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

Su Su Hlaing, Christy Ne Win
Assistant Research Officer
Forest Research Institute

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Abstract

This research paper investigated drying characteristics and proposed drying schedules of plantation teak at different ages 40-, 37-, 32- and 20-year-old in Sagaing Region. The method used in this research was Quick Drying Test method developed by Terazawa (1965). The study revealed that slight deformations (class 2) were found in plantation teak at different ages 40-, 37-, 32- and 20-year-old investigated. There was no initial check (class 1) in 37-, 32- and 20-year-old plantation teak, but small end checks (class 3) were occurred in 40-year-old plantation teak during the early drying stage. There was no internal checks or honeycombing (class 1) in samples of three ages 40-, 37- and 32-year-old plantation teak whilst small narrow or mild internal checks (class 2) were found in samples of 20- year-old plantation teak. According to the results obtained from the test, moderate schedule should be used to prevent initial checks, deformation and honeycomb defects because these defects are related to initial temperature and relative humidity. Consequently, in the kiln drying of 25 mm thick lumber to get below 10% moisture content, 40-year-old plantation teak should be dried by the proposed drying schedule ($D_{34}W_{34}$) with the moderate initial-final temperature range of 55-80˚C, wet bulb depression range of 4-30˚C, high humidity range of 81-22 % to prevent deformation and checks. The 20-year-old plantation teak should be dried by the proposed drying schedule ($D_{44}W_{45}$) with the moderately higher initial-final temperature range of 60-85˚C, wet bulb depression range of 5-30˚C, relative humidity range of 77-23% to prevent deformation and honeycombing. The 37-year-old and 32-year-old plantation teak can be mixed and dried together by using the same proposed drying schedule of ($D_{44}W_{44}$) with the moderately higher initial-final temperature range of 60-85˚C, wet bulb depression range of 5-30˚C and relative humidity range of 77-23 % to prevent them from the deformation.

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

စစ်ကိုင်းတိုင်းဒေသကြီးအတွင်းရှိ သက်တမ်းအမျိုးမျိုးရှိသော စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများနှင့် အဆိုပြုပေါင်းဖိုဇယားများအား လေ့လာဖော်ထုတ်ခြင်း

