MOE = 23 \times F \times L^3 / (1296 \times D \times I)$$

where MOE is the modulus of elasticity (Young’s Modulus),
F, L and I are as above.
D is the deflection at midspan.

The strengths obtained from bending test are obviously important in the uses of bamboos as beam, rafter, purlin, etc.

3.2.2.2 Compression parallel to grain test

The specimens were taken from the bottom part, middle part and top part of each culm. These specimens were marked with the letters B, M, and T respectively. The length of the specimen is equal to the outside diameter, and the specimens were without any node. The end planes of the specimens were perfectly at right angles to the length of the specimen.

The load was applied continously during the test to cause the movable head of the machine to travel at a constant rate of 0.01 mm per second. The maximum compressive strength and modulus of elasticity was calculated from the test.

MCS = F / A,

where MCS is the maximum compressive strength,
F is the maximum load, and
A is the cross-sectional area on which the maximum load was applied.

MOE = F’ x L / (A x D)

where MOE is the modulus of elasticity,
F’ is the load at the proportional limit,
L is the length of the test specimen
A is the cross-sectional area and
D is the deflection at proportional limit

The formula for calculating MOE is from BS:373:1957.

The maximum compressive strength is of quite value in the use of bamboos as post, column, etc. Similarly, MOE is also important when short columns, short posts, etc. are used.

3.2.2.3 Shear parallel to grain

The test were carried out in the same machine as in compression test and bending test. The specimen was supported at the lower end over two quarters, opposite one another, and loaded at the upper end over the two quarters, which were not supported. This way to support and to load the specimen resulted in four shear areas.

The specimens were taken from the bottom part, middle part and top part of each culm. They were marked with the letters B, M and T respectively. About half of shear test specimens were with a node. And the rest were without. The length of the specimen was equal to the outer diameter. The end surfaces of the specimen were at right angles to the length of the specimen; end surfaces were flat.

From the test, the maximum shearing strength was calculated with the formula:

$$MS = F / A$$

where MS is the maximum shearing strength,
F is the maximum load, and
A is the total area where shear was taken place.

Shear strength of bamboo is very important in the uses as joints.

4. Data Analysis

In this research, the influence of two factors on physical and mechanical properties has been analyzed for a single clump: culms and culm height.

Factor A: Culms with 6 levels of source of variation : 1-6

Factor B: Culm height with 3 levels of sources of variation : Bottom (B) : Middle (M) : Top (T)

The amount of repetition = 3 specimens

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

$$Yijk = \mu + Ai + Bj + (AB)ij + \varepsilon ijk,$$

where

Yijk = Value of variable Y due to the effect of the i^{th} level of culm and j^{th} level of culm height at k^{th} repetition.

μ = Mean value of expectation of variable Y

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

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

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

εijk = Experimental error

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 was added to the above model.

Factor C: clumps with 7 levels of source of variation

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

$$Y_{ijkl} = \mu + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + \varepsilon_{ijkl}$$

where,

Y_{ijkl}	=	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
A_i	=	Influence of i^{th} level of culms
B_j	=	Influence of j^{th} level of culm height
C_k	=	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 tested per section for some properties. More than one specimen were required for parallel testing.

5. Results and discussion

5.1 Physical properties

5.1.1 Moisture content

The mean moisture contents of tested bamboo species are shown in Table 3. It ranges from 53 % in Thana wa to 103 % in Kayin wa. This variation might be due to differences in some inherent factors such as structure and chemical composition, and certain external factors such as site, climate, etc (Soenardi Prawirohatmodjo, 1988). The moisture content of bamboo is found to be very high. This finding was proved correct by Xiaobo Li (2004).

Table 3: Average moisture content of tested bamboo species (%)

Sr. No.	Species	Bottom	Middle	Top	average
1	Htiyo wa	88.49	77.43	65.52	77.34
2	Kayin wa	107.75	105.12	94.21	102.92
3	Wabomyetsangye wa	108.88	98.17	78.93	96.01
4	Tabindaing wa	71.58	72.79	74.15	72.86
5	Thana wa	51.59	53.31	56.14	53.68
6	Wabogyi wa	51.87	44.06	47.78	47.97
7	Wagyi wa	122.74	68.57	58.67	83.15
8	Wanwe wa	56.06	52.13	49.55	52.58
9	Waya wa	113.60	100.62	90.85	101.80

Analysis of variance of the data showed that the species and position of the specimen have a highly significant effect on the moisture content of the bamboo. It is found that the moisture content decreases with height in almost all tested bamboo species (Table 3). This finding was proved true by Xiaobo Li (2004). In the vertical direction, the amount of fiber increases with the parenchyma decreasing (W. Liese, 1980). The decreasing moisture content could be related to decreasing parenchyma and increasing fiber contents.

5.1.2 Shrinkage

Table 4: Longitudinal shrinkage of bamboos from green to oven-dry condition (%)

Sr. No	Species	Bottom	Middle	Top	Average
1	Htiyo wa	0.130	0.130	0.125	0.128
2	Kayin wa	0.073	0.171	0.199	0.139
3	Wabomyetsangye wa	0.037	0.220	0.127	0.122
4	Tabindaing wa	0.162	0.192	0.164	0.173
5	Thana wa	0.164	0.172	0.142	0.159
6	Wabogyi wa	0.150	0.199	0.207	0.186
7	Wagyi wa	0.356	0.263	0.172	0.262
8	Wanwe wa	0.134	0.098	0.126	0.119
9	Waya wa	0.222	0.214	0.178	0.204

The longitudinal shrinkage of the tested bamboo species are shown in Table 4. It ranges from 0.119 % in Wanwe to 0.262% in Wagyi. The significant effect of species and the position along the culm was observed on the longitudinal shrinkage from green to oven-dry condition. 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.

Table 5: Diameter shrinkage of bamboo from green to oven-dry condition (%)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	7.975	7.081	6.392	7.165
2	Kayin wa	7.912	8.657	7.093	7.876
3	Wabomyetsangye wa	5.976	6.829	8.042	6.885
4	Tabindaing wa	7.031	6.739	6.303	6.691
5	Thana wa	5.417	5.513	5.653	5.527
6	Wabogyi wa	4.412	4.818	5.001	4.836
7	Wagyi wa	10.657	6.802	8.511	8.985
8	Wanwe wa	7.264	7.668	6.878	7.270
9	Waya wa	13.137	12.029	11.933	12.377

It can be found that the diameter shrinkage decrease with height in most bamboo species. It is the highest in Waya wa (12.377%) and the least in Wabogyi wa (4.836%). There is a significant effect of species on the diameter shrinkage and so also is along the culm. Analysis of the data shows that there is a significant effect of species and culm height on the diameter shrinkage from green to oven-dry.

Table 6: Wall-thickness shrinkage from green to oven-dry condition (%)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	8.897	10.419	10.416	9.898
2	Kayin wa	13.628	11.252	10.026	11.868
3	Wabomyetsangye wa	10.511	11.907	11.968	11.400
4	Tabindaing wa	11.024	10.544	9.145	10.258
5	Thana wa	6.235	6.254	6.578	6.356
6	Wabogyi wa	3.755	5.111	6.006	4.960
7	Wagyi wa	12.215	6.297	6.234	8.088
8	Wanwe wa	10.106	10.330	10.078	10.171
9	Waya wa	14.730	14.390	15.158	14.762

According to Table 6, the wall thickness shrinkage from green to oven-dry condition is not definitely increasing or decreasing. The highest wall thickness shrinkage is found in Waya wa and the least shrinkage in Wabogyi wa. Species and culm height have a significant effect on the wall-thickness shrinkage.

The average volumetric shrinkage of the tested bamboos are shown in Table 7. The highest volumetric shrinkage is found in Kayin wa and the least in Wabogyi wa. In most bamboo species, the volumetric shrinkage is found decreasing with height. There is a significant effect of species and culm height on the volumetric shrinkage.

