Leaflet No. 1/2022

The Republic of the Union of Myanmar
Ministry of Natural Resources and Environmental Conservation
Forest Department

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

Dr. Cho Cho Myint, Assistant Research Officer
Win Oo Naing, Assistant Research Officer
Forest Research Institute, Yezin

February, 2023

Contents

List of Tables

List of Figures

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

Dr. Cho Cho Myint, Assistant Research Officer
Win Oo Naing, Assistant Research Officer

Abstract

In this research, physical and mechanical properties of plantation teak at different ages in Bago Region were investigated. Different ages 25, 30 and 34 years old plantation teak were collected from Taung Zarmari Reserve and 20 years old plantation teak was collected from Letpan Aung Mya Reserve in Bago Township, Bago District, Bago 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, density, specific gravity, fiber saturation point and water absorption were significantly different among different ages. It was found that 20 years old plantation teak had the highest basic specific gravity and was even higher than that of natural teak whereas basic specific gravity of 25 and 30 years old plantation teak were lower than that of natural teak. Specific gravity of 34 years old plantation teak was nearly the same as that of natural teak. Shrinkage was significantly different in three directions (radial, tangential and longitudinal) but swelling was significantly different only in two directions (radial and tangential) for different ages of plantation teak. It was found that 34 years old plantation teak had the highest tangential shrinkage value whereas 20 years old plantation teak had the highest tangential swelling value. Except 25 years old plantation teak, dimensional stability of all tested plantation teak was greater than that of natural teak. 30 years old plantation teak absorbed water most while fiber saturation point of 20 years old plantation teak is the highest. According to the classification of wood based on basic specific gravity, 25and 30 years old plantation teak would be in “Moderately Heavy” whereas 20 and 34 years old plantation teak in “Heavy”. According to classification of strength properties, all tested plantation teak would be in Group (II). Therefore, the selected plantation teak studied in this research is fit to use as construction material.

Key words: density, plantation teak, specific gravity, shrinkage, strength properties

ပဲခူးတိုင်းဒေသကြီးအတွင်းရှိသက်တမ်းအမျိုးမျိုးရှိသောစိုက်ခင်းကျွန်း၏ ရူပနှင့် အင်အားဆိုင်ရာဂုဏ်သတ္တိကိုလေ့လာခြင်း

ဒေါက်တာချိုချိုမြင့်၊ လက်ထောက်သုတေသနအရာရှိ
ဝင်းဦးနိုင်၊ လက်ထောက်သုတေသနအရာရှိ

စာတမ်းအကျဉ်းချုပ်

ဤစာတမ်းတွင် ပဲခူးတိုင်းဒေသကြီးအတွင်းရှိ သက်တမ်းအမျိုးမျိုးရှိသော စိုက်ခင်းကျွန်းတို့၏ ရူပနှင့်အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကို စမ်းသပ်လေ့လာထားပါသည်။ စမ်းသပ်သည့် ၂၅နှစ်သား၊ ၃၀နှစ်သားနှင့် ၃၄နှစ်သား စိုက်ခင်းကျွန်းများကို ပဲခူးတိုင်းဒေသကြီး၊ ပဲခူးခရိုင်၊ ပဲခူးမြို့နယ်ရှိ တောင်ဇာမရီကြိုးဝိုင်းနှင့် ၂၀ နှစ်သားစိုက်ခင်းကျွန်းကို လက်ပံအောင်မြကြိုးဝိုင်းတို့မှ သက်တမ်းတစ်မျိုးစီအတွက် သစ်နမူနာတစ်ပင်စီ စုဆောင်းခဲ့ပါသည်။ ရူပနှင့်အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကိုASTM D-143-52 (2007) နည်းစနစ်၊ BS-373 (1957)နည်းစနစ်နှင့် ဂျာမန် နည်းပညာ(DIN- 52184) တို့ကို အသုံးပြု၍ စမ်းသပ်ခဲ့ပါသည်။ ရူပဆိုင်ရာဂုဏ်သတ္တိများတွင် အစိုဓာတ်ပါဝင်မှု၊ သိပ်သည်းမှု၊ ရေချိန်သိပ်သည်းဆ၊ သစ်သားမျှင်များရေပြည့်ဝအမှတ်နှင့် ရေစုပ်ယူမှုတို့မှာ သက်တမ်းတစ်ခုနှင့် တစ်ခုအကြားတွင် သိသိသာသာ ကွာခြားမှု ရှိကြောင်း တွေ့ရှိခဲ့ပါသည်။ ၂၀နှစ်သားစိုက်ခင်းကျွန်း၏ ရေချိန်သိပ်သည်းဆမှာ စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းအားလုံးတွင် အကြီးဆုံးဖြစ်ပြီး သဘာဝကျွန်းထက်ကြီးသော်လည်း ၂၅ နှစ်သားနှင့် ၃၀ နှစ်သား စိုက်ခင်းကျွန်းတို့၏ ရေချိန်သိပ်သည်းဆမှာ သဘာဝကျွန်းအောက်ငယ်ကြောင်း တွေ့ရှိခဲ့ပါသည်။ ၃၄ နှစ်သားစိုက်ခင်းကျွန်း၏ ရေချိန်သိပ်သည်းဆမှာ သဘာဝကျွန်းနှင့် တူညီကြောင်း တွေ့ရှိခဲ့ပါသည်။ ကျုံ့မှုတွင် နှစ်ကွင်းအပြိုင်၊ နှစ်ကွင်းထောင့်မှန်ကျနှင့် သစ်ကြောအလိုက် လားရာဘက် သုံးခုလုံး၌ သိသိသာသာ ကွာခြားမှုရှိသော်လည်း ကြွမှုတွင် နှစ်ကွင်းအပြိုင်နှင့် နှစ်ကွင်းထောင့်မှန်ကျ လားရာဘက်နှစ်ခု၌သာ သိသိသာသာ ကွာခြားမှုရှိကြောင်း တွေ့ရှိခဲ့ပါသည်။ ၃၄ နှစ်သားစိုက်ခင်းကျွန်း၏ နှစ်ကွင်းနှင့်အပြိုင်ကျုံ့မှုမှာ အမြင့်ဆုံးဖြစ်ပြီး ၂၀ နှစ်သား စိုက်ခင်းကျွန်း၏ နှစ်ကွင်းနှင့်အပြိုင်ကြွမှုမှာ အမြင့်ဆုံးဖြစ်ကြောင်း တွေ့ရှိခဲ့ပါသည်။ ၂၅ နှစ်သား စိုက်ခင်းကျွန်းမှလွဲ၍ စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းအားလုံး၏ ပုံသဏ္ဍာန်တည်မြဲမှုမှာ သဘာဝကျွန်းထက် ကြီးကြောင်း တွေ့ရှိခဲ့ပါသည်။ ရေစုပ်ယူမှုတွင် ၃၀ နှစ်သားကျွန်းမှာ ရေစုပ်ယူမှု အများဆုံးဖြစ်ပြီး ၂၀နှစ်သား စိုက်ခင်းကျွန်း၏ သစ်သားမျှင်များ ရေပြည့်ဝအမှတ်မှာ အမြင့်ဆုံးဖြစ်ပါသည်။ ရေချိန်သိပ်သည်းဆပေါ် အခြေခံ၍ အုပ်စုခွဲခြားရာတွင် ၂၅နှစ်သားနှင့် ၃၀နှစ်သား စိုက်ခင်းကျွန်းတို့မှာ အသင့်အတင့်လေးသော အုပ်စုတွင်ရှိပြီး၊ ၂၀နှစ်နှင့် ၃၄ နှစ်သား စိုက်ခင်းကျွန်းတို့မှာ လေးသောအုပ်စုတွင် ရှိပါသည်။ အင်အားဆိုင်ရာရလဒ်များအရ အုပ်စုခွဲခြားရာတွင် စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းအားလုံးတို့မှာအုပ်စု (၂) တွင်ရှိပါသည်။ ထို့ကြောင့် ဤသုတေသနတွင် စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းအားလုံးသည် ဆောက်လုပ်ရေးလုပ်ငန်းများတွင် အသုံးပြုရန် သင့်လျော်ပါသည်။