စုစုလှိုင်၊ ခရစ္စတီနေဝင်း
လက်ထောက်သုတေသနအရာရှိ

စာတမ်းအကျဉ်းချုပ်

ဤသုတေသနစာတမ်းတွင် စစ်ကိုင်းတိုင်းဒေသကြီးမှ **သက်တမ်းအမျိုးမျိုး (၄၀ နှစ်၊ ၃၇ နှစ်၊ ၃၂ နှစ် နှင့် ၂၀ နှစ်) ရှိသော စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများနှင့် အဆိုပြုပေါင်းဖိုဇယား**တို့ကို လေ့လာတင်ပြထားပါသည်။ စမ်းသပ်ဆောင်ရွက်ရာတွင် လျှင်မြန်စွာအခြောက်ခံစမ်းသပ်နည်းကို အသုံးပြုထားပါသည်။ လေ့လာတွေ့ရှိချက်များအရ စမ်းသပ်ခဲ့သည့် **သက်တမ်းအမျိုးမျိုးရှိသော** စိုက်ခင်းကျွန်းများသည် ပုံပျက်မှုများ အနည်းငယ် (အဆင့် ၂) ဖြစ်ပေါ်သည်ကို တွေ့ရှိခဲ့ရပါသည်။ ကနဦးကွဲအက်မှုများသည် သက်တမ်း ၃၇ နှစ်၊ ၃၂ နှစ်နှင့် ၂၀နှစ်သား စိုက်ခင်းကျွန်းများတွင် ဖြစ်ပေါ်ခြင်းမရှိ (အဆင့် ၁) သည်ကို တွေ့ရှိရပြီး ၄၀ နှစ်သားစိုက်ခင်းကျွန်းတွင် ထိပ်ကွဲအက်မှုများ အနည်းငယ် (အဆင့် ၃) ဖြစ်ပေါ်မှုရှိသည်ကို တွေ့ရှိခဲ့ရပါသည်။ အတွင်းပိုင်း အက်ကွဲမှုများသည် သက်တမ်း ၄၀ နှစ်၊ ၃၇ နှစ်နှင့် ၃၂နှစ်သား စိုက်ခင်းကျွန်းများတွင် မဖြစ်ပေါ်သည် (အဆင့် ၁) ကို တွေ့ရှိရပြီး ၂၀ နှစ်သား စိုက်ခင်းကျွန်း၏ အချို့သောသစ်နမူနာများတွင် အတွင်းပိုင်း အက်ကွဲမှုများ အနည်းငယ် (အဆင့်–၂) ဖြစ်ပေါ်သည်ကို တွေ့ရှိရပါသည်။ ကနဦးကွဲအက်ခြင်းများ၊ *ပုံပျက်မှုနှင့် အတွင်းပိုင်းအက်ကွဲမှုများသည် ကနဦးအပူချိန်၊ စိုထိုင်းဆတို့နှင့်ဆက်စပ်လျက်ရှိနေသောကြောင့် ယင်းအပြစ်အနာအဆာများမှ ကာကွယ်ရန် အလယ်အလတ်ဖြစ်သော ပေါင်းဖိုဇယားအား အသုံးပြုသင့်ပါသည်။* သို့ဖြစ်ပါ၍ ၂၅ မီလီမီတာထု စိုက်ခင်းကျွန်းသစ်ခွဲသားများအား အစိုဓါတ်ပမာဏ ၁၀ ရာခိုင်နှုန်းအောက် ရရှိရန် ပေါင်းဖိုဖြင့် အခြောက်ခံရာတွင် သက်တမ်း ၄၀ နှစ်သား စိုက်ခင်းကျွန်းအား ကွဲအက်မှုနှင့် ပုံပျက်မှုများမှကာကွယ်ရန် အဆိုပြု ပေါင်းဖိုဇယား ($D_{34}W_{34}$), အပူချိန် ၅၅–၈၀ ဒီဂရီစင်တီဂရိတ်၊ အခြောက်သာမိုမီတာ (dry bulb)နှင့် အစိုသာမိုမီတာ (wet bulb) တို့၏ အပူချိန်ခြားနားမှု (wet bulb depression) ၄–၃၀ ဒီဂရီစင်တီဂရိတ်၊ စိုထိုင်းဆ ၈၁–၂၂ ရာခိုင်နှုန်းဖြင့်လည်းကောင်း၊ သက်တမ်း၂၀နှစ်သား စိုက်ခင်းကျွန်းအား ပုံပျက်မှုနှင့် အတွင်းပိုင်းအက်ကွဲမှုများ ဖြစ်ပေါ်ခြင်းမှ ကာကွယ်ရန် အဆိုပြုပေါင်းဖိုဇယား ($D_{44}W_{45}$), အပူချိန် ၆၀–၈၅ ဒီဂရီစင်တီဂရိတ်၊ အပူချိန်ခြားနားမှု ၅–၃၀ ဒီဂရီ စင်တီဂရိတ်နှင့် စိုထိုင်းဆ ၇၇–၂၃ ရာခိုင်နှုန်းဖြင့် အခြောက်ခံသင့်ပါသည်။ ၃၇ နှစ်သားနှင့် ၃၂ နှစ်သား စိုက်ခင်းကျွန်းများအား ပုံပျက်မှုမှ ကာကွယ်ရန် အဆိုပြု ပေါင်းဖိုဇယား ($D_{44}W_{44}$), အပူချိန် ၆၀–၈၅ ဒီဂရီစင်တီဂရိတ်၊ အပူချိန်ခြားနားမှု ၅–၃၀ ဒီဂရီစင်တီဂရိတ်၊ စိုထိုင်းဆ ၇၇–၂၃ ရာခိုင်နှုန်းဖြင့် အတူတကွအခြောက်ခံနိုင်ပါသည်။

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

1. Introduction

Teak (*Tectona grandis* L.f.) is one of the most highly valuable hardwood species and has many uses. Currently, natural teak forests are rapidly disappearing and old-growth teak is significantly decreasing. Consequently, almost all teak growing tropical countries including Myanmar, India, Laos and Thailand that have natural teak forests are depending mainly on teak plantations because of the enduring global demand for teak wood products; it has good economic prospects as a plantation species for fine woods (William Ladrach, 2009). Although teak was once managed on rotations of 80 to 100 years, current rotation lengths have been shortened to 20 or 25 years for commercial wood production (William Ladrach, 2009). Teak trees are harvesting at different ages and this harvest rate results in a lesser quality in wood but acceptable for furniture production (Kollert and Cherubini 2012). Wood from natural teak is quite stable and durable. On the other hand, plantation teakwood is more likely to crack and warp as a result of the fast growth. These inferior wood qualities become constraints for producing high quality wood products for more competitive markets (Listyanto et al. 2016). It requires more maintenance to make up for these inferior wood qualities and appropriate wood drying is one of the best ways to ensure high quality wood products and efficiently utilize.

