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Investigation on Drying Characteristics and Proposed Kiln Schedules of Plantation Teak at Different Ages in Bago Region

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Investigation on Drying Characteristics and Proposed Kiln Schedules of Plantation Teak at Different Ages in Bago Region

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Abstract

In this research, drying characteristics and proposed kiln schedules of plantation teak at different ages 34, 30, 25, and 20 years old in Bago Region were investigated. Each sample tree was used for each age and wood specimens were prepared parallel to growth rings from the heartwood portion which is free from defects, knots and decay. A quick-drying test by Terazawa (1965) was used in this experiment. The results showed that no initial checks (grade 1) were observed but mild to moderate deformations (grade 3) were found in four ages of plantation teak. There was no internal check (grade 1) in 20 and 25 years old plantation teak whilst moderately small and large internal checks (grade 3) were observed in 34 and 30 years old plantation teak. Deformation and internal checks are related to initial temperature and relative humidity. Therefore moderate schedule should be used to prevent these characteristics. Based on the drying characteristics, two proposed kiln schedules were developed in this study. The proposed kiln schedule ($D_{44}W_{44}$) for 34 and 20 years old plantation teak was similar to those of 14 years old plantation teak from Yetashe Township, 25 years old plantation teak from Leway Township, and 37 and 32 years old plantation teak from Wuntho Township which have been tested previously. But, this proposed kiln schedule for 20 years old plantation teak was found to be slightly milder than the schedule from Oktwin Township and Wuntho Township. Similarly, the proposed kiln schedule ($D_{45}W_{45}$) for 30 years old and 25 years old plantation teak in this study was milder than the schedule for 30 years old plantation teak from Thandwe Township and slightly higher than the proposed kiln schedule for the 25 years old plantation teak from Leway Township. According to the findings, plantation teak at different ages had slight differences in drying characteristics, and proposed kiln schedules were also a little different. However, being plantation teak of the same species, 25 mm thick lumber obtained from these ages can be mixed and dried together. If the lumber dries together, the proposed kiln schedule ($D_{44}W_{44}$) with the moderately higher initial-final temperature range of 60-85˚C, initial-final wet bulb depression range of 5-30˚C and initial-final relative humidity range of 77-23 % should be used to prevent deformation and internal checks. At the end of the drying process, equalization and conditioning treatment should be carried out to obtain more uniform moisture content and to relieve drying stress within and among the lumbers.

Key Words: deformation, honeycombing, initial check, initial-final temperature, initial-final relative humidity, plantation teak, quick drying test

ပဲခူးတိုင်းဒေသကြီးအတွင်းရှိ သက်တမ်းအမျိုးမျိုးရှိသော စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှု ဆိုင်ရာသွင်ပြင်လက္ခဏာများနှင့် အဆိုပြုပေါင်းဖိုဇယားများအား လေ့လာဖော်ထုတ်ခြင်း

စုစုလှိုင်၊ လက်ထောက်သုတေသနအရာရှိ

သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်းချုပ်

ဤသုတေသနတွင် ပဲခူးတိုင်းဒေသကြီးမှ ၃၄ နှစ်၊ ၃၂ နှစ်၊ ၂၅နှစ် နှင့် ၂၀ နှစ် သက်တမ်းရှိသော စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများနှင့် အဆိုပြုပေါင်းဖိုဇယားများအား လေ့လာစမ်းသပ်ထားပါသည်။ သက်တမ်းတစ်မျိုးစီအတွက် သစ်နမူနာပင် တစ်ပင်စီအား အသုံးပြုခဲ့ပြီး အမျက်၊ အပြစ်အနာအဆာများ လွတ်ကင်းသည့် အနှစ်သားမှ သစ်နမူနာများအား နှစ်ကွင်းနှင့်အပြိုင် ခွဲစိတ်ပြင်ဆင်ခဲ့ပါသည်။ စမ်းသပ် ဆောင်ရွက်ရာတွင် Terazawa (1965) ၏ လျှင်မြန်စွာအခြောက်ခံစမ်းသပ်နည်းကို အသုံးပြု ထားပါသည်။ လေ့လာတွေ့ရှိချက်များအရ စမ်းသပ်ခဲ့သော စိုက်ခင်းကျွန်းသက်တမ်း လေးမျိုးတွင် ကနဦးကွဲအက်မှုများ ဖြစ်ပေါ်ခြင်းမရှိ (အဆင့် ၁) သည်ကို တွေ့ရှိရပြီး ပုံပျက်မှုများ အတော်အတန် (အဆင့် ၃) ဖြစ်ပေါ်သည်ကို တွေ့ရှိရပါသည်။ အတွင်းပိုင်း အက်ကွဲမှုများသည် သက်တမ်း ၂၅ နှစ်နှင့် ၂၀နှစ်သား စိုက်ခင်းကျွန်းများတွင် ဖြစ်ပေါ်မှုမရှိ (အဆင့် ၁) သော်လည်း ၃၄ နှစ်နှင့် ၃၀ နှစ်သား စိုက်ခင်းကျွန်းများတွင် အတွင်းပိုင်း အက်ကွဲမှုများ အနည်းငယ်မှအတော်အတန် (အဆင့်-၃) ဖြစ်ပေါ်သည်ကို တွေ့ရှိရပါသည်။ ပုံပျက်မှုနှင့် အတွင်းပိုင်းအက်ကွဲမှုများသည် ကနဦးအပူချိန်၊ စိုထိုင်းဆများနှင့် ဆက်စပ်လျက် ရှိနေသောကြောင့် ယင်းစရိုက်လက္ခဏာများမှ ကာကွယ်ရန် အလယ်အလတ်ဖြစ်သော ပေါင်းဖိုဇယားအား အသုံးပြုသင့်ပါသည်။ ဤလေ့လာမှုတွင် အခြောက်ခံမှုဆိုင်ရာ စရိုက် လက္ခဏာများအပေါ်အခြေခံပြီး အဆိုပြုပေါင်းဖိုဇယားနှစ်ခုကို ဖော်ထုတ် ရရှိခဲ့ပါသည်။ သက်တမ်း ၃၄ နှစ်နှင့် ၂၀ နှစ်သား စိုက်ခင်းကျွန်းအတွက် ရရှိခဲ့သော အဆိုပြုပေါင်းဖိုဇယား ($D_{44}W_{44}$) သည် ယခင်စမ်းသပ်ပြီးသော ဝန်းသိုမြို့နယ်မှ ၃၇ နှစ်နှင့် ၃၂ နှစ်သား စိုက်ခင်းကျွန်း၊ လယ်ဝေးမြို့နယ်မှ ၂၅ နှစ်သား စိုက်ခင်းကျွန်း၊ ရေတာရှည်မြို့နယ်မှ ၁၄ နှစ်သား စိုက်ခင်းကျွန်းများ၏ အဆိုပြုပေါင်းဖိုဇယားများနှင့် ဆင်တူပါသည်။ သို့သော် ၂၀ နှစ်သား စိုက်ခင်းကျွန်းအတွက် အဆိုပြုထားသည့် ဤပေါင်းဖိုဇယားသည် ဝန်းသိုမြို့နယ်နှင့် အုတ်တွင်းမြို့နယ်မှ ၂၀နှစ်သား စိုက်ခင်းကျွန်းအတွက် ရရှိသော ပေါင်းဖိုဇယားထက် အနည်းငယ်ပျော့ကြောင်း တွေ့ရှိရပါသည်။ အလားတူ သက်တမ်း ၃၀ နှစ်နှင့် ၂၅ နှစ်သား