Table 7: Volumetric shrinkage of bamboos from green to oven-dry condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	22.891	21.780	17.109	20.632
2	Kayin wa	26.707	27.612	25.967	26.755
3	Wabomyetsangye wa	19.269	23.805	17.894	20.310
4	Tabindaing wa	16.195	17.446	16.872	16.843
5	Thana wa	9.922	10.328	13.359	11.203
6	Wabogyi wa	8.059	10.067	8.790	8.964
7	Wagyi wa	32.126	20.371	17.930	23.476
8	Wanwe wa	18.033	18.316	16.894	17.748
9	Waya wa	23.675	24.798	27.040	25.149

The shrinkage values of Thana wa and Wabogyi wa are found to be very low in comparison with those of other bamboos. This could be due to losses of some moisture before testing. Bamboo is not like wood. In wood, shrinkage occurs when wood loses moisture under fiber saturation point. So, it will not be a problem in finding shrinkage in wood even though the moisture is lost if the loss of moisture is above fiber saturation point. But in bamboos, bamboo starts shrinking from green condition even when the moisture content is in the order of 100-150% (R. Gnanaharan, 1993). These two bamboo species could not be tested immediately after arrival. So, it is believed that some shrinking had already taken place before testing could be carried out.

5.1.3 Density

Table 8: Green Density of bamboos (kg/m^3)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	1132	1080	1076	1096
2	Kayin wa	894	881	878	886
3	Wabomyetsangye wa	1065	1095	1110	1088
4	Tabindaing wa	1006	1076	1131	1072
5	Thana wa	1036	1088	1121	1082
6	Wabogyi wa	787	936	976	898
7	Wagyi wa	1053	1069	1087	1070
8	Wanwe wa	1027	1038	1044	1036
9	Waya wa	1140	1136	1134	1137

The green density of the tested bamboo species ranges from 886 kg/m^3 in Kayin wa to 1137 kg/m^3 in Waya wa (Table 8). 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 green density. Clumps and culms also have significant effects on green density for some species, but not for all.

It is very clear that green density increases with height in almost all species (Table 8) . This is due the increase in the concentration of vascular bundles and the higher amount of silica in the upper portion (Jamludin Kasim, 1993; Liese, 1987; Abd. Latif et. al., 1992; Jamaludin et. al., 1992).

Table 9: Air-dry density of bamboo (kg/m^3)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	829	854	884	857
2	Kayin wa	544	534	563	547
3	Wabomyetsangye wa	684	712	791	726
4	Tabindaing wa	730	784	821	779
5	Thana wa	869	900	915	895
6	Wabogyi wa	644	821	836	765
7	Wagyi wa	706	845	881	836
8	Wanwe wa	828	862	884	858
9	Waya wa	659	709	748	705

The air-dry density of tested bamboos are shown in Table 9, which ranges from 547 kg/m3 in Kayin wa and 895 kg/m3 in Thana wa. The possible reasons are given above for this variation. As in green density, species and culm height have significant effects on air-dry density.

The oven-dry density of the tested bamboo species are given in Table 10. The highest oven-dry density is in Wanwe wa and the least in Kayin wa. Generally, it also increases with height. The effect of species, clumps and culm height are significant at 95% probability level. Other effects such culms, and the interaction are not significant at the same level.

Table 10: Oven-dry density of bamboos (kg/m^3)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	811	808	812	811
2	Kayin wa	613	612	614	613
3	Wabomyetsangye wa	669	752	748	719
4	Tabindaing wa	692	738	753	728
5	Thana wa	762	804	834	800
6	Wabogyi wa	571	729	749	681
7	Wagyi wa	698	788	834	773
8	Wanwe wa	807	839	843	830
9	Waya wa	706	752	813	757

Basic density is used for comparing species, and estimating product weight. It is the most important one among different kinds of density. To estimate it, the smallest weight i.e. oven-dry weight and the largest volume, i.e. green volume were used.

The average basic density of tested bamboo species ranges from 451 kg/m^3 in Kayin wa to 707 kg/m^3 in Thana wa. It is found that the basic density increases with height in all tested bamboo species. The effects of species, clumps, section and the interaction between clumps and culms are significant at 95% probability level, which mean that there are significant differences between species, among clumps of the same species, along different height of the same culm.

Table 11: Basic density of bamboos (kg/m^3)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	613	622	664	633
2	Kayin wa	449	441	464	451
3	Wabomyetsangye wa	553	575	633	585
4	Tabindaing wa	590	629	654	625
5	Thana wa	688	712	722	707
6	Wabogyi wa	526	656	666	614
7	Wagyi wa	487	647	701	612
8	Wanwe wa	661	685	700	682
9	Waya wa	538	575	602	571

5.1.4 Specific gravity

Specific gravity is a measure of the density of a substance. The specific gravity of a substance is a comparison of its density to that of water. The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on the anatomical structure (Xiaobo Li, 2004).

Table 12: Basic specific gravity of bamboos

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	0.613	0.622	0.664	0.633
2	Kayin wa	0.449	0.441	0.464	0.451
3	Wabomyetsangye wa	0.553	0.575	0.633	0.585
4	Tabindaing wa	0.590	0.629	0.654	0.625
5	Thana wa	0.671	0.712	0.722	0.702
6	Wabogyi wa	0.526	0.656	0.666	0.614
7	Wagyi wa	0.507	0.647	0.684	0.618
8	Wanwe wa	0.661	0.685	0.700	0.682
9	Waya wa	0.538	0.575	0.602	0.571

The basic specific gravity of tested bamboos are shown in Table 12, which ranges from 0.451 in Kayin wa to 0.702 in Thana wa. Species, clumps and sections have significant effects on basic specific gravity. As in densities, it also increases with height in all species.

The oven-dry specific gravity and air-dry specific gravity of tested bamboo species are given in Table 13 and Table 14, respectively. They all increase with height. Normally, the oven-dry specific gravity is the largest, and the basic specific gravity is the smallest.

Table 13: Oven-dry specific gravity of tested bamboo species

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	0.794	0.786	0.789	0.790
2	Kayin wa	0.613	0.612	0.614	0.613
3	Wabomyetsangye wa	0.669	0.752	0.748	0.719
4	Tabindaing wa	0.692	0.738	0.753	0.728
5	Thana wa	0.759	0.799	0.834	0.798
6	Wabogyi wa	0.575	0.716	0.754	0.669
7	Wagyi wa	0.698	0.799	0.834	0.777
8	Wanwe wa	0.807	0.839	0.843	0.830
9	Waya wa	0.706	0.752	0.813	0.757

Table 14: Air-dry specific gravity of tested bamboo species

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	0.681	0.684	0.731	0.698
2	Kayin wa	0.485	0.476	0.503	0.488
3	Wabomyetsangye wa	0.652	0.700	0.733	0.696
4	Tabindaing wa	0.652	0.700	0.733	0.696
5	Thana wa	0.752	0.799	0.817	0.790
6	Wabogyi wa	0.574	0.713	0.740	0.664
7	Wagyi wa	0.530	0.723	0.770	0.674
8	Wanwe wa	0.739	0.769	0.789	0.766
9	Waya wa	0.589	0.633	0.668	0.630