Improper wood drying causes cracking problems, discoloration, distortions which devalue the final product and substantial losses for the wood industries. The method used and proper control are important to achieving the appropriate production level, quality, and costs (E Basri & R Pari, 2019). Even though there are several methods in wood drying, kiln drying is the most commonly commercial used method to reach targeted moisture content within a reasonable drying time. Kiln drying schedule is a vital component in determining the success of the kiln drying process and good drying quality comes from the perfect drying schedule.

Drying schedule is a series of dry and wet-bulb temperatures that characterizes the temperature and relative humidity in the kiln and are adjusted according to the wood moisture content at various stages of a drying process. It is often applied in order to dry lumber at the fastest possible rate without causing objectionable degrades (Wengert, 2006) with a reduction of the drying time, energy consumption and to avoid severe drying conditions not to exceed the strength of the wood at any given temperature and moisture content. Drying defect is any characteristic or blemish in a wood product that occurs during the drying process and reduces the product’s intended value. Drying characteristics of wood depend on certain factors such as wood species, ages, drying method, drying period or drying schedule, wood properties and so on (Wengert, 2006 and Simpson,1989).

Every wood is not easy to be kiln-dried without any defect because each wood species has its own sensitivity to drying temperature. Thus, kiln drying schedules vary based on species, ages, initial moisture content, thickness, defects, and end-uses of dried lumber. Lack of understanding the drying schedule of each species leads to higher drying cost, drying time and low quality of the finished products (Effah, 2014). There is no information on drying characteristics and drying schedule of plantation teak at different ages from the same localities. A major challenge for wood based industries in timber drying is to reduce the drying time and the loss of product due to the drying defects. It is, therefore, important to understand the drying characteristics and the appropriate drying 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 proper drying schedule based on drying characteristics
(3) to improve the efficiency of wood drying process of plantation teak at different ages by applying the drying schedules prepared based on Terazawa's method.

3. Materials and Method

3.1. Materials

3.1.1. Sample collection, preparation and equipment

Plantation teak at different ages 40-year-old, 37-year-old, 32-year-old and 20-year-old from the same location were studied in this study. One sample tree for each age was randomly collected from Phelay Reserve which is situated in Wuntho Township, Katha District in Sagaing Region. Eighteen flat-sawn green specimens from the heartwood portion of the logs which are free defects, knot and decay were prepared into 20 mm x 100 mm x 200 mm in thickness, width and length, respectively. After that, the samples were kept in plastic bins of water to maintain moisture content before the drying test.

Equipment used in this research were laboratory oven (operating temperature 103±2^{o}C), electric balance (weighing range 0-3,000g, minimum readability 0.1g), digital caliper (maximum length 200 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 quick-drying test at 103±2°C by Terazawa (1965) as described by Ofori and Brentuio (2010). Testing procedures are as follow;

3.2.1. Observation of drying characteristics or drying defects

Six specimens were experimented in each drying test and they were placed stand erect at more than 75 mm apart each to heat evenly in the oven at temperature of 103 ± 2°C. Before running the test, each specimen was weighed and recorded as initial green weight to calculate the initial moisture content of the samples. During the first eight hours, the test specimens were weighed and initial checks including surface checks, end checks and end to surface checks were critically observed, measured and recorded. Afterwards, re-weighing, two observations and measurements were made on the 24th and 30th hours on the second day and on the 48th hour on the third day until oven-dry condition was reached. During drying and monitoring processes, checks occurring, movements of maximum check and check closing were observed and recorded.

When the test specimens reached oven-dry condition, they were taken out from the oven and the final weights of all samples recorded. Afterwards, the test specimens were cut in half to observe honeycombing and to measure the deformation. To determine the deformation, the maximum (A) and minimum (B) thicknesses of each specimen along its freshly cut face were measured with digital clipper. The difference between the two measurements (A-B) recorded as deformation and 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 defects

The measurements of checks, deformation and honeycombing were classified based on Table 1 and Table 2, according to the detailed procedure of Terazawa (1965). The class of 1 to 8 in initial checks and deformation, and 1 to 6 in honeycombing are used. It is noted that defect type class 1 is the mildest and class 8 is the most severe.

