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Investigation on Chemical, Physical and Mechanical Properties of Some Myanmar Bamboo Species

Khin May Lwin, Assistant Research Officer
Khin Maung Sint, Range Officer
Su Myint Than, Research Assistant 2
Cho Cho Myint, Research Assistant 3
Forest Research Institute
Yezin

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မြန်မာ့ဝါးအချို့တို့၏ ဓာတု၊ ရူပနှင့်အင်အားဆိုင်ရာဂုဏ်သတ္တိများကိုလေ့လာခြင်း

ခင်မေလွင်၊ လက်ထောက်သုတေသနအရာရှိ
ခင်မောင်ဆင့်၊ တောအုပ်ကြီး
စုမြင့်သန်း၊ သုတေသနလက်ထောက် -၂
ချိုချိုမြင့်၊ သုတေသနလက်ထောက် -၃
သစ်တောသုတေသနဌာန၊ ရေဆင်း

အကျဉ်းချုပ်

ဝါးအသုံးချခြင်းနှင့် ဝါးထွက်ပစ္စည်းပြုလုပ်သည့်နည်းစနစ်များသည် ဝါးမျိုးအလိုက် ကွဲပြားသော ဂုဏ်သတ္တိများပေါ်တွင် မူတည်ပါသည်။ အိုင်တီတီအို ဝါးစီမံကိန်းတွင် ဆောင်ရွက် ရမည့် လုပ်ငန်းများထဲမှ တစ်ခုအပါအဝင်ဖြစ်သော ဓာတု၊ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကို သစ်တောသုတေသနဌာန၊ ရေဆင်းရှိ သစ်ဓာတုဌာနစိတ်နှင့် သစ်ရူပနှင့်အင်အား ဌာနစိတ်တို့တွင် စမ်းသပ်လေ့လာခဲ့ပါသည်။ တင်း၊ ကျသောင်း၊ မျှင်၊ သိုက်၊ ဝါးဘိုးနှင့် ဝါးနက်တို့ကို စမ်းသပ်ခဲ့ခြင်းဖြစ်ပါသည်။ စမ်းသပ်ခဲ့သော ဓာတု၊ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများပေါ် မူတည်၍ သင့်တော်သော ဝါးအသုံးချနည်းများကို လေ့လာတင်ပြထားပါသည်။

Investigation on Chemical, Physical and Mechanical Properties **of Some Myanmar Bamboo Species**

Khin May Lwin, Assistant Research Officer
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Cho Cho Myint, Research Assistant 3
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, chemical, physical and mechanical properties of six bamboo species were investigated in Wood Chemistry Section and Timber Physics and Mechanics Section, Forest Research Institute, Yezin. Tin (*Cephalostachyum pergracile* Munro.), Kyathaung (*Bambusa polymorpha* Munro.), Myin (*Dendrocalamus strictus* Nees.), Thaik (*Bambusa tulda* Roxb.), Wabo (*Dendrocalamus brandisii* Kurz.) and Wanet (*Dendrocalamus longispathus* Kurz.) were investigated. Based on the results of the chemical, physical and mechanical properties, the appropriate end uses of the bamboos were briefly discussed.

Contents

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1 Introduction

Bamboo, which belongs to Poaceae, the grass family, is a perennial plant, and is extremely varied. It belongs to over a hundred genera, covering over 1000 different species, ranging in size from less than a few feet to well over 100 feet in height. Myanmar has more than 90 bamboo species over the country.

Bamboo is called "wood of the poor" in India, "friend of people" in China and simply "Brother" in Vietnam, a testimony to its many varied essential uses. It is one of the most tremendous living resources in the world. Its strength and durability lend it to many uses-from use as a structural building material to a food source.

Bamboo timber has much good merit, such as rapid growth, high yield, early maturing, fine quality and versatile usage. Bamboo is made of long cellulose fibers that run parallel to each other over the entire length of the stalk. These longitudinal open cells, which act to carry water to feed the bamboo, are incased in lignin, a substance which strongly binds the fibres together. These fibers are most densely concentrated closer to the outer protective surface of the stalk, whereas the innermost fibers are the weakest and most starchy.

It is one of the most important renewable forest produce, which has the capability to produce maximum biomass per unit area and time as compared with other forest species. It plays a vital role in the daily life of the rural and tribal people in Myanmar in numerous ways, from house construction and agricultural implements to food and weapons. The edible part of bamboo shoot may help solve nutritional deficiency of the rural poor. Nowadays, the bamboo industrial entrepreneurs and local people produce value-added bamboo products, which become high value-added export products. Bamboo has been proved a potential source of cash.

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.

The properties determining the best uses of bamboos are:

- the height of the culm (the total height)
- the usable length of the culm
- the outer diameter at the bottom and at the top
- the wall thickness
- the length of internode
- the straightness of the culm
- the mechanical properties
- the physical properties
- the natural durability and preservation
- the chemical constituents

If the data for the above mentioned properties be obtained or found out, appropriate bamboo species could be selected for specific purpose or use.

For the efficient utilization of bamboos, Bamboo Products Processing Section, the ITTO Bamboo Project have to identify promising bamboo species for quality bamboo products by analyzing the chemical, physical and mechanical properties for 15 main bamboo species, which are commonly used for furniture, handicraft and pulp and paper. From the priority 15 species, six bamboo species, Tin wa (*Cephalostachyum pergarcile*), Kyathaung wa (*Bambusa polymorpha*), Myin wa (*Dendrocalamus strictus*), Thaik wa (*Bambusa tulda*), Wabo wa (*Bambusa brandisii*) and Wanet wa (*Dendrocalamus longispathus*) had already been investigated and presented in this paper.

By conducting physical and mechanical tests, the useful data can be obtained:

- to establish characteristic strength functions,
- to arrive at the allowable stresses, and
- to establish the relationship between mechanical properties and factors such as moisture content, mass per volume, growth site, position along the culm, presence of node or internode, etc.

These physical and mechanical properties are of quite importance in uses of bamboo where strength and dimensional stability is essential.

The chemical composition of bamboo is of special interest and great importance to the pulp and paper industry, bamboo based industry and preservation for quality bamboo products. The interesting chemical composition of bamboo, such as hot water solubility, 1% NaOH solubility, alcohol/benzene solubility, cellulose, ash, silica, and starch contents are investigated.

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

2 Literature review

The composition and structure of bamboo material are different in meaning. Composition means the matters of which bamboo material is composed, this is studied from the view point of chemistry. The structure of bamboo material is observed under microscopes of different magnifying power. This is studied from the view of point of anatomy.

The chemical constituents of the bamboo culm tissue provide the food for the attacking organisms. The main components of bamboo are similar to those of wood. Mainly are cellulose as a skeleton (approximately 40 %), hemi-cellulose as a matrix (approximately 25 %) and lignin as an incrusting material (approximately 25 %); these values are comparable with those of wood. Minor components are water-soluble compounds, such as sugars, starch, tannins, waxes and inorganic salts. The composition varies slightly according to species, age, culm part and growing conditions.

Hemi-cellulose consists of pentosan mostly, the amount of hexosan is very little. More than 90 % of hemi-celluse is xylan, the experiment shows: bamboo xylan is D-glucuranate arabinoxylan, containing 4 oxygen-methyl-D-glucuranate, L-arabinose, and D-xylose. The molecule ratio is 1.0: 1.0-1.3:24-25. The composition of arabinoxylan of bamboo is different from that of needled and broad leaved trees. The polymerized molecules of bamboos are more than that of trees. The pentose content of bamboo is 19-23 %, approaching to that of broad-leaved trees, much higher than that of needled-leaved trees (10-15 %). This means it is acceptable to extract uronic acid in the process of pulping and hydrolysis (Zhang Qisheng et al., 2001).

Lignins are generally classified into three major groups based on their structural monomar units. Gymnosperm lignin is a dehydrogenation polymer of conifer alcohol. Angiosperm lignin is a mixed dehydrogenation polymer of conifery and sinapyl (2) alcohols, and grass lignin is composed of mixed dehydrogenation polymer of coniferyl-, sinapyl- and p-coumaryl (3) alcohols. in grass lignin p-cumaric is esterified to the side chains of the lignin polymer (Takayashi Higuchi, 1987).

