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Study on Physical and Mechanical Properties of Plantation Teak at Different Ages in Sagaing Region

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စစ်ကိုင်းတိုင်းဒေသကြီးအတွင်းရှိ သက်တမ်းအမျိုးမျိုးရှိသောစိုက်ခင်းကျွန်း၏ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိကိုလေ့လာခြင်း

ဒေါက်တာချိုချိုမြင့်၊ လက်ထောက်သုတေသနအရာရှိ
ဝင်းဦးနိုင်၊ လက်ထောက်သုတေသနအရာရှိ
ချောရူပါစိုး၊ သုတေသနလက်ထောက်-၂

စာတမ်းအကျဉ်း

ဤစာတမ်းတွင် စစ်ကိုင်းတိုင်းဒေသကြီးအတွင်းရှိ သက်တမ်းအမျိုးမျိုး(၂၀၊ ၃၂၊ ၃၇ နှင့် ၄၀) နှစ် ရှိသော စိုက်ခင်းကျွန်း၏ ရူပနှင့်အင်အားဆိုင်ရာဂုဏ်သတ္တိများကို စမ်းသပ်လေ့လာထားပါသည်။ စမ်းသပ်သည့် စိုက်ခင်းကျွန်းများကို စစ်ကိုင်းတိုင်းဒေသကြီး၊ ကသာခရိုင်၊ ဝန်းသိုမြို့နယ်ရှိ ဖီလေးကြိုးဝိုင်းမှ သက်တမ်းတစ်မျိုးစီအတွက် သစ်နမူနာ တစ်ပင်စီ စုဆောင်းခဲ့ပါသည်။ ရူပနှင့်အင်အားဆိုင်ရာဂုဏ်သတ္တိများကို ASTM D-143-52 (2007) နည်းစနစ် ၊ BS-373 (1957) နည်းစနစ် နှင့် ဂျာမန်နည်းပညာ (DIN- 52184) တို့ကို အသုံးပြု၍ စမ်းသပ်ခဲ့ပါသည်။ ရူပဆိုင်ရာဂုဏ်သတ္တိများတွင် အစိုဓာတ်ပါဝင်မှု၊ ရေချိန်သိပ်သည်းဆ၊ သိပ်သည်းမှု နှင့် ရေစုပ်ယူမှုတို့မှာ သက်တမ်းတစ်ခုနှင့်တစ်ခုအကြားတွင် သိသိသာသာ ကွာခြားမှုရှိကြောင်း တွေ့ရှိခဲ့ပါသည်။ ထို့ပြင် ကျုံ့မှုတွင် လားရာဘက်သုံးခုလုံး၌ သက်တမ်းတစ်ခုနှင့်တစ်ခုအကြား သိသိသာသာ ကွာခြားမှုရှိသော်လည်း ကြွမှုတွင် နှစ်ကွင်းအပြိုင်လားရာ၌သာ သိသိသာသာ ကွာခြားမှု ရှိကြောင်း တွေ့ရှိခဲ့ပါသည်။ သက်တမ်းအကြီးဆုံး ၄၀ နှစ်သားကျွန်း၏ ရေချိန်သိပ်သည်းဆမှာ အနည်းဆုံး ဖြစ်ပြီး စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းအားလုံး၏ ရေချိန်သိပ်သည်းဆမှာ သဘာဝကျွန်းအောက် နည်းကြောင်း တွေ့ရှိခဲ့ပါသည်။ ထို့ပြင် အစိုဓာတ်ပါဝင်မှု ၁၂ ရာခိုင်နှုန်း အခြေအနေတွင် ၄၀ နှစ်သားကျွန်း၏ သိပ်သည်းမှုမှာ အနည်းဆုံးဖြစ်ပြီး စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်း အားလုံး၏ သိပ်သည်းမှုမှာ သဘာဝကျွန်းထက်ကြီးကြောင်း တွေ့ရှိခဲ့ပါသည်။ သက်တမ်းအငယ် ဆုံး ၂၀ နှစ်သားကျွန်းမှာ ကျုံ့ကြွမှု အနည်းဆုံးဖြစ်ပြီး ၄၀ နှစ်သားကျွန်းမှလွဲ၍ စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်း အားလုံး၏ ပုံသဏ္ဍာန်တည်မြဲမှုမှာ သဘာဝကျွန်းထက်ကြီးကြောင်း တွေ့ရှိခဲ့ပါသည်။ ရေစုပ်ယူမှုတွင် ၄၀ နှစ်သားကျွန်းမှာ ရေစုပ်ယူမှု အများဆုံးဖြစ်ကြောင်း တွေ့ရှိခဲ့ပါသည်။ ရေချိန်သိပ်သည်းဆပေါ် အခြေခံ၍ အုပ်စုခွဲခြားရာတွင် သက်တမ်း ၂၀၊ ၃၂၊ နှင့် ၃၇ နှစ်သား စိုက်ခင်းကျွန်းတို့မှာ လေးသောအုပ်စုတွင်ရှိပြီး ၄၀နှစ်သားကျွန်းမှာ အသင့်အတင့်လေးသော အုပ်စုတွင်ရှိပါသည်။ အင်အားဆိုင်ရာရလဒ်များအရ အုပ်စုခွဲခြားရာတွင် သက်တမ်း ၃၂၊ ၃၇ နှင့် ၄၀ နှစ်သား စိုက်ခင်းကျွန်း တို့မှာ အုပ်စု (၁) တွင်ရှိပြီး ၂၀ နှစ်သား စိုက်ခင်းကျွန်းမှာ အုပ်စု (၂) တွင်ရှိပါသည်။ ထို့ကြောင့် စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်း အားလုံးသည် အဆင့်မြင့် ပရိဘောဂများ ပြုလုပ်ရန်နှင့် ဆောက်လုပ်ရေးလုပ်ငန်းများတွင် အသုံးပြုရန် သင့်လျော်ပါသည်။

Study on Physical and Mechanical Properties of Plantation Teak at Different Ages in Sagaing Region