စိုက်ခင်းကျွန်းအတွက် အဆိုပြုထားသည့် ပေါင်းဖိုဇယား ($D_{45}W_{45}$) သည် သံတွဲမြို့နယ်မှ ၃၀ နှစ်သား စိုက်ခင်းကျွန်းထက် ပျော့နေပြီး လယ်ဝေးမြို့နယ်မှ သက်တမ်း ၂၅ နှစ်ရှိ စိုက်ခင်းကျွန်းအတွက် အဆိုပြုထားသည့် ပေါင်းဖိုဇယားထက် အနည်းငယ်မြင့်သည်ကို တွေ့ရှိရပါသည်။ ဤလေ့လာမှုရလာဒ်များအရ သက်တမ်း ၃၄ နှစ်၊ ၃၀ နှစ်၊ ၂၅ နှစ် နှင့် ၂၀ နှစ်သား စိုက်ခင်းကျွန်းများသည် အခြောက်ခံမှုဆိုင်ရာ စရိုက်လက္ခဏာများ အနည်းငယ်ကွဲပြားပြီး အဆိုပြုထားသည့် ပေါင်းဖိုဇယားသည် အနည်းငယ် ကွာခြားမှုရှိပါသည်။ သို့သော်လည်း မျိုးစိတ်တူ စိုက်ခင်းကျွန်းများ ဖြစ်ခြင်းကြောင့် ၎င်းတို့မှ ရရှိသော ၂၅ မီလီမီတာထု သစ်များအား ရောနှော၍ အတူတကွ အခြောက်ခံနိုင်ပါသည်။ ထိုသို့ အခြောက်ခံရာတွင် အတွင်းပိုင်းကွဲအက်မှုနှင့် ပုံပျက်မှုများမှ ကာကွယ်ရန် အလယ်အလတ်ဖြစ်သော အဆိုပြုပေါင်းဖိုဇယား ($D_{44}W_{44}$), အပူချိန် ၆၀-၈၅ ဒီဂရီ စင်တီဂရိတ်၊ အပူချိန်ခြားနားမှု ၅-၃၀ ဒီဂရီစင်တီဂရိတ်၊ စိုထိုင်းဆ ၇၇-၂၃ ရာခိုင်နှုန်းကို အသုံးပြုသင့်ပါသည်။ အခြောက်ခံမှု ပြီးဆုံးသည့်အချိန်တွင် ပေါင်းဖို၌ အခြောက်ခံထားသော သစ်များအတွင်း အစိုဓါတ်ပမာဏများ ညီမျှစေရန် အစိုဓါတ်ညှိပေးခြင်း လုပ်ငန်းစဉ်နှင့် တင်းအားများလျှော့ချခြင်း လုပ်ငန်းစဉ်များ ဆောင်ရွက်ပေးသင့်ပါသည်။

Investigation on Drying Characteristics and Proposed Kiln Schedules of Plantation Teak at Different Ages in Bago Region