The specific features of bamboo lignin lie in the existence of dehydrogenated polymerides and 5-10% of acrylic ester. The lignin content of bamboo of 1 year of age is in the range of 20-25%, approaching to broad-leaved wood and some grass (such as wheat straw), slightly less than needle-leaved. Less lignin content means less consumption of chemicals in pulping process and easier pulping process.

The chemical composition of bamboo is of special interest to the pulp and paper industry and will directly influence the quality of pulp and resultant paper. The following components and percentage are generally cited: holocellulose (61-71%), lignin (20-30%), ash (1-5 (-9)%, solubility in cold water (1.6-4.6), hot water solubility (3.1-7.0), alcohol-benzene and water solubility implies increased consumption of chemicals in pulping. The other nutrient substances such as protein (1.5-6%), glucose (2%), starch (2.2-5.18%), as well as fat and wax (2.8-3.55%) are still included. So they are very susceptible to mould rotting and moth eating during their transportation and storage, which factors make their span of use much shorter.

It can also provide information for bamboo preservation. The 1% NaOH solubility indicates the amount of low molecular weight carbohydrates consisting mainly of hemicellulose and degraded cellulose; as such , it may indicate the degree of decay, e.g. by fungi, heat and oxidation. Silica is the main constituent in ash and ultimately present problem for the pulp and paper making process. The silica content of bamboo culm is generally higher than that of wood (0.5-4.0%) and mostly deposited in the epidermis. Since bamboo contains more impurities than wood, cooking is more costly and pulp yield is less (Drasfield and Widjaja, 1995).

However, different constituents are preferred by fungi and insects. The starch content is of considerable importance for its vulnerability to insects and staining fungi. The starch granula are accumulated in the parenchyma cells, in culm fibers and subterranean rhizome. The amount of starch varies generally between 2-6%, but can reach up to 10%. It is influenced by age, height and site, whereby the lower part contains less starch than the middle and top portions (Walter et. al., 2003)

The proximate chemical compositions of bamboo culms are generally similar to those of hardwoods, except that alkaline extract, ash and silica contents are higher than in hardwoods. High silica content causes scaling during evaporation of the spent liquor for recovery of the chemicals in pulping.

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 Indonesia, a comparative study on moisture contents and strength properties of green and air-dried bamboos was conducted and showed that there was a general increase in strength properties from green to air-dried condition. However, the increase in strength from the green to air-dried condition was much lower than that in wood. The author concluded that there seemed to be little risk involved in using green bamboos for construction purposes as far as strength is concerned (Soenardi Prawirohatmodjo, 1988).

Moreover, the study in *Gigantochloa pseudoarundinacea* in West Java showed that slope-inhabiting bamboos are higher in specific gravity, bending and tensile strength than those in valley (Tavip Soeprayitno, et. al., 1988).

Harendra Nath Mishra mentioned that as compared to some constructional timbers, bamboos possess better strength and can thus be suitably used for structural purposes. Due to its physical form with nodes and cross partition walls, the bamboo culm has a high strength to weigh ratio. Hence, it can make lighter but stronger structural components for houses at comparatively low cost (Harendra Nath Mishra, 1988).

However, not all bamboos are suitable for construction purposes. In India, bamboos with a great wall thickness having close nodes and which grow on ridges and warmer areas are considered good for structural uses, particularly for use in columns, beams, roof, rafters, purlins and trusses. Depending on the availability and cost, the following species are selected for home construction in India (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 china, a lot of research works on bamboos have been done: Research on bamboo taxonomy, anatomy, pest and diseases, bamboo plantation techniques, genetic breeding, bamboo processing technology, bamboo shoot processing technology, bamboo charcoal, research on bamboo processing machines.

In Myanmar, some research works on bamboos have been done, but there still exist a lot to be investigated on bamboo utilization techniques. There is only one research paper concerning bamboo physics and mechanics, in which specific gravity, compression strength parallel to grain and bending strength of green Tin and Kyathaung wa Bamboos were investigated and mentioned (Khin Maung Maung, et. al., 1970). The testing procedure followed ASTM standards of testing small clear specimens.

Today, INBAR has prepared a draft ISO standard for testing physical and mechanical properties of bamboos (INBAR, 2001). Therefore, it is of 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 most abundant and well-known six bamboo species were selected for testing chemical constituents and physical and mechanical properties. These species are:

(1) Kyathaung wa (*Bambusa polymorpha* Munro.)
(2) Tin wa (*Cephalostachyum pergracile* Munro.)
(3) Myin wa (*Dendrocalamus strictus* Nees.)
(4) Wabo wa (*Dendrocalamus brandisii* Kurz.)
(5) Wanet wa (*Dendrocalamus longispathus* Kurz.)
(6) Thaik wa (*Bambusa tulda* Roxb.)

Table 1: Diameter of the tested bamboo species measured at green condition (mm)

Species	Average	Bottom	Middle	Top
Kyathaung wa	65.13	69.11	66.06	61.08
Tin wa	40.42	43.69	41.27	36.23
Myin wa	33.92	39.05	34.37	29.91
Wabo wa	80.49	83.41	81.09	77.41
Wanet wa	70.63	72.43	71.66	68.40
Thaik wa	39.85	49.06	39.66	33.79

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

Species	Average	Bottom	Middle	Top
Kyathaung wa	9.19	14.28	8.02	5.95
Tin wa	8.32	13.87	6.36	4.87
Myin wa	10.46	14.09	10.32	8.24
Wabo wa	9.10	13.88	7.80	5.99
Wanet wa	8.62	13.38	7.41	5.81
Thaik wa	14.23	22.37	13.47	9.84

The first three species were collected from Ngalaik Forest Reserve, Pyinmana Township, Yamethin District, Mandalay Division and the others from Hlwegyi, Pinlaung Township, Shan State. Among the collected species, Wabo wa is the largest bamboo and Myin wa is the smallest (Table 1). Thaik wa and Myin wa have culms with the highest wall thickness (Table 2).

Myin wa is very common in Upper and Lower Myanmar. Under favourable conditions the culms are 15 meters long and 75 to 100 mm diameter; when growing in dry localities, they are much smaller and often solid, hence the name "male bamboo". The walls are always comparatively thick. The culms are useful for building, lance shafts, tent poles and tool-handles.