Table 1. Classification of initial checks and deformation

Class no	Initial Checks		Deformation (A-B) mm
	End checks(mm)	Surface check(mm)	
1	No check	No check	0~0.3
2	Small checks L<10 W< 0.8	Small checks L<50 W<0.5	0.3~0.5
3	Small checks L >10 W< 0.8	Small to medium checks 5<L<100 1<W<1.5	0.5~0.8
4	Medium checks L<10 0.8<W<1.5	Medium to large checks L<150 W<1.5	0.8~1.2
5	Medium to large checks L>10 0.8<W<1.5	Large checks L >150 W>1.5	1.2~1.8
6	Large checks L >10 W< 0.8	Large checks L>150 W>1.5	1.8~2.5
7	Large checks L>10 W< 0.8	Large checks L>150 W>1.5	2.5~3.5
8	Large checks L>10 W< 0.8	Large checks L>150 W>1.5	> 3.5

Note: L is length, W is Width.

Table 2. Classification of honeycomb (internal checks)

Class no.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Degree of internal check	No check	1 wide or 2 narrow checks	2-3 wide checks; 4-5 narrow check; 1 wide and 3 narrow	4-5 wide; 7-9 narrow;1wide and 4-6 narrow	6-8 wide; 15 narrow; 4 wide and 6-8 narrow	15-17 wide or continuous checks

3.2.3. Estimation of drying condition

Table 3 shows the critical condition of drying on each of the three drying defects classifications. The most severe defect was used as primary indicator to estimate the drying conditions, i.e. initial and final temperatures as well as initial wet bulb depression and used as indicators to determine the proposed drying schedule for each age of plantation teak.

Table 3. Relationship between drying condition and class of drying defects (modified Terazawa method) by Basri, 2011.

Type of defects	Drying condition (^{o}C)	Class of drying defects							
		1	2	3	4	5	6	7	8
Initial check(D_1)	Initial temperature	70	65	60	55	50	40	38	38
	Initial wet bulb depression	6.5	5.5	4	4	3	2	2	2
	Final temperature	95	90	85	80	70	65	50	50
Deformation(D_2)	Initial temperature	70	66	58	54	50	40	38	38
	Initial wet bulb depression	6.5	6	5	4	4	3	3	3
	Final temperature	95	88	83	80	70	65	50	50
Honeycomb(D_3)	Initial temperature	70	55	50	48	48	45	-	-
	Initial wet bulb depression	6.5	4.5	4	3	3	2.5	-	-
	Final temperature	95	83	77	73	71	70	-	-

3.2.4. Kiln Schedule Determination

According to the class of defects (initial checks-D_1, deformation-D_2, honeycombing-D_3) and initial moisture content U_a, patternized kiln schedule code number for each age of plantation teak was determined from Figure 1 and 2 provided by Terazawa (1965).

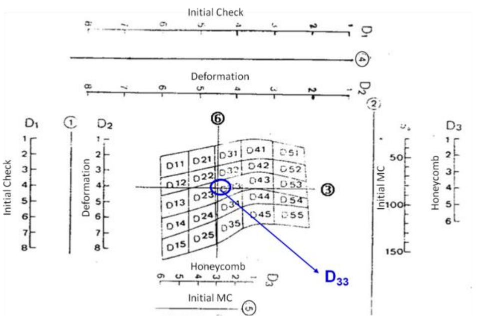


Figure 1. Chart for the code number of patternized dry bulb temperature schedule (Terazawa, 1965)

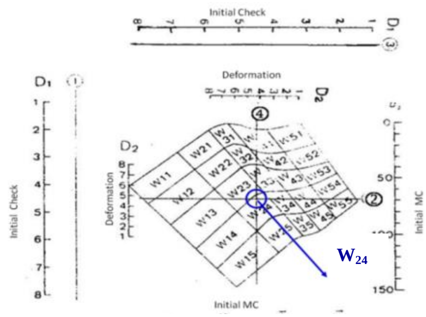


Figure 2. Chart for the code number of patternized wet-bulb depression schedule (Terazawa, 1965)

After getting the schedule code number, the value of dry bulb temperature (DBT) and wet bulb depression (WBD) were established by using moisture content as indicator from Table 4 and 5. These values combined with the relative humidity chart provided by Terazawa (1995) and further used to develop the proposed drying schedule. Each experiment was replicated three times to get the better results.