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Abstract

In this research, physical and mechanical properties of plantation teak at different ages were investigated. Different ages 20, 32, 37 and 40 years of plantation teak were selected for the study. Selected plantation teak was colected from Phelay Reserve in Wuntho Township, Katha District, Sagaing Region. Only one sample tree was collected for each age. Physical and mechanical properties were tested by following ASTM D-143-52 (2007) standard BS-373 (1957) standard and German standard DIN (52184). In physical properties, it was found that moisture content, basic specific gravity, density and water absorption were significantly different among different ages. Shrinkage was significantly different in three direction (radial, tangential and longitudinal) for different ages of plantation teak but swelling was significantly different only in tangential direction for different ages of plantation teak. It was found that 40 years old plantation teak had the lowest basic specific gravity whereas the basic specific gravity of all tested plantation teak was lower than that of natural teak. At 12% moisture content, 40 years old plantation teak had the lowest density while the densities of all tested plantation teak were greater than that of natural teak. It was found that 20 years old plantation teak had the lowest shrinkage and swelling value. Except 40 years old plantation teak, dimensional stability of all tested plantation teak was greater than that of natural teak. 40 years old plantation teak absorbed water most. According to the classification of wood based on basic specific gravity, 40 years old plantation teak would be in “Moderately Heavy” whereas 20, 32 and 37 years old plantation teak in “Heavy”. According to classification of strength properties, 32, 37 and 40 years old plantation teak would be in Group (I), and 20 years old plantation teak would be in Group (II). Therefore, the selected plantation teak studied in this research is suitable to make high quality wood products and to use as construction material.

Key words: shrinkage, plantation teak, specific gravity, dimensional stability, wood properties

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1. Introduction

Teak is a Royal tree and is also popular all over the world. Natural teak has many desirable properties such as durability, stability, good strength, good color and texture such as good appearance. However, natural teak is becoming rare. So, teak plantations are now being established rapidly. Therefore, plantation teak will be used more in the future. However, plantation teak is not well recognized as natural teak.

During 2008 and 2009, "Study on Utilization of Plantation Teak Pre-Project" was conducted in collaboration with Forest Department and CFC/ITTO 73 FT PPD 68/03 Rev.2 (1). Physical and mechanical properties of plantation teak at different ages (14, 20, 25 and 30 years) were studied during that project. 14 years old teak was collected from Yetashe Township while 20 years old from Oktwin Township. Whereas 25 years old teak was collected from Leway Township, the 30 years old was obtained from Thandwe Township. According to the research findings, it was found that the properties of plantation teak varied from one age to another and also from one locality to another. Moreover, significant variations were also found in the same tree.

Since plantation teak of different ages has been collected from different localities, it is quite difficult to conclude that the variation in properties is due to different ages or different localities. It is thus suggested that the properties of plantation teak at different ages growing in the same locality should be tested as properties may vary from one locality to another. Therefore, in this research, physical and mechanical properties of plantation teak at different ages in Sagaing region were studied.

2. Objectives

The objectives of this research are:

(1) to study physical and mechanical properties of plantation teak at different ages in Sagaing Region

(2) to suggest the best use of these plantation teak based on result findings, and

(3) to use the data for wood entrepreneurs and scientific researchers.

3. Materials and Methods

In this research, plantation teak of different ages was selected from teak plantations in Sagaing Region. Different ages 20, 32, 37 and 40 years of plantation teak were collected from Phelay Reserve, Wuntho Township, Katha District. One sample tree was collected for each age. Wood specimens were prepared according to American Society for Testing Material ASTM D-143-52 (2007), British standard BS-373 (1957) and German standard (DIN-52184). Oven, digital caliper, balance and autograph timber testing machine were used in this research. Moisture content, density, specific gravity and shrinkage were determined according to ASTM D-143-52 (2007) standard. Density and specific gravity were determined at different moisture contents (initial, 12 % and oven dry). Shrinkage in radial, tangential and longitudinal directions were determined from green to oven dry and from green to 12% MC. Swelling in radial, tangential and longitudinal directions and water absorption were determined from oven dry to green condition by using German standard (DIN-52184).

Mechanical properties were tested for green condition and air-dried condition by using BS-373 (1957) standard. Tested properties and size of specimen for different ages of plantation teak are shown in Table 1.

Table 1. Tested properties and size of specimen for different ages of plantation teak

Sr. No	Properties	Size of specimen (mm)
1	Moisture content, Specific gravity, Density	25 x 25 x 100
2	Shrinkage (Radial, Tangential, longitudinal)	25 x 25 x 100
3	Swelling (Radial, Tangential, Longitudinal)	30 x 30 x 10
4	Water absorption	30 x 30 x 10
5	Static bending	20 x 20 x 300
6	Compression parallel to grain	20 x 20 x 80
7	Compression perpendicular to grain	20 x 20 x 60

4. Results and Discussion

4.1 Physical Properties

4.1.1 Moisture content

Average moisture content values of plantation teak at different ages are 86.81 % for 20 years old plantation teak, 87.78 % for 32 years old plantation teak, 89.34 % for 37 years old plantation teak and 95.72 % for 40 years old plantation teak as shown in Table 2. Moisture content was investigated to know initial moisture content of plantation teak at different ages. It has significant effects on wood properties such as shrinkage, swelling, density and mechanical properties. The difference in average moisture content in teak wood is due to its age and location, and perhaps also the season of the year when it is harvested. It is reported that location of growing will also affect wood moisture content (Wahyudi, 2013; as cited in Hadinata and Kozakiewicz, 2020).

Table 2 Moisture content of plantation teak at different ages

Age (years)	No. specimens	Minimum MC%	Maximum MC%	Mean MC%	Standard deviation
20	16	67.33	106.29	86.81	12.09
32	17	67.08	101.90	87.78	7.90
37	15	79.69	95.38	89.34	5.10
40	17	85.07	103.19	95.72	5.31

MC % = moisture content percent

4.1.2 Density

Wood densities of plantation teak of different ages at initial, 12% MC and oven dry conditions are shown in Table 3. According to the results, the mean density of 40 years old plantation teak is not the highest. Generally, older trees would have higher wood density values (Wanneng et. al., 2014) but the results did not confirm this. Moreover, Bhat and Priya (2004) also reported that 21 years old plantation teak showed higher density than 65 years old plantation teak collected from different locations. In addition, the authors also found that plantation teak of the same age from different localities had significant difference in density.