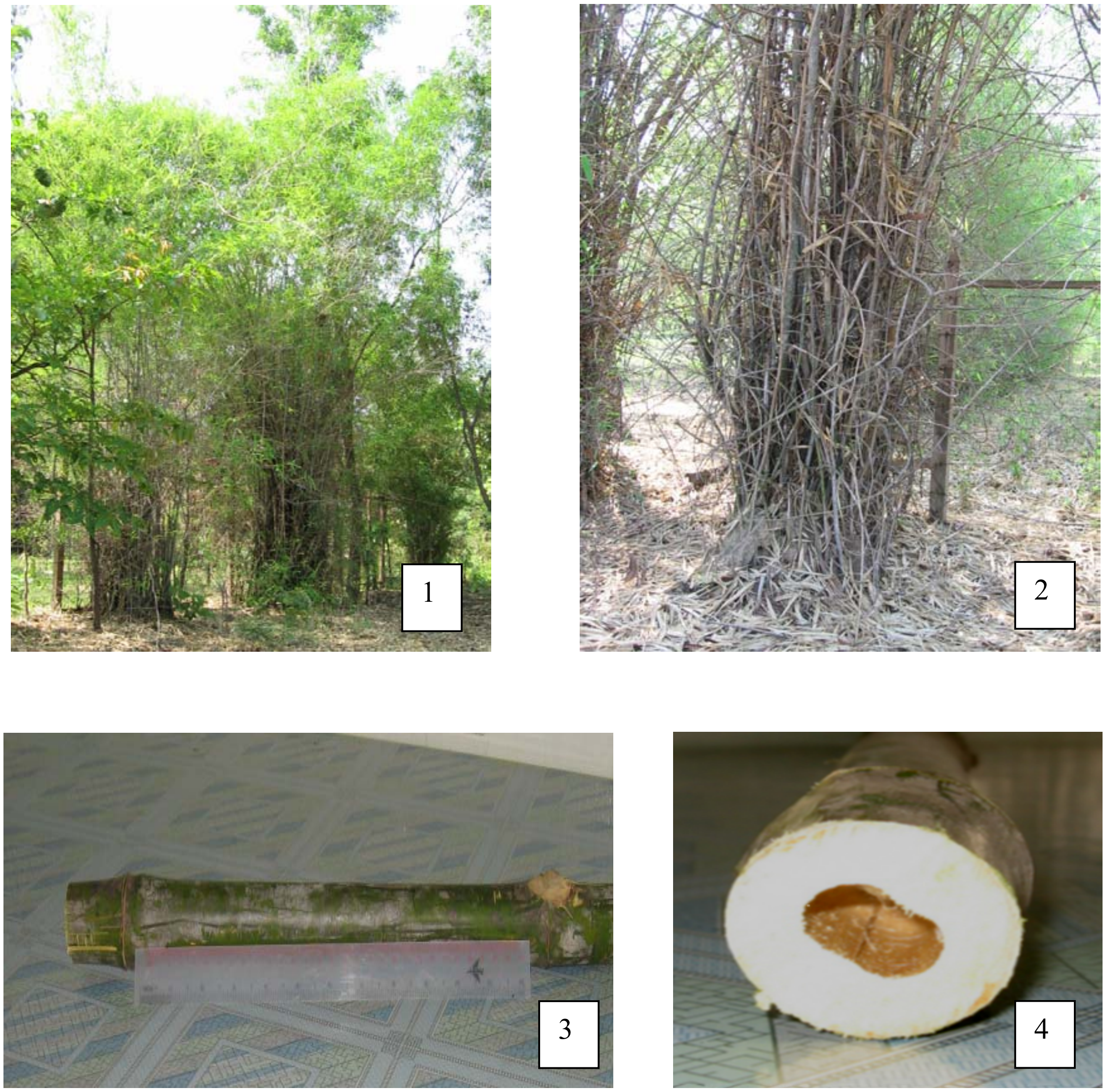

Figure 1: Photos showing some parts of Myin wa

Kyathaung wa attains about 24 meter in height with culms 75 to 125 mm diameter. It is easily known by its ashy-white culms. It is very common in the Pegu Yoma and one of the most useful bamboos in Myanmar. It is in great demand for building.

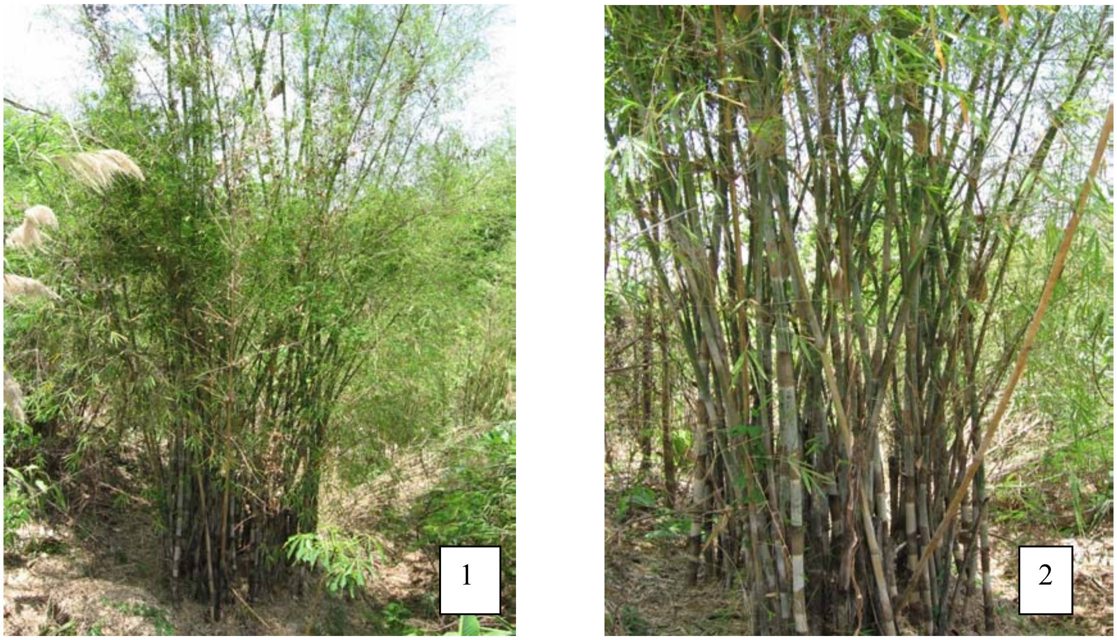

Figure 2: Photos showing some parts of Kyathaung wa

Culms of Tin wa are 12-15 meter high and attains 35-90 mm diameter. Tin wa is a very useful bamboo; perhaps the best known and most useful in Myanmar. This is the species used for cooking glutinous rice and it is particularly suited for split bamboo work. It is also the favourite bamboo for dunnage in Yangon

Figure 3: Photos showing some parts of Tin wa

The culms of Thaik wa are 15-18 meters high and attain 75-100 mm diamter. The culms are dark-green. Thaik wa is a strong, useful, thick-walled bamboo, but the culms are not always straight. They are used for building, basket-work and mats.

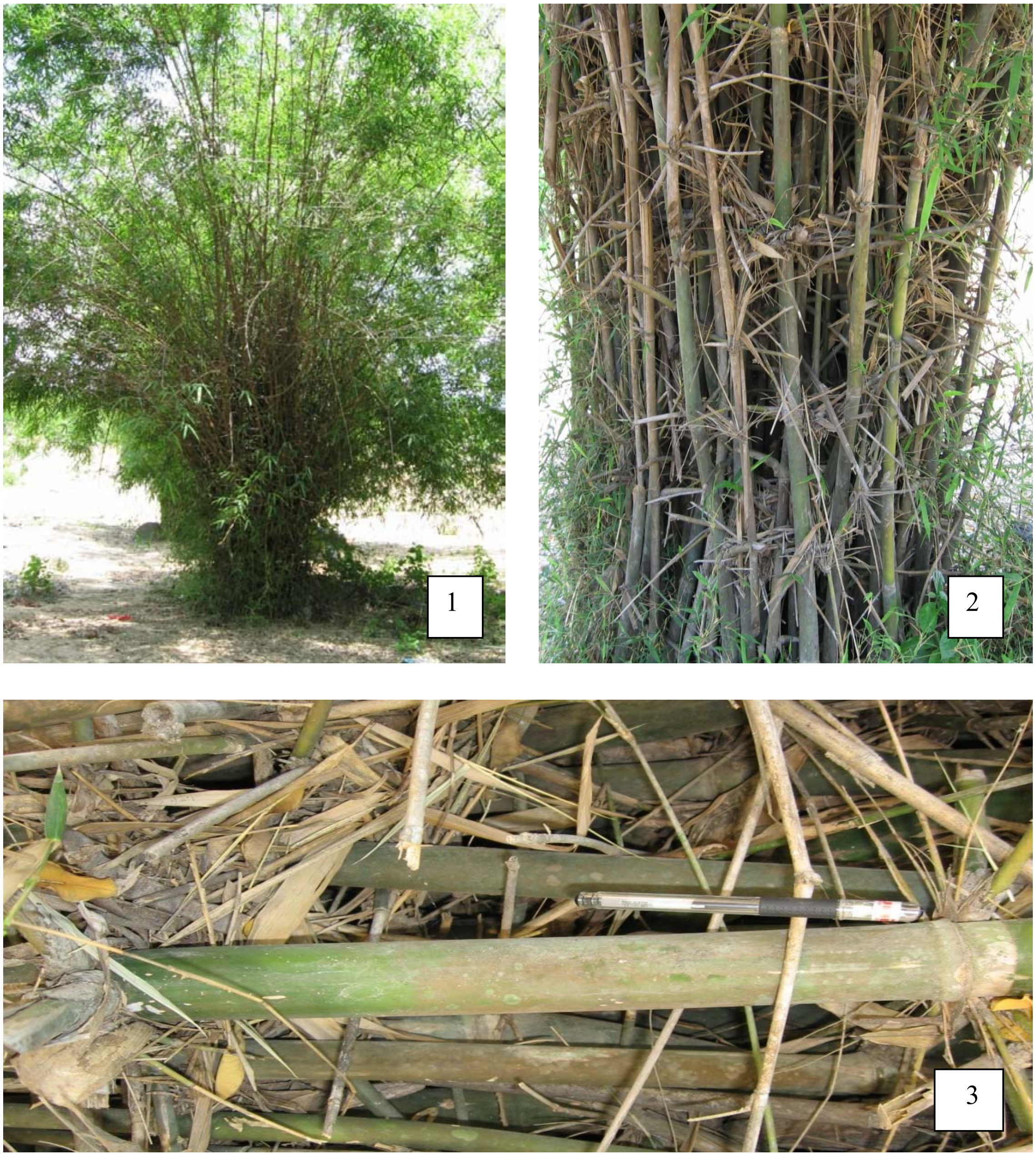

Figure 4: Photos showing some parts of Thaik wa

The culms of Wanet wa are about 18 meters high and attain 75-100 mm diameter with long internodes. The nodes are 300-600 mm or more apart.