5.2 Mechanical properties

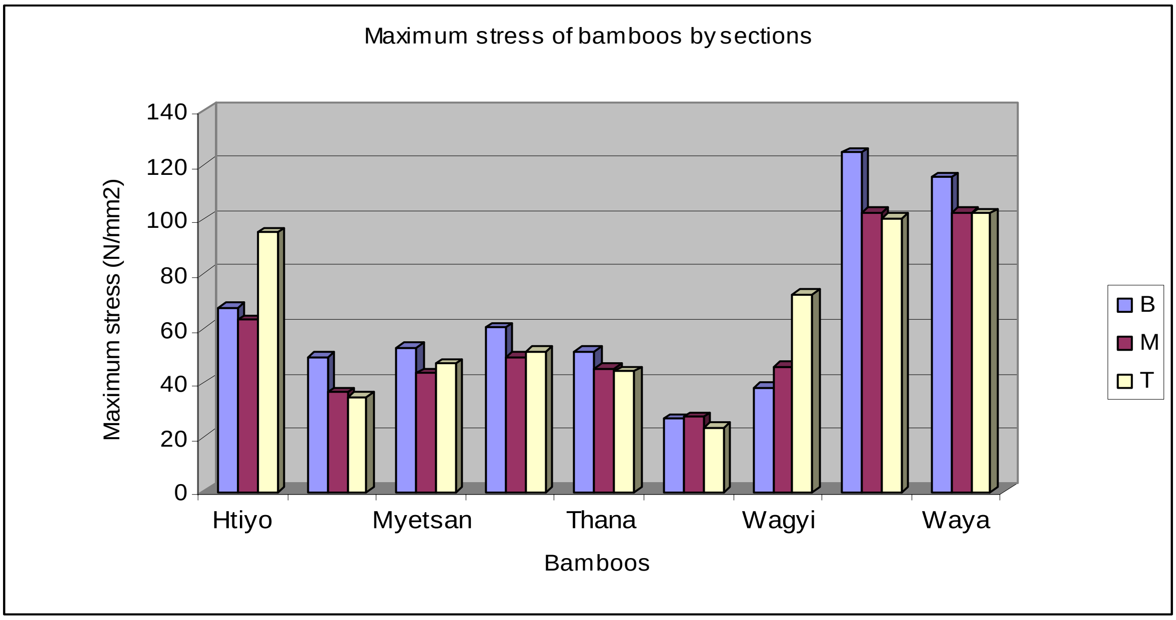
5.2.1 Static bending test

5.2.1.1 Maximum stress

Table 15: Maximum stress at green condition (N/mm^2)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	67.55	62.91	95.07	74.52
2	Kayin wa	49.50	36.51	34.94	42.21
3	Wabomyetsangye wa	52.89	43.60	47.08	48.57
4	Tabindaing wa	60.09	49.53	51.50	54.04
5	Thana wa	51.53	45.35	44.23	47.31
6	Wabogyi wa	26.86	27.34	23.70	26.22
7	Wagyi wa	38.34	45.80	72.41	52.36
8	Wanwe wa	124.49	102.58	100.22	109.10
9	Waya wa	115.29	102.45	102.25	107.12

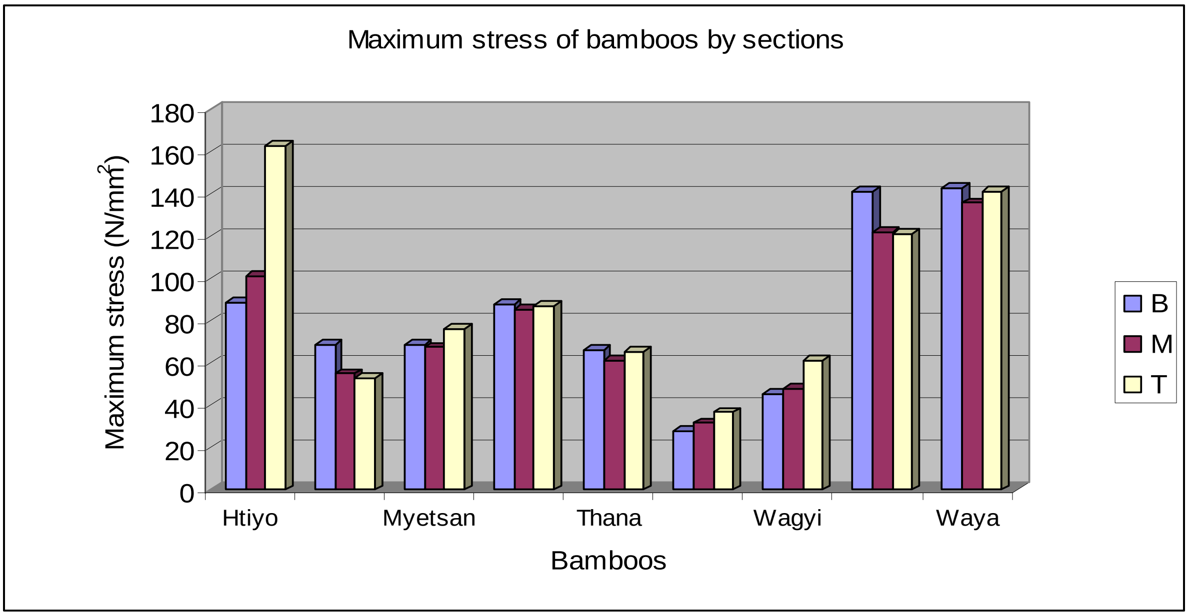
The maximum stress of bamboos ranges from 26.22 N/mm^2 in Wabogyi to 109.10 N/mm^2 in Wanwe while green (Table 15) and from 32.09 N/mm^2 in Wabogyi wa to 139.82 N/mm^2 in Waya wa at 12% moisture content. Waya is almost solid or with a very small hollow. So, it is quite good for construction uses. There are significant effects of species, clump and sections on green and air-dry conditions. It is found that the maximum stress increases with decrease in moisture content. This finding supports the statement made by W. Liese, which is the moisture content has a similar influence on the strength as it has in timber (W. Liese, 1985).



Graph 1: Maximum stress of tested bamboos at green condition

The values at green and air-dry condition are not much different from each other, for example in Wabogyi. The finding follows the remark of W. Liese, which is the difference between the air-dry and green condition are sometimes relatively small, especially for bending and cleavage (W. Liese, 1985).

Janssen pointed out that the bending stress decreases with the height of the culm (Elizabeth A. Widjaja, et. al., 1985). This statement does not hold true for all tested bamboo species, but for most of the tested bamboo species (Graph 1). The same trend is applicable only to the green results. In air-dry condition, some species show an increasing trend in bending stress with height. Some species show the middle portion with the least values (Graph 2).



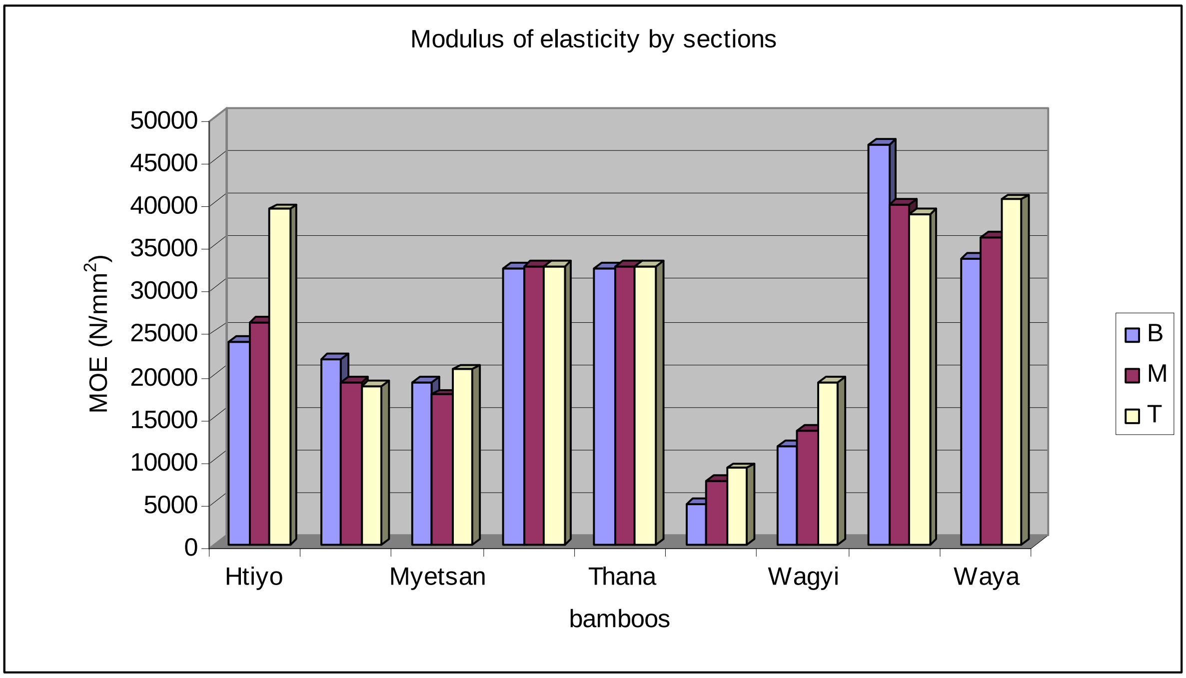
Graph 2: Maximum stress of tested bamboos at air-dry condition

Table 16: Maximum stress of tested bamboo at air-dry condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	88.88	100.94	163.05	119.59
2	Kayin wa	68.82	55.08	52.83	61.96
3	Wabomyetsangye wa	69.03	67.43	76.33	70.39
4	Tabindaing wa	87.73	85.64	87.18	86.82
5	Thana wa	66.43	61.31	65.30	64.35
6	Wabogyi wa	28.09	31.59	36.60	32.09
7	Wagyi wa	45.13	47.82	61.48	52.29
8	Wanwe wa	140.96	121.89	121.38	128.08
9	Waya wa	142.82	135.83	140.93	139.82

5.2.1.2 Modulus of elasticity

The modulus elasticity of tested bamboos at green and air-dry condition are given in Table 17 and Table 18, respectively. The maximum modulus of elasticity is found in Wanwe wa for green and air-dry condition. The least modulus of elasticity was observed in Wabogyi wa. It shows that Wanwe wa has a higher resistance to deformation than Wabogyi.