1. Introduction

Teak (*Tectona grandis* Linn.f.) is one of the most highly valuable tropical hardwood species in the international market for the production of high quality timber due to its many favorable properties. It grows naturally in India, Myanmar, the Lao People's Democratic Republic, and Thailand, and it is harvested at approximately 80 years old (Damayanti et.al, 2018). Wood from natural teak or old grown teak has better quality with being quite stable and durable. Natural teak trees in Myanmar, India, and Thailand are mostly cut down three years after being girdled (Tint et. al., 1995). At that time, the moisture content of the cut teak was around 25-30%. The lumbers obtained from these logs are also partially dried, reducing drying time with fewer defects (Chit, W., 2019). Teak is included in moderately refractory species as far as its kiln seasoning characteristics are concerned (Mya, 1996 and Gupta et.al., 2017). It can be dried well and is not liable to check, split, and warp but it is relatively slow (Mya, 1966).

Nowadays, due to the shortage of older teak trees and the use of plantation teak, traditional logging often results in cracks in the tops of the logs as the wood dries faster. The wood obtained from the operation of the logs is also cracked. As a result, unlike wood from older natural teak, wood from plantation teak tends to crack in furniture because of the high variation of moisture content in the wood and harvesting at different ages. This harvesting rate results in a lesser quality in wood (Kollert et.al, 2012). Therefore, more maintenance requires making up lesser quality wood from plantation teak, and only drying the wood can solve these problems to utilize efficiently and ensure high quality wood products.

Wood drying is a critical part of most wood product manufacturing processes. Kiln drying has become one of the most important reducing moisture content in wood and has minimized structural distortion and wood defects. The drying ability of wood depends on the initial moisture content, density of wood, and drying condition (Korkut et.al, 2007). The drying of wood also causes various drying defects such as end check, surface check, honeycombing or internal check and deformation due to transferring heat and mass during drying (Yin, et.al 2021). Drying defects are any characteristic or blemish in a wood product and reduces the product's intended value. Drying characteristics of wood depends on certain factors such as tree age, position within the tree, board thickness and width, cutting pattern, climate, location and latitude, initial moisture content (Berrocal, et.al, 2017), density of wood, wood species, drying method, and drying schedule (Simpson,199; Wengert, 2006). An appropriate kiln drying schedule is an important factor in determining the success of the drying process. The differences in temperature and humidity during wood drying affect the grade of the final products (Carlsson, et. al, 1998*)*. Kiln drying schedules vary based on species, initial moisture content, thickness, defects, and end-uses of lumber (Effah, 2014).

A major challenge for wood-based industries in wood drying is to minimize energy consumption, drying time, and costs, and finally to reduce the loss of product due to drying defects. It is, therefore, important to understand the drying characteristics and the proper kiln schedules which are basic requirements in processing timber and finished products from different ages of plantation teak.

2. Objectives

The objectives of this study are:

(1) to investigate the drying characteristics of plantation teak at different ages
(2) to formulate the proper kiln schedules based on the drying characteristics
(3) to improve the efficiency of the wood drying process of plantation teak at different ages by using these kiln schedules

3. Materials and Method

3.1. Materials

3.1.1. Sample collection, preparation, and equipment

Different ages 20, 25, 30 and 34 years of plantation teak in Bago Region were studied in this study. Three ages 25, 30 and 34 years of plantation teak were collected from Taung Zarmani Reserve, Bago Township, and 20 years old plantation teak was collected from Latpen Aung Mya Reserve, Bago Township. Each sample tree was collected for each age and eighteen flat-sawn green specimens from the heartwood portion of the logs, which are free from defects, knots, and decay, were prepared into 20 mm x 100 mm x 200 mm in thickness, width, and length, respectively. After preparation of the required size, sawdust adhering to them was removed, the specimens labeled on the surface, and green moisture content maintained within each plastic container of water before running the test.

Equipments used in this research were laboratory oven (operating temperature 103±2°C), electric balance (weighing range 0-3,000g, minimum readability 0.1g), digital caliper (maximum length 150 mm, minimum readability 0.05 mm) to measure length and width of defects and deformation.

3.2. Method

The method used in this experiment was the Quick Drying Test at 103±2°C developed by Terazawa (1965) which was modified and adjusted by Jankowski (1992) and Hisada et.al. (1986). This method was originally designed and developed at the Forestry & Forest Product Research Institute of Japan (FFPRI). Experimental procedures are as follows:

3.2.1. Observation of drying characteristics or drying defects

Before running the test, each specimen was weighed and recorded as initial weight to calculate the initial moisture content of the samples. Six specimens were experimented in each drying test and specimens were placed stand erect at more than 75 mm apart each to heat evenly in the oven at the temperature of 103 ± 2°C. During the drying experiment, at the first eight hours, the test specimens were weighed to get the change in sample masses, and initial checks including surface checks, end checks, and end-to-surface checks were critically observed, measured, and recorded. Afterwards, re-weighing, observations and measurement were made twice daily on the second and subsequent days until oven-dry condition was reached. During drying and monitoring processes, checks occurring, movements of the maximum check, and check closing were observed and recorded.

When the test specimens reached the oven-dry condition, they were taken out from the oven and the final weights of all samples recorded. The moisture content of each sample was calculated according to the standard formula based on the oven-dry weight. Afterwards, the test specimens were cut in half to observe honeycombing and to measure the deformation. Deformation was determined with reference to the guidelines of the Quick Dry Test, and the mean value was determined. Likewise, the number of honeycombs and their sizes on newly exposed faces were examined and counted carefully.