Figure 5: Photos showing some parts of Wanet wa

Wabo wa is a large bamboo, the culm being 25-30 meters high and attaining 125-180 mm diamter. It is found in evergreen forests of Myanmar, especially in lower parts. It is also called Kyalo-wa.

3.2 Methods

Bamboo culms were selected from various clumps in the standing condition. Seven to ten 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.

Before felling, one ring was marked at a height of one meter from the ground with silver paint. The name of the species, the name of locality, the age of the culms and date of felling and transportation were recorded.

3.2.1 Chemical Properties

The approximate chemical analysis of bamboo is based on TAPPI methods using three replicates, which were randomly cut from each portion. For chemical study, each bamboo was divided into three portions, Bottom (B), Middle (M) and Top (T). All samples were ground to 60-80 mesh size.

The following chemical properties were tested:

(i)	Hot water solubility	TAPPI	T 207 (1978)
(ii)	1% NaOH solubility	TAPPI	T 212 (1978)
(iii)	Alcohol/benzene solubility	TAPPI	T 204 (1978)
(iv)	Cellulose	TAPPI	T 203 (1978)

(v) Ash TAPPI T 15 (1978)
(vi) Silica
(vii) Starch

3.2.1.1 Hot water solubility

Hot water solubility method provides a measure of the tannins, gums, sugars, coloring matter, and starches in the sample.

Oven-dried ground 60-80 mesh size sample (2±0.1 g) was weighed and plashed in a flask and 100 ml of distilled water was added. Then the flask was attached with reflex condenser and placed in the boiling water bath at (100º C). Boiling was continued for three hours. After boiling, the content of the flask was filtered with a previously oven-dried, cooled and weighed 1-G-1 crucible. The residue in the flask was washed with hot water and poured in the same crucible to filter all content in the flask. The crucible with content was kept in an oven at (105±2º C) for eight hours. After eight hours, the crucible was removed from oven and cooled in desiccators. After cool, it was weighed. Oven drying, cooling and weighing were repeated until constant weight of the crucible with content was obtained. Material dissolve in hot water was calculated when the weight of crucible with content obtained. Then, hot water solubility percent was calculated. The same procedure was repeated for each of the remaining samples.

% of Hot water solubility = (A - B)/A x 100

Where, A = OD Wt. of sample in gram
B = OD Wt. of sample after extraction with hot water

3.2.1.2 1%NaOH Solubility

A one percent solution of caustic soda (NaOH) is used in determining the degree of fungus decay that has taken place in a given sample. As the sample decays, the percentage of alkali soluble material increases in proportion to the decrease in pulp yield caused by the decay.

Oven-dried sample (2 ±0.1g) was taken in a conical flask (250 ml) and 100ml 1%NaOH solution was added. Then the flask was fitted with water condenser and placed in the boiling water bath at 100 C for 1 hour. After boiling, the content of the flask was filtered with 1-G-1 crucible and the residue in the flask was washed with the distilled water until the residual material become acid free. The crucible was dried in oven at (105 ± 2º C) for eight hours. After drying, the crucible was cooled in desiccators and weighed. Oven drying cooling and weighing were repeated until constant weight of the crucible with content is obtained. Then 1% NaOH solubility percent was calculated. The sample producer was repeated for each of the remaining samples.

% of NaOH solubility = (A - B) / A 100

Where A = OD Wt. of sample in gram
B = OD Wt. of sample after extraction with 1%NaOH

3.2.1.3 Alcohol - Benzene Solubility

Alcohol - Benzene Solubility of raw material consists of all components soluble in organic solvent. It principally consists of all components soluble in organic solvent. It principally consists of resins, fatty acid, their esters, waxes and saponifiable substances. Low single organic substance is capable of removing the substances.

Oven-dried sample 5 g was weighed and placed in a previously oven-dried, cooled and weighed porous thimble. Then, thimble was placed in a soxhlet apparatus and extracted with (250 - 300 ml) alcohol-benzene mixture (33 parts of ethyl alcohol and 67 parts of benzene) for six hours or until the color of mixture was clear. After extraction, thimble was removed from the soxhlet apparatus and dried in the oven at (105±2ºC) for eight hours. After oven drying, thimble was cooled in desiccators and weighed. Oven drying, cooling and weighing were repeated until constant weight of the thimble with content was obtained. Alcohol-benzene solubility percent was calculated when the constant weight of thimble with content was obtained. The same procedure was repeated for each of the remaining samples.

% of Alcohol-benzene solubility = (A - B)/A x 100

Where, A = OD Wt. of sample in gram
B = OD Wt. of sample after extraction with alcohol-benzene

3.2.1.4 Holocellulose content

Holocellulose is the major component of cell wall material (60-80 %). It is comprised of the total carbohydrate with cellulose, hemicellulose fraction, carbohydrate lignin and cellulosis raw material. However, slight retention of lignin in holocellulose and slight degradation of hollocellulose during the process of each determination can not be ignored. Physical and chemical study of holocellulose gives an idea about quality and quantity of pulp and paper to produce.

Oven-dried extracted free sample (5 g) was weighed and placed in a flask (500ml) 160 ml of distilled water, sodium chlorite (1.5 g) and glacial acetic acid (0.5 ml) were added to the flask. The flask was covered with cap and placed in the water bath at 70-80º C for one hour. After one hour sodium chlorite (1.5 g) and acetic acid (0.5 ml) were again added to the flask. This process was repeated 4-5 times or until the content in the flask became white. Then, the content in the flask was filtered with 1-G-2 crucible. After filtration, the crucible was washed with distilled water and finally with acetone. The crucible was dried in an oven at 105±2 ºC for eight hours. After eight hours, crucible was removed from oven, cooled in desiccators, and weighed. Oven drying, cooling and weighing were repeated until the constant weight of the crucible with content was obtained. Holocellulose content was calculated when the constant weight of crucible with content obtained. The same procedure was repeated for each of the remaining samples.

% of Holocelluse content = (C-B)/A x 100
Where A = OD Wt. of extracted free sample in gram
B = OD Wt. of 1-G-2 crucible in gram
C = OD Wt. of 1-G-2 crucible with content in gram

3.2.1.5 Ash content

The ash content in any raw material can be estimated for the mineral salt like silica, calcium, magnesium, etc. present in the meal.

Carefully weighed oven dried sample (2 g) was placed in a previously oven dried, cooled and weighed crucible. The crucible was ignited in a Muffle furnace at 575±25 ºC for four hours. After ignition, crucible was cooled in desiccators and weighed. Heating, cooling and weighing were repeated until constant weight of the crucible with ash was obtained. As content was calculated when the constant weight of the crucible with as obtained. The same procedure was repeated for each of the remaining samples.

% of Ash content = (C-B)/A x 100
Where A = OD Wt. of sample in gram
B = OD Wt. of crucible in gram
C = OD Wt. of crucible with ash content in gram

3.2.1.6 Silica content

Oven-dried sample 5 g was placed in a beaker and 15 ml of concentrated nitric acid was added. Then 5 ml of 75% perchloric acid was slowly added. The beaker was heated on a hot plate until the mixture became white. After heating, 15 ml of dilute hydrochloric acid was added. The content in the beaker was filled with Whitman No. 4. The residue was washed with distilled water (at least 500 ml) to free chlorine-ion. The residue and filter paper were placed in a previously oven-dried, cooled and weighed crucible when the filter paper dried. The crucible was ignited in an electric furnace at (600-700º C) for 15 minutes. Then the crucible was cooled in desiccators and weighed. Ignition, cooling and weighing were repeated until the constant weight of the crucible with content was obtained.