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

1. Introduction

Teak is known as the most popular species in tropical countries and is also popular all over the world. The botanical name of teak is (*Tectona grandis* Linn.f.) and the family is Lamiaceae. It grows naturally in India, Laos, Myanmar, Thailand and Cambodia. Natural teak has many desirable properties such as high natural durability, high dimensional stability, good strength, good color and texture such as good appearance. Teak is known for its incredible durability and water resistance. Teak also has a high oil content which gives it the highest decay-resistance among all natural wood products. All these properties make it suitable for ship construction, yachts, building construction, flooring, indoor and outdoor furniture, veneer, carvings, frames, and more. However, natural teak is becoming rare. So, teak plantations are now being established on a large scale. Therefore, plantation teak will be used more in the future. However, plantation teak is not well recognized as natural teak.

During 2008 and 2009,a plantation teak 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 were studied during the project. Different ages 14,20,25 and 30 year-old teak were collected from different localities. According to the research findings, 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.

So, during 2019-2021, physical and mechanical properties of plantation teak at different ages of Sagaing Region were studied. In that study, plantation teak of different ages (20, 32, 37 and 40 years) was collected from Wintho township, Kathar district, Sagaing region. According to the research findings, it was found that age has a significant influence on the properties of plantation teak in the same locality.

Therefore, in this research, physical and mechanical properties of plantation teak at different ages in Bago region were studied.

2. Objectives

The objectives of this research are:

(1) to study physical and mechanical properties of plantation teak at different ages of Bago 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 Bago Region. Plantation teak of 25,30 and 34 years was collected from Taung Zarmari Reserve and 20-years old plantation teak was obtained from Letpan Aung Mya Reserve, Bago Township, Bago District, Bago Region. One sample tree was collected for each age. Wood specimens were prepared according to ASTM D-143-52 (2007) standard, British standard BS-373 (1957) and German standard (DIN-52184). Moisture content, density, specific gravity and shrinkage were determined in accordance with standard ASTM D-143-52 (2007). Shrinkage in radial, tangential and longitudinal directions was 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 following BS-373 (1957) standard. Tested wood properties and size of specimen for different ages of plantation teak are shown in Table 1.

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

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

4. Results and Discussion

4.1 Physical Properties

4.1.1 Moisture content

Table 2 shows the moisture content of plantation teak at different ages. Mean moisture contents are 90.71 % for 20 years old plantation teak, 118.02 % for 25 years old plantation teak, 109.06 % for 30 years old plantation teak and 87.71 % for 34 years old plantation teak. These results are characterized by similar variation coefficients: 6.48%, 5.57%, 6.56% and 6.94%, respectively. The oldest plantation teak in this study has the lowest moisture content, which is quite similar to that of the youngest plantation teak as well. Thus, it is quite different to mention whether the trend is increasing or decreasing with age.

Average moisture content of 20 years old plantation teak in this study, 90.71% is lower than that of 20 years old plantation teak from Oktwin township,95.3% (Naing,2009) and higher than that of 20 years old plantation teak from Wintho township, 86.81% (Myint, et al, 2021). And then, the average moisture content of 25 years old plantation teak in this study, 118.02 % is higher than that of 25 years old plantation teak from Leway township, 61.5% (Naing, 2009). The moisture content 109.06% of 30 years old plantation teak in this study is higher than that of 30 years old plantation teak from Thandwe township, 78.2% (Naing, 2009). The difference in average moisture content in teak wood can be due to its age, location and perhaps also the season of the year when it is harvested (Hadinata and Kozakiewicz, 2020).

Table 2. Moisture content of plantation teak at different ages

Age (years)	No. specimens	Mean MC%	Minimum MC%	Maximum MC%	Standard deviation	CV%
20	10	90.71	81.70	98.49	5.88	6.48
25	9	118.02	109.25	130.41	6.57	5.57
30	19	109.06	95.92	125.22	7.15	6.56
34	20	87.71	77.73	98.11	6.09	6.94

MC % = moisture content percent, CV%= coefficient of variation percent

4.1.2 Density

Table 3. Wood densities of plantation teak at different ages

Age (years)	No. of specimens	Green density (kgm^{-3})			12% MC density (kgm^{-3})			Basic density (kgm^{-3})		
		Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%
20	10	1172	18	1.54	764	28	3.66	615	21	3.41
25	9	1034	44	4.26	575	32	5.57	475	25	5.26
30	19	1020	82	8.04	593	45	7.59	488	34	6.97
34	20	1118	32	2.86	738	26	3.52	596	19	3.19

MC = moisture content; SD = standard deviation, CV % = coefficient of variation (%)

Wood densities of plantation teak at different ages are given in Table 3. According to the results, the mean density of 20 years old plantation teak is the highest among the tested plantation teak. Bhat and Priya (2004) reported that 21years old plantation teak showed higher density than 65 years old plantation teak collected from different locations.