In the study, the mean density at 12% MC of 20 years old plantation teak is 701 kgm^{-3} while 32 years old plantation teak is 726 kgm^{-3}, 37 years old 726 kgm^{-3} and 40 years old 682 kgm^{-3}, respectively. The basic density of this research is comparable to those of 50-70 years old plantation teak in East Timor (Minranda, Sousa and Pereira, 2011). But, mean air dry density of 20 years old plantation teak in this study (701 kgm^{-3}) is lower than that of other study in Myanmar (731 kgm^{-3}). The mean air dry density of 20 years old plantation teak studied in Laos was 708 kgm^{-3} (Wanneng et. al., 2014), which is almost the same with the air dry density value of 20 years old plantation teak in this study. In Brazil, the 14 years old teak has lower density than 22 years old plantation teak (Polatol et. al., 2003). Whereas 22 years old Brazilian teak is comparable to the results of this research, 14 years old Brazilian teak has much lower density than the plantation teak in this research. The densities in this research are higher than those of 15 years old plantation teak in Malaysia (Josue and Imiyabir, 2011), 21 years old and 65 years old Indian plantation teak (Bhat and Priya, 2004), 6.5 years old Australian plantation teak, and 6, 10 and 15 years old Solomon planation teak (Hope et. al., 2011). The comparison of wood density of plantation teak of different ages at 12% MC in this study with those of other study is shown in Figure 1 (Forest Department, 2009).

Table 3 Wood densities of plantation teak at different ages

Age (years)	No. of specimens	Initial MC density (kgm^{-3})		12% MC density (kgm^{-3})		Oven dry density (kgm^{-3})		Basic density (kgm^{-3})	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
20	16	1062	52	701	23	610	18	569	17
32	17	1102	28	726	23	606	17	587	17
37	15	1112	26	726	22	631	18	588	16
40	17	1085	36	682	34	604	25	555	26

MC = moisture content; SD = standard deviation

Analysis of variance (ANOVA) (Table 4) shows that the wood density of plantation teak at different ages are significantly different at α= 0.05. Air dry density is compared for significant difference among different ages by Tukey's test. 40 years old plantation teak has the lowest air dry density value of 682 kgm^{-3} and significantly differs from ages 32 and 37 but does not significantly differ from 20 years old plantation teak. Age is found to have a significant effect on density of 10, 15 and 20 years old plantation teak from wet and dry localities in Ghana (Amoah and Inyong, 2019). In Malaysia, the density is from 515 to 805 for 8 years old, 514 to 893 for 16 years old and 534 to 961 for 28 years old plantation teak. Thus, the authors conclude that there is a tendency for the density to increase as the trees age (Fui et. al. 2007). In Indonesia, 40 years old plantation teak has significantly higher density than 10 years old plantation teak (Darmawan et. al., 2015). Similarly, plantation teak of 7-10 years rotation has a lesser basic density than plantation teak of 40-60 years rotation in Indonesia ((Rizanti et. al., 2018). Thus, these findings agrees that the density of plantation teak increases with age.

On the other hand, it is found that basic density did not increase considerably with increasing age in 9-year- old teak growing in wet site (3500 mm per year) of Costa Rica (Moya, 2001; as cited in Forest Department, 2009). Similarly, Cordero and Kanninen (2003) also found that wood dry density increased slightly with age, and there was a significant difference between 8 years old (the youngest) and 47 years old (oldest) teak only. When testing samples of 16, 38, 39 and 76 years old teak from Indonesia and samples of 5, 41, 55 and 63 years old teak from India, it is found that the density shows a large variation among trees. But the authors concludes that the density at the outermost part of trunk is not affected by the growth rate or the tree age (Okuyamat et. al. 2003). Bhat and Indira (1997) tested 13, 21, 55 and 65 years old plantation teak grown in India and found that there was no significant difference in density. Some other authors also confirm that there is no significant difference in wood density among different ages (Wanneng et. al., 2014; Richter, 2003).

It should be noted that wood density depends not only on the growth rate of tree (age) but also on other factors such as the plantation site (soil), geographic location (plain or hill) and climate (wind and annual rainfall) (Wanneng et al., 2014). And then, within a given species, density of oven dry wood varies because of anatomical characteristics such as the ratio of earlywood to latewood and heartwood to sapwood. For a limited number of species, minerals and extractable substances may also affect density (Forest Products Laboratory, 2010). The density of wood varies, depending on the amount of material (cell wall) and voids (cell cavities) present in a certain volume (Tsoumis, 1991).

