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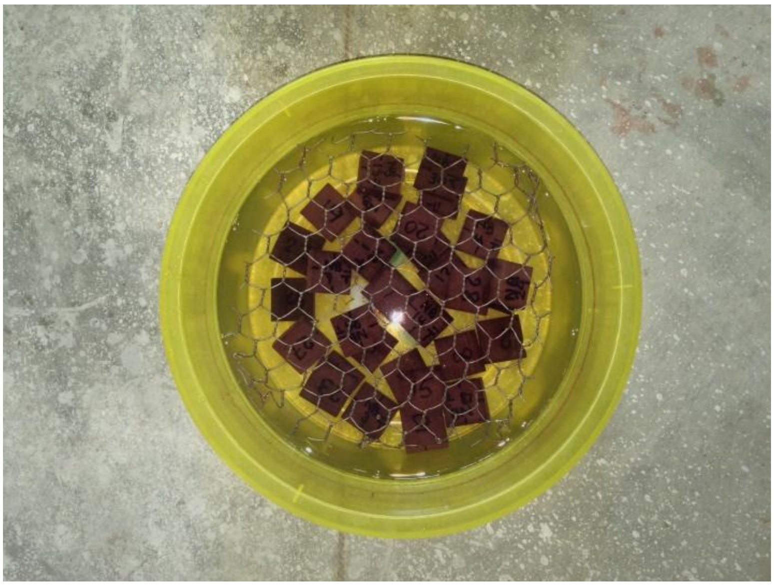
Comparison of swelling behavior and water absorption of four hardwood species



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ဒေါက်တာချိုချိုမြင့်၊ သုတေသနလက်ထောက်-၂
ဒေါ်ချောရူပါစိုး၊ သုတေသနလက်ထောက်-၃
ဦးဝင်းဦးနိုင်၊ လက်ထောက်သုတေသနအရာရှိ
သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်း

ဤစာတမ်းတွင် မြန်မာ့သစ်မျိုး လေးမျိုး၏ ရေနှင့်ဆက်စပ်နေသော ဂုဏ်သတ္တိ များကို စမ်းသပ်ထားပါသည်။ အထူးသဖြင့် ကွဲမှု၊ ရေစုပ်ယူမှု၊ ရေချိန်သိပ်သည်းဆနှင့် အစိုဓာတ်ပါဝင်မှုတို့ကို စမ်းသပ်ထားခြင်းဖြစ်ပါသည်။ ရေချိန်သိပ်သည်းဆများအရ နဘဲနှင့် ဖျောက်ဆိပ်သစ်မျိုးများကို“လေးသောသစ်များ”ဟုသတ်မှတ်နိုင်ပြီး လယ်ဇနှင့် ဒီဒူး သစ်မျိုးများကို အတန်အသင့်လေးသော သစ်မျိုးများဟု ခေါ်ဆိုနိုင်ပါသည်။ ဖျောက်ဆိပ်သစ်သည် ကွဲမှုအများဆုံးဖြစ်သည်ကို တွေ့ရပြီး ဒီဒူးသစ်သည် ကွဲမှု အနည်းဆုံး ဖြစ်ပါသည်။ ဖျောက်ဆိပ်သစ်သည် ရေချိန်သိပ်သည်းဆ အမြင့်ဆုံး မဟုတ်သော်လည်း အခြားသစ်များထက် ပို၍ကွဲခြင်းဖြစ်ပါသည်။ အမှန်မှာ ရေချိန်သိပ်သည်းဆ အမြင့်ဆုံးဖြစ်သည့် နဘဲသည် အများဆုံး ကွဲသင့်သော်လည်း မကွဲခဲ့ပါ။ အကြောင်းမှာ နဘဲတွင် ဖျောက်ဆိပ်ထက် ဓာတုအနယ်အနှစ်များ ပိုမိုပါဝင်ခြင်းကြောင့်ဖြစ်ပါသည်။ ၎င်းတို့ ပါဝင်ခြင်းဖြင့် ကျုံ့ခြင်း၊ ကွဲခြင်းကိုလျော့နည်းစေပါသည်။ စမ်းသပ်သည့် သစ်မျိုးများ အနက် (၃) မျိုးသည် အသားငြိမ်မှုတွင် T/R အချိုး ၂.၂ ခန့်ရှိပြီး လယ်ဇသည် ၂ အောက် လျော့နည်း သည်ကို တွေ့ရသည်။ စနစ်တကျ အခြောက်ခံ သုံးစွဲပါက ကျုံ့ခြင်း၊ ကွဲခြင်းကြောင့် ဆိုးရွားသည့် ပြဿနာများ မဖြစ်ပေါ်နိုင်ဟု သုံးသပ်ပါသည်။ ရေစုပ်မှုနှင့် ပတ်သက်၍ ရေချိန် သိပ်သည်းဆ အများဆုံး ဖြစ်သော နဘဲသည် အနည်းဆုံး စုပ်ယူသည်ကို တွေ့ရပါသည်။ ရေချိန်သိပ်သည်းဆများသဖြင့် ဆဲလ်နံရံထူပြီး အနယ်အနှစ်တို့ ရှိခြင်းကြောင့် ရေနေနိုင်မည့် နေရာဆဲလ်ခေါင်း အနည်းငယ်သာ ရရှိနိုင်သောကြောင့်ဖြစ်ပါသည်။ ရေချိန်သိပ်သည်းဆ အနည်းဆုံး ဒီဒူးသစ်သည် အများဆုံး ရေစုပ်ယူသည်ကို တွေ့ရပါသည်။ ဆဲလ်နံရံပါးသဖြင့် ရေနေနိုင်မည့် နေရာအများအပြား ရှိနေသောကြောင့် ရေအများဆုံး စုပ်ယူနိုင်ခြင်းဖြစ်ပါသည်။ အစိုဓာတ်ပါဝင်မှုတွင်လည်း ရေချိန်သိပ်သည်းဆ များသော နဘဲတွင် အနည်းဆုံးဖြစ်ပြီး ရေချိန်သိပ်သည်းဆ အနည်းဆုံးဖြစ်သော ဒီဒူးတွင် အများဆုံး ဖြစ်ပါသည်။ ဆဲလ်နံရံထူထဲပြီး ရေနေရာ ဆဲလ်ခေါင်းကျဉ်းသောကြောင့် နဘဲတွင် အနည်းဆုံး ဖြစ်ရခြင်းဖြစ်ပါသည်။