% of Silica content = (C-B)/A x 100
Where A = OD Wt. of sample in gram
B = OD Wt. of crucible in gram
C = OD Wt. of crucible with silica content in gram

3.2.1.7 Starch content

Starch is normal constituent in sapwood of the hardwood and softwood species, where it is frequently found in the parenchymatous tissues. Starch is readily recognized from the blue color formed upon staining with diluted solution of iodine by using colorimeter spectronic 20.

The specimens were chipped, dried at 50 ºC in oven and ground before being passed sulphuric acid and used for starch analysis with methods suggested by Browning (1978) and Humphreys and Kelly (1961).

3.2.2 Physical Properties

Each bamboo culm was divided into three equal parts: Bottom, Middle, and Top. From the base of each part, the specimens for testing physical properties were cut and prepared. The physical properties tested were:

(1) Moisture content
(2) Density and specific gravity
(3) Diameter shrinkage
(4) Longitudinal shrinkage

(5) Wall thickness shrinkage
(6) Volumetric shrinkage

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

3.2.2.1 Moisture content

The test specimens 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.

$$MC\% = (W-W_o) \times 100 / W_o,$$

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

3.2.2.2 Density and specific gravity

The density of a bamboo test specimen is a ratio of its weight to its volume. The test specimens were weighed while green, and its green volume was determined by water displacement method. After air-drying to attain a constant weight, the volume was determined again. Then, they were dried in an oven at a temperature of 103±2ºC. After attaining a constant weight under oven-drying, the volume was measured again.

Four different kinds of density are mentioned in this paper. They are:

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

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 based on oven-dry weight and air-dry volume and
(3) Specific gravity based on oven-dry weight and oven-dry volume.

3.2.2.3 Shrinkage

Shrinkage of bamboo was observed in the outer diameter, in the wall-thickness, and in the length of the test specimens. Markings were done on the specimens to facilitate taking of 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:

$$S_o\,\% \quad = (L1\text{-}L3)/L1 \times 100$$

where S_o % is the shrinkage of a specimen from green to oven-dry condition
L1 is the green dimension of the specimen and
L2 is the dimension of the specimen after oven-drying.

3.2.3 Mechanical Properties

The mechanical properties of bamboos depend on:

- The species itself
- The age at which the bamboo has been cut
- The moisture content
- The position along the culm
- The position of the nodes and the internodes

The mechanical properties of bamboo tested are bending, shear and compression parallel to grain. Tensile test could not be done due to lack of equipments for gripping the specimens. In addition, the results of bending test could not be mentioned and discussed in this paper because the specimens dried so quickly and green test could not be done. They will be collected, and green bamboos will be tested later.

3.2.3.1 Compression parallel to grain

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 outer diameter, and the specimens are without any node. The end planes (surfaces) of the specimens are perfectly at right angle to the length of the specimen; the end planes are flat.

The tests were carried out on an Autograph Universal Timber Testing Machine. The load was applied continuously during the test to cause the movable head of the machine to travel at a constant rate of 0.01 mm per second (0.6 mm/minute). The maximum compressive stress was calculated from the test.

3.2.3.2 Shear parallel to grain

The tests were carried out in the same machine as in compression 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; the end surfaces were flat.

The wall thicknesses and the lengths of the specimens were measured at all four shear areas. The load was applied continuously during the test at a constant speed of 0.01 mm per second (0.6 mm/minute). The ultimate shear stress was calculated from the test.

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.

$$Yijkl = \mu + Ai + Bj + Ck + (AB)ij + (AC)ik + (BC)jk + (ABC)ijk + \varepsilon ijkl$$

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.

5 Results and Discussions

5.1 Chemical properties

Table 3 shows the ash content in different portions of culm of six bamboo species.

Table 3: Ash contents of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	7.0407	7.540	6.968	6.614
Thaik wa	3.3513	3.308	3.288	3.458
Tin wa	5.0287	5.140	5.203	4.743
Wabo wa	2.3937	2.643	2.228	2.310
Myin wa	7.5513	8.029	7.506	7.119
Wanet wa	1.9880	2.352	1.816	1.796

It was found that Myin wa and Kyathaung wa were high in ash content. The ash content of the six bamboo species ranged from 1.5 % to 7.5%. Ash content (0.8-9.75 %) of bamboo culm can be used for machine made products such as skewer and chopsticks (Semana et. al., 1967).

Table 4: Silica content of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	5.0580	5.403	5.272	4.580
Thaik wa	1.5997	1.736	1.707	1.356
Tin wa	3.7693	4.204	3.540	3.564
Wabo wa	0.9773	1.253	0.931	0.748
Myin wa	5.1403	5.272	5.262	4.887
Wanet wa	0.7563	0.874	0.660	0.735

Table 4 showed that Myin wa and Kyathaung wa were also high in silica content (5%). High silica content causes scaling during evaporation of the spent liquor for recovery of the chemicals in pulpings.

Table 5: Hot water solubility of the tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	10.4883	10.250	9.195	12.020
Thaik wa	10.5947	10.235	11.467	10.082
Tin wa	15.3173	13.256	16.120	16.576
Wabo wa	13.3940	12.481	14.114	13.587
Myin wa	13.5243	13.594	13.549	13.430
Wanet wa	13.2200	12.352	14.1230	13.188

The extractive contents, particularly the cold and hot water soluble are important in the predetermination of water soluble extractives such as tannin, starch, sugar, pectin, and phenolic compounds within the woody materials (Janis, 1969). The results in table 5 showed that the six tested bamboo species contained high concentration of hot water soluble (10-15%), which may influence the susceptibility to insect and fungal attacks (Plank, 1950).

Table 6: 1% NaOH solubility of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	25.9843	26.481	25.151	26.321
Thaik wa	25.1280	24.903	24.447	26.034
Tin wa	27.9180	28.584	28.504	26.663
Wabo wa	28.8760	26.624	30.629	29.375
Myin wa	29.8200	26.733	31.052	31.675
Wanet wa	27.9533	25.970	28.239	29.651

The 1% NaOH solubility varied (25-30%). The highest values for all three parts are observed in Myin wa (29.82%). Thaik wa is low in hot water solubility and 1% NaOH solubility content due to the low content of sugar groups.

Table 7: Alcohol-Benzene solubility of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	6.3250	6.311	6.411	6.334
Thaik wa	7.2790	7.421	7.091	7.325
Tin wa	6.2473	6.571	6.171	6.000
Wabo wa	10.7030	11.069	10.937	10.103
Myin wa	7.5680	7.994	7.364	7.346
Wanet wa	8.8923	8.760	9.074	8.843

Regarding the alcohol-benzene solubility of tested bamboo species, it was found that Wabo wa possessed the highest average value (10.7%) while Tin-wa was the lowest (6.2%) (Table 7).

Table 8: Starch content of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	0.4143	0.174	0.341	0.728
Thaik wa	0.3323	0.218	0.334	0.445
Tin wa	0.5490	0.403	0.971	0.273
Wabo wa	2.543	0.768	2.343	4.519
Myin wa	0.9530	0.615	1.214	1.030
Wanet wa	1.5967	0.450	2.203	2.173

The starch content of the selected bamboo species were determined using colourimetric measurement of the color formed in the reaction of amylose in bamboo starch with iodine. The average value of starch content were found the highest in Wabo wa (2.5%) (Table 8). Especially, top portion of Wabo culm is highest in starch content. Except Wabo wa and Wanet wa, the starch content of other tested species is lower than 1%. Bamboo species with less than 1% starch content is considered as good quality for construction purposes (Sulthoni, 1985).

Table 9: Cellulose content of tested bamboo species (%)

Species	Average	Bottom	Middle	Top
Kyathaung wa	48.3737	48.974	49.412	46.735
Thaik wa	46.9803	49.259	46.067	45.615
Tin wa	42.3500	45.144	41.442	40.464
Wabo wa	48.2080	52.587	46.428	45.609
Myin wa	49.8160	51.645	50.183	47.620
Wanet wa	47.2687	49.239	47.239	45.328

Table 9 showed that all six bamboo species contained required amount of cellulose contents (40-48%). The cellulose content of a plant material is important to industries like pulp, paper and wood hydrolysis because it is a key factor affecting the quality of these products.