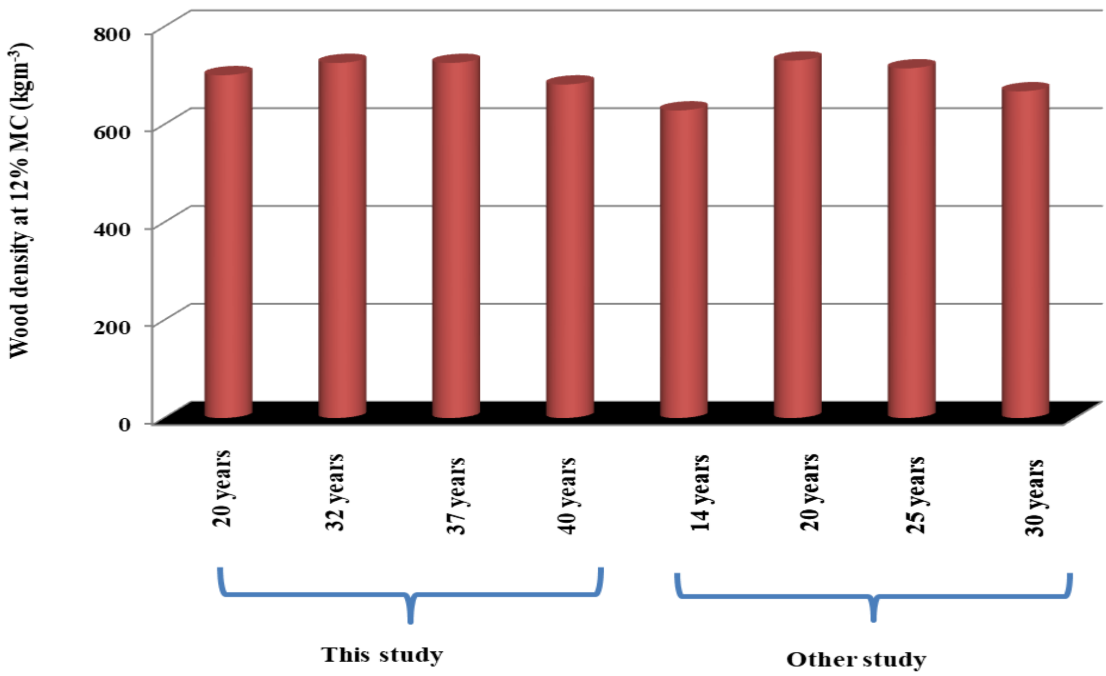

Figure 1 Wood density of plantation teak of different ages obtained in this study compared with density from other study (Forest department, 2009); MC = moisture content

Table 4 Analysis of variance for physical properties of plantation teak at different ages

Property	Interaction	Sum of squares	Df	Mean square	F value	p value
Density 12%	Between Ages	21215	3	7072	10.51	0.00*
Basic Density	Between Ages	11583	3	3861	10.53	0.00*
Basic specific gravity	Between Ages	0.01	3	0.004	10.53	0.00*
Specific gravity (12 % MC)	Between Ages	0.02	3	0.006	10.51	0.00*
Radial shrinkage (G to OD)	Between Ages	12.46	3	4.15	54.16	0.00*
Tangential shrinkage (G to OD)	Between Ages	3.39	3	1.28	10.78	0.00*
Longitudinal shrinkage (G to OD)	Between Ages	0.30	3	0.10	7.48	0.00*
Radial Shrinkage (G to 12% MC)	Between Ages	4.48	3	1.49	54.16	0.00*
Tangential Shrinkage (G to 12% MC)	Between Ages	1.21	3	0.41	10.78	0.00*
Longitudinal Shrinkage (G to 12%MC)	Between Ages	0.11	3	0.04	7.48	0.00*
Radial swelling (OD to G)	Between Ages	2.12	3	0.71	2.56	0.06 ns
Tangential swelling (OD to G)	Between Ages	39.90	3	13.30	35.37	0.00*
Longitudinal swelling (OD to G)	Between Ages	0.17	3	0.06	0.91	0.44 ns
Water absorption	Between Ages	40124	3	13375	269.2	0.00*

*= significant ($p<0.05$), ns = not significant ($P>0.05$), OD = Oven dry, G = Green, MC= moisture content

4.1.3 Specific gravity

Specific gravity of plantation teak at different ages is shown in Table 5. According to the results, the basic specific gravity of 32 and 37 years old plantation teak has the same value. The results are unexpected because normally older trees would have higher values of specific gravity. But, this study shows that specific gravity of 40 years old plantation teak is lower than that of 20, 32, and 37 years old plantation teak. The comparison of basic specific gravity of plantation teak at different ages obtained in this study and other study is shown in Figure 2. It is found that the basic specific gravity of 20 years old plantation teak in this study is slightly lower than that of 20 years old plantation teak from other study.

ANOVA (Table 4) shows that basic specific gravity of plantation teak at different ages is significantly different. Then, basic specific gravity of plantation teak at different ages is compared for significant difference by Tukey's test. 40 years old plantation teak has the lowest basic specific gravity value of 0.555, significantly differs from ages 32 and 37 with the values of 0.587 and 0.588 but does not significant differ from 20 years old plantation teak with the value of 0.569. 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). In Costa Rica, the specific gravity of plantation teak trees is found to vary with age and also from the inside to the outside of the bole (Moya, 2001 as cited in Ladrach, 2009).

According to Negi (1997), wood can be classified into six groups based on their basic specific gravity. 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, 40 years old plantation teak will be in “Moderately Heavy” Group whereas other ages (20, 32 and 37) in “Heavy” Group.

Table 5 Specific gravity of plantation teak at different ages

Age (years)	No. of specimens	Basic specific gravity		A t 12% MC specific gravity		Oven dry specific gravity	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
20	16	0.569	0.02	0.626	0.02	0.610	0.02
32	17	0.587	0.02	0.648	0.02	0.606	0.02
37	15	0.588	0.02	0.648	0.02	0.631	0.02
40	15	0.555	0.03	0.609	0.03	0.604	0.02