Comparison of swelling behavior and water absorption of four hardwood species

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Abstract

This research paper investigated water-related properties of four Myanmar timber species, especially swelling, water absorption, specific gravity and moisture content. Based on their specific gravity, Nabe and Pyaukseik are termed “Heavy Wood” whereas Leza and Didu are “Moderately Heavy Wood”. Pyaukseik is found to swell the highest while Didu swells the lowest. Although Pyaukseik does not have the highest specific gravity, it swells higher than other tested species. In fact, Nabe, with the highest specific gravity, should swell the highest, but it does not. This could be due to the higher presence of extractives in Nabe than in Pyaukseik, which reduces shrinkage and swelling. Among the tested species, three are found to have a tangential to radial swelling ratio of about 2.2 whereas the other (Leza) has a ratio less than 2. This means that adverse impacts of shrinkage or swelling cannot occur when putting them into use if they are properly dried before they are used. With regard to water absorption, Nabe with the highest specific gravity absorbs the least amount. This is due to its thick cell wall, small lumens, and extractives, thereby creating small space available for water. Didu with the lowest specific gravity absorbs the highest amount. This is due to its thin cell wall and large lumens, thus large space becoming available for water. With regard to moisture content, Nabe with the highest specific gravity has the lowest amount of moisture content whereas Didu has the lowest specific gravity and thus the highest moisture content. Species with high specific gravity contain thick-walled cells with small cavities, and thus have small spaces available for water entry. Species with low specific gravity contain thin-walled cells with large cavities which are available for water entry.

Key Words: Basic specific gravity, Swelling, Water absorption, Moisture content

1. Introduction

Wood is a hygroscopic material (Forest Product Laboratory 2010). Wood used in various houses and buildings can mostly be called dry wood. If green wood is used in buildings under construction, it will dry as it desorbs moisture to the environment. If such dry timber used in building comes in contact with water due to many reasons such as getting wet with rain water, relative humidity becoming high, etc., it will absorb water. Then, it will not only get swollen, but also become easily susceptible to attacks by bacteria, fungus, insects and microorganisms (Ibach, 2005).

Wood species vary in wood anatomy and extractive content, thereby causing water absorption to vary among wood species (Dinwoodie, 2000). Thus, swelling due to water absorption can vary accordingly. Therefore, it is crucially important to study water absorption of some timber species.