At 12% MC, 20years old plantation teak has a density of 764 kgm^{-3}while 25 years old plantation teak has 575 kgm^{-3}, 30 years old 593 kgm^{-3} and 34 years old 738 kgm^{-3}, respectively. A coefficient of variation of about 10% is considered suitable for describing the variability of oven dry density within common domestic species (Forest products Laboratory, 2010). In this study, the coefficient values for different ages of plantation teak are lower than 10%.This means that mean density of plantation teak at different ages are not much dispersed, and the results are assumed to be precise. The mean air-dry density of 20 years old plantation teak (764 kgm^{-3}) is higher than those of 20 years old plantation teak from Oktwin township (731 kgm^{-3}) and Wintho Township (701 kgm^{-3}). And then, the air-dry density of 20 years old plantation teakin this study (764 kgm^{-3}) is higher than that of20 years old plantation teak in Laos (708 kgm^{-3}) (Wanneng et. al., 2014).And then, the mean air dry density of 25 years old plantation teak in this study (575 kgm^{-3}) is lower than that of 25 years old plantation teak from Leway township (715 kgm^{-3})and 25 years old plantation teak from Laos (664 kgm^{-3}) (Wanneng et. al., 2014).The mean air dry density of 30 years old plantation teak in this study (593 kgm^{-3}) is lower than that of 30 years old plantation teak from Thandwe township (668 kgm^{-3}).Figure 1 shows the comparison of wood density of plantation teak of different ages at 12% moisture content in this study and other studies.

Wood densities of plantation teak at different ages are significantly different at α = 0.05 as shown in Table 4. Air dry density is compared for significant differences among different ages by Tukey's test. 20 years old plantation teak has the highest air-dry density of 764 kgm^{-3} and significantly differs from ages 25 and 30 but does not significantly differ from 34 years old plantation teak. Age is found to have a significant effect on the density of 10, 15 and 20 years old plantation teak from wet and dry localities in Ghana (Amoah and Inyong, 2019). 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.

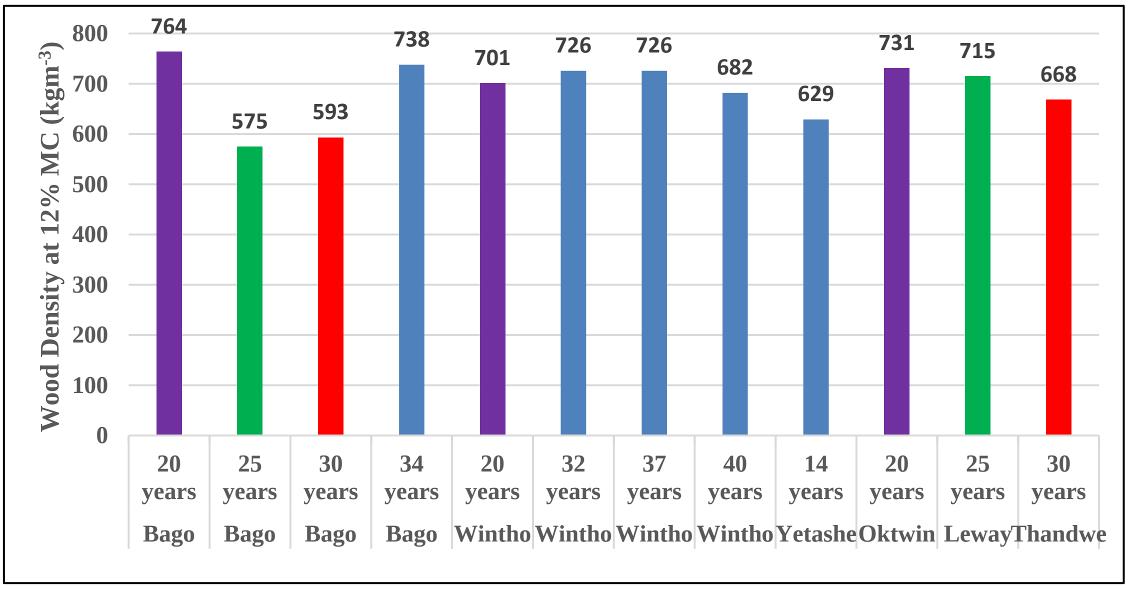

Figure 1. Comparison of wood densities of plantation teak of different ages at 12% MC in this study and other studies (Naing, W.O, 2009)and (Myint, C. C et al, 2021).

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). Densities of 13,21 and 35 years old teak from short rotation plantations and 35 years old home garden teak did not differ significantly (Bha, 1995; Bhat et al., 2001; Thulasidas and Bhat, 2009;Moya, 2001 as cited in Forest Department, 2009).

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).Moreover, within a given species, the 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).

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

Wood properties	**Interaction**	**Sum of squares**	**df**	**Mean square**	**F value**	**p value**
Moisture content %	Between Ages	8364.5	3	2788.20	65.96	0.00*
Green Density	Between Ages	201632	3	67211	22.98	0.00*
Density 12%	Between Ages	374494	3	124831	102.04	0.00*
Basic Density	Between Ages	208199	3	69400	101.13	0.00*
Basic specific gravity	Between Ages	0.21	3	0.069	101.13	0.00*
Specific gravity (12 % MC)	Between Ages	0.30	3	0.10	102.04	0.00*
Radial shrinkage (G to OD)	Between Ages	8.14	3	2.71	20.81	0.00*
Tangential shrinkage (Gto OD)	Between	10.62	3	3.54	24.02	0.00*

	Ages					
Longitudinal shrinkage (G to OD)	Between Ages	0.31	3	0.10	6.68	0.00*
Radial Shrinkage (G to 12% MC)	Between Ages	2.93	3	0.98	20.81	0.00*
Tangential Shrinkage (G to 12% MC)	Between Ages	3.83	3	1.27	24.02	0.00*
Longitudinal Shrinkage (G to 12%MC)	Between Ages	0.11	3	0.04	6.68	0.00*
Radial swelling (ODto G)	Between Ages	24.66	3	8.22	56.10	0.00*
Tangential swelling (OD to G)	Between Ages	125.07	3	41.69	137.79	0.00*
Longitudinal swelling (OD to G)	Between Ages	0.12	3	0.04	0.52	0.67ns
Water absorption	Between Ages	90440	3	30147	190.40	0.00*
Fiber saturation point	Between Ages	304.43	3	101.48	52.60	0.00*

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

4.1.3 Specific gravity

Table 5. Specific gravity of plantation teak at different ages

Age (years)	No. of specimens	Basic specific gravity			A t 12% MC specific gravity		
		Mean	Standard deviation	CV%	Mean	Standard deviation	CV%
20	10	0.615	0.02	3.25	0.682	0.03	4.40
25	9	0.475	0.03	6.32	0.514	0.03	5.84
30	19	0.488	0.03	6.15	0.529	0.04	7.56
34	20	0.596	0.02	3.36	0.659	0.02	3.03

Table 5 shows the specific gravity of plantation teak of different ages. According to the results, 20 years old plantation teak has the highest specific gravity value and 25 years old plantation has the lowest value. The coefficient of variation for specific gravity can be high up to 10% (Forest products laboratory, 2010).In this study, coefficient of variation for specific gravity is found to be less than 10% for different ages of plantation teak, meaning that specific gravity values for different ages of plantation teak are to be precise.