According to the data of all tables, it showed that ash and silica contents are high in bottom part of the culm and hot water solubility and 1% NaOH solubility constituents are high in top part of the culm. It meant that silica and mineral contents were deposited at the bottom part and some other extractives such as tannin, starch, sugar, pectin and phenolic compound at the top of the culm.

5.2 Physical Properties

5.2.1 Moisture content

The mean moisture contents of different bamboo species are shown in Table 10. The moisture content decreases with height in these bamboo species. It could be because the parenchyma cells content decreases from bottom to top (Liese, 1980, Soenardi, 1988). Analysis of variance of the data showed that the species, position of the specimens in the culm and clumps all have a significant effect on the moisture content of the bamboo. The lowest moisture content is found in Thaik wa and the highest in Tin wa. The moisture contents of the bamboos range from 40.64% to 71.35%. 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.

It can be found that the highest moistures occur in Myin wa, Kyathaung wa and Tin wa. This might be due to soaking. They were soaked before testing to prevent moisture loss and shrinking.

Table 10: Green moisture contents of different bamboo species (%)

Species	Average	Bottom	Middle	Top
Myin wa	70.69	80.45	70.07	64.22
Kyathaung wa	67.31	73.42	65.27	63.85
Thaik wa	40.64	49.809	41.02	34.03
Tin wa	71.35	80.21	68.60	65.43
Wabo wa	49.57	71.16	44.33	36.04
Wanet wa	44.45	64.33	40.05	32.48

5.2.2 Shrinkage

Table 11: Longitudinal shrinkage of bamboos from green to oven-dry condition (%)

Species	Average	Bottom	Middle	Top
Myin wa	0.148	0.178	0.151	0.125
Kyathaung wa	0.213	0.269	0.222	0.168
Thaik wa	0.186	0.192	0.199	0.171
Tin wa	0.106	0.144	0.092	0.081
Wabo wa	0.162	0.188	0.161	0.141
Wanet wa	0.210	0.238	0.269	0.142

Different types of shrinkage of different bamboo species are shown in Tables 11-14. The longitudinal shrinkage of bamboo is quite small as in wood. Compared to shrinkage in diameter and wall-thickness, it is negligible. It is quite clear that it decreases with height.

Table 12: Diameter shrinkage of bamboo from green to oven-dry condition (%)

Species	Average	Bottom	Middle	Top
Myin wa	7.73	7.32	8.36	7.48
Kyathaung wa	6.70	6.95	6.87	6.35
Thaik wa	7.46	6.96	7.68	7.63
Tin wa	6.80	7.12	6.59	6.69
Wabo wa	4.66	5.44	4.29	4.18
Wanet wa	4.95	5.59	5.02	4.38

It can be found that the diameter shrinkage decreases with height in most bamboo species. It is the highest in Myin wa and the smallest in Wabo wa.

Table 13: Wall-thickness shrinkage from green to oven-dry condition (%)

Species	Average	Bottom	Middle	Top
Myin wa	9.53	9.05	9.90	9.46
Kyathaung wa	11.03	10.86	11.68	10.63
Thaik wa	10.25	8.88	11.04	10.46
Tin wa	7.42	7.63	7.48	7.15
Wabo wa	5.17	5.86	4.47	5.15
Wanet wa	5.84	6.79	5.61	5.28

The wall thickness shrinkage decreases with heights in some bamboos (Tin wa, Wabo wa and Wanet wa). In other bamboos, it is not decreasing or increasing with height and they show the highest in middle part.

Table 14: Volumetric shrinkage (%)

Species	Average	Bottom	Middle	Top
Myin wa	19.73	18.39	20.84	19.74
Kyathaung wa	18.58	17.84	18.66	19.15
Thaik wa	10.32	11.31	10.67	9.35
Tin wa	22.46	21.94	22.17	23.28
Wabo wa	14.02	17.87	14.88	10.14
Wanet wa	15.11	19.74	15.49	11.25

In some bamboos, the volumetric shrinkage decreases with heights as in Thaik wa, Wabo wa and Wanet wa. In Tin wa and Kyathaung wa, it increases with height. In Myin wa, the middle part shows the highest.

It is unbelievable that the volumetric shrinkage of Thaik wa is so small, which is almost the same with its wall-thickness shrinkage.

5.2.3 Density

They are the indices of other properties, especially of mechanical properties. The densities of different bamboos are shown in Tables 15-18.

Table 15: Green density (kg/m^3)

Species	MC%	Average	Bottom	Middle	Top
Myin wa	70.69	1150	1140	1151	1557
Kyathaung wa	67.31	1094	1070	1092	1117
Thaik wa	40.64	1062	1036	1067	1076
Tin wa	71.35	1073	1054	1082	1082
Wabo wa	49.57	1038	1013	1042	1055
Wanet wa	44.45	1078	1067	1079	1085

It is the ratio of the green weight of the bamboo to its green volume. It increases with height in these bamboo species. Green volume does not change above fiber saturation point, but the green weight will increase with increasing moisture content. Thus, the moisture content of the species will affect the green weight. Therefore, green density is not a very good index for comparison of different bamboo species.

Table 16: Air-dry density at 12% moisture content (kg/m^3)

Species	Average	Bottom	Middle	Top
Myin wa	856	795	857	898
Kyathaung wa	826	778	833	862
Thaik wa	925	838	925	986
Tin wa	781	724	793	825
Wabo wa	896	741	925	999
Wanet wa	968	817	992	1065

The air-dry densities increase with heights. Although the highest air-dry densities are found in Thaik wa and Wanet wa, the highest green densities are found in Myin wa.

Table 17: Oven-dry densities at 0 % moisture content (kg/m^3)

Species	Average	Bottom	Middle	Top
Myin wa	848	780	861	885
Kyathaung wa	810	759	817	848
Thaik wa	843	774	850	883
Tin wa	819	761	833	861
Wabo wa	822	729	860	868
Wanet wa	891	817	919	928

As in green and air-dried densities, the oven-dry densities increase with heights. It is the highest in Wanet wa.

Table 18: Basic density (kg/m^3)

Species	Average	Bottom	Middle	Top
Myin wa	680	637	681	710
Kyathaung wa	659	624	665	685
Thaik wa	759	693	759	805
Tin wa	632	592	646	658
Wabo wa	707	598	729	780
Wanet wa	758	653	775	825

It is the ratio of oven-dry weight of bamboo to its green volume. The volume and the weight can not be affected by moisture content. It is the best index for comparison of different bamboo species. According to the results, Thaik wa and Wanet wa are said to have the highest strength among these bamboos because they have the highest basic density.

The densities of bamboos vary significantly from species to species, from clump to clump of the same species, and from bottom to top of the same culm. It is found that there is no significant variation in the culms of the same clump.

Generally, the densities of the bamboo species increase with increasing heights. It could be explained by the increased amount of fibres (Liese, 1980) and the increase in wall-thickness of the fibres (Tavip et. al, 1988). The densities of bamboo mainly depend on the density of vascular bundles and their composition (Qisheng et. al, 2002). Within the culm, the total number of vascular bundles decreases from bottom to top, and their denseness increases correspondingly (Liese, 1980).

5.2.4 Specific gravity

It is the ratio of the density of bamboo to the density of water at 4ºC. When the volume of bamboo is measured in cubic centimeter and the weight in grams, the specific gravity is the same as density, but it is without unit because water has a density of 1.000 g/cm^3 at 4ºC. The major difference is that the specific gravity is always based on oven-dry weight.

Table 19: Basic specific gravity

Species	Average	Bottom	Middle	Top
Myin wa	0.680	0.637	0.681	0.710
Kyathaung wa	0.659	0.624	0.665	0.685
Thaik wa	0.759	0.693	0.759	0.805
Tin wa	0.632	0.592	0.646	0.658
Wabo wa	0.707	0.598	0.729	0.780
Wanet wa	0.758	0.653	0.775	0.825

The basic specific gravity, based on green volume, increases with heights in all tested bamboo species as in density. It is the best index for comparison of different bamboo species as it accounts for the actual amount of fibers per unit volume. According to the data in Table 12, Thaik wa and Wanet wa are the best bamboos because they have the highest basic specific gravity values.

Other specific gravities of different bamboos are shown in Tables 20 and 21.