Changes of relative humidity in the environment cause wood to absorb or desorb moisture from the environment. Below fiber saturation point, wood will swell when absorbing moisture from the environment whereas it will shrink when desorbing its water to the environment. Shrinkage can cause bending, twisting, holes and performance problems in timbers. In rainy season, such problems as difficulties in closing and opening windows, doors and drawers and rising of flooring timber are those arising from wood swelling when dry wood absorbs moisture from the environment. Therefore, it is quite important to know shrinkage and swelling behaviors of various wood species. Shrinkage of most Myanmar timber species has been tested and is available in most literature. However, swelling behavior is still unknown for most Myanmar timber species. If swelling data are available, those with minimal swelling can be used to keep away from swelling and shrinkage-related problems. Moreover, measures to minimize water absorption can also be investigated for those species with high swelling.

Thus, the objective of this research paper is to investigate water-related properties of four hardwood species, to compare these properties among them and recommend their possible uses.

2. Literature Review

Specific gravity of wood is its single most important physical property because most mechanical and physical properties of wood are closely correlated to specific gravity (Schmulsky & Jones, 2011). Species with higher specific gravity generally are strong and have higher mechanical properties, swell and shrink higher than those with lower specific gravity.

Wood is a hygroscopic material. It shrinks below fiber saturation point as it dries and loses its bound water. It swells as it gains water in its cell walls (Forest Products Laboratory, 2010). Wood is also an anisotropic material, i.e it shrinks and swells irregularly in three different tangential, radial and longitudinal directions (Tsoumis, 1991). According to Dinwoodie (2000), longitudinal shrinkage is always an order of magnitude less than transverse. In the transverse plane, radial shrinkage is usually some 60-70% of the corresponding tangential figure (Dinwoodie, 2000).

There are many factors involved in the proportion of swelling and shrinkage; these include anatomical characteristics, cellulose content, wood density, cell wall thickness and the proportion of earlywood and latewood (Sekhar & Rajput 1967; Cave 1972; Eligon *et al.* 1992).

This shrinkage can result in warping, checking, and splitting of the wood, which in turn can lead to decreased utility of wood products, such as loosening of tool handles, gaps in flooring, or other performance problems. Therefore, it is important that the dimensional stability be understood and considered when a wood product will be exposed to large moisture fluctuations in service (Forest Products Laboratory, 2010).

The ratio of total tangential shrinkage / swelling to total radial shrinkage / swelling (T/R) or partial tangential shrinkage / swelling to partial radial shrinkage / swelling (T12/R12) is used as an index of dimensional stability (Ofori and Brentuo, 2010). Lower ratios are desirable as cupping of boards during drying would be reduced. When these values are closer to 1, the dimensional stability of the material is higher, indicating that the quality of the material is higher (Göker et al., 2000). Ratios higher than 1.5 are considered pronounced and this pronounced differential shrinkage is likely to cause wide splits, checks and distortions if the necessary precautions are not taken during the kiln drying (Ofori et al., 2009). However, some authors reported that the ratios higher than 2.2% are considered to be high (Rijsdijk & Laming, 1994; Jouse, 2004).

Wood is used for many applications because of its many excellent material properties (such as a good strength to weight ratio, aesthetic appearance etc.), but it also has such a number of disadvantages as dimensional changes in response to altering atmospheric conditions, susceptibility to biological attack and changes in appearance when exposed to weathering, which place restrictions on the potential end-uses of wood (Roger and Rowell, 2005; Hill 2006). Wood can gain and lose moisture from and to its surrounding environment (Hagstrom, 2010). Moisture exists in wood as both liquid moisture in the cell voids or lumens (free water) and as moisture in the cell wall (bound water). The moisture content of green wood is defined as the total amount of free and bound water in the living tree (Rowell 2005). The moisture content of green wood varies from species to species and depends on the specific gravity. Lumen volume decreases as the specific gravity increases so the green moisture content decreases with increasing specific gravity (Feist and Tarkow ,1967).

Depending on its moisture content, wood properties differ. In the same piece of wood, most mechanical properties increase with decreasing moisture content. The higher the moisture content of the wood, it is more subject to the attack of decay fungi and other biological attacks. Thus, the amount of the moisture in the wood is quite important for its dimensional stability, performance and durability.

3. Materials and Methods

3.1 Materials

Leza (*Lagerstroemia tomentosa* Presl), Pyaukseik (*Holoptelea integrifolia* Planch), Didu (*Bombax insigne* Wall) and Nabe (*Lennea coromandelica* (Houtt.) Merr. species were selected from wood samples collected for "Introducing Myanmar's Lesser Used Timber Species to the World Market" ITTO Project. One sample tree for each species was used to investigate swelling behavior and water absorption. The number and size of specimens were shown in Table 1. Size of specimens and testing procedures were in accordance with the procedures given in DIN 52184. The photos of selected samples, water absorption test and measurement of dimensions were shown in Figures (1-6).