3.2.2. Classification of drying characteristics or defects

The measurements of checks, deformation, and honeycombing were decided by the scaled values ranging from 1 to 6 for initial checks and honeycomb, from 1 to 8 for deformation (Tables 1 and 2).

Table 1. Classification of initial checks based on Terazawa (1965) and modified by Jankowski (1992) and honeycombing

Class no	Initial Checks		Honeycombing (internal checks)
	End check(mm)	Surface check(mm)	
1	No check	No check	No check
2	Small checks L<10 W< 0.8	Small checks L<50 W<0.5	Large 1 Small 2
3	Small checks L >10 W< 0.8	Small to medium checks 5<L<100 1<W<1	Large 2 Small 4-5 Large 1 & small 3
4	Medium checks L<10 0.8<W<1.5	Medium to large checks L<150 W<1.5	Large 4 Small 7-9 Large 1 & small 4-6
5	Medium to large checks L>10 0.8<W<1.5	Large checks L >150 W>1.5	Large 6-8 Small 15 Large 4 & small 6-8
6	Large checks L >10 W >1.5		Large15-17 small checks appearing continuously

Note: L = check length, W= check width
Source: Jankowski (1992) , Terazawa (1965)

Table 2. Classification of Deformation

Deformation	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
A-B (mm)	0~0.3	0.3~0.5	0.5~0.8	0.8~1.2	1.2~1.8	1.8~2.5	2.5~3.5	> 3.5

Source: Terazawa (1965)

3.2.3. Kiln Schedule Determination

The patternized kiln schedule code number for each age of plantation teak was determined from the cross points of the straight lines drawn using a combination of initial checks-D_1, deformation-D_2, honeycombing-D_3, and initial moisture content U_a by Figure 1 and 2.

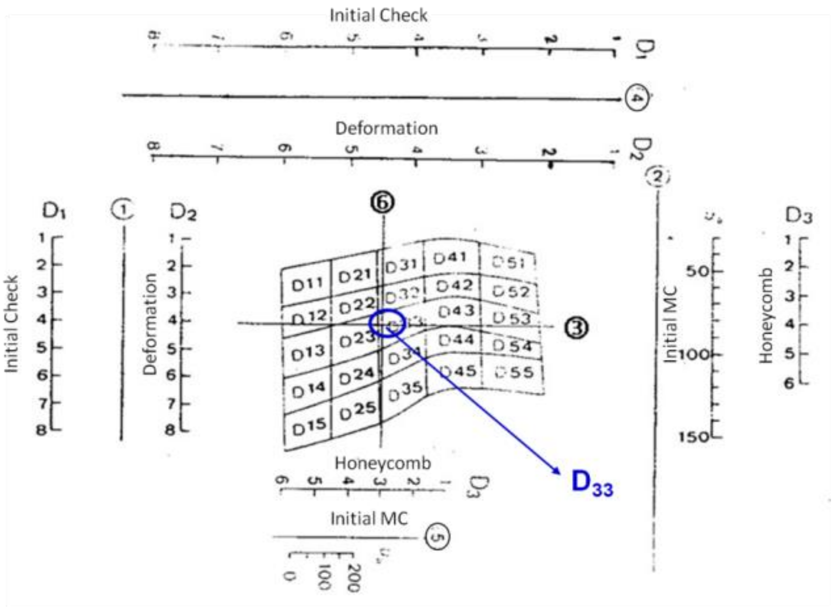

Figure 1. Chart for the code number of patternized dry-bulb temperature schedule (based on Hisadaet.al, 1986)

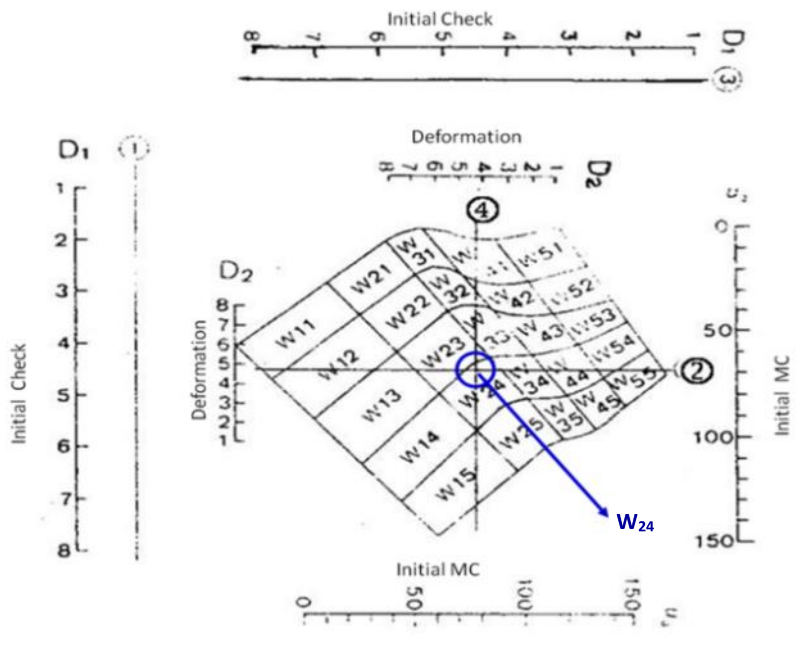

Figure 2. Chart for the code number of patternized wet-bulb depression schedule (based on Hisadaet.al, 1986)

After getting the schedule code number, the values of dry bulb temperature (DBT) and wet bulb depression (WBD) were determined by using moisture content as an indicator from Tables 3 and 4. These values were combined with the relative humidity values, and used to develop the proposed kiln schedule.