Table 20: Oven-dry specific gravity (Based on oven-dry volume)

Species	Average	Bottom	Middle	Top
Myin wa	0.848	0.780	0.861	0.885
Kyathaung wa	0.810	0.759	0.817	0.848
Thaik wa	0.843	0.774	0.850	0.883
Tin wa	0.819	0.761	0.833	0.861
Wabo wa	0.822	0.729	0.860	0.868
Wanet wa	0.891	0.817	0.919	0.928

Table 21: Air-dried specific gravity (based on air-dry volume)

Species	Average	Bottom	Middle	Top
Myin wa	0.764	0.709	0.764	0.802
Kyathaung wa	0.738	0.695	0.744	0.769
Thaik wa	0.826	0.749	0.825	0.880
Tin wa	0.697	0.647	0.708	0.736
Wabo wa	0.800	0.661	0.826	0.892
Wanet wa	0.864	0.730	0.886	0.951

5.3 Mechanical Properties

5.3.1 Compression strength parallel to grain

The data on maximum crushing stress are presented in Table 22. Analysis of the data shows that moisture content (green and air-dry), species and clumps of the same species have a marked effect on the maximum crushing stress. The maximum crushing stress increases with decreasing moisture content (Fig. 1 and Fig. 2). The position of specimens in a culm affects the maximum crushing stress only in some species, but the stress increases with increasing height in all species. It is due to the greater number of sclerenchyma cells at the top than the bottom. Among the tested species, Myin wa and Tin wa are found to be the best bamboos in terms of strength, but the culms are small. Wabo wa has the least compression stress.

Table 22: Maximum crushing strength (N/mm^2)

Species	Seasoning	MC%	Average	Bottom	Middle	Top
Myin wa	Green	66.48	50.31	47.95	47.72	54.43
	Air-dry	11.37	70.28	67.98	73.11	69.65
Kyathaung wa	Green	85.62	40.72	34.36	43.20	44.16
	Air-dry	11.57	63.91	50.47	71.44	83.12
Thaik wa	Green	77.15	44.23	40.99	43.60	46.91
	Air-dry	12.64	67.35	58.72	66.89	68.29
Tin wa	Green	70.58	45.34	43.45	45.69	46.87
	Air-dry	10.37	76.98	59.10	86.56	96.63
Wabo wa	Green	91.92	38.60	30.70	45.57	47.07
	Air-dry	11.99	54.73	48.27	58.48	62.14
Wanet wa	Green	80.72	44.47	37.27	48.45	52.87
	Air-dry	12.11	57.34	54.02	55.45	66.04

By assuming that the fibre saturation point of bamboo is 20 %, the increase in maximum crushing strength from green to air-dry condition is found to be 4.6% per one percent decrease in moisture content for Myin wa, 6.7% for Kyathaung wa, 7.1% for Thaik wa, 7.2% for Tin wa, 5.2% for Wabo wa and 3.7% for Wanet wa.

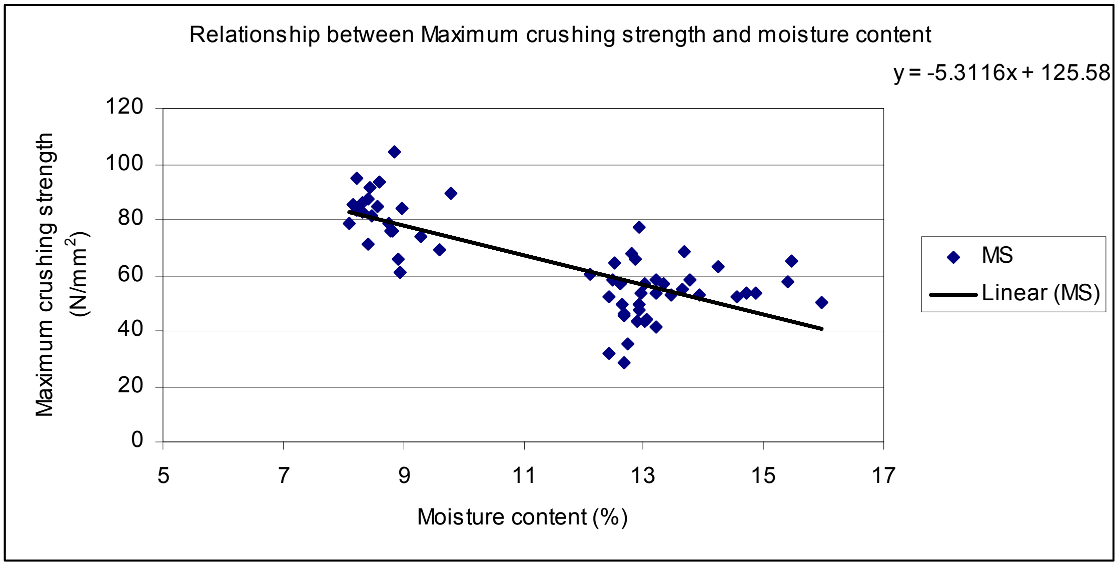

Figure 6: Graph showing the relation between maximum crushing stress and moisture content in Kyathaung wa.

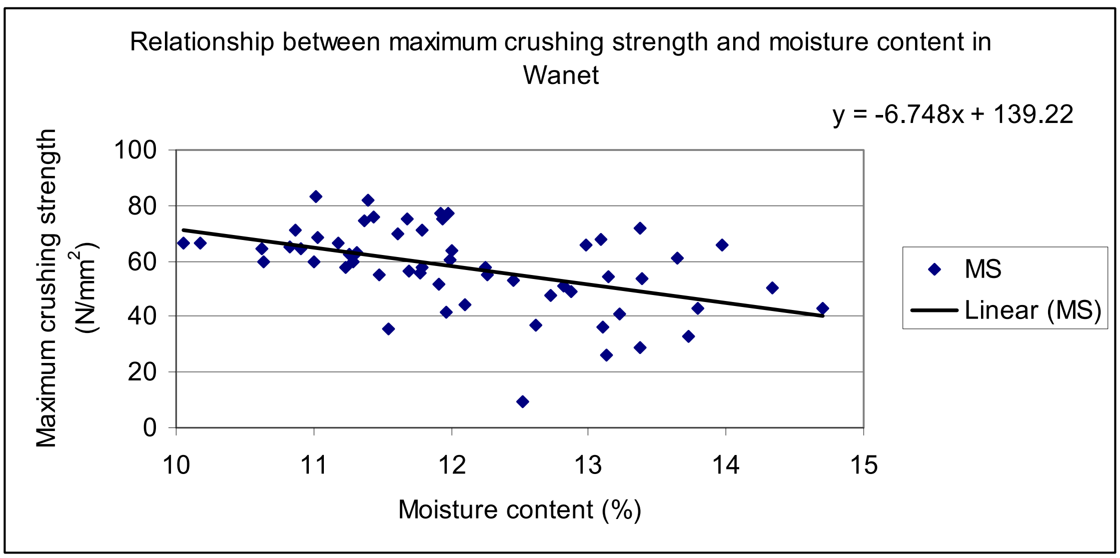

Figure 7: Graph showing relation between maximum crushing strength and moisture content in Wanet wa.

5.3.2 Shearing strength parallel to grain

Shearing strength is very important in the uses of bamboos as in joints in structural buildings and furniture making. An analysis of the data shows that there is a significant difference among species. The presence of node has a significant effect on the shearing strength in most tested species of such as Kyathaung wa, Thaik wa, Tin wa, Wabo wa and Wanet wa in green condition and Wabo wa in air-dry condition. Moisture content (Green and air-dry) has a significant effect on shearing strength in all tested bamboo species. Shearing strength increases with decreasing moisture content (Fig. 3 & Fig. 4). There is no significant effect of culm height on shearing strength.