Table 1: Number and size of specimen for each species

Sr. No	Species	Scientific Name	Size of specimen $(mm)^3$	Number of specimens per tree
1	Leza	*Lagerstroemia tomentosa* Presl	30 x 30 x 10	30
2	Pyaukseik	*Holoptelea integrifolia* Planch	30 x 30 x 10	30
3	Didu	*Bombax insigne* Wall	30 x 30 x 10	30
4	Nabe	*Lennea coromandelica* (Houtt.) Merr	30 x 30 x 10	30

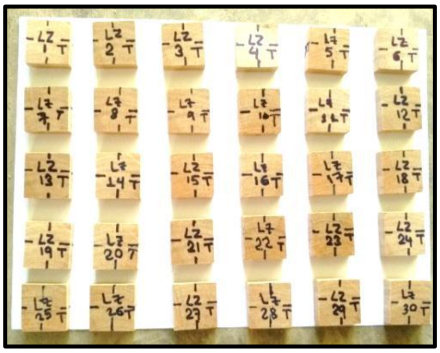
Figure 1: Photo showing Leza wood sample

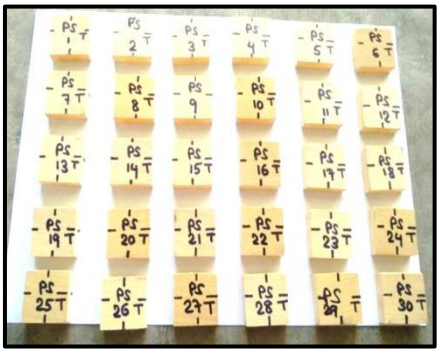
Figure 2: Photo showing Pyaukseik wood sample

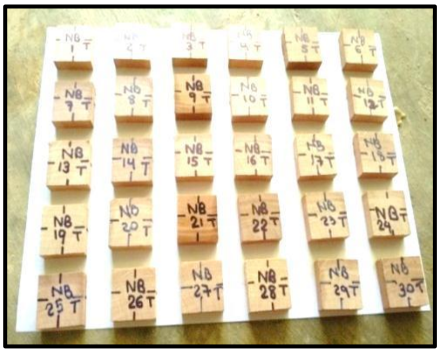

Figure 3: Photo showing Didu wood sample

Figure 4: Photo showing Nabe wood sample

Figure 5: Photo showing water absorption testing of wood sample

Figure 6: Photo showing measurement of dimensions of wood sample

3.2 Methods

3.2.1 Specific gravity

Specific gravity is defined as the ratio of the density of a substance to the density of water at a specified reference temperature, typically 4 °C (39 °F), where the density of water is 1.000 g/cm^3 (Forest Products Laboratory, 2010]. In case of wood, its density is defined as the ratio of its weight to its volume (Schmulsky and Jones, 2011; Forest Products Laboratory 2010; Dinwoodie, 2000). Thus, specific gravity of wood is obtained by dividing its density by the density of water. In fact, basic specific gravity is based on its green volume and oven-dry weight. Thus, the basic specific gravity of wood is calculated as follows:

$$\textit{Basic specific gravity} = \frac{\textit{Oven} - \textit{dry weight}}{\textit{Green volume}} \, x \, \frac{1}{\textit{Density of water}}$$

3.2.2 Swelling

Radial, tangential and longitudinal swelling is calculated according to DIN 52184 as follows:

$$S_R = \frac{L_s - L_o}{L_0}\ x\ 100 \quad (\%)$$

$$S_T = \frac{L_s - L_o}{L_0}\ x\ 100 \quad (\%)$$

$$S_L = \frac{L_s - L_o}{L_0}\ x\ 100 \quad (\%)$$

where S_R, S_T and S_L are radial, tangential and longitudinal swelling of a specimen, respectively. L_s and L_o represent radial or tangential or longitudinal dimensions of the specimen in saturated and oven-dry conditions. The dimensions of specimens before and after soaking in water were measured using a digital caliper.