The comparison of basic specific gravity of plantation teak at different ages obtained in this study and other studies is shown in Figure 2. It is found that the basic specific gravity of 20 years old plantation teak in this study is higher than that of 20 years old plantation teak from Oktwin and Wintho townships. But, the basic specific gravity of 25 years old plantation teak in this study is lower than that of 25 years old plantation teak from Leway township. And the basic specific gravity of 30 years old plantation teak in this study is lower than that of 30 years old plantation teak from Thandwe township.

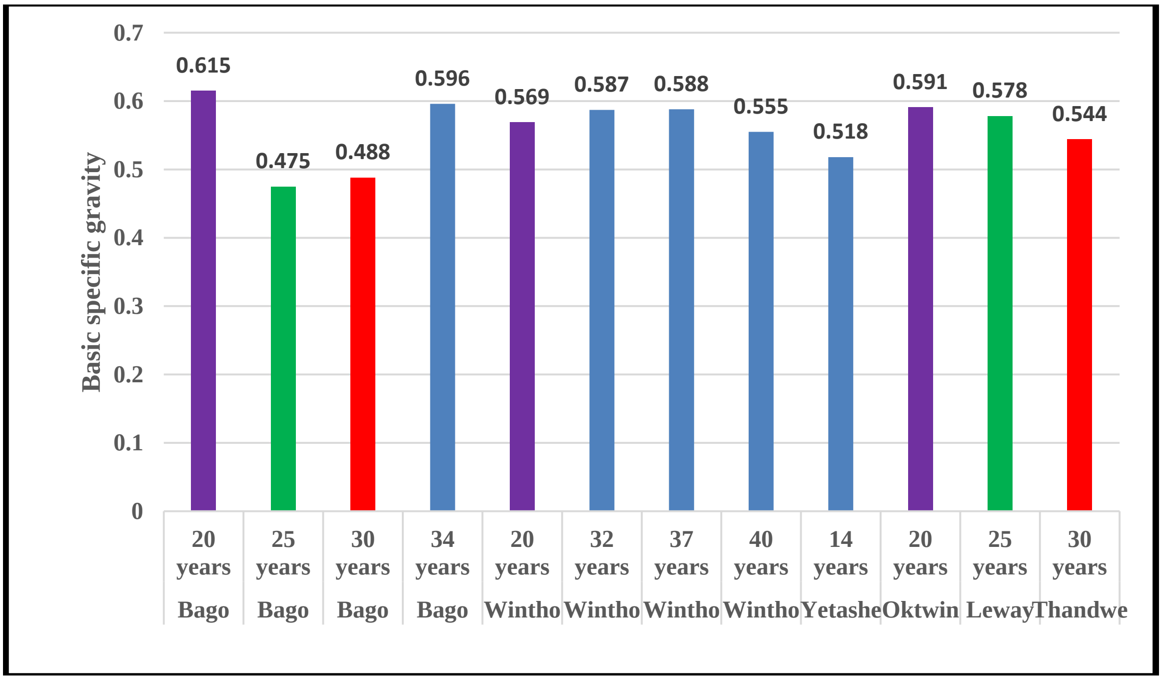

Figure 2 Comparison of basic specific gravity of plantation teak of different ages in this study and other studies (Naing, W.O, 2009) and (Myint, C. C et al, 2021)

Basic specific gravity of plantation teak at different ages is significantly different as shown in Table 4. The basic specific gravity of plantation teak at different ages is compared for significant difference by Tukey's test. 20 years old plantation teak has the highest basic specific gravity value of 0.615, significantly differs from ages 25 and 30 with the values of 0.475 and 0.488 but does not significantly differ from 34 years old plantation teak with the value of 0.596.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).

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, 25 and 30 years old plantation teak will be in "Moderately Heavy" Group whereas 20and 34 years old teak will be in "Heavy" Group.

4.1.4 Shrinkage

Radial, tangential and longitudinal shrinkage values for different ages of plantation teak are shown in Table6.(a-c). It is found that tangential shrinkage is the highest, greater than twice of radial shrinkage for different ages of plantation teak except 25 years old plantation teak. Longitudinal shrinkage is the lowest. 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) (Forest Products Laboratory, 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 (a) Radial shrinkage value for different ages of plantation teak

Age (years)	Number of Specimen	Radial shrinkage (%)					
		from Green to oven dry			from Green to 12% MC		
		Mean	SD	CV%	Mean	SD	CV%
20	15	2.26	0.31	13.72	1.36	0.19	13.97
25	9	2.60	0.28	10.77	1.56	0.17	10.90
30	18	2.08	0.16	7.69	1.25	0.09	7.20
34	19	2.15	0.31	14.42	1.29	0.19	14.73

Table 6 (b) Tangential shrinkage value for different ages of plantation teak

Age (years)	Number of Specimen	Tangential shrinkage (%)					
		from Green to oven dry			from Green to 12% MC		
		Mean	SD	CV%	Mean	SD	CV%
20	8	5.22	0.37	7.09	3.13	0.22	7.03
25	8	4.41	0.41	9.30	2.65	0.25	9.43
30	18	4.47	0.33	7.38	2.68	0.20	7.46
34	7	5.61	0.51	9.09	3.37	0.30	8.90

Table 6 (c) Longitudinal shrinkage value for different ages of plantation teak

Age (years)	Number of Specimen	Longitudinal shrinkage (%)					
		from Green to oven dry			from Green to 12% MC		
		Mean	SD	CV%	Mean	SD	CV%
20	18	0.40	0.19	47.50	0.24	0.11	45.83
25	9	0.29	0.12	41.38	0.17	0.07	41.18
30	19	0.26	0.08	34.78	0.16	0.05	31.25
34	20	0.23	0.08	34.78	0.14	0.05	35.71

The shrinkage from green to ovendry is from 2.08% to 2.60% in radial direction, from 4.41% to 5.61% in tangential direction and from 0.23% to 0.40% in longitudinal direction. Shrinkage variability is characterized by a coefficient of variation of approximately 15% (Forest products Laboratory, 2010).In radial shrinkage results, coefficients of variation for all ages are less than 15%, which might mean that the results are to be reliable. The coefficients of variation for tangential shrinkage at different ages of plantation teak are less than 15%. Therefore, the results are to be reliable. In longitudinal shrinkage results, the coefficients of variation are relatively high, in comparison with those of radial and tangential shrinkage, which means that the individual values of each age are much dispersed.