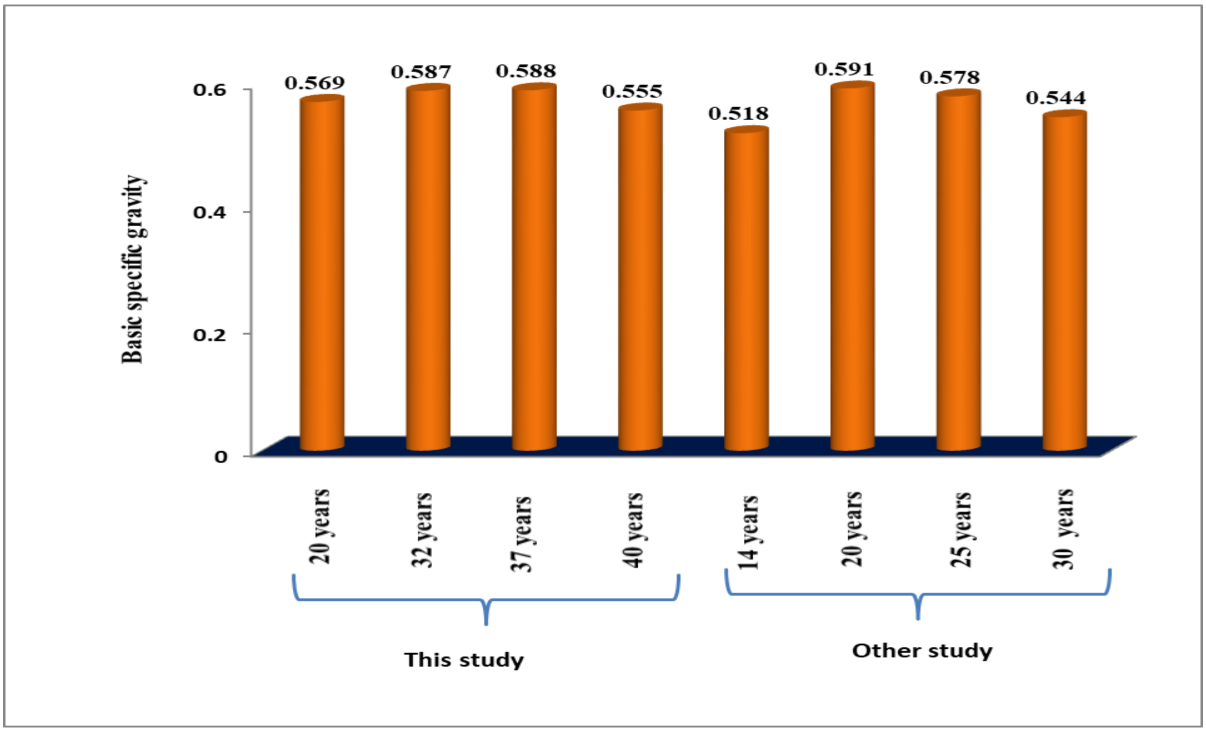

Figure 2 Comparison of basic specific gravity of plantation teak of different ages obtained in this study and other study (Forest department, Myanmar 2009)

4.1.4 Shrinkage

Shrinkage values in radial, tangential and longitudinal directions for different ages of plantation teak are shown in Table 6. It is found that tangential shrinkage value is the highest, twice of radial shrinkage value for different ages of plantation teak except 40 years old plantation teak. Longitudinal direction has the lowest shrinkage compared with the other radial and tangential directions. Wood is an anisotropic material. It shrinks (swells) most in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally) (Wood handbook, 2010). Prawirohatmodjo (2012) stated that the microfibril structures in cell walls caused wood shrinkage to be higher in its tangential than radial and longitudinal part (Hadinata and Kozakiewicz 2020). Thus, it can be found that shrinkage in tangential direction is higher than those in radial and longitudinal direction in all ages.

Table 6 Shrinkage in the radial, tangential and longitudinal directions

Ages	Radial shrinkage (%)				Tangential shrinkage (%)				Longitudinal shrinkage (%)			
	from Green to oven dry		from Green to 12% MC		from Green to oven dry		from Green to 12% MC		from Green to oven dry		from Green to 12% MC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
20	2.05	0.28	1.23	0.27	4.05	0.33	2.43	0.20	0.41	0.11	0.25	0.07
32	2.00	0.24	1.20	0.14	4.61	0.36	2.76	0.21	0.51	0.11	0.31	0.07
37	2.15	0.27	1.29	0.16	4.15	0.33	2.49	0.20	0.33	0.09	0.20	0.05
40	3.22	0.34	1.93	0.20	4.50	0.24	2.70	0.14	0.36	0.15	0.22	0.09

The shrinkage from green to oven dry is from 2.00% to 3.22% in radial direction, from 4.05% to 4.61% in tangential direction and from 0.33% to 0.51% in longitudinal direction. These values are somewhat higher than those of natural teak. However, all shrinkage values in this research are lower than those of Indonesian plantation wood (Hardiyanto and Prayitno, 2006) and those of 14 and 20 years old Brazilian teak (Polatol et. al., 2003) and similar to those of 7-8 years old Brazilian plantation teak (Laming and van der Zee, 2007). But the results in this research are found to be higher than those of plantation teak of 10, 15, 20 and 25 years from Laos, which shrinks radially about 2.1 to 2.24% and tangentially about 3.43 to 3.54% (Wanneng et al., 2014).

ANOVA (Table 4) indicates that shrinkage values of plantation teak of different ages are significantly different at significant value ($\alpha = 0.05$) compared with statistic of probability value ($p = 0.00$). Tangential shrinkage from green to oven dry is compared for significant difference by Tukey's test. The youngest age 20 years old plantation teak has the lowest shrinkage value of 4.05, significantly differs from ages 32 and 40 with the values of 4.61 and 4.5 but does not significantly differ from 37 years old plantation teak with the value of 4.15. In Nigeria, it is found that volumetric, radial and tangential shrinkage decreases from 15 years old to 25 years old plantation teak (Amiandamhen and Izekor, 2017). In Indonesia, 40 years old plantation teak has higher radial and longitudinal shrinkage than 10 years old plantation teak whereas tangential shrinkage is completely different (Darmawan et. al., 2015). Except tangential shrinkage, the other shrinkage significantly differs between different ages.

Wood in building usually has a wood moisture content of 5% to 15%. So, the most important value in wood shrinkage studies is the shrinkage from initial moisture content to 12% MC. Comparison of radial and tangential shrinkage of plantation teak in this study and other study is shown in Table 7. The comparison shows that the shrinkage values in this study are lower than those of the other study. However, the results are completely different from tangential shrinkage on conventional teak wood which has 5.2% (Martawijaya et al. 2005). This is due to its age and growth location (Hadinata and Kozakiewicz 2020).

Table 7 Comparison of radial and tangential shrinkage of plantation teak in this study and other study

Properties	Plantation teak (This study)				Plantation teak (Forest Department, 2009)			
	20 yrs	32 yrs	37 yrs	40 yrs	14 yrs	20 yrs	25yrs	30yrs
Radial shrinkage from green to oven dry	2.05	2.00	2.15	3.22	2.3	2.7	2.7	2.7
Tangential shrinkage from green to oven dry	4.05	4.61	4.15	4.50	5.2	5.2	5.0	5.6

4.1.5 Swelling

Swelling values from oven dry to green condition for plantation teak of different ages is shown in Table 8. According to results, tangential swelling is the largest, radial welling the second largest and longitudinal swelling the lowest. Swelling value in tangential direction is slightly higher than two times swelling value in radial direction. ANOVA (Table 4) indicates that tangential swelling values for plantation teak of different ages are significantly different at significant value ($\alpha = 0.05$) compared with the statistics of probability value ($p = 0.00$). Tangential swelling from oven dry to green is compared for significant difference by Tukey's test. The youngest age 20 years old plantation teak has the lowest swelling value of 4.51, significantly differs from ages 32 and 40 with the values of 6.07 and 5.24, but does not significantly differ from 37 years old plantation teak with the value of 4.88.