3.2.3 Swelling Anisotropy

The ratio of total tangential swelling to total radial swelling (T/R) or partial tangential swelling to partial radial swelling (T12/R12) is defined as swelling anisotropy. Thus, it is calculated from total tangential swelling to total radial swelling as follows:

$$Swelling\ Anisotropy = \frac{S_T}{S_R}$$

3.2.4 Water absorption

Water absorption was determined as follows:

$$WA = \frac{W_{end} - W_{start}}{V}\ (kg/m^3)$$

where WA is water absorption by a specimen, W_{start} and W_{end} weights of the specimen at the start and after a specific time (after 1, 2, 3, 4 hour, etc.), V volume of the specimen through which water diffuses.

3.2.5 Moisture content

Moisture content was calculated as follows:

$$M.C\% = \frac{\text{Wend} - \text{Wstart}}{Wstart}\ x\ 100$$

where M.C% is the moisture content of wood specimen, ***Wstart*** and ***Wend*** weights of specimen at the start and after a specific time soaking (after 1, 2, 3, 4 hour, etc.).

4. Data analysis

In this research, minimum, maximum, mean and standard deviation were calculated by using Statistica Software.

5. Results and Discussion

5.1 Specific gravity

Table 2: Basic specific gravity of four hardwood species

Species	Mean	N	Std. Dev.	Minimum	Maximum
Leza	0.485	30	0.007	0.478	0.514
Pyaukseik	0.591	30	0.009	0.565	0.605
Didu	0.442	30	0.012	0.428	0.467
Nabe	0.648	30	0.008	0.635	0.663

The basic specific gravities of four species are shown in Table 2. They range from 0.442 to 0.648. Nabe has the highest whereas Didu has the lowest among them. Leza and Pyaukseik have specific gravities between the two. Species with higher specific gravity tend to have higher amount of wood substances in the same amount of volume (Zobel and Jett, 1995). Specific gravity is the best single criterion of strength and directly correlates with shrinkage and swelling, the pulp yield and heat transmission (Schmulsky and Jones, 2011; Dinwoodie and Desh, 1991).

The basic specific gravities of the tested species are compared with those of the same species tested by other authors as shown in Table 3. Leza has a lower basic specific gravity in this research than in other research findings. All authors found that Pyaukseik and Nabe have almost the same basic specific gravity. Didu has a higher basic specific gravity in this research than in the Handbook of Lesser-Used Timber Species.

Table 3: Comparison of basic specific gravities of tested timber species with those of the same tested by other authors

Species	This Paper	Dr. Khin Maung Sint	Handbook of Lesser-Used Timber Species.
Leza	0.485	0.553	0.583
Pyaukseik	0.591	0.580	0.570
Didu	0.442	-	0.360
Nabe	0.648	-	0.67

According to Negi (1997), wood can be classified into six groups based on their basic specific gravity (based on oven-dry weight and green volume). Woods with basic specific gravity of 0.28 and less are considered to be very light, 0.28 to 0.42 light, 0.42 to 0.56 moderately heavy, 0.56 to 0.70 heavy, 0.70 to 0.85 very heavy and above 0.85, extremely heavy. In accordance with this classification system, Leza and Didu will be in "Moderately Heavy" Group whereas Pyaukseik and Nabe in "Heavy" Group. Heavy woods are suitable for structural applications.

Table 4: ANOVA of basic specific gravity

Analysis of Variance (Marked effects are significant at p< .05000

	SS Effect	Df Effect	MS Effect	SS Error	Df Error	MS Error	F	p
Basic specific gravity	0.806604	3	0.268868	0.009329	116	0.000080	3343.181	0.00

According to ANOVA as shown in Table 4, the basic specific gravity is found to differ significantly among the tested species. Wood technologists have accepted that wood specific gravity varies greatly within and between species (Negi 1997; Forest Products Laboratory 2010; Dinwoodie 2000). This variation is attributed to many factors such as site, climate, geographic location, growth stresses, anatomical structure, etc (Forest Products Laboratory 2010; Santini et al., 2012).

5.2 Swelling of tested timber species

Table 5: Swelling from oven dry to saturated state

No.	Species	Direction	Mean (%)	Number of specimen	Standard deviation	Minimum (%)	Maximum (%)
1	Leza	Radial	3.946	30	0.236	3.496	4.452
		Tangential	7.176	30	0.438	6.415	7.995
		Longitudinal	0.628	30	0.299	-0.297	1.184
2	Pyaukseik	Radial	4.433	30	0.353	3.822	5.478
		Tangential	9.799	30	1.010	6.406	11.879
		Longitudinal	0.944	30	0.366	0.492	1.804
3	Didu	Radial	2.806	30	0.358	2.369	3.705