Table 4indicates that shrinkage values of plantation teak at different ages are significantly different at significant value (α= 0.05).Tangential shrinkage values from green to oven dry are also compared for significant difference by Tukey's test. 34 years old plantation teak has the highest shrinkage value of 5.61, significantly differs from ages 25 and 30 with the values of 4.41 and 4.47 but does not significantly differ from the 20 years old plantation teak with the value of 5.22.

Comparison of radial and tangential shrinkage of plantation teak in this study and other study is shown in Table 7. The comparison shows that tangential shrinkage of 20 years old plantation teak in this study (5.22 %) is the same as that of 20 years old plantation teak from Oktwin township (5.20%) and higher than that of 20 years old plantation teak from Wintho township (4.05%). And then, shrinkage values of 30 years old plantation teak in this study are lower than those of 30 years old plantation teak from Thandwe township.

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

Age (years)	Locality	Radial shrinkage from green to oven dry (%)	Tangential shrinkage from green to oven dry (%)	Remarks
20	Bago	2.26	5.22	This study
25	Bago	2.60	4.41	
30	Bago	2.08	4.47	
34	Bago	2.15	5.61	
20	Wintho	2.05	4.05	(Myint, C. C et al, 2021).
32	Wintho	2.00	4.61	
37	Wintho	2.15	4.15	
40	Wintho	3.22	4.50	
14	Yetashe	2.30	5.20	(Naing, W.O, 2009)
20	Oktwin	2.70	5.20	
25	Leway	2.70	5.00	
30	Thandwe	2.70	5.60	

4.1.5 Swelling

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	CV%	Mean	SD	CV%	Mean	SD	CV%
20	30	2.96	0.46	15.54	7.33	0.47	6.41	0.56	0.29	51.79
25	17	2.49	0.39	15.66	5.64	0.47	8.33	0.54	0.27	50.00
30	30	1.69	0.33	19.53	4.63	0.65	14.04	0.47	0.27	57.45
34	30	2.42	0.34	14.05	4.86	0.34	7.00	0.51	0.28	54.90

Swelling in radial, tangential, and longitudinal directions is shown in Table 8. According to results, tangential swelling is the largest, radial welling the second largest and longitudinal swelling the lowest. Swelling values in tangential direction are higher than twice of the swelling values in radial direction except 34 years old plantation teak. ANOVA (Table 4) indicates that radial and tangential swelling values for plantation teak at different ages are significantly different at significant value ($\alpha = 0.05$). 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 highest swelling value of 7.33, significantly differs from ages 25, 30 and 34 the values of 5.64, 4.63 and 4.86.

According to the results, 20 years old plantation teak is found to swell the highest and 30 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 (Grekin and Verkasalo, 2010).20 years old teak with the highest specific gravity swells the highest. The 25 years old with the lowest specific gravity does not swells the lowest and is found to swell higher than 30 and 34 years old. 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 (Forest Products Laboratory 2010).

The longitudinal swelling value of plantation teak is 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 swelling values of 20 years old plantation teak from Bago is higher than those of 20 years old plantation teak from Oktwin and Wintho townships. The swelling values of 30 years old plantation teak in this study is lower than that of 30 years old plantation teak from Thandwe.

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

Age (years)	Locality	Radial Swelling from oven dry to green (%)	Tangential Swelling from oven dry to green (%)	Remarks
20	Bago	2.96	7.33	This study
25	Bago	2.49	5.64	
30	Bago	1.69	4.63	
34	Bago	2.42	4.86	
20	Wintho	1.94	4.51	(Myint, C. C et al, 2021).
32	Wintho	2.16	6.07	
37	Wintho	1.99	4.88	
40	Wintho	2.27	5.24	
14	Yetashe	1.96	4.84	(Myint, C. C et al, 2014).
20	Oktwin	2.15	4.99	
25	Leway	2.69	5.08	
30	Thandwe	1.97	4.77	

4.1.6 Water absorption

Table 10 shows the water absorption of plantation teak at different ages. According to results, 30 years old plantation teak absorbs more water than 20,25and 34 years old plantation teak. This could be attributed to their densities. 30 years old teak has the lowest green density and thus absorbs water most. 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})				
		Mean	Minimum	Maximum	SD	CV%
20	30	588	557	605	11	1.87
25	17	582	564	589	7	1.20
30	30	641	611	670	16	2.50
34	30	567	532	583	12	2.12

As shown in Table 4, 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 34 years old plantation teak has the lowest water absorption value of 567kgm^{-3}, significantly differs from ages 20, 25 and 30 with the values of 588 kgm^{-3}, 582 kgm^{-3} and 641kgm^{-3}.

Table 11. Comparison of water absorption of plantation teak in this study and other studies

Age (years)	Locality	Water absorption (kgm^{-3})	Remarks
20	Bago	588	This study
25	Bago	582	
30	Bago	641	
34	Bago	567	
20	Wintho	612	(Myint, C. C et al, 2021).
32	Wintho	571	
37	Wintho	582	
40	Wintho	613	
14	Yetashe	618	(Myint, C. C et al, 2014).
20	Oktwin	572	
25	Leway	579	
30	Thandwe	617	

Comparison of water absorption of plantation teak in this study and other studies is shown in Table 11. Water absorption of 20 years old plantation teak from Bago township is higher than that of 20 years old plantation teak from Oktwin township but lower than that of 20 years old plantation teak from Wintho township. Water absorption of 30 years old Bago plantation teak is higher than that of Thandwe plantation teak.

4.1.7 Fiber saturation point

Table 12. Fiber saturation point of plantation teak at different ages.

Age (years)	No. of specimens	Fiber saturation point(%)				
		Mean	Minimum	Maximum	SD	CV%
20	30	17.35	15.15	20.52	0.24	1.38
25	17	13.89	12.20	16.41	1.02	7.34
30	30	13.01	10.04	17.12	1.88	14.45
34	30	14.97	12.68	17.03	1.00	6.68

Fiber saturation point of plantation teak at different ages is shown in Table 12. According to results, the fiber saturation point of 20 years old plantation teak is the highest and 30 years old the lowest. Generally, fiber saturation point is assumed to be at about 28% but varies with timber species depending on the amount of deposits on cell lumina (Forest products Laboratory, 2010).