Table 3. Patterned dry bulb temperature schedule

Moisture content (%)	Dry bulb temperature for each schedule type (°C)																								
	D 11	D 12	D 13	D 14	D 15	D 21	D 22	D 23	D 24	D 25	D 31	D 32	D 33	D 34	D 35	D 41	D 42	D 43	D 44	D 45	D 51	D 52	D 53	D 54	D 55
60					45					50					55					60					70
				45					50					55					60					70	
50					50					55					60					65					75
			45					50					55					60					70		
40		45		50			50		55			55		60			60		65			70		75	
																					70				
	45		50		55	50		55		60	55		60		65	60		65		70			75		
		50					55					60		65			65		70			75			80
30				55					60												75			80	
	50	55	55		60	55	60	60			60	65	65		70	65	70	70		75			80		
										65				70					75			80			
	55	60	60	60		60	65	65	65		65	70	70			70	75	75			80				
20					65										75					80			85	85	85
	60	65	65	65		65	70	70	70	70	70	75	75	75		75	80	80	80		85	85			
	70	70	70	70	70	75	75	75	75	75	80	80	80	80	80	85	85	85	85	85	90	90	90	90	90
10																									

Source: Hisada et.al. (1986)

Table 4. Patterned wet bulb depression schedule

Moisture Content (%)	Wet bulb depression for each schedule type (°C)																								
	W 11	W 12	W 13	W 14	W 15	W 21	W 22	W 23	W 24	W 25	W 31	W 32	W 33	W 34	W 35	W 41	W 42	W 43	W 44	W 45	W 51	W 52	W 53	W 54	W 55
																									7
80																				5					
															4									7	8
70																			5	6					
										3				4	5								7	9	10
60					2													5	7	8		7			
									3	4			4	5	7		5				7		9	12	13
50					3													7	9	11		10			
				2				3				4	5			5	7				9				
45									4 5	6				8	10								13	15	16
			2	3			3	4			4	5	7			7	9	10			12				
40					5														13	14		15			
		2	3	4		3	4	6	7		6	7	9			10	12	13			16				
35										9				12	13								19	20	20
	2	3	5	6	8	5	6	8	9		9	10	12			14	15	16	18		20	20			
30																				19					
	3	5	7	8		8	10	11	12	14	13	15	16	18	18	20	20	20			25	25	25	25	
25	4				12														24						25
	5																								
	7	9	10	11		13	15	16	16		20	21	21			25	25	25			30	30	30	30	
20	10									20				25	23					25					
		15	16	16	18	21	22	22	21		30	30	30			30	30	30	30						30
15	14																								
	20	25	25	25	25	30	30	30	30	30				30	30					30					
10																									

Source: Hisada et.al. (1986)

4. Results and Discussion

4.1. Observation and classification of drying characteristics

Table 5 shows the average values of initial moisture content, types, and degree of drying characteristics of plantation teak at four different ages from Bago Region.

Table 5. Initial moisture content, types, and degree of drying characteristics of four different ages of plantation teak from Bago Region

Age group (year)	Initial moisture content (%)	Degree of drying characteristics		
		Initial Checks	Deformation	Honeycombing
34 years old	94.29	1	3	3
30 years old	109.51	1	3	3
25 years old	112.64	1	3	1
20 years old	93.04	1	3	1

The average initial moisture content values of 20 years old, 25 years old, 30 years old, and 34 years old plantation teak were 93.04%, 112.64%, 109.51%, and 94.29% respectively. The average initial moisture content value was investigated to determine the proposed kiln schedule of plantation teak at four different ages. Drying rate and susceptibility to drying characteristics or defects are related to the moisture content of wood, and kiln schedules are usually based on moisture content. At the beginning of the Quick-Drying Test, due to the high moisture content, the fibers in the outer wood dry first and begin to shrink. However, the inner has not yet begun to dry and shrink. Therefore, the inner prevents the outer wood from shrinking completely. Therefore, the outer goes into tense and the inner into compressed causing a defect of the wood, i.e. surface check, end check, internal check, or honeycombing and deformation.

In observation of the drying characteristics, 34, 30, 25, and 20 years old plantation teak showed no occurrence of initial checks (D_1). Since initial checks were not found, four ages of plantation teak owned the same rank with the lowest scoring level of 1. Mild to moderate deformations (D_2) were observed in four ages of plantation teak and average values were 0.6 mm in 20 years old plantation teak and 0.8 mm in the remaining three ages. The results showed that four ages of plantation teak were found in the same grade of deformation 3. It is assumed that deformation occurs due to the high content of initial moisture. In general, higher moisture content causes the wood sample to warp (Ofori, et. al, 2005 and Basri *et al.*, 2015). Deformation can be caused by differences between radial and tangential shrinkage in the wood when it dries (Simpson,1991). At the same species, the wetter the wood is, the higher the difference between tangential and radial shrinkage (Basri, et. al, 2019). Severe deformation on the cross-section of the board is a serious defect and the presence of these defects in dry wood causes difficulties in further processing. It affects the wood quality (Yuniarti, 2017).