		Tangential	6.132	30	1.252	3.366	7.436
		Longitudinal	0.745	30	0.334	0.191	1.629
4	Nabe	Radial	3.019	30	0.426	2.322	3.791
		Tangential	6.355	30	0.463	5.643	7.472
		Longitudinal	0.738	30	0.486	0.000	1.915

Swelling behavior of the tested timber species is shown in Table 5. In this research, radial swelling ranges from about 2.8% to 4.4%, tangential swelling from about 6.1 to 9.8% and longitudinal swelling from 0.6 to 0.9%. According to Skaar (1988), the order of magnitude of the total shrinkage in "normal" wood is 3 to 6 % in radial direction, 6 to 12 % in tangential direction and 0.05 to 0.3 % in longitudinal direction. Radial and tangential shrinkage of all tested species are found within the ranges except longitudinal shrinkage, in which all species are higher than 0.3%.

Again, Rowell (2005) states that most radial and tangential shrinkage values are less than 6% and 10%, respectively. All tested species are found to swell less than 6% in radial direction and less than 10% in tangential direction, and thus are within the limits.

Among the tested species, Pyaukseik is found to swell the highest and Didu the lowest. This is due to the fact that swelling is affected by specific gravity and the species with higher specific gravity swell higher (Ofori et al., 2009; Grekin and Verkasalo, 2010). Therefore, Didu with the lowest specific gravity swells the lowest. However, Pyaukseik with lower specific gravity is found to swell higher than Nabe. Nabe with the highest specific gravity does not swell the highest. It may probably be due to the presence of a high amount of extractives, which reduces shrinkage/swelling due to their bulking effect (Forest Products Laboratory, 1957). There are also other factors affecting shrinkage and swelling like size and shape of specimen and the rate of drying (Schmulsky and Jones, 2011 and Forest Products Laboratory 2010).

In general, radial shrinkage is about half of tangential shrinkage of the same species. This also holds true for the tested timber species. There are many reasons explaining this phenomenon: the restricting effect of the ray on the radial plane, the increased thickness of middle lamella on the tangential plane, the difference in the degree of lignifications between radial and tangential cell walls, the small difference in microfibrallar angle between the two walls and earlywood-latewood interaction (Dinwoodie 2000; Forest Products Laboratory 1957; Peck 1957; Clarke 1930 and Time, 1998).

Among the tested species, Pyaukseik has the largest longitudinal swelling (0.94%) whereas Leza swells the least (0.63%). Typically, total longitudinal shrinkage / swelling is only 0.1-0.2% for most species and rarely exceeds 0.4% (Haygreen and Bowyer 1996). Actually, longitudinal shrinkage / swelling is also affected by the specific gravity, that is, the species with the higher specific gravity swells longitudinally higher than those with lower specific gravity (Hanns 1969; Ofori and Brentuo 2010). Thus, these two species will have higher longitudinal swelling. Moreover, longitudinal shrinkage and swelling is high in juvenile wood and reaction wood (Forest Products Laboratory 2010). Although longitudinal shrinkage / swelling is considered negligible because of being small, wood with excessive longitudinal shrinkage / swelling should be avoided in use where longitudinal stability is required. Thus, all tested species should be used in caution especially in cupboard where dimensional stability is demanded.

According to ANOVA as shown in Tables 6, swelling also greatly differs among species and directions in the same tree. Shrinkage and swelling varies greatly within and between species (Schmulsky and Jones 2011; Forest Products Laboratory 2010). Environmental differences among sites produce differences in density, anatomical structure, extractives, chemical composition and/or mechanical stress of the wood, and these in turn affect shrinkage and swelling (Tsoumis 1991).

Table 6: ANOVA of swelling of four species

Fffect	**SS**	**Degree of freedom**	**MS**	**F**	**p**
Species	186.708	3	62.236	184.05	0.00
Direction	2636.429	2	1318.215	3898.25	0.00
Species* Direction	123.040	6	20.507	60.64	0.00
Error	117.678	348	0.338		

5.3 Swelling anisotropy of four species

Table 7: Swelling anisotropy of four species

No.	**Species**	**Swelling Anisotropy (%)**	**Standard deviation**
1	Leza	1.83	0.164
2	Pyaukseik	2.23	0.306
3	Didu	2.22	0.529
4	Nabe	2.14	0.325

The swelling anisotropy of tested timber species are shown in Table 7. Three tested species are found to have a tangential to radial swelling ratio of about 2.2 whereas Leza has a ratio less than 2. This means that shrinkage or swelling problems can occur when putting them into use, but if they are properly dried before they are used, these problems can be controlled.