ANOVA (Table 4) indicates that the fiber saturation point of plantation teak at different ages is significantly different at significant value (α = 0.05). Thus, the fiber saturation point of plantation teak at different ages is compared for significant difference by Tukey's test.

Table 13 Comparison of fiber saturation point of plantation teak in this study and other studies.

Age (years)	Locality	Fiber saturation point (FSP) (%)	Remarks
20	Bago	17.35	This study
25	Bago	13.89	
30	Bago	13.01	
34	Bago	14.97	
20	Wintho	12.21	Forest Research Institute, Yezin (2021)
32	Wintho	13.63	
37	Wintho	11.99	
40	Wintho	14.21	
14	Yetashe	13.39	(Myint, C. C et al, 2014).
20	Oktwin	12.89	
25	Leway	13.83	
30	Thandwe	13.09	

The youngest age 20 years old plantation teak has the highest fiber saturation point of 17.35%, significantly differs from ages 25,30 and 34 with the values of 13.89%**,** 13.01%and 14.97%. Comparison of fiber saturation point of plantation teak in this study and other study is shown in Table 13. The fiber saturation point of 20 years old Bago plantation teak is higher than those of 20 years old Oktwin and Wintho plantation teak. The fiber saturation point of 30 years old Bago plantation teak is the same as that of 30 years old Thandwe plantation teak.

4.2 Mechanical Properties

4.2.1 Static Bending

Table 14. 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)	Moisture content (%)	Number of specimens	Modulus of Elasticity(Nmm^{-2})			Modulus of Rupture (Nmm^{-2})			Fiber Stress at Proportional Limit (Nmm^{-2})		
			Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%
20	68.30	15	10686	2247	21.03	80	8	10.00	51	6	11.76
	12.00	7	11314	1517	13.41	98	10	12.20	61	7	11.48
25	103.91	6	10722	1283	11.97	66	13	19.70	41	7	17.07
	12.00	8	10946	1290	11.79	81	10	12.35	49	5	10.20
30	105.81	16	9646	1690	17.52	71	4	5.63	45	3	6.67
	12.00	16	10081	1797	17.83	84	7	8.33	53	5	9.43
34	82.29	13	10758	1580	14.69	76	6	7.89	50	5	10.00
	12.00	17	11804	3254	27.57	91	9	9.89	56	6	10.71

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 14. The number of specimens per age, standard deviation and coefficient of variation are also given.

The value of coefficient of variation for modulus of elasticity can be high up to 22% (Forest products laboratory, 2010). For all ages, the coefficient of variations of modulus of elasticity at green condition are less than 22% which means that the results are to be reliable. Butin age 34, the coefficient of variation of modulus of elasticity at 12% moisture content is larger than 22% which might mean that the result is not to be reliable. According to the test results, it can be found that 34 years old plantation teak possesses the highest modulus of elasticity in both green and air-dry conditions.

The value of coefficient of variation for modulus of rupture can be high up to 16% (Forest products laboratory, 2010). In age 25, the coefficient of variation of modulus of rupture at green condition is larger than 16%. But, in all ages, the coefficient of variations of modulus of rupture at 12% moisture content are less than 16%, which might mean that the results are to be reliable. According to the test results, it can be found that 20 years old plantation teak possesses the highest modulus of rupture in both green and air-dry conditions.

The value of coefficient of variation for fiber stress at proportional limit can be high up to 22% (Forest products laboratory, 2010). At all ages, the coefficient of variations of fiber stress at proportional limit at green and 12% moisture content are less than 22%, which might mean that the results are to be assumed to be precise and reliable.

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 using Statistica (One way ANOVA).The analysis of variance in Table 17 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)

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 youngest age 20years old plantation teak has the highest modulus of rupture and fiber stress at proportional limit, significantly differs from ages 25 and 30but not significantly differs from age 34.

4.2.2 Compression Parallel to Grain

Table 15. 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 (Nmm^{-2})			Fiber Stress at Proportional Limit (Nmm^{-2})		
			Mean	SD	CV%	Mean	SD	CV%
20	80.63	19	30	6	20.00	29	7	24.14
	12.00	15	51	5	9.80	45	5	11.11
25	99.48	6	31	3	9.68	29	3	10.34
	12.00	8	36	2	5.56	33	3	9.09
30	85.59	19	26	4	15.38	24	4	16.67
	12.00	16	40	4	10.00	38	5	13.16
34	82.65	10	24	9	37.5	23	9	39.13
	12.00	17	40	3	7.5	39	4	10.26

Mean values 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 15.The number of specimens per age and standard deviation and coefficient of variations are also given. The value of coefficient of variation for maximum crushing strength can be high up to 18% (Forest products laboratory, 2010).At green condition, coefficient of variation of maximum crushing strength for the youngest age 20 and the oldest age 34 are larger than 18%which mean that the results are not to be acceptable. Other ages 25 and 30, the coefficient of variation at green and at 12% moisture content are lower than 18%. The results are to be assumed to be precise and reliable.

The value of coefficient of variation for fiber stress at proportional limit can be high up to 24% (Forest products laboratory, 2010).At green condition, the coefficient of variation for the highest age34 and the lowest age 20is larger than 24%.But,at both green and 12 % moisture content, coefficient of variations for age 25 and 30 are less than 24%. Thus, the results are to be precise and reliable.

Analysis of variance in Table 17 shows that MCS and FS@PL of plantation teak at different ages are significantly different both green and at 12% moisture content condition.

Maximum crushing strength and fiber stress at proportional limit of plantation teak at different ages are compared for significant difference by Tukey’s test. At green condition, 20 years old plantation teak significantly differs in MCS from 34 years old plantation teak. At 12% moisture content, 20 years old plantation teak significantly differs in MCS from age 25, 30 and 34.

In FS@PL,25 years old plantation teak significantly differs from 30 years old plantation teak at green condition whereas the youngest age 20 years old plantation teak significantly differs from ages 25,30 and 34at 12% moisture content.