Honeycombing or internal check (D_3) was not found in 20 and 25 years old plantation teak and classified as the same grade 1, whereas moderately small and large internal checks (honeycombing) were observed in 34, and 30 years old plantation teak with the same grade 3. The formation of honeycombing is affected by the initial moisture content of the wood, the wood mass loss, the presence of pith and the fast drying process (Johansson, 2005 as cited in Yang and Normand, 2012). It could weaken the wood's strength (Phonetip *et al.*, 2017 as cited in Basri, et. al, 2019), thus affecting its quality and value. Deformations and honeycombing of plantation teak at different ages are shown in Figure 3 to 6.

Figure 3. Deformation and honeycombing in 34 years old plantation teak

Figure 4. Deformation and honeycombing in 30 years old plantation teak

Figure 5. Deformation in 25 years old plantation teak

Figure 6. Deformation in 20 years old plantation teak

4.2. Determination of patternized kiln schedule codes

There are 25 patterns of kiln schedule codes; from the mildest schedule D_{11}-D_{15}, to the highest schedule D_{51}-D_{55} for dry-bulb temperature (DBT), and also from mildest schedule W_{11}-W_{15}, to the highest schedule W_{51} - W_{55} for Wet-bulb depression (WBD).

Based on the drying characteristics and initial moisture content, a kiln schedule ($D_{44}W_{44}$) was proposed for 34 and 20 years old plantation teak, and a kiln schedule ($D_{45}W_{45}$) was proposed for 30 years old and 25 years old plantation teak.

4.3. Formulation of proposed kiln schedules

A proposed kiln schedule determines temperature and relative humidity based on the type and degree of defects. Based on the schedule code number as shown in Table 3 and Table 4, dry bulb temperatures (DBT), wet bulb depressions (WBD), and moisture contents (MC) at each step of the drying process were determined as follows:

According to schedule code $D_{44}W_{44}$, the step of dry bulb temperature changes were 60; 65; 70; 75; 80; 85˚C and wet bub depression values were; 5;7;9;13;18;24;30˚C for 34 and 20 years old plantation teak. $D_{45}W_{45}$ was expressed the temperature changes 60; 65;70; 75; 80; 85˚C and wet bub depression values 5; 6; 8; 11; 14; 19; 25; 30˚C for 30 and 25 years old plantation teak. Together, the dry-bulb temperature and the wet-bulb depression determine the relative humidity.

The classification of moisture content levels with adjustments was expressed as follows: Above 65; 65~55; 55~45; 45 ~ 35; 35~25, 25 ~ 20, 20~ 15, and less than 15% as the final step in the drying process were for 34 and 20 years old plantation teak. Above 75; 75~ 65; 65 ~ 55; 55 ~ 45; 45 ~ 35; 35 ~ 30; 30 ~ 25; 25 ~ 15; less than 15% as the final step of the drying process were for 30 and 25 years old plantation teak. After determining the values, detailed the proposed kiln drying schedules were set up as shown in Tables 6 and 7.

Table 6. Proposed kiln schedule ($D_{44}W_{44}$) for 34 and 20 years old plantation teak

Step no.	Moisture content Range (%)	DBT(˚C)	WBD(˚C)	WBT(˚C)	R.H(%)
1	Above 65	60	5	55	77
2	65 ~ 55	60	7	53	69
3	55 ~ 45	60	9	51	62
4	45 ~ 35	65	13	52	51
5	35 ~ 25	70	18	52	40
6	25 ~ 20	75	24	51	30
7	20 ~15	80	30	50	22
8	15 to Final	85	30	55	23

DBT= Dry Bulb Temperature, WBD = Wet Bulb Depression, RH = Relative Humidity

This schedule $D_{44}W_{44}$ is described by moderately higher temperature and relative humidity at the start of drying to effect faster moisture diffusion and surface evaporation. The initial temperature of 60°C is held constant until the moisture content is reduced to 45%, while the relative humidity (RH) is gradually reduced to maintain fast drying. As the drying process goes on, the moisture content of wood will decrease, and the dry bulb temperature is gradually increased from 60°C to 85°C until to reach the target final moisture content.

According to schedule $D_{44}W_{44}$, 25 mm thick lumber of 34 and 20 years old plantation teak should be dried at moderately higher initial-final temperature range of 60˚- 85˚C, initial-final wet bulb depression range of 5˚-30˚C and initial-final humidity range of 77-23 % with changes in moisture content.

Table 7. Proposed drying schedule ($D_{45}W_{45}$) for 30 and 25 years old plantation teak

Step no.	Moisture content Range (%)	DBT(˚C)	WBD(˚C)	WBT(˚C)	R.H(%)
1	Above 75	60	5	55	77
2	75 ~ 65	60	6	54	73
3	65 ~ 55	60	8	52	66
4	55 ~ 45	65	11	54	57
5	45 ~ 35	65	14	51	48
6	35 ~ 30	70	19	51	38
7	30~ 25	75	19	56	40
8	25 ~ 15	80	25	55	30
9	15 to Final	85	30	55	23

DBT= Dry Bulb Temperature, WBD = Wet Bulb Depression, RH = Relative Humidity

This schedule is also described by moderately higher temperature and relative humidity at the start of drying. The initial temperature of 60°C is held constant until the moisture content is reduced to 55%. The relative humidity (RH) is decreased gradually to maintain fast drying. From moisture content 55% to the target final moisture content, dry bulb temperature is gradually increased from 60°C to 85°C to induce faster moisture diffusion from the interior to the surface of the wood.