Graph 3: Modulus of elasticity of tested bamboos at air-dry condition

The modulus of elasticity has an increasing trend with height in most species. It supports the statement of W. Liese and Zenita B. Espiloy who pointed out that for bending strength and modulus of elasticity, higher values were obtained from the upper part (W. Liese, 1985; Zenita B. Espiloy, 1985)). There are significant effects of species, clumps and sections on modulus of elasticity.

Table 17: Modulus of elasticity of tested bamboo at green condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	22216	23451	31586	25560
2	Kayin wa	19968	16556	17616	18367
3	Wabomyetsangye wa	14433	15129	44853	26417
4	Tabindaing wa	29317	25189	26112	26998
5	Thana wa	20611	19100	20372	20014
6	Wabogyi wa	7628	13587	12110	10997
7	Wagyi wa	6601	11426	20483	12952
8	Wanwe wa	46704	40719	40323	42582
9	Waya wa	31494	30797	31081	31117

Table 18: Modulus of elasticity of tested bamboo species at air-dry condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	23680	25939	39242	30033
2	Kayin wa	21675	19022	18499	20330
3	Wabomyetsangye wa	19020	17528	20491	18860
4	Tabindaing wa	32418	32529	32567	32504
5	Thana wa	32418	32529	32567	32504
6	Wabogyi wa	4829	7473	8921	7082
7	Wagyi wa	11546	13292	18963	15022
8	Wanwe wa	46771	39881	38693	41782
9	Waya wa	33452	35930	40394	36454

5.2.2 Compression test

5.2.2.1 Maximum crushing strength

The maximum crushing strengths at green condition and air-dry condition are shown in Table 19 and Table 20, respectively. It ranges from 14.22 N/mm2 in Kayin wa to 44.93 N/mm2 in Htiyo wa at green condition. Similarly, Kayin wa has the least and Htiyo wa the higest value at air-dry condition. The maximum crushing strength of Kayin wa is very low, compared to those of other tested bamboos. Normally the strength increases with height. It supports the finding of Elizabeth A. Widjaja, who found that the compression strength as well as the percentage of sclerenchyma fiber increases from the bottom to the top in *Dendrocalmus giganteus* and *Gigantochloa robusta* (Lizabeth A. Widjaja, 1985). There are significant effect of species on maximum crushing strength at green and air-dry condition. But the effects of sections and clumps, and culms are significant in some bamboos only. It supports the statement of W. Liese, who remarked that it seems that resistance to compression parallel to the grain is more or less uniform, hardly being affected by the height of the culm (W. Liese, 1985).

Table 19: Maximum crushing strength of bamboo at green condition (N/mm^2)

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	43.11	45.29	46.35	44.93
2	Kayin wa	12.81	15.87	14.97	14.22
3	Wabomyetsangye wa	24.45	28.18	30.33	27.65
4	Tabindaing wa	32.78	32.78	34.13	33.23
5	Thana wa	37.03	36.50	39.94	37.75
6	Wabogyi wa	25.70	32.29	41.01	33.10
7	Wagyi wa	24.18	37.39	45.83	35.84
8	Wanwe wa	39.15	42.32	39.54	40.33
9	Waya wa	32.53	33.84	35.81	34.01

Table 20: Maximum crushing strength of bamboo at air-dry condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	64.88	75.58	77.98	72.57
2	Kayin wa	49.01	46.09	38.16	44.92
3	Wabomyetsangye wa	70.57	62.24	63.55	63.59
4	Tabindaing wa	57.21	60.74	61.47	59.81
5	Thana wa	71.29	77.41	79.12	76.01
6	Wabogyi wa	43.38	61.43	56.96	53.57
7	Wagyi wa	35.91	55.22	64.36	51.75
8	Wanwe wa	66.55	71.61	76.02	71.32
9	Waya wa	48.61	52.83	54.41	51.95

5.2.2.2 Modulus of elasticity

The modulus of elasticity of bamboo at green and air-dry condition are given in Table 21 and Table 22, respectively. The least modulus of elasticity is found in Tabindaing wa and the highest in Wabomyetsangye wa at green condition, and at air-dry condition, the least in Tabindaing and the highest in Thana wa. It increases with height, but the significant difference occurs only in some species.

Table 21 : Modulus of elasticity of bamboos at green condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	1737	1954	1372	1692
2	Kayin wa	1024	1144	859	1012
3	Wabomyetsangye wa	2309	1916	2066	2097
4	Tabindaing wa	893	751	895	846
5	Thana wa	1392	1396	2168	1629
6	Wabogyi wa	1541	1709	1709	1661
7	Wagyi wa	1251	1858	2092	1822
8	Wanwe wa	1364	1629	1642	1545
9	Waya wa	1007	1048	1062	1038

Table 22: Modulus of elasticity of bamboos at air-dry condition

Sr. No.	Species	Bottom	Middle	Top	Average
1	Htiyo wa	2478	3013	2491	2655
2	Kayin wa	1788	2687	1834	2124
3	Wabomyetsangye wa	4463	3386	3228	3404
4	Tabindaing wa	1127	1439	1548	1371
5	Thana wa	2467	2966	2943	2797
6	Wabogyi wa	1432	2209	2471	2041
7	Wagyi wa	1499	2201	2986	2249
8	Wanwe wa	1971	2105	2358	2141
9	Waya wa	1510	1548	2201	1753

5.2.3 Shear test

5.2.3.1 Maximum shearing strength

The maximum shearing strengths of bamboo are shown in Table 23 and Table 24 at green and air-dry condition, respectively. At green condition, it ranges from 4.70 N/mm^2 in Tabindaing wa to 14.29 N/mm^2 in Htiyo wa. At air-dry condition, the range is from 6.99 N/mm^2 in Tabindaing wa to 23.66 N/mm^2 in Htiyo wa. It is found that the air-dry bamboo has higher strength, which increases with decreasing moisture content (Graph 4). 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..