According to results, 32 years old plantation teak is found to swell the highest and 20 years old the lowest. This is due to the fact that swelling is affected by specific gravity and thus the species with higher specific gravity swell higher (Ofori et al., 2009; Grekin and Verkasalo, 2010). 40 years old with the lowest specific gravity does not swells the lowest and is found to swell higher than 37 years old. Similarly, 37 years old teak 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).

Table 8 Swelling in the radial, tangential and longitudinal directions

Age (years)	No. of specimens	Swelling from oven dry to green (%)					
		Radial		Tangential		Longitudinal	
		Mean	SD	Mean	SD	Mean	SD
20	30	1.94	0.45	4.51	0.55	0.58	0.25
32	30	2.16	0.37	6.07	0.60	0.61	0.21
37	30	1.99	0.50	4.88	0.76	0.61	0.28
40	30	2.27	0.71	5.24	0.52	0.52	0.26

The other radial and longitudinal swelling values of plantation teak are not significantly different among different ages. Comparison of radial and tangential swelling of plantation teak in this study and other study is shown in Table 9. The comparison shows that the swelling values in this study are lower than that of the other study. And then, swelling values of 20 years old plantation teak in this study is lower than that of 20 years old plantation teak in other study.

Table 9 Comparison of radial and tangential swelling of plantation teak in this study and other study

Properties	Plantation teak (This study)				Plantation teak (Forest department,2009).			
	20 yrs	32 yrs	37 yrs	40 yrs	14 yrs	20 yrs	25yrs	30yrs
Radial swelling from oven dry to green	1.94	2.16	1.99	2.27	1.96	2.15	2.69	1.97
Tangential swelling from oven dry to green	4.51	6.07	4.88	5.24	4.84	4.99	5.08	4.77

4.1.6 Water absorption

Water absorption of plantation teak at different ages is shown in Table 10. According to results, 20 and 40 years old plantation teak absorbs water more than 32 and 37 years old plantation teak. This could be attributed to their densities. 20 and 40 years old teak has the lowest densities and thus absorbs water most. 32 and 37 years old teak has the highest densities and thus absorbs water at the lowest amount. Sint and Hapla (2009) found that timbers with higher densities absorb less water or solution than those with lower densities. Again, among timbers of the same density, those with deposits in cell lumina show lower absorption than those without deposits (Sint 2010; Sint et. al. 2011). Moreover, the absorption is also influenced by anatomical structure of timber species (Sint et. al. 2013; Sint et. al. 2012).

Table 10 Water absorption of plantation teak at different ages

Age (years)	**No. of specimens**	**Water absorption (kgm^{-3})**			**Standard deviation**
		Minimum	Maximum	Mean	
20	30	599.82	626.93	611.56	6.71
32	30	557.87	585.29	570.65	6.78
37	30	570.70	593.87	582.42	6.35
40	30	591.88	625.56	612.72	8.22

ANOVA (Table 4) indicates that maximum water absorption of plantation teak at different ages is significantly different at significant value (α = 0.05). Maximum water absorption of plantation teak at different ages is compared for significant difference by Tukey's test. The oldest age 40 years old plantation teak has the highest water absorption value of 612.72 kgm^{-3}, significantly differs from ages 32 and 37 with the values of 570.65 kgm^{-3} and 582.42 kgm^{-3} but does not significantly differ from the youngest age 20 years old plantation teak with the value of 611.56 kgm^{-3}.

4.2 Mechanical Properties

4.2.1 Static Bending

The mean modulus of elasticity, modulus of rupture and fiber stress at proportional limit of plantation teak at different ages at green and 12% moisture content are given in Table 11. The number of specimens per age and standard deviation are also given. According to the test results, it can be found that 40 years old plantation teak possesses the highest MOE and the lowest MOR and FS@PL in both green and air dry condition. For significant difference, the effect of age on modulus of elasticity, modulus of rupture and fiber stress at proportional Limit at green and 12% moisture content are tested with the use of Statistica (One way ANOVA).The analysis of variance in Table 14 shows that modulus of elasticity of plantation teak at different ages is not significantly different at both green and air dry condition but modulus of rupture and fiber stress at proportional limit of plantation teak at different ages are significantly different at both green and air dry condition. In Indonesia, 40 years old plantation teak has higher MOE and MOR than 10 years old plantation teak (Darmawan et. al., 2015). Similarly, 65 years old plantation teak has higher MOE and MOR than 21 years old plantation teak in India (Bhat and Priya, 2004)

Table 11 Mean Modulus of Elasticity, Modulus of Rupture and Fiber Stress at Proportional Limit of plantation teak at different ages at green and 12% moisture content (Nmm^{-2})

Age (years)	Condition	Number of specimen	Modulus of Elasticity (MOE) (Nmm^{-2})		Modulus of Rupture (MOR) (Nmm^{-2})		Fiber Stress at Proportional Limit (FS @PL) (Nmm^{-2})	
			Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
20	Green	15	11390	1740.48	77	5.65	48	3.97
	12% MC	16	12178	1646.64	99	6.83	64	5.82
32	Green	15	11466	2292.43	84	7.40	55	6.39
	12% MC	16	13534	1852.26	104	10.57	69	9.54
37	Green	9	10924	1043.04	85	5.17	54	4.05
	12% MC	16	12784	2566.06	102	8.55	65	6.15
40	Green	14	12506	1310.49	71	8.82	45	6.39
	12% MC	39	13896	2896.24	90	7.81	59	6.03

Modulus of rupture and fiber stress at proportional limit of plantation teak at different ages are compared for significant difference by Tukey's test. In air dry condition, the oldest age 40 years old plantation teak has the lowest MOR and significantly differs from ages 20, 32 and 37, respectively. And the oldest age 40 years old plantation teak has the lowest FS@PL, significantly differs from ages 32 and 37, but does not significantly differ from age 20.