According to schedule $D_{45}W_{45}$, moderately higher initial-final dry bulb temperature range of 60- 85˚C, initial-final wet bulb depression range of 5-30˚C, and the initial-final humidity range of 77-23% with the moisture content changes should be used in the drying of 25 mm thick lumber from 30 and 25 years old plantation teak to get below 10% moisture content. However, in this schedule, it can be found that the initial wet bulb depression range is a little bit larger, and humidity range is lower than the schedule $D_{44}W_{44}$ until the moisture content of 30% is reached. After that, the different condition applies until the moisture content of 15% is reached, and the drying condition is the same at the final step. Schedule $D_{45}W_{45}$ is a little severer than schedule $D_{44}W_{44}$. It is due to the higher initial moisture content in 30 and 25 years old plantation teak. Table 8 summarizes the Quick Dry test results of plantation teak at different ages.

Table 8. Summary of Quick dry test results of plantation teak at different ages

Age group (year)	Initial moisture content (%)	Grade of drying characteristics			Proposed Drying Condition(ºC)			Patternized schedule codes
		Initial Checks	Defor mation	Honey Comb	Initial DBT	Initial WBD	Final DBT	
34 year old	94.29	1	3	3	60	5	85	$D_{44}W_{44}$
30 year old	109.51	1	3	3	60	5	85	$D_{45}W_{45}$
25 year old	112.19	1	3	1	60	5	85	$D_{45}W_{45}$
20 year old	93.04	1	3	1	60	5	85	$D_{44}W_{44}$

4.4. Comparison of drying characteristics and proposed kiln schedules of plantation teak at different ages in this study and the previous studies

Drying characteristics and proposed kiln schedules of 34, 30, 25, and 20 years old plantation teak in this study are compared with those of 30, 25, and 20 years old plantation teak in the previous studies. Some other plantation teak tested as 37 years old, 32 years old and 14 years old plantation teak is also included for comparison as shown in Table 9.

Table 9. Comparison of drying characteristics and proposed kiln schedules of plantation teak at different ages in this study and other study

Ages (year)	Location (Township)	MC %	Grade of Drying characteristics			Proposed kiln schedule			Schedule code	Remarks
			Initial checks	Deformation	Honey comb	Initial DBT(ºC)	WBD (ºC)	Final DBT (ºC)		
37	Wuntho	87.27	1	2	1	60	5	85	$D_{44}W_{44}$	Hlaing, S. S et.al, 2021
34	Bago	94.29	1	3	3	60	5	85	$D_{44}W_{44}$	This study
30	Thandwe	67.10	1	1	1	70	5	90	$D_{55}W_{43}$	Soe, A. et.al., 2009
	Bago	109.51	1	3	3	60	5	85	$D_{45}W_{45}$	This study
32	Wuntho	98.34	1	2	1	60	5	85	$D_{44}W_{44}$	Hlaing, S. S. et.al., 2021
25	Lewe	88.30	1	1	1	60	5	85	$D_{44}W_{44}$	Soe, A. et.al., 2009
	Bago	112.64	1	3	1	60	5	85	$D_{45}W_{45}$	This study
20	Oaktwin	100.20	1	1	2	60	5	85	$D_{44}W_{45}$	Soe, A.et.al., 2009
	Bago	93.04	1	3	1	60	5	85	$D_{44}W_{44}$	This study
	Wuntho	102.67	1	2	2	60	5	85	$D_{44}W_{45}$	Hlaing, S. S. et.al., 2021
14	Yetashe	86.69	1	1	1	60	5	85	$D_{44}W_{44}$	Soe, A. et.al., 2009

The comparison shows that all plantation teak at different ages investigated are insusceptible to initial checks. But 34, 30, 25, and 20 years old plantation teak in Bago

Township are susceptible to deformation like 37, 32, and 20 years old plantation teak from Wuntho Township. On the other hand, 34 and 30 years old plantation teak from Bago Township and 20 years old plantation teak from Wuntho Township are susceptible to honeycombing and deformation during the Quick Drying Test. Honeycombing and deformation are generally related to the initial and final temperatures and the initial relative humidity but not to the final relative humidity (Terazawa, 1965). The grade of deformation is high, indicating the wood tends to collapse, so the drying temperature should not be high (Terazawa. 1965). Therefore, a moderate schedule should be used to prevent deformation and honeycombing.

The proposed kiln schedule ($D_{44}W_{44}$) for 34 and 20 years old plantation teak from Bago Township is similar to those of 14 years old plantation teak from Yetashe Township, 25 years old plantation teak from Leway Township (Soe, et. al, 2009) and 37 and 32 years old plantation teak from Wuntho Township (Hlaing, et. al., 2021) although drying characteristics are different. It can be said that, the drying characteristics are a few different due to the difference in regions and ages, but the proposed kiln schedules are the same.