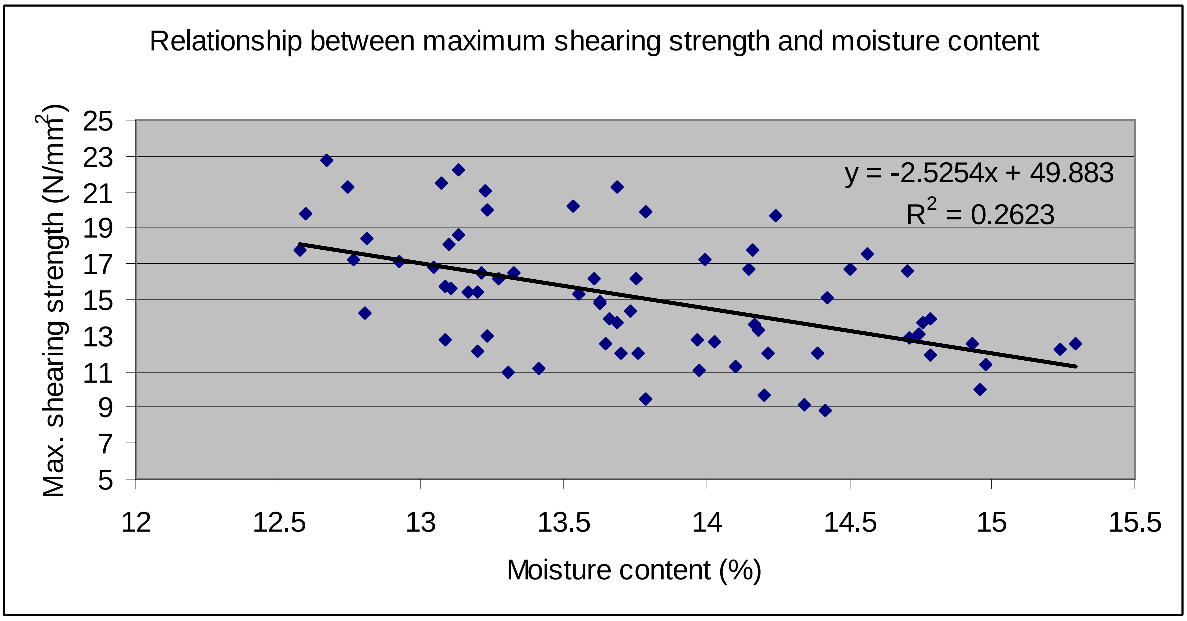
Table 23: Maximum shearing strength of bamboos at green condition (N/mm^2)

Part of Culm	Htiyo	Kayin	Myetsan-gye	Tabin-daing	Thana	Wabo-gyi	Wagyi	Wanwe	Waya
B	12.48	8.27	6.74	4.41	10.93	6.88	6.12	11.99	8.61
WN	12.68	9.52	6.85	3.78	12.45	7.41	6.06	11.75	7.74
N	12.29	7.03	6.64	5.18	9.42	6.59	6.17	12.23	9.58
M	13.05	6.55	7.13	4.93	11.10	10.82	9.14	13.53	9.19
WN	12.69	6.36	7.54	4.18	12.38	10.49	9.10	13.60	9.43
N	13.39	6.73	6.72	5.99	10.24	11.16	9.18	13.47	7.99
T	17.42	7.74	7.91	4.82	11.27	11.33	10.57	14.29	11.30
WN	17.19	7.58	8.21	4.13	13.94	10.77	9.97	14.46	11.14
N	17.63	7.85	7.09	5.67	10.01	11.88	11.22	14.12	13.95
All Groups	14.29	7.62	7.17	4.70	11.08	9.86	8.51	13.27	9.39

Table 24: Maximum shearing strength of bamboos at air-dry condition (N/mm^2)

Part of Culm	Htiyo	Kayin	Myetsangye	Tabin	Thana	Wabogyi	Wagyi	Wanwe	Waya
B	20.45	14.66	11.24	6.74	18.59	9.50	7.40	21.39	12.66
WN	19.80	14.06	11.74	6.04	19.20	9.78	7.05	20.91	13.00
N	21.15	15.19	10.90	7.60	18.13	9.25	7.71	21.88	11.94
M	22.85	12.90	15.64	7.10	20.19	14.22	11.09	23.83	14.98
WN	22.79	12.18	16.06	6.20	21.26	14.79	10.11	24.18	15.18
N	22.91	13.62	15.17	8.51	19.62	13.71	12.15	23.47	11.02
T	27.83	15.51	18.54	7.16	20.34	14.51	13.15	25.62	18.08
WN	26.89	14.35	17.39	6.44	20.53	14.60	12.63	27.34	17.94
N	28.78	16.83	19.83	8.38	20.26	14.41	13.71	23.91	18.98
All Groups	23.66	14.34	14.97	6.99	19.64	12.64	10.66	23.58	15.07

Notes: 'B' means Bottom, 'M' Middle and 'T' Top for Table 23 and Table 24.
'WN' means Without Node and 'N' With Node for Table 23 and Table 24.



Graph 4: Relationship between maximum shearing strength and moisture content

6. Conclusion and recommendations

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. The limits of these properties of the three groups are as follows (Anon, 1993).

Table 25: 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

According to this classification, Htiyo wa, Wanwe wa and Waya wa will be in Group I, which will be the best for construction uses. Tabindaing wa and Wagyi will be in Group II, but Tabindaing is too small to be used in construction in spite of its high strength. Wabomyetsange wa and Thana wa will be in Group III. According to this classification, Wabogyi wa and Kayin wa will be not suitable for construction purposes.

The basic specific gravity of the above tested bamboo species is 0.609 on average, the minimum being 0.451 and the maximum 0.702. In India, the average basic specific gravity of 20 species is 0.639, ranging from 0.515 to 0.817. The average basic specific gravity is found somewhat lower than that of Indian bamboos. Still, the basic specific gravity of the tested bamboos are to be comparable to those of some construction timber species. Most tested bamboos have higher specific gravity than Binga (0.553), Hnaw (0.583), Kayin-byu (0.574), Kaunghmu (0.475), Kyun (0.598), Leza (0.522), Nabe (0.497), Pyinma (0.518), Sagawa (0.426), Taungthayet (0.551), Thingadu (0.589), Thitka (0.558), Tinyu (0.470), Yemane (0.419) and Zinbyun (0.531). Htiyo wa, Tabindaing wa, Thana wa, Wabogyi wa, Wagyi wa and Wanwe wa have similar basic specific gravity to Zaungbale (0.610), Thingan (0.637), Taukkyan (0.707), Lein (0.625) and Kanyaung (0.706).

The maximum crushing strength of the tested bamboos except Kayin and Wabomyetsangye wa is higher those of some construction timber species such as Binga (29 N/mm^2), Chinyok (28 N/mm^2), Hnaw (32 N/mm^2), Lein (30 N/mm^2), Leza (30 N/mm^2), Ma-u-lettanshe (24 N/mm^2), Myaukngo (24 N/mm^2), Nabe (32 N/mm^2), Pyinma (27 N/mm^2), Taungpetwun (30 N/mm^2), Taungthayet (25 N/mm^2), Tawthayet (26 N/mm^2), Thabye (32 N/mm^2), Thande (32 N/mm^2), Thingadu (28 N/mm^2), Thitpayaung (32 N/mm^2), Yemane (26 N/mm^2) and Zaungbale (32 N/mm^2). Htiyo and Wanwe is similar to Yon (39 N/mm^2), Yinma (40 N/mm^2), Thande (39 N/mm^2), Pyaukseik (37 N/mm^2), and Kyetyo (41 N/mm^2) in maximum crushing strength.

The shearing strength of most tested bamboos is higher than those of some construction timbers such as Yemane (7.24 N/mm^2), Nabe (8.10 N/mm^2), etc.

The static bending strength (modulus of rupture) of Htiyo wa, Wanwe wa and Waya wa is found to be higher than those of most timber species, such as Binga, Chinyok, Dwabok, Dwani, Hnaw, Kokko, Lein, Leza, Kyetyo, Leza, Myaukchaw, Myaukngo, Nabe, Sit, Taukkyan, Tawthayet, Taungthayet, etc.

According to the tested properties, it can be found that the tested bamboo species are comparable to those of some construction timber in terms of strength. 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. How, the natural durability of bamboos is very low compared to wood. Thus, it requires preservation treatment. Moreover, the size of bamboo is so small in comparison with wood that it will not be suitable for some constructions. In addition, almost all tested bamboos show high shrinkage and thus it suggests the utilization of mature bamboos and seasoning before putting them into services.