Another study investigated mechanical properties of plantation teak of different ages, but did not compare the properties for significant difference among different ages (Forest Department, 2009). In Indonesia, plantation teak of age 1-10 years has the lowest MOE and MOR, but plantation teak of age 11-20 and age 21-30 has no significant difference between the properties (Djati et. al. 2015).

4.2.2 Compression Parallel to Grain

Table 12 Mean maximum crushing strength and fiber stress at proportional limit of plantation teak at different ages at green and 12% moisture content (Nmm^{-2})

Age (years)	Moisture content (%)	No. of specimens	Maximum Crushing Strength (MCS) (Nmm^{-2})		Fiber Stress at Proportional Limit (FS @PL) (Nmm^{-2})	
			Mean	Standard deviation	Mean	Standard deviation
20	75.10	11	12	6.08	11	5.82
	12%	16	32	11.52	28	11.13
32	73.59	14	26	7.55	24	7.66
	12%	11	28	14.36	26	13.67
37	79.01	13	29	6.78	27	6.55
	12%	13	31	12.89	28	12.22
40	83.57	15	31	2.92	29	3.33
	12%	9	33	7.79	31	8.44

Mean value of maximum crushing strength and fiber stress at proportional limit of plantation teak at different ages at green and 12% moisture content are shown in Table 12. The number of specimens per age and standard deviation are also given. According to the results, 40 years old plantation teak possesses the highest MCS and FS@Pl at both green and 12% moisture content. Analysis of variance in table 14 shows that MCS and FS@PL of plantation teak at different ages are significantly different in green condition but not at 12% moisture content. Maximum crushing strength and Fiber stress at proportional limit of plantation teak at different ages are compared for significant difference by Tukey's test. In green condition, the oldest age 40 years old plantation teak has the highest MCS with the value of 31 Nmm^{-2}, significantly differs from ages 20 years old plantation teak with the value of 12 Nmm^{-2} but does not significantly differ from ages 32 and 37 with the values of 26 Nmm^{-2} and 29 Nmm^{-2}. In FS@PL value, the youngest age 20 years old plantation teak significantly differs from ages 32, 37 and 40.

Bhat and Priya (2004) found that in the same locality, older plantation teak of 65 years has a higher MCS than younger plantation teak of 21 years. However, when comparing MCS of plantation teak of different ages from different localities, it is quite difficult to conclude that the significant difference is due to different ages or different provinces. Therefore, it is reported that there is a great variability within each wood characteristic presented among plantation-grown teak and thus the worst quality as well as the best can sometimes be found out on the same site if various genetic materials have been planted (Thulasidas and Bailleres, 2017).

4.2.3 Compression Perpendicular to Grain

The mean fiber stress at proportional limit of plantation teak at different ages at green and 12% moisture content are given in Table 13. The number of specimen per age and standard deviation are also given. According to the results, at both green and 12% moisture content, 40 years old plantation teak possesses the highest FS@PL but 37 years old plantation teak possesses the lowest FS@PL. Analysis of variance in table 14 shows that FS@PL of plantation teak at different ages is significantly different at both green and air dry condition. Fiber stress at proportional limit of plantation teak at different ages is compared for significant difference by Tukey's test. At green condition, the oldest age 40 years old plantation teak has the highest FS@PL, significantly differs from age 37 but does not significantly differ from ages 20 and 32. At air dry condition, the youngest age 20 years old plantation teak has the highest FS@PL, significantly differs from age 37 and 40 but does not significantly differ from age 32.

Table 13 Fiber Stress at Proportional Limit of plantation teak at different ages (Nmm^{-2})

Age (years)	Moisture content (%)	No. of specimens	Fiber Stress at Proportional Limit (FS @PL) (Nmm^{-2})	
			Mean	Standard deviation
20	89.38	16	5.21	2.28
	12%	15	8.85	3.48
32	81.71	16	6.49	2.00
	12%	16	7.95	3.05
37	78.61	12	4.87	1.06
	12%	10	5.23	0.95
40	87.38	16	6.92	1.76
	12%	12	7.80	2.56

Table 14 Analysis of variance for teak of different ages (20, 32, 37 and 40) in mechanical properties

Property	condition	Interaction	Sum of squares	Df	Mean square	F value	p value
MOE (Nmm^{-2}) (static bending)	Green	Ages	1.64E+07	3	5.49E+06	1.83	0.153
	12% MC	Ages	3.91E+07	3	1.3E+07	2.12	0.104
MOR (Nmm^{-2}) (static bending)	Green	Ages	1626.7	3	542.2	10.89	0.00*
	12% MC	Ages	3477.5	3	1159.2	16.62	0.00*
FS@PL (Nmm^{-2}) (static bending)	Green	Ages	931.5	3	310.5	10.46	0.00*
	12% MC	Ages	1302.8	3	434.3	9.43	0.00*
MCS (Nmm^{-2}) (compression parallel) to grain)	Green	Ages	2535.52	3	845.17	23.24	0.00*
	12% MC	Ages	100.14	3	33.38	0.23	0.875 ns
FS@PL (Nmm^{-2}) (compression parallel to grain)	Green	Ages	2373.96	3	791.32	21.89	0.00*
	12% MC	Ages	135.45	3	45.15	0.33	0.801 ns
FS@PL (Nmm^{-2}) (compression perpendicular to grain)	Green	Ages	42.08	3	14.03	3.98	0.012*
	12% MC	Ages	78.40	3	26.14	3.30	0.028*

* Significant (α= 0.05), ns = not significant, MC= moisture content, MOE= modulus of elasticity, MOR= modulus of rupture, FS@PL= fiber stress at proportional limit, MCS = maximum crushing strength

Table 15 Comparison of mechanical properties of plantation teak in this study and other study

Properties	Plantation teak (This study)				Plantation teak (Forest Department, 2009)			
	20 yrs	32 yrs	37 yrs	40 yrs	14 yrs	20 yrs	25yrs	30yrs
Static Bending								
MOE (Nmm^{-2})	12178	13534	12784	13896	9491	10570	11480	10550
MOR (Nmm^{-2})	99	104	102	90	98	105	114	95
FS@PL(Nmm^{-2})	64	69	65	59	60	63	21	59
Compression parallel to Grain								
MCS (Nmm^{-2})	32	28	31	33	46	50	53	44
FS@PL(Nmm^{-2})	28	26	28	31	38	42	45	38
Compression perpendicular to Grain								
FS@PL(Nmm^{-2})	9	8	5	8	12	13	14	11

Comparison of mechanical properties of plantation teak in this study and other studies is shown in Table 15. The comparison shows that the value of MOE in this study is higher than that of the other study. But, the value of MCS in this study is lower than that of the other study. The lowest MOR is found in 40 years old plantation teak. It is found that some mechanical properties of 20 years old plantation teak in this study are lower than that of the other study.