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

Table 16. Fiber Stress at Proportional Limit of plantation teak at different ages at green and 12% moisture content (Nmm^{-2})

Age(years)	Moisture content (%)	Number of specimens	Fiber Stress at Proportional Limit (FS @PL) (Nmm^{-2})		
			Mean	Standard deviation	CV%
20	76.72	15	4	1	25.00
	12.00	16	9	2	22.22
25	114.96	7	3	1	33.33
	12.00	8	6	3	50.00
30	117.42	14	3	1	33.33
	12.00	17	5	1	20.00

34	80.10	14	7	4	57.14
	12.00	17	10	3	30.00

The mean fiber stress at proportional limit of plantation teak at different ages at green and 12% moisture content are given in Table 16.The number of specimens per age, standard deviation and coefficient of variation are also given. According to the results, at both green and12% moisture content, 34 years old plantation teak possesses the highest FS@PL and 30 years old plantation teak possesses the lowest FS@PL.Analysis of variance in Table 17 shows that FS@PL of plantation teak at different ages is significantly different at both green and 12% moisture content. 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 34 years old plantation teak significantly differs from ages 20, 25 and 30. At air dry condition, the oldest age 34 years old plantation teak significantly differs from ages 25 and 30 but does not significantly differ from the youngest age 20.The coefficient of variation for fiber stress at proportional limit can be high up to 28% (Forest products laboratory,2010).At green and 12% moisture content, the coefficient value of ages 34 and 25is greater than 28% but the coefficient value of the youngest age 20 years old plantation teak is less than 28% which mean that the result is reliable.

Table 17. Analysis of variance for plantation teak of different ages (20, 25, 30 and 34) in mechanical properties

Property	**condition**	**Interaction**	**Sum of squares**	**df**	**Mean square**	**F value**	**p value**
MOE (Nmm^{-2}) (Static bending)	Green	Ages	1.26E+07	3	4.20E+06	1.27	0.295 ns
	12% MC	Ages	2.52E+07	3	8.39E+06	1.52	0.223 ns
MOR (Nmm^{-2}) (Static bending)	Green	Ages	1157.00	3	385.70	6.96	0.00*
	12% MC	Ages	1474.40	3	491.50	6.21	0.00*
FS@PL (Nmm^{-2}) (Static bending)	Green	Ages	642.29	3	214.10	8.12	0.00*
	12% MC	Ages	654.50	3	218.20	7.29	0.00*
MCS (Nmm^{-2}) (Compression parallel)	Green	Ages	454.59	3	151.53	4.45	0.00*
	12% MC	Ages	1595.76	3	531.92	36.49	0.00*
FS@PL (Nmm^{-2}) (Compression parallel)	Green	Ages	439.43	3	146.48	3.88	0.00*
	12% MC	Ages	742.75	3	247.58	11.47	0.00*
FS@PL (Nmm^{-2}) (Compression perpendicular)	Green	Ages	139.24	3	46.41	10.99	0.00*
	12% MC	Ages	239.03	3	79.68	16.90	0.00*

* 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 18. Comparison of mechanical properties of plantation teak in this study and other studies

Locality	Age (years)	Properties					
		Static bending			Compression Parallel to grain		Compression Perpendicular to grain
		MOE (Nmm^{-2})	MOR (Nmm^{-2})	FS@PL (Nmm^{-2})	MCS (Nmm^{-2})	FS@PL (Nmm^{-2})	FS@PL (Nmm^{-2})
Bago	20	11314	98	61	51	45	9
Bago	25	10946	81	49	36	33	6

Bago	30	10081	84	53	40	38	5
Bago	34	11804	91	56	40	39	10
Wintho	20	12178	99	64	32	28	9
Wintho	32	13534	104	69	28	26	8
Wintho	37	12784	102	65	31	28	5
Wintho	40	13896	90	59	33	31	8
Yetashe	14	9491	98	60	46	38	12
Oktwin	20	10570	105	63	50	42	13
Leway	25	11480	114	21	53	45	14
Thandwe	30	10550	95	59	44	38	11

The comparison of mechanical properties of plantation teak in this study and other studies is shown in Table 18. It shows that MOE value of Bago plantation teak is lower than that of Wintho plantation teak and nearly the same as that of Oktwin, Leway and Thandwe plantation teak. But, MCS value of Bago plantation teak is higher than that of Wintho plantation teak and nearly the same as that of Yetashe, Oktwin, Leway and Thandwe plantation teak. MOR value of Bago plantation teak is lower than that of Wintho, Oktwin and Leway plantation teak. In MCS, Wintho plantation teak has the lowest whereas Oktwin and Leway has the highest.

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 19. It can be found that specific gravity values of 25 and 30 years old plantation teak are lower than that of natural teak. But, specific gravity value of 20 years old plantation teak is higher than that of natural teak. Specific gravity value of 34 years old plantation teak is nearly the same as that of natural teak.

Green density values of plantation teak at different ages are greater than that of natural teak. Ages30and 34 years old plantation teak have lower radial shrinkage than natural teak. But, 25 years old plantation teak has higher radial shrinkage than natural teak. Radial shrinkage of 20 years old plantation teak is the same as that of natural teak. Tangential shrinkage values of plantation teak at different ages are higher than that of natural teak. It can be found that tangential shrinkage values of plantation teak at different ages are less than 7%. Except 25 years old plantation teak, dimensional stability of 20, 30 and 34 years old plantation teak is greater than that of natural teak. Dimensional stability of plantation teak at different ages is greater than 2 except 25 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, 25 years old plantation teak could be suitable for making high quality wood products.

Table 19. 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 from green to oven dry	Tangential shrinkage from green to oven dry	Dimensional stability
1	Plantation Teak (20 years)	90.71	0.615	1172	2.26	5.22	2.31
		12.0	0.682	764	1.43	3.13	
2	Plantation Teak	118.02	0.475	1034	2.60	4.41	1.70

	(25 years)	12.0	0.514	575	1.78	2.65	
3	Plantation Teak (30 years)	109.06	0.488	1020	2.08	4.47	2.15
		12.0	0.529	593	1.25	2.68	
4	Plantation Teak (34 years)	87.71	0.596	1118	2.15	5.61	2.61
		12.0	0.659	738	1.29	3.37	
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 20. 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	10686	80	30
		Air dry	11314	98	51
2	Plantation teak (25 years)	Green	10722	66	31
		Air dry	10946	81	36
3	Plantation teak (30 years)	Green	9646	71	26
		Air dry	10081	84	40
4	Plantation teak (34 years)	Green	10758	76	24
		Air dry	11804	91	40
5	Natural teak*	Green	11535	79	40
		Air dry	13011	103	60

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

Comparison of mechanical properties of plantation teak at different ages in this study and natural teak is shown in Table 20.Itcanbe seen that in static bending test and compression parallel to grain test, the strength properties of plantation teak at different ages at air-dry condition 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, all tested plantation teak would be 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.