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Appendix I

Mechanical properties of 15 bamboo species

Species	Part of Culm	Seasoning	M.C	Static Bending		Compression parallel to grain		Shear	
				MS	MOE	MS	MOE	MS (N)	MS (WN)
			%	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
1	2	3	4	5	6	7	8	9	10
Htiyo	Bottom	Green	76.82	67.6	22216	43.11	1737	12.29	12.68
		Air-dried	12.00	88.88	23680	62.56	2403	23.01	17.48
	Middle	Green	67.24	62.9	23451	45.29	1953	13.39	12.69
		Air-dried	12.00	100.94	25939	64.64	2658	18.72	17.37
	Top	Green	51.27	95.1	31586	46.35	1371	17.63	17.19
		Air-dried	12.00	163.05	39242	64.81	1987	23.40	22.01
	Average	Green	65.20	119.59	25560	44.93	1692	14.44	14.19
		Air-dried	12.00	88.8	30033	64.00	2349	21.71	18.95
Myin	Bottom	Green	71.20	139.0	22216	47.94	2457	-	8.66
		Air-dried	12.00	160.9	20810	66.18	2983	-	18.05
	Middle	Green	60.83	144.8	23451	48.23	2531	9.35	9.11
		Air-dried	12.00	151.8	21814	70.40	3326	20.94	21.12
	Top	Green	54.78	166.9	31586	51.82	2934	11.24	8.79
		Air-dried	12.00	201.7	33264	67.60	3499	17.17	30.85
	Average	Green	61.56	157.2	25751	49.33	2660	6.86	8.85
		Air-dried	12.00	171.5	25296	68.06	3269	19.06	23.34
Kyathaung	Bottom	Green	86.89	49.9	20287	34.38	2160	8.75	8.82
		Air-dried	12.00	89.8	23835	54.76	7232	14.20	12.94
	Middle	Green	80.79	37.2	16978	43.22	2998	8.85	7.22
		Air-dried	12.00	61.8	18812	65.44	3782	16.34	15.43
	Top	Green	75.89	42.6	20566	44.13	3309	9.44	7.29
		Air-dried	12.00	55.6	19268	63.88	4129	15.56	15.07
	Average	Green	80.70	43.2	19277	40.58	2842	9.01	7.78
		Air-dried	12.00	69.1	20638	61.36	5048	15.37	14.48
Tabindaing	Bottom	Green	78.97	60.1	29317	32.78	893	5.18	3.78
		Air-dried	12.00	87.7	32368	55.82	1117	7.87	6.05
	Middle	Green	74.75	49.5	25189	32.78	751	5.99	4.18
		Air-dried	12.00	85.64	30925	57.87	1366	8.71	6.33
	Top	Green	72.82	51.5	26112	34.13	895	5.67	4.13
		Air-dried	12.00	87.18	31062	59.24	1496	8.39	6.45
	Average	Green	75.57	54.0	26873	33.23	846	5.61	4.03
		Air-dried	12.00	86.82	31451	57.64	1326	8.32	6.27
Thaik	Bottom	Green	80.95	125.9	81279	39.64	1715	10.11	7.49
		Air-dried	12.00	207.2	47886	49.88	3851	14.54	15.51
	Middle	Green	70.23	131.7	85083	44.54	2240	13.02	7.98
		Air-dried	12.00	160.5	73848	70.17	3786	16.33	20.84
	Top	Green	65.54	126.4	65211	49.41	2619	16.65	8.35
		Air-dried	12.00	167.4	53920	68.29	3249	20.09	19.62
	Average	Green	71.47	128.0	77191	44.53	2256	13.26	7.94
		Air-dried	12.00	178.4	48552	62.78	3629	16.98	18.65

Appendix I: Continued -

Species	Part of Culm	Seasoning	M.C	Static Bending		Compression parallel to grain		Shear	
				MS	MOE	MS	MOE	MS (N)	MS (WN)
			%	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
1	2	3	4	5	6	7	8	9	10
Thanawa	Bottom	Green Air-dried	73.09 12.00	51.5 66.43	20611 21377	37.02 57.47	1392 2067	12.45 16.82	9.42 14.66
	Middle	Green Air-dried	64.54 12.00	45.4 61.31	19099 22737	36.50 57.93	1396 2192	12.38 18.47	10.24 15.88
	Top	Green Air-dried	65.25 12.00	44.2 65.30	20372 23074	39.93 61.90	2168 2709	13.94 18.45	10.01 18.68
	Average	Green Air-dried	69.02 12.00	47.3 64.35	20027 22396	37.75 59.10	1628 2322	12.92 17.91	9.89 16.41
Tin	Bottom	Green Air-dried	76.30 12.00	116.0 149.8	41010 34525	43.45 58.43	2118 4118	9.66 15.21	8.15 14.55
	Middle	Green Air-dried	64.21 12.00	85.3 133.4	31213 36204	45.68 66.11	2958 4049	10.40 18.11	8.38 16.17
	Top	Green Air-dried	52.40 12.00	91.1 121.4	34737 40539	46.86 70.80	3446 4524	- -	8.50 19.87
	Average	Green Air-dried	64.71 12.00	97.5 134.9	35653 37090	45.33 65.11	2856 4230	6.69 16.66	8.34 16.86
Wabo	Bottom	Green Air-dried	88.09 12.00	25.8 45.4	10586 11589	32.30 48.12	3613 6004	7.89 10.65	8.03 12.37
	Middle	Green Air-dried	62.87 12.00	26.7 35.2	16163 10833	45.42 58.52	3424 4424	9.26 12.11	5.30 12.64
	Top	Green Air-dried	53.76 12.00	35.4 44.4	12576 12001	46.84 62.24	3606 4791	10.24 11.63	5.58 12.49
	Average	Green Air-dried	70.23 12.00	29.3 41.7	13108 11475	41.52 56.30	3566 5073	9.13 11.46	6.30 12.50
Wabogyi	Bottom	Green Air-dried	53.95 12.00	26.9 28.09	7628 4447	25.70 49.82	1541 1410	6.59 10.37	7.41 11.03
	Middle	Green Air-dried	48.92 12.00	27.3 31.59	13587 6821	32.29 72.19	1708 2333	11.16 14.43	10.49 16.26
	Top	Green Air-dried	43.85 12.00	23.7 36.60	12110 8402	41.01 60.72	1709 2607	11.88 15.16	10.77 15.96
	Average	Green Air-dried	48.83 12.00	26.2 32.09	11108 6556	33.10 60.91	1661 2117	9.88 13.32	9.59 14.41
Wagyi	Bottom	Green Air-dried	86.72 12.00	38.34 71.89	6601 27475	24.18 37.53	1251 1525	6.17 8.78	6.06 8.30
	Middle	Green Air-dried	48.68 12.00	45.80 72.91	11426 22663	37.39 48.93	1858 2102	9.18 10.10	9.09 11.54
	Top	Green Air-dried	41.99 12.00	72.41 70.80	20483 23039	45.83 58.59	2092 2702	11.22 12.49	9.97 12.68
	Average	Green Air-dried	59.22 12.00	52.36 71.86	12952 24392	35.80 48.35	1821 2110	8.86 10.46	8.37 10.84

Appendix I: continued –

Species	Part of Culm	Seasoning	M.C	Static Bending		Compression parallel to grain		Shear	
				MS	MOE	MS	MOE	MS (N)	MS (WN)
			%	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
1	2	3	4	5	6	7	8	9	10
Wanet	Bottom	Green Air-dried	82.78 12.00	50.9 61.6	22621 20977	37.30 61.20	4103 7478	8.99 12.88	8.40 12.47
	Middle	Green Air-dried	75.61 12.00	44.4 55.3	21740 18868	47.19 55.24	3255 4445	11.14 13.92	6.15 13.53
	Top	Green Air-dried	59.77 12.00	49.6 50.6	21934 21650	51.67 64.31	3984 4280	10.79 15.66	6.56 14.80
	Average	Green Air-dried	74.77 12.00	48.3 55.8	22098 20498	45.39 60.25	3838 5401	10.31 14.15	7.04 13.60
Wanwe	Bottom	Green Air-dried	63.34 12.00	124.5 141.6	46704 46773	39.15 62.51	1328 1888	12.23 25.96	11.75 19.99
	Middle	Green Air-dried	58.41 12.00	102.6 119.1	40719 39983	42.32 59.88	1350 1865	13.47 25.25	13.59 21.60
	Top	Green Air-dried	53.46 12.00	100.2 117.3	40323 38941	39.54 57.45	1167 1718	14.12 23.89	14.46 23.26
	Average	Green Air-dried	58.42 12.00	109.1 126.0	42582 41899	40.34 59.95	1281 1824	13.27 25.03	13.27 21.62
Waya	Bottom	Green Air-dried	95.76 12.00	115.3 141.9	31494 33394	32.53 53.06	1007 1648	9.58 13.07	7.74 16.61
	Middle	Green Air-dried	93.07 12.00	102.5 132.3	30796 35447	33.84 60.18	1048 1731	7.99 12.39	9.43 17.77
	Top	Green Air-dried	83.42 12.00	102.3 136.8	31081 39446	35.81 57.51	1062 2458	13.95 20.14	11.04 20.18
	Average	Green Air-dried	91.54 12.00	106.7 137.0	31124 36096	34.06 56.92	1038 1946	10.51 15.20	9.40 18.19
Kayin	Bottom	Green Air-dried	93.25 12	49.50 68.82	19968 21675	12.81 49.01	1024 1788	7.03 15.19	9.52 14.06
	Middle	Green Air-dried	90.74 12	36.51 55.08	16555 19021	15.87 46.09	1144 2687	6.73 13.62	6.36 12.18
	Top	Green Air-dried	77.07 12	34.94 52.83	17616 18498	14.97 38.16	859 1834	7.85 16.83	7.58 14.35
	Average	Green Air-dried	87.02 12	42.21 58.91	18367 20330	14.22 44.92	1012 2124	7.20 15.21	7.82 13.53
Wabo-myetsangye	Bottom	Green Air-dried	83.13 12	52.89 69.03	14432 19020	24.45 70.57	2309 4463	6.64 10.90	6.85 11.74
	Middle	Green Air-dried	77.81 12	43.60 67.43	15128 17528	28.17 62.24	1916 3386	6.72 15.17	7.54 16.06
	Top	Green Air-dried	72.12 12	47.08 76.33	44852 20491	30.33 63.55	2066 3228	7.09 19.83	8.21 17.39
	Average	Green Air-dried	77.69 12	48.57 70.93	26417 18860	27.65 65.45	2097 3404	6.82 15.3	7.53 15.06