4.2.4 Comparison of properties of plantation teak at different ages and natural Teak

Some physical properties of plantation teak at different ages are compared with those of natural teak (Win Kyi, 1993) shown in Table 16. It can be found that specific gravity values of plantation teak at different ages are lower than that of natural teak. But, density values of plantation teak at different ages are greater than that of natural teak. Except 40 years old plantation teak, plantation teak of ages 20, 32 and 37 years has lower radial shrinkage than natural teak. Tangential shrinkage of 20 and 37 years old plantation teak is lower than that of natural teak. But, 32 and 40 years old plantation teak has greater tangential shrinkage than natural teak. It can be found that tangential shrinkage values of plantation teak at different ages are less than 7%. Except 40 years old plantation teak, dimensional stability of 20, 32 and 37 years old plantation teak is greater than that of natural teak. However, the dimensional stability of plantation teak at different ages is less than 2 except 32 years old plantation teak. Win Kyi (2000) stated that those timbers which have dimensional stability less than or equal to 2.0 and dimensional changes i.e. radial shrinkage and tangential shrinkage less than or equal to 3.5% and 7.0% are found to be suitable for making high quality wood products. Thus, plantation teak at different ages could be suitable for making high quality wood products.

Table 16 Comparison of physical properties of plantation teak at different ages in this study and those of natural teak

No	Species	Moisture content (%)	Specific gravity	Density (kg/m3)	Radial Shrinkage	Tangential Shrinkage	Dimensional Stability
1	Plantation Teak (20 years)	86.81	0.569	1062	2.05	4.05	1.98
		12.0	0.626	701	1.23	2.43	
2	Plantation Teak (32 years)	87.78	0.587	1102	2.00	4.61	2.31
		12.0	0.648	726	1.20	2.76	
3	Plantation Teak (37 years)	89.34	0.588	1112	2.15	4.15	1.93
		12.0	0.648	726	1.29	2.49	
4	Plantation Teak (40 years)	95.72	0.555	1085	3.22	4.50	1.40
		12.0	0.609	682	1.93	2.70	
5	Natural Teak	51.8	0.598	913	2.30	4.20	1.83
		12.0	0.664	740	1.38	2.52	

*Data source: Physical and mechanical properties of some Myanma Timbers (Kyi, 1993).

Table 17 Comparison of mechanical properties of plantation teak at different ages in this study and natural teak

No	Species	Condition	Static bending (Nmm^{-2})		Compression Parallel to grain (Nmm^{-2})
			MOE	MOR	MCS
1	Plantation teak (20 years)	Green	11390	77	12
		Air dry	12178	99	32
2	Plantation teak (32 years)	Green	11466	84	26
		Air dry	13534	104	28
3	Plantation teak (37 years)	Green	10924	85	29
		Air dry	12784	102	31
4	Plantation teak (40 years)	Green	12506	71	31
		Air dry	13896	90	33
5	Natural teak*	Green	11535	79	40
		Air dry	13011	103	60

*Data source: Physical and mechanical properties of some Myanma Timbers (Kyi, 1993)

Mechanical properties of plantation teak at different ages investigated in this study are compared with those of natural teak as shown in Table 17. It can be seen that in static bending test, the strength properties of plantation teak at different ages are nearly the same as those of natural teak. In compression parallel to grain test, the strength properties of plantation teak at different ages are lower than those of natural teak.

According to classification of strength properties of Negi (1997), two factors such as modulus of elasticity and modulus of rupture are taken into account for end-use of timbers as construction material. According to this grouping, plantation teak at different ages (32, 37 and 40) years old plantation teak would be in Group I and 20 years old plantation teak in Group II. This grouping is based on strength properties at 12% moisture content. Thus, plantation teak at different ages is fit to use as construction material.

Conclusion

The results of physical and mechanical properties of plantation teak at different ages can be summarized as follows:

- Moisture content, wood density and basic specific gravity of plantation teak at different ages are significantly different. The oldest age 40 years old plantation teak has the lowest basic specific gravity. Based on basic specific gravity, it could be concluded that plantation teak at different ages 20, 32, 37 and 40 years investigated in this research are lower than natural teak.
- Shrinkage and swelling values for different ages of plantation teak are significantly different. The youngest age 20 years old plantation teak has the lowest shrinkage and swelling.
- Tangential shrinkage of 20 and 37 years old plantation teak is lower than that of natural teak. But, 32 and 40 years old plantation teak has greater tangential shrinkage than natural teak.
- Except 40 years old plantation teak, 20, 32 and 37 years old plantation teak has lower radial shrinkage than natural teak.
- Dimensional stability of plantation teak at different ages is greater than that of natural teak. That means plantation teak is not as stable as natural teak.
- Maximum water absorption of plantation teak at different ages is significantly different. The oldest age 40 years old plantation teak has the highest water absorption,
- In static bending test, 40 years old plantation teak possesses the highest MOE but the lowest MOR and FS@PLvalue. The strength properties of plantation teak at different ages are nearly the same those of natural teak.
- In compression parallel to grain test, MCS and FS@PL of plantation teak at different ages are significantly different at green condition but not significantly different at 12% moisture content. The oldest age 40 years old plantation teak has the highest MCS. The strength properties of plantation teak at different ages are lower than those of natural teak.
- In compression perpendicular to grain test, the oldest 40 years old plantation teak possess the highest FS@PL but 37 years old plantation teak possesses the lowest. FS@PL value of plantation teak at different ages is significantly different.
- According to the results of physical and mechanical properties, 20, 32, 37 and 40 years old plantation teak studied in this research are suitable to make high quality wood products and to use as construction material.

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