Table 23: Maximum shearing stress (N/mm^2)

Species	Seasoning	MC%	Average		Bottom		Middle		Top	
			N	WN	N	WN	N	WN	N	WN
Myin wa	Green	67.93	10.3	8.9	-	8.7	9.3	9.1	11.2	8.8
	Air-dry	12.11	18.8	20.1	17.0	18.0	20.3	21.02	19.7	21.4
Kyathaung wa	Green	84.38	9.0	7.5	8.8	8.8	8.8	7.2	9.4	7.3
	Air-dry	11.87	15.1	15.6	14.2	13.0	16.4	16.0	15.3	16.0
Thaik wa	Green	81.26	12.8	8.0	10.1	7.5	13.0	8.0	16.6	8.3
	Air-dry	12.80	16.0	16.8	13.8	13.6	16.0	18.2	20.0	17.9
Tin wa	Green	77.97	10.0	8.3	9.7	8.2	10.4	8.4	-	8.5
	Air-dry	11.06	16.8	20.1	14.7	17.7	17.7	19.4	21.4	23.4
Wabo wa	Green	94.77	9.0	6.1	7.9	8.0	10.2	5.3	9.3	5.6
	Air-dry	12.05	11.0	12.9	10.6	11.6	11.9	13.2	10.9	13.8
Wanet wa	Green	81.11	10.1	7.0	9.0	8.4	11.1	6.1	10.8	6.6
	Air-dry	12.62	13.6	13.1	12.4	12.1	13.5	12.7	15.1	14.2

"Note: N = With Node, WN = Without Node"

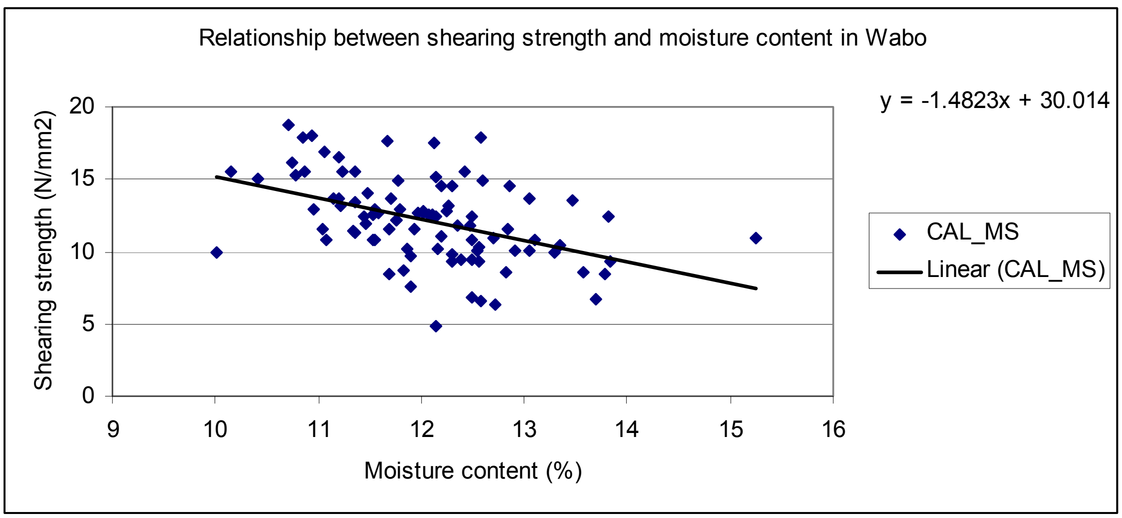

Figure 8 : Graph showing relation between shearing strength and moisture content in Wabo wa

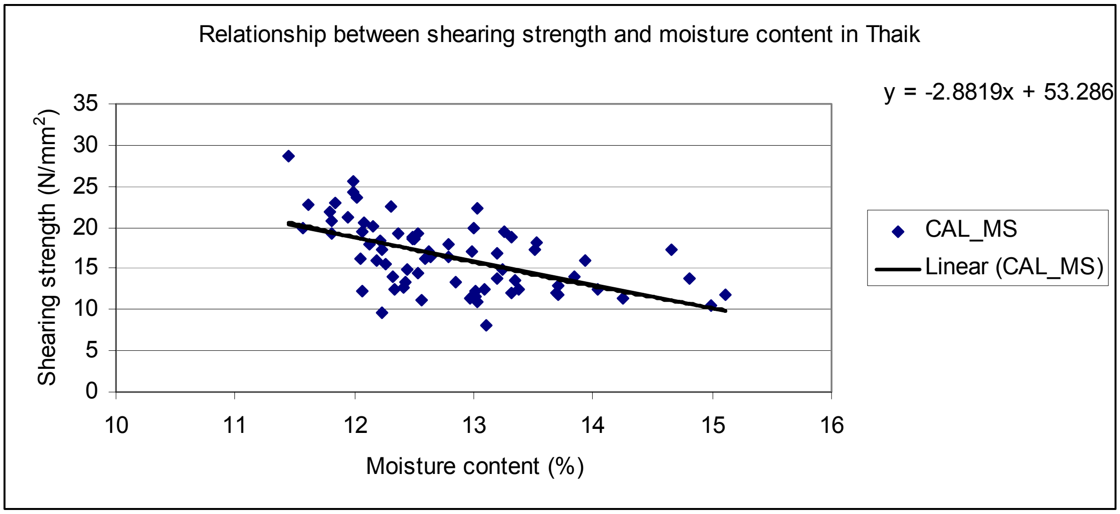

Figure 9 : Graph showing relation between shearing strength and moisture content in Thaik wa

Among the tested bamboo species, the highest shearing strength is found in Myin wa and the least in Wabo wa.

6 Conclusions and recommendations

According to the chemical composition, all tested bamboo species can be used for machine made products such as skewer, chopstick, parquet and mat board. However, all tested species are susceptible to insect and fungus attacks. Therefore, it would be necessary to treat with appropriate preservatives before putting into uses. Wabo wa, for example, has the highest nutrient content, according to the experiment, and can be made the high quality products, but at the same time, it needs more preservative treatments.

Cellulose content of tested bamboo species are favorable for pulp and paper making, but they also have a high silica content, which disturbs the chemical recovery systems in chemical pulping. Because of the silica and mineral contents, it will be difficult to recover black liquor in the pulping process of basal. Due to richness of some other extractives such as tannin, starch, sugar, pectin and phenolic compound, more preservation treatment will be necessary for the use of top parts. Otherwise, fungi and insects will attack them because of sugar content.

The season also determines the amount of starch considerably. It is higher in the dry season than in the rainy season because starch has been utilized for new shoots in the rainy season. Seasonal changes of starch content should be considered when planning for harvest. The culm should preferably be cut when the amount of starch is the lowest. The period depends much on the geographical region as well.

The basic specific gravity of the tested bamboo species ranges from 0.63 to 0.76 in average. This value is higher than those of some construction timber species such as Binga (0.553), Hnaw (0.583), Kanyin-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 (0.47), Yemane (0.419), and Zinbyun (0.531). Thaik wa and Wanet wa might be better than In (0.726), and Eucalypt (0.713). They are similar to Zaungbale (0.61), Yon (0.739), Thingan (0.637), Thadi (0.71), Taukkyan (0.707), Lein (0.625), and Kanyaung (0.706).

The compressive strength of the tested bamboo species is higher than those of Binga (52 N/mm^2), Hnaw (45 N/mm^2), In (47 N/mm^2), Lein (47 N/mm^2), Leza (49 N/mm^2), Nabe (26 N/mm^2), Pyinma (50 N/mm^2), Sit (39 N/mm^2), Thingan (46 N/mm^2), Taungthayet (39 N/mm^2), Thadi (42 N/mm^2), Yemane (33 N/mm^2) and Tinyu (43 N/mm^2).

Most tested bamboo species are in shearing strength higher than Zinbyun (11.55 N/mm^2), Zaungbale (9.85 N/mm^2), Yemane (7.24 N/mm^2), Tinyu (9.06 N/mm^2), Taungthayet (10.55 N/mm^2), Thadi (11.32 N/mm^2), Pyinma (11.62), Nabe (8.10 N/mm^2), Leza (9.83 N/mm^2), Hnaw (10.38 N/mm^2) and Binga (10.07 N/mm^2)

According to the tested properties, it can be found that the tested bamboo species are comparable to some construction timbers in terms of strengths. Moreover, bamboo grows very rapidly and once successfully planted, bamboo plants keep on rhizoming, shooting and maturing every year. Therefore, it might be a substitute of timber in the future. However, 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 into services.

The test results reveal that bamboos tested are good enough to use in buildings as flooring, walling, roofing, round bamboo furniture making, ply bamboo furniture making and in many other purposes. The drawbacks might be that they can be easily and very shortly attacked by insects, especially powder post beetles, and the small size of the culm. Another drawback will be the hollow cavity of the culms. Thus, the best way will be to convert them into restructured bamboos, which will prevent the early attack by insects and limited uses of bamboos due to small size and hollow cavity.

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