Appendix II

Physical Properties of 15 Myanmar Bamboo Species

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage			
						Diameter	Wall Thickness	Longitu-dinal	Volume tric
			%	-	Kg/m^3	%	%	%	%
Kyathaung	Bottom	Green Air-dried Oven-dried	73.42 12.00 0	0.624 0.695 0.759	1070 778 759	- 4.170 6.950	- 6.517 10.86	- 0.207 0.269	- 10.704 17.840
	Middle	Green Air-dried Oven-dried	65.27 12.00 0	0.665 0.744 0.817	1092 833 817	- 4.123 6.870	- 7.011 11.68	- 0.188 0.222	- 11.199 18.660
	Top	Green Air-dried Oven-dried	63.85 12.00 0	0.685 0.769 0.848	1117 862 848	- 3.180 6.350	- 6.376 10.63	- 0.101 0.168	- 11.491 19.150
	Average	Green Air-dried Oven-dried	67.31 12 0	0.659 0.738 0.810	1094 826 810	- 4.020 6.700	- 6.619 11.03	- 0.161 0.161	- 11.150 18.580
Htiyo	Bottom	Green Air-dried Oven-dried	88.49 12.0 0	0.613 0.681 0.794	1132 829 811	- 4.785 7.975	- 5.338 8.897	- 0.078 0.130	- 13.745 22.891
	Middle	Green Air-dried Oven-dried	77.43 12.0 0	0.622 0.692 0.786	1080 854 807	- 4.249 7.081	- 6.251 10.419	- 0.078 0.130	- 13.068 21.780
	Top	Green Air-dried Oven-dried	65.52 12.0 0	0.664 0.746 0.800	1076 884 812	- 3.835 6.392	- 6.249 10.416	- 0.075 0.125	- 10.266 17.109
	Average	Green Air-dried Oven-dried	77.34 12.0 0	0.633 0.706 0.790	1096 857 811	- 4.299 7.165	- 5.939 9.898	- 0.077 0.128	- 12.379 20.632
Myin	Bottom	Green Air-dried Oven-dried	80.45 12.0 0	0.637 0.709 0.780	1140 819 790	- 4.221 7.034	- 5.157 8.596	- 0.106 0.176	- 11.035 18.392
	Middle	Green Air-dried Oven-dried	70.07 12.0 0	0.681 0.765 0.861	1151 880 873	- 4.941 8.234	- 5.782 9.636	- 0.090 0.150	- 12.504 20.841
	Top	Green Air-dried Oven-dried	64.22 12.0 0	0.710 0.802 0.885	1157 922 896	- 4.384 7.307	- 5.480 9.133	- 0.076 0.127	- 11.843 19.739
	Average	Green Air-dried Oven-dried	70.69 12.0 0	0.680 0.764 0.848	1150 881 861	- 4.532 7.554	- 5.525 9.208	- 0.089 0.148	- 11.837 19.728

Appendix II: Continued -

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage Diameter	Shrinkage Wall Thickness	Shrinkage Longitu-dinal	Shrinkage Volume tric
			%	-	Kg/m^3	%	%	%	%
Tapindaing	Bottom	Green Air-dried Oven-dried	71.58 12.0 0	0.590 0.652 0.692	1006 730 692	- 4.219 7.031	- 6.614 11.024	- 0.097 0.162	- 9.717 16.195
	Middle	Green Air-dried Oven-dried	72.79 12.0 0	0.629 0.700 0.738	1076 784 738	- 4.043 6.739	- 6.326 10.544	- 0.115 0.192	- 10.468 17.446
	Top	Green Air-dried Oven-dried	74.15 12.0 0	0.654 0.733 0.753	1131 821 753	- 3.782 6.303	- 5.487 9.145	- 0.098 0.164	- 10.123 16.872
	Average	Green Air-dried Oven-dried	72.86 12.0 0	0.625 0.696 0.728	1072 779 728	- 4.014 6.691	- 6.155 10.258	- 0.104 0.173	- 10.106 16.843
Thaik	Bottom	Green Air-dried Oven-dried	49.81 12.0 0	0.693 0.749 0.774	1036 838 774	- 4.175 6.958	- 5.328 8.880	- 0.115 0.192	- 6.154 10.256
	Middle	Green Air-dried Oven-dried	41.02 12.0 0	0.759 0.825 0.850	1067 925 850	- 4.605 7.675	- 6.626 11.044	- 0.119 0.199	- 6.401 10.669
	Top	Green Air-dried Oven-dried	34.03 12.0 0	0.805 0.880 0.883	1075 986 883	- 4.578 7.630	- 6.277 10.461	- 0.102 0.171	- 5.313 8.854
	Average	Green Air-dried Oven-dried	40.64 12.0 0	0.759 0.826 0.843	1062 925 843	- 4.475 7.458	- 6.152 10.254	- 0.111 0.186	- 5.904 9.840
Thana	Bottom	Green Air-dried Oven-dried	51.59 12.0 0	0.671 0.752 0.759	1036 869 762	- 3.250 5.417	- 3.741 6.235	- 0.099 0.164	- 5.953 9.923
	Middle	Green Air-dried Oven-dried	53.31 12.0 0	0.712 0.799 0.799	1089 900 804	- 3.308 5.513	- 3.752 6.254	- 0.103 0.172	- 6.197 10.328
	Top	Green Air-dried Oven-dried	56.14 12.0 0	0.722 0.817 0834	1121 915 834	- 3.392 5.653	- 3.947 6.578	- 0.085 0.142	- 8.015 13.359
	Average	Green Air-dried Oven-dried	53.68 12.0 0	0.702 0.790 0.800	1082 895 800	- 3.316 5.527	- 3.813 6.356	- 0.096 0.159	- 6.722 11.203