5. Conclusion

Except longitudinal swelling and modulus of elasticity from static bending test, physical and mechanical properties of plantation teak at different ages are significantly different. The youngest age, 20 years old plantation teak has the highest basic specific gravity and its value is higher than that of natural teak. Specific gravity of 34 years old plantation teak is nearly the same as that of natural teak. Tangential shrinkage values of plantation teak at different ages are higher than that of natural teak. The youngest age, 20 years old plantation teak has the highest swelling value. Dimensional stability of 25 years old plantation teak is lower than that of natural teak. The oldest age 34 years old plantation teak has the lowest water absorption. Fiber saturation point of 20 years old plantation teak is the highest. The oldest age, 34 years old plantation teak possesses the highest Modulus of elasticity. But, the lowest age 20 years old plantation teak possesses the highest modulus of rupture, fiber stress at proportional limit and maximum crushing strength. The strength properties of plantation teak at different ages are lower than those of natural teak. According to the results of physical and mechanical properties, 20, 25, 30 and 34 years old plantation teak studied in this research are suitable to make high quality wood products and to use as construction material.

6. Acknowledgements

I would like to thank to Director General, Forest Department and Director, Forest Research Institute, Yezin for giving me permission to do this research. I would like to express my deepest appreciation and gratitude to who helped me in sample preparation. I am very much grateful to all of the people who support me with information for this paper. My special thanks are expressed to people who help me wood sample collection from Taung Zarmari Reserveand Letpan Aung Mya Reserve, Bago Township, Bago District, Bago Region.

7. References

Amoah, M., &Inyong, S. (2019). Comparison of some physical, mechanical and anatomical properties of smallholder plantation teak (Tectona grandis Linn. f.) from dry and wet localities of Ghana. *Journal of the Indian Academy of Wood Science*, *16*(2), 125-138.

Bhat, K. M., & Priya, P. B. (2004). Influence of provenance variation on wood properties of teak from the Western Ghat region in India. *Iawa Journal*, *25*(3), 273-282.

Darmawan, W., Nandika, D., Sari, R. K., Sitompul, A., Rahayu, I., & Gardner, D. (2015). Juvenile and mature wood characteristics of short and long rotation teak in Java. *IAWA journal*, *36*(4), 428-442.

Dinwoodie, J.M., (2000): Timber: Its nature and behavior. Building Research Establishment, and Honorary Professor, University of Wales.

Forest department (2009). Wood quality of teak (Tectona grandis Linn.f) from short rotation plantations and home- garden forestry practices in India. Proceedings of the Regional Workshop on Development of Plantation Teak Utilization in the ASEAN Region; 2009 July 7-10; Yangon, Myanmar, Forest department and CFC/ITTO, pp. 49-53.

Forest Product Laboratory (1957) Shrinking and swelling of wood in use, Information Reviewed and Reaffirmed, USDA, Forest Service, No. 736

Forest Products Laboratory (2010). Wood Handbook-Wood as an Engineering Material, United State Department of Agriculture, Forest Service, Forest Products Laboratory. General Technical Report, FPL-GTR-190

Grekin, M. &Verkasalo, E. (2010) Variations in basic density, shrinkage and shrinkage anisotropy of Scots pine wood from mature mineral soil stands in Finland Sweden, Baltic Forestry, 16(1):113-`25

Hadinata, M.E &Kozakiewicz, P. (2020). An investigation of selected properties of teak wood from 9-year-old plantation forest in Indonesia, Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology No. 110, 2020: 61-72

Kyi, W. (1993). Physical and mechanical properties of some Myanmar timber species, Timber Digest, Information Series on the Utilization of Myanmar Timbers, Vol. 1, No. 3, FRI, Yezin, Myanmar.

Kyi, W. (2000) Dimensional stability of fifty-four lesser-used timber species of Myanmar. International workshop on introducing Myanmar's lesser used timber species to the world market. ITTO Project PD 31/96 REV.2(M.F.I)Yangon, Myanmar

Myint, C. C et al, (2014)Investigation on Anisotropy, Fiber Saturation Point, Swelling and Periodical Water Uptake of Plantation Teak at Different Ages.Research Conference, Forest Research Institute, Yezin

Myint, C. C et al, (2021) Study on Physical and Mechanical Properties of Plantation Teak at Different Ages in Sagaing Region.Research Conference, Forest Research Institute, Yezin.

Naing, W.O, (2009) Investigation on Physical Properties of Plantation Teak at Different Ages. Proceedings of the Regional Workshop on Development of Plantation Teak Utilization in the ASEAN Region; 7-10 July, 2009, Central Forestry

Development Training Centre (CFDTC), Yangon, Myanmar. Forest department and CFC/ITTO 73 FT PPD 68/03 Rev.2 (I).

Negi, S.S.,I.F.S, (1997): Wood Science and Technology. Applied Forestry Series No.2. Dehra Dun (India).

Rizanti, D. E., Darmawan, W., George, B., Merlin, A., Dumarcay, S., Chapuis, H., ... &Gerardin, P. (2018). Comparison of teak wood properties according to forest management: short versus long rotation. *Annals of forest science*, *75*(2), 1-12.

Sint, K. M. Adamopoulos, S., Koch, G., Hapla, F. &Militz, H. (2013) Wood anatomy and topochemistry of *Bambox ceiba* L and *Bombax insigne* Wall, BioResources 8(1): 530-544

Sint, K. M. Adamopoulos, S., Koch, G., Hapla, F.&Militz, H. (2012) Impregnation of *Bombax ceiba* and *Bombax insigne* wood with N-methylol melamine compound, Wood Science and Technology, DOI 10.1007/s00226-012-0482-y

Sint, K. M. and Hapla, F. (2009) Utilization potential of Myanmar lesser-used timber species, forstarchiv 80, 129–131

Sint, K.M and Myint, C.C (2009) Investigation on Mechanical Properties of Plantation Teak at Different Ages. In: Proceeding of Regional Workshop of CFC/ITTO 73 FT PPD 68/03 Rev.2 (I). CFDTC, Hmawbi, Yangon, Myanmar.

Sint, K.M. (2010) Promotion of utilization potential of Bombax ceiba Linn and Bombax insigne Wall through enhance of wood quality and technological properties by modification with melamine resin, Sierke Verlag, Göttingen

Sint, K.M., Militz, H. Hapla, F. and Adamopolous, S. (2011) Treatability and penetration indices of four lesser-used Myanmar hardwoods. WOOD RESEARCH 56 (1): 2011 13-22

Thulasidas, P. K., &Bailleres, H. (2017) Wood quality for advanced used of teak from natural and planted forests. Editor. Kollert, W., and Kleine, M. (2017). The global teak supply: Analysis, evaluation and future potential of teak. IUFRO World Series Volume 36

Tsoumis, G., (1991): Science and Technology of Wood: Structure, Properties, Utilization, Aristotelian University, Thessaloniki, Greece.

Wanneng PX et al.(2014). Physical Properties of *Tectona grandis* grown in LAOS, Journal of Tropical Forest Science 26(3): 389-396