Table4. Patternized dry bulb temperature schedule

Moisture content (%): 60, 50, 40, 30, 20, 10

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

Table5. Patternized wet bulb depression schedule

MC (%): 80, 70, 60, 50, 45, 40, 35, 30, 25, 20, 15, 10

Schedule type	Wet bulb depression for each schedule type (°C)
W 11	2, 3, 4, 5, 7, 10, 17, 20
W 12	2, 3, 6, 9, 15, 25
W 13	2, 3, 5, 7, 10, 16, 25
W 14	2, 3, 4, 6, 8, 11, 16, 25
W 15	2, 3, 5, 8, 12, 18, 25
W 21	3, 5, 8, 13, 21, 30
W 22	3, 4, 6, 10, 15, 22, 30
W 23	3, 4, 6, 8, 11, 16, 22, 30
W 24	3, 4.5, 7, 9, 12, 16, 21, 30
W 25	3, 4, 6, 9, 14, 20, 30
W 31	4, 6, 9, 13, 20, 30
W 32	4, 5, 7, 10, 15, 21, 30
W 33	4, 5, 7, 9, 12, 16, 21, 30
W 34	4, 5, 8, 12, 18, 25, 30
W 35	4, 5, 7, 10, 13, 18, 23, 30
W 41	5, 7, 10, 14, 20, 25, 30
W 42	5, 7, 9, 12, 15, 20, 25, 30
W 43	5, 7, 10, 13, 16, 20, 25, 30
W 44	5, 7, 9, 13, 18, 24, 30
W 45	5, 6, 8, 11, 14, 19, 25, 30
W 51	7, 9, 12, 16, 20, 25, 30
W 52	7, 10, 15, 20, 25, 30
W 53	7, 9, 13, 19, 25, 30
W 54	7, 9, 12, 15, 20, 25, 30
W 55	7, 8, 10, 13, 16, 20, 25, 30

4. Results and Discussion

4.1. Drying characteristics and classification

The results comprised of initial moisture content, the type and class of drying defects obtained for the plantation teak at different ages are shown in Table 6.

Table 6. Type and class of drying defects of plantation teak at different ages

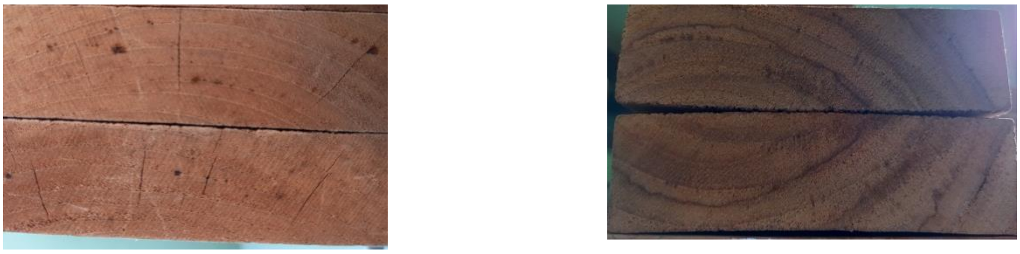
Age group (year)	Initial moisture content (%)	Class of drying defects		
		Initial Checks	Deformation	Honeycomb
40-year-old	96.22	3	2	1
37-year-old	87.27	1	2	1
32-year-old	98.34	1	2	1
20-year-old	102.67	1	2	2

Green moisture content of the different ages 40-, 37-, 32- and 20-year-old plantation teak investigated varies from one age to another. Average initial moisture content was 96.22% in 40-year-old, 87.27% in 37-year-old, 98.34% in 32-year-old and 102.67% in 20-year-old plantation teak, respectively. The 20-year-old plantation teak showed the highest and 37-year-old was the lowest in initial moisture content. Early in the Quick-Drying Test, when the moisture content is high, the fibers in the outer wood dry first and begin to shrink. However, the inner has not yet begun to dry and shrink. Consequently, the inner prevents the outer wood from shrinking fully. Thus, 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, there was no initial check in three ages 37-32-and 20-year-old plantation teak while small end checks were occurred in some samples of 40-year-old plantation teak during the early drying stage and become stronger with the drying process going on (Fig 3). The main reason for the end checks is the high temperature which makes them moisture moves much faster in the longitudinal direction than in either transverse direction. Therefore, the ends of boards dry faster than the middle and stresses develop at the ends (Simpson WT, 1991). Consequently, it is important to avoid using the high temperature and control the drying condition in the early stage of drying is important.