Appendix II: Continued -

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage			
						Diameter	Wall Thickness	Longitu-dinal	Volume tric
			%	-	Kg/m^3	%	%	%	%
Tin	Bottom	Green	80.21	0.592	1054	-	-	-	-
		Air-dried	12.0	0.647	771	4.271	4.576	0.087	13.162
		Oven-dried	0	0.761	755	7.119	7.627	0.144	21.936
	Middle	Green	68.60	0.646	1082	-	-	-	-
		Air-dried	12.0	0.708	830	3.955	4.486	0.055	13.302
		Oven-dried	0	0.833	828	6.592	7.476	0.092	22.171
	Top	Green	65.43	0.658	1082	-	-	-	-
		Air-dried	12.0	0.736	868	4.017	4.288	0.049	13.968
		Oven-dried	0	0.861	865	6.693	7.146	0.081	23.280
	Average	Green	71.35	0.632	1073	-	-	-	-
		Air-dried	12.0	0.697	818	4.079	4.451	0.063	13.474
		Oven-dried	0	0.819	811	6.799	7.418	0.106	22.456
Wabo	Bottom	Green	71.16	0.598	1013	-	-	-	-
		Air-dried	12.0	0.661	741	3.265	3.514	0.113	10.720
		Oven-dried	0	0.729	729	5.442	5.857	0.188	17.867
	Middle	Green	44.33	0.729	1042	-	-	-	-
		Air-dried	12.0	0.821	925	2.578	2.681	0.097	8.926
		Oven-dried	0	0.860	860	4.297	4.468	0.161	14.876
	Top	Green	36.04	0.780	1055	-	-	-	-
		Air-dried	12.0	0.867	999	2.510	3.093	0.085	6.084
		Oven-dried	0	0.868	868	4.183	5.155	0.141	10.140
	Average	Green	49.57	0.707	1038	-	-	-	-
		Air-dried	12.0	0.783	896	2.798	3.103	0.097	8.414
		Oven-dried	0	0.822	822	4.664	5.171	0.162	14.023
Wabogyi	Bottom	Green	51.87	0.526	787	-	-	-	-
		Air-dried	12.0	0.574	643	2.647	2.253	0.090	4.836
		Oven-dried	0	0.575	571	4.412	3.755	0.150	8.059
	Middle	Green	44.05	0.656	936	-	-	-	-
		Air-dried	12.0	0.713	821	2.891	3.067	0.120	6.040
		Oven-dried	0	0.716	729	4.818	5.111	0.199	10.067
	Top	Green	47.78	0.666	976	-	-	-	-
		Air-dried	12.0	0.740	836	3.001	3.604	0.124	5.274
		Oven-dried	0	0.754	749	5.001	6.006	0.207	8.789
	Average	Green	47.97	0.614	898	-	-	-	-
		Air-dried	12.0	0.664	765	2.902	2.976	0.112	5.379
		Oven-dried	0	0.669	681	4.836	4.960	0.186	8.964

Appendix II: Continued -

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage			
						Diameter	Wall Thickness	Longitu-dinal	Volume tric
			%	-	Kg/m^3	%	%	%	%
Wagyi	Bottom	Green	122.75	0.507	1053	-	-	-	-
		Air-dried	12.0	0.530	705	6.394	7.329	0.213	19.276
		Oven-dried	0	0.698	698	10.657	12.215	0.356	32.126
	Middle	Green	68.57	0.647	1069	-	-	-	-
		Air-dried	12.0	0.723	844	4.081	3.778	0.158	12.222
		Oven-dried	0	0.799	788	6.802	6.297	0.263	20.371
	Top	Green	58.67	0.684	1087	-	-	-	-
		Air-dried	12.0	0.792	880	5.106	3.740	0.103	10.758
		Oven-dried	0	0.834	834	8.511	6.234	0.172	17.931
	Average	Green	83.15	0.618	1070	-	-	-	-
		Air-dried	12.0	0.683	836	5.391	4.853	0.157	14.085
		Oven-dried	0	0.777	773	8.985	8.088	0.262	23.476
Wanet	Bottom	Green	64.33	0.654	1067	-	-	-	-
		Air-dried	12.0	0.730	817	3.353	4.071	0.143	11.486
		Oven-dried	0	0.817	817	5.588	6.786	0.238	19.744
	Middle	Green	40.05	0.775	1079	-	-	-	-
		Air-dried	12.0	0.869	973	3.013	3.367	0.161	9.291
		Oven-dried	0	0.909	909	5.021	5.612	0.269	15.485
	Top	Green	32.48	0.825	1085	-	-	-	-
		Air-dried	12.0	0.889	996	2.628	3.167	0.085	6.747
		Oven-dried	0	0.899	899	4.380	5.279	0.142	11.245
	Average	Green	44.45	0.758	1078	-	-	-	-
		Air-dried	12.0	0.824	923	2.968	3.506	0.126	9.068
		Oven-dried	0	0.873	874	4.947	5.843	0.210	15.113
Wanwe	Bottom	Green	56.06	0.661	1027	-	-	-	-
		Air-dried	12.0	0.739	828	4.358	6.063	0.080	10.820
		Oven-dried	0	0.807	807	7.263	10.106	0.134	18.033
	Middllle	Green	52.13	0.685	1038	-	-	-	-
		Air-dried	12.0	0.769	862	4.601	6.198	0.059	10.990
		Oven-dried	0	0.839	839	7.668	10.330	0.098	18.316
	Top	Green	49.55	0.700	1044	-	-	-	-
		Air-dried	12.0	0.789	884	4.127	6.047	0.076	10.137
		Oven-dried	0	0.843	843	6.878	10.076	0.126	16.894
	Average	Green	52.58	0.682	1036	-	-	-	-
		Air-dried	12.0	0.766	858	4.362	6.102	0.071	10.649
		Oven-dried	0	0.830	830	7.270	10.171	0.119	17.748

Appendix II: Continued -

Species	Part of Culm	Seasoning	M.C	Specific Gravity	Density	Shrinkage: Diameter	Shrinkage: Wall Thickness	Shrinkage: Longitu-dinal	Shrinkage: Volume tric
			%	-	Kg/m^3	%	%	%	%
Waya	Bottom	Green	113.60	0.538	1140	-	-	-	-
		Air-dried	12.0	0.589	659	7.872	8.838	0.133	14.205
		Oven-dried	0	0.706	706	13.137	14.730	0.222	23.675
	Middle	Green	100.62	0.575	1136	-	-	-	-
		Air-dried	12.0	0.633	709	7.217	8.634	0.128	14.879
		Oven-dried	0	0.752	752	12.029	14.390	0.214	24.798
	Top	Green	90.85	0.602	1133	-	-	-	-
		Air-dried	12.0	0.668	748	7.160	9.095	0.107	16.224
		Oven-dried	0	0.813	812	11.933	15.158	0.178	27.040
	Average	Green	101.80	0.571	1137	-	-	-	-
		Air-dried	12.0	0.630	705	7.420	8.857	0.122	15.090
		Oven-dried	0	0.757	757	12.377	14.762	0.204	25.149
Kayin	Bottom	Green	107.75	0.449	894	-	-	-	-
		Air-dried	12.00	0.485	544	4.74	8.17	0.04	16.02
		Oven-dried	0	0.612	612	7.91	13.63	0.07	26.71
	Middle	Green	105.12	0.441	881	-	-	-	-
		Air-dried	12.00	0.476	534	5.19	6.75	0.10	16.57
		Oven-dried	0	0.611	612	8.66	11.25	0.17	27.61
	Top	Green	94.21	0.464	878	-	-	-	-
		Air-dried	12.00	0.503	563	4.26	6.02	0.12	15.58
		Oven-dried	0	0.613	613	7.09	10.03	0.20	25.97
	Average	Green	102.92	0.451	885	-	-	-	-
		Air-dried	12	0.488	547	4.73	7.12	0.08	16.05
		Oven-dried	0	0.613	612	7.88	11.87	0.14	26.75
Wabo-myetsangye	Bottom	Green	108.88	0.553	1065	-	-	-	-
		Air-dried	12	0.611	684	3.59	6.31	0.02	11.56
		Oven-dried	0	0.669	669	5.98	10.51	0.04	19.27
	Middle	Green	98.17	0.575	1095	-	-	-	-
		Air-dried	12	0.636	712	4.10	7.14	0.13	14.28
		Oven-dried	0	0.752	752	6.83	11.91	0.22	23.80
	Top	Green	78.96	0.633	1110	-	-	-	-
		Air-dried	12	0.706	791	4.83	7.18	0.08	10.74
		Oven-dried	0	0.748	748	8.04	11.97	0.13	17.89
	Average	Green	96.01	0.584	1088	-	-	-	-
		Air-dried	12	0.648	726	4.13	6.84	0.07	12.18
		Oven-dried	0	0.719	719	6.89	11.40	0.12	20.31