5.4 Water absorption

The water absorption values of four species are shown in Table 8. According to these results, Didu has the highest water absorption which reached 257, 285, 309 and 334 kg/m^3 after 1, 2, 3 and 4 hours, respectively. But, Leza has the lowest which reached 67, 79, 90 and 97 kg/m^3 after 1, 2, 3 and 4 hours, respectively.

Water absorption is generally influenced by wood types (sapwood or heartwood), extractives, density or specific gravity and wood directions (Maclean 1935). The main influencing factor is extractive. In this research, Nabe with the highest specific gravity is found to absorb the lowest amount of water. This might be due to its more content of extractives compared to other three species. In this research, only heartwood samples were used and thus wood types will not have any influence on water absorption. Similarly, water penetration was allowed to enter the wood from all three directions and thus, wood direction will have no influence on the water absorption.

Table 8: Water absorption of tested timber species for the first four hours (kg/m^3)

Species	No. of samples	Avg. water absorption (±SD)			
		After 1 hr	After 2 hr	After 3 hr	After 4 hr
Leza	30	67 (±3.3)	79 (±5.6)	90 (±11.7)	97 (±5.0)
Pyaukseik	30	123 (±5.2)	160 (±6.8)	188 (±7.9)	213 (±8.9)
Didu	30	257 (±107.8)	285 (±103.7)	309 (±96.9)	334 (±93.2)
Nabe	30	78 (±4.0)	90 (±3.3)	100 (±4.7)	108 (±5.2)

Figure 7 shows the results of water absorption (WA) of wood samples of four species for the whole test period. The water absorption average values after 46 days of soaking are 629, 602, 666 and 552 kg/m^3 for Leza, Pyaukseik, Didu and Nabe, respectively. Nabe with the highest specific gravity absorbed the least amount. This is due to its thick cell wall, small lumens, and extractives, thus small space available for water. Didu with the lowest specific gravity absorbed the largest amount. This is due to its thin cell wall and large lumens, thus large space available for water. Thus, Leza, Pyaukseik and Nabe are more favourable for structural applications than Didu in term of water absorption. However, there are nowadays many technologies available which reduce water absorption, improve dimensional stability and durability and enhance even some mechanical properties. By application of such technologies as thermal modification, chemical modification, surface modification and impregnation modification, these tested species will be fitted to most purposes including structural applications.

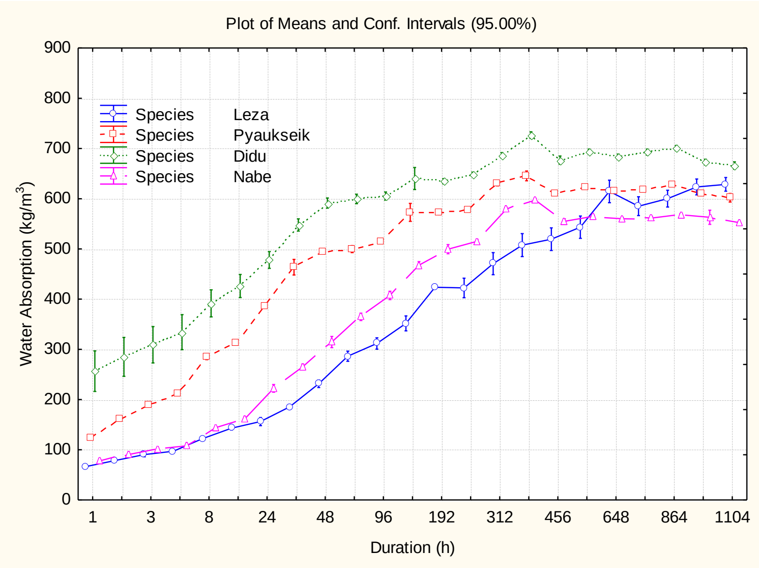

Figure 7: Water absorption versus soaking time

5.5 Moisture Content

Wood components in residential buildings and industrial applications are periodically exposed to liquid water in the form of rain or water vapour. An increase in 2 or 3% of water vapour can cause reduction in strength properties of timber structures. Also wood is attacked by microorganisms when the moisture content exceeds the fiber saturation point (FSP) (Okoh, 2014). Thus, the amount of water absorbed by the wood is also a decisive factor for its structural integrity. The moisture contents of wood samples of the tested species were determined after water-soaking for 46 days (1104 h) and shown in Table 9.