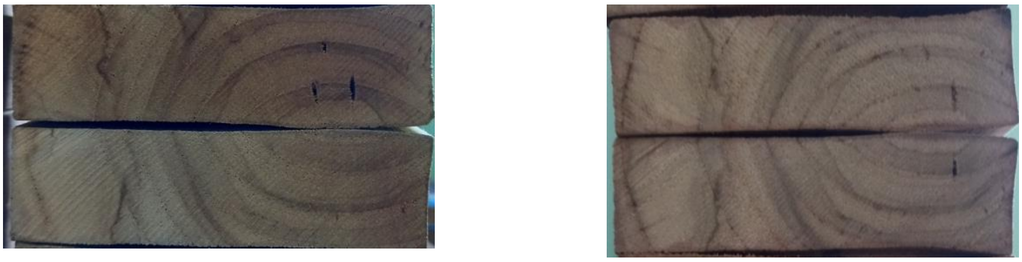
Slight deformations (D_2) were observed and their average values were 0.4mm, 0.3mm, 0.4mm and 0.4mm in samples of plantation teak at different ages 40-, 37-, 32- and 20-year-old, respectively. Deformation was the lowest in 37-year-old plantation teak and the remaining three ages 40-, 32- and 20-year-old were the same value (Fig 3-5). It is assumed that the occurrence of deformation is due to the high content of initial moisture. In general, higher moisture content causes wood sample to warp (Ofori & Brentuo, 2005; Basri *et al.*, 2015). Naturally, free water in the wet wood will be the first moisture component to evaporate from the wood cell lumen during a drying process. The free water movement shrinks the cell wall lumen and causes uneven shrinkage between wood surfaces and inside the wood causes the wood to warp (Glass & Zellinka, 2010). Simpson WT. (1991) also states that deformation can be caused by differences between radial and tangential shrinkage in the wood when it dries. It affects the wood quality (Karnita, 2017).

Internal check or honeycombing (D_3) was not observed in samples of three ages 40-, 37- and 32-year-old plantation teak whilst slight internal checks were found in some samples of 20-year-old plantation teak (Fig 5). Honeycombing is the separation of the fibers in the interior of the piece, usually along the rays. Johansson (2005) mentions that the presence of honeycomb defect is affected by the initial moisture content of the wood, the wood mass loss, the presence of pith and the speed of drying process. It could weaken the wood strength, thus affecting the quality and the value of wood (Phonetip *et al.*, 2017). Therefore, it is required to choose the best drying condition or drying schedule that will not allow the development of any deformation and honeycombing in the wood.



Fig(3) End checks and Deformation in 40-year-old plantation teak

Fig(4) Deformation in 37- and 32-year-old plantation teak



Fig(5) Deformation and honeycombing in 20-year-old plantation teak

Based on the classification of the drying defects showed in Table 1 and Table 2, 40-year-old plantation teak was classified into class 3 and class 1 for the remaining three ages 37- 32- and 20-year-old in terms of initial check (D_1). Class 2 was for all different ages investigated in terms of deformation (D_2). Class1 for 40-, 37-, 32-year-old plantation teak and class 2 for 20-year-old plantation teak were in terms of honeycombing (D_3), respectively.

According to the results, it was found that all different ages 40- 37- 32- and 20-year-old plantation teak investigated were slightly susceptible to deformation. Drying characteristics of the oldest 40-year-old plantation teak was higher the 20-year old plantation teak. However, drying characteristics of 37- and 32-year-old plantation teak were similar.

4.2. Estimation of drying condition

According to Quick Drying Test, the estimated drying conditions, the mildest conditions (viz. overall lowest initial temperature, overall smallest initial wet bulb depression, and final temperature) were selected because the drying condition is inferred from the most severe class of defects so it would be the mildest one and more safely.