But, the proposed kiln schedule ($D_{44}W_{44}$) for 20 years old plantation teak from Bago Township in this study is found to be slightly milder than the schedule from Oktwin Township (Soe, et. al, 2009) and Wuntho Township (Hlaing, et. al, 2021). Similarly, the proposed kiln schedule ($D_{45}W_{45}$) for 30 and 25 years old plantation teak from Bago Township is found to be milder than the schedule for 30 years old plantation from Thandwe Township (Soe, et. al, 2009) and a little severe than the proposed kiln schedule for 25 years old plantation teak from Leway Township (Soe, et. al,2009). Listyanto (2010) stated that the most recommended drying schedule for wood from 25 years old teak in Java is the schedule with an initial dry bub temperature in 70^{0}C, relative humidity in 71% and the final temperature in 90^{0}C. It can be said that the proposed kin schedule is slightly different, just as drying characteristics differ due to the same age but different location. The reason possibly lies on the difference in initial moisture content. According to the previous study by Soe, et. al, (2009), 25 mm thick lumbers could be steam kiln dried without any defects to obtain the target moisture content of 8-10% by proposed kiln schedule $D_{44}W_{44}$ for 25, 14 years old plantation teak and $D_{44}W_{45}$ for 20 years old plantation teak.

For that reason, 25 mm thick lumber from 34, 30, 25, and 20 years old plantation teak in Bago Township can be mixed and dried together because of plantation teak of the same species. If the lumber dries together, schedule ($D_{44}W_{44}$), which is a milder one among the proposed kiln schedules of plantation teak at different ages tested should be used. In schedules $D_{44}W_{44}$ and $D_{45}W_{45}$ from this study, although initial dry bulb temperatures at the start of drying are the same, the wet bulb depression in schedule $D_{45}W_{45}$ is larger than that of schedule $D_{44}W_{44}$. The larger wet-bulb depression and the lower relative humidity (RH) in the proposed kiln schedule $D_{45}W_{45}$ may induce faster drying. Even if the dry bulb temperature is held constant as in schedule ($D_{45}W_{45}$), lowering the RH would lead to the higher drying potential of the air and rapid drying. Wengert (1991) stated that rapid or extremely fast drying causes splits and checks. Initial checking is strictly related to initial relative humidity and less to initial temperature (Ofori, 2010). To prevent checks and splits, the large wet bulb depression value should not be used in the early stage of drying, and drying conditions should be slow. Moderately refractory woods including teak can be dried free from defects with moderately rapid drying conditions (i.e. a maximum dry-bulb temperature of 85°C can be used) (Redman, 2000 as cited in Effah, 2012). Therefore, the proposed kiln schedule ($D_{44}W_{44}$) would be better for preventing drying defects and may be moderately rapid drying without defects or with as few defects as possible.

5. Conclusion

According to the results obtained from this study, it can be concluded as follows:

Plantation teak at different ages 34, 30, 25, and 20 years old in Bago Region were susceptible to deformation (class 3), but there was no occurrence of initial checks in the early stages of drying (class 1). Honeycombing or internal checks were not found (class 1) in 20 and 25 years old plantation teak, whereas moderately small and large internal checks were observed (class 3) in 34, and 30 years old plantation teak.

Based on the drying characteristics, two proposed kiln schedules, ($D_{44}W_{44}$) for 34 and 20 years old plantation teak and ($D_{45}W_{45}$) for 30 and 25 years old plantation teak were developed in this study. The proposed kiln schedule ($D_{44}W_{44}$) for 34 and 20 years old plantation teak is similar to those of 14 years old plantation teak from Yetashe Township, 25 years old plantation teak from Leway Township and 37 and 32 years old plantation teak from Wuntho Township. But, this proposed kiln schedule for 20 years old plantation teak is slightly milder than the schedule from Oktwin Township and Wuntho Township. Similarly, the proposed kiln schedule ($D_{45}W_{45}$) for 30 and 25 years old plantation teak in this study is milder than the schedule for 30 years old plantation teak from Thandwe Township and slightly severer than the proposed kiln schedule for the 25 years old plantation teak from Leway Township.

According to the findings, plantation teak at different ages had slight differences in drying characteristics, and proposed kiln schedules were also a little different. However, being plantation teak of the same species, wood from 34, 30, 25, and 20 years old plantation teak in Bago Region can be mixed and dried in the same kiln. If the wood dries together, the proposed kiln schedule ($D_{44}W_{44}$) with the moderately higher initial-final temperature range of 60-85˚C, initial-final wet bulb depression range of 5-30˚C and initial-final relative humidity range of 77-23 % should be used to prevent deformation and internal checks. At the end of the drying process, equalization and conditioning treatment should be carried out to obtain more uniform moisture content and to relieve drying stress within and among the lumbers.

This drying condition would cause moderately rapid drying without objectionable drying defects or with as few defects as possible to reduce the production cost and energy consumption increasing the economic benefit. These drying schedules are intended for 25 mm thick lumber drying. So, it is still possible to be modified based on the kiln drying condition and dimensional sizes of the lumber.

These research findings would be useful for knowledge of wood properties related to drying and wood-based industries to make the efficient uses of plantation teak at different ages investigated. It is assumed that the wood from plantation teak would present satisfactory behavior when subject to these schedules.

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