Nabe among the tested species absorbed the least amount while Didu did the largest amount. Leza and Pyaukseik are just between two groups. Among many other factors affecting water absorption of wood species, specific gravity is one of the decisive factors. As shown in Table 9, Nabe with the highest specific gravity has the lowest amount of moisture content. Didu has the lowest specific gravity and thus, the highest moisture content. Species with high specific gravity contain thick-walled cells with small cavities, and thus have small spaces available for water entry. Species with low specific gravity contain thin-walled cells with large cavities which are available for water entry.

Table 9: Moisture contents of tested species

Species	Moisture content (%)	Standard deviation
Leza	129.7	8.3
Pyaukseik	101.9	4.2
Didu	150.9	6.7
Nabe	85.3	1.2

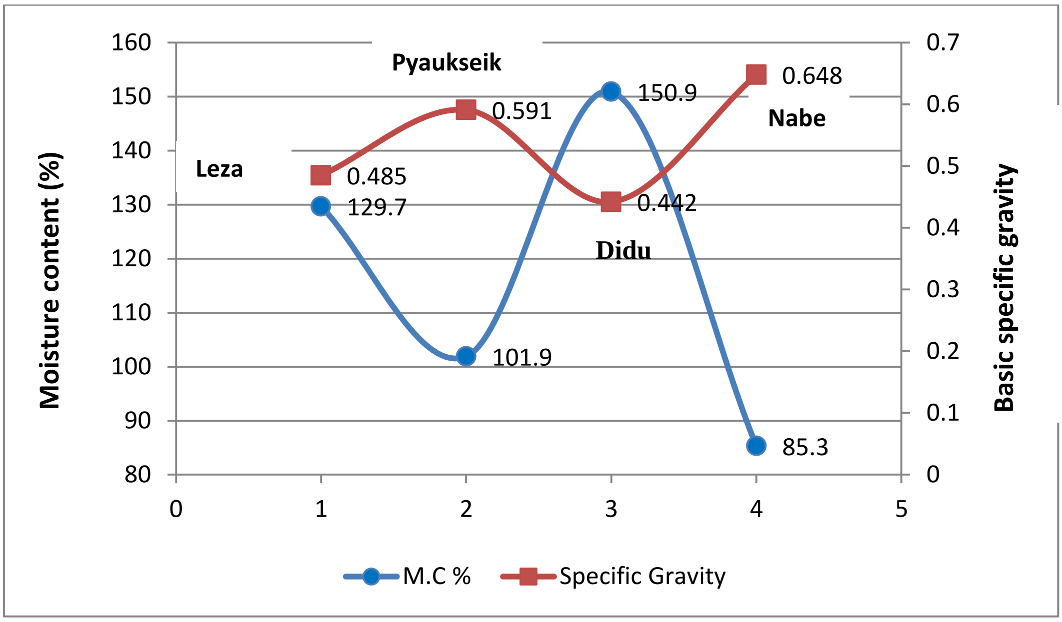

Figure 8: Relationship between specific gravity and moisture content

6. Conclusion

Basic specific gravity, swelling, swelling anisotropy, water absorption and moisture content of four hardwood species were determined to assess their swelling behaviors in response to water soaking. Among tested four hardwood species, Nabe has the highest specific gravity and Didu the lowest among them. Swelling is affected by specific gravity and thus, the species with higher specific gravity swell higher. Therefore, Didu swells the lowest. However, Pyaukseik with lower specific gravity is found to swell higher than Nabe. Nabe with the highest specific gravity does not swell the highest possibly due to a high amount of extractive content, which reduces shrinkage/swelling due to their bulking effect. There are also other factors affecting shrinkage and swelling like size and shape of specimen and the rate of drying.

Swelling anisotropy is the index of dimensional stability of timber. All tested species are found to have a higher tangential to radial swelling ratio than 1.5, but to swell about at 2.2%. Nabe with the highest specific gravity absorbed the least amount of water. This is due to its thick cell wall, small lumens and extractives, thus small space available for water. Nabe with the highest specific gravity has the lowest amount of moisture content. Didu has the lowest specific gravity and thus, the highest moisture content.

According to the findings in this research, Leza can be used in furniture due to its low swelling anisotropy. Other timber species are not suitable for uses where dimensional stability is required. Didu has a low specific gravity and thus it is not suitable as construction timber. Nabe and Pyaukseik can be used for construction due to their high basic specific gravity. All these species are recommended for indoor applications for their high ability to absorb moisture.

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