From the classification of drying defects, it was suggested that honeycombing and initial check were expressing the lowest drying conditions for 20- and 40-year-old plantation teak. On the other hand, the drying conditions were the same for 37- and 32-year-old plantation teak. Therefore, initial-final dry bulb temperature of 55-83˚C and initial wet bulb depression of 4.5˚C were estimated for 20-year-old plantation teak and initial-final dry bulb temperature of 60-85˚C and initial wet bulb depression of 4˚C were estimated for 40-year-old plantation teak. Drying condition of initial-final dry bulb temperature range 66-88˚C and initial wet bulb depression of 6˚C were estimated for the remaining ages 37- and 32-year-old plantation teak and shown in Table 7 .

Table 7. Estimated drying condition of plantation teak at different ages

Age group (year)	Classification of drying characteristics			Estimated Drying Condition(ºC)		
	Initial checks	Deformation	Honeycombing	Initial DBT	Initial WBD	Final DBT
40-year-old	3	2	1	60	4	85
37-year-old	1	2	1	66	6	88
32-year-old	1	2	1	66	6	88
20-year-old	1	2	2	55	4.5	83

4.3. Determination of patternized kiln schedule codes

According to Figure 1 and 2 provided by Terazawa (1965), the patternized kiln schedule codes for each age of plantation teak were determined based on the combination of three types of drying defects and initial moisture content. Quick Drying Test has provided 25 patterns of kiln drying schedule codes for dry-bulb temperature (DBT) ranging from the mildest schedule D_{11}-$D_{15,}$ to the highest schedule D_{51}-D_{55} and also Wet-bulb depression (WBD) ranging from mildest schedule W_{11}-$W_{15,}$ to the highest schedule W_{51} - W_{55}.

Using the above result, drying schedule ($D_{34}W_{34}$) was proposed for 40-year-old plantation teak, ($D_{44}W_{44}$) was proposed for 32- and 37-year-old plantation teak and ($D_{44}W_{45}$) was proposed for 20-year-old plantation teak.

4.4. Formulation of proposed kiln drying schedules

A proposed kiln-drying schedule determines both temperature and relative humidity based on the type and degree of defects. Based on the schedule code number created by Terazawa (1965) as shown in Table 4 and Table 5, dry bulb temperatures (DBT), wet bulb depressions (WBD) and moisture contents (MC) at each step of the drying process were determined as follow;

According to schedule code $D_{34}W_{34}$, the step of dry bulb temperature changes were 55; 60; 65; 70; 75; 80˚C and wet bub temperature values; 4;5;8;12;18;25;30˚C for 40-year-old plantation teak. $D_{44}W_{44}$, the step of dry bulb temperature changes were 60; 65; 70; 75; 80; 85˚C and wet bub temperature values were; 5;7;9;13;18;24;30˚C for 37- and 32-year-old plantation teak. $D_{44}W_{45}$ was expressed the temperature changes 60; 65;70; 75; 80; 85˚C and wet bub temperature values 5; 6; 8; 11; 14; 19; 25; 30˚C for 20-year-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 60; 60~50; 50~ 40; 40 ~30; 30 ~ 20, 20 ~ 15 and 15% to final step in the drying process was for 40-year-old plantation teak. Above 65; 65~55; 55~45; 45 ~ 35; 35~25, 25 ~ 20, 20~ 15 and less than 15% as final step in the drying process was for 37- and 32-year-old plantation teak. Above 75; 75~ 65; 65 ~ 55; 55 ~ 45; 45 ~ 35; 35 ~ 25; 25 ~ 20; 20 ~ 15; less than 15% as the final step of drying process was for 20-year-old plantation teak. After determining the values, detailed the proposed kiln drying schedules were set up as shown in Table 8 to 10.

Table 8. Proposed drying schedule ($D_{34}W_{34)}$ for 40- year-old plantation teak

Step No.	Moisture content Range (%)	DBT(˚C)	WBD(˚C)	RH(%)
1	Above 60	55	4	81
2	60 ~ 50	55	5	76
3	50 ~ 40	60	8	66
4	40 ~ 30	65	12	54
5	30 ~ 20	70	18	40
6	20 ~15	75	25	28
7	15 to Final	80	30	22

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

According to schedule $D_{34}W_{34}$, 25 mm thick lumber of 40-year-old plantation teak should be dried with moderate initial-final dry bulb temperature range of 55-80˚C, initial-final wet bulb depression range of 4-30˚C, high initial-final humidity range of 81-22 %. This drying condition is milder than the estimated drying condition (moderately higher initial-final temperature range of 60-85˚C, initial wet bulb depression of 4 ˚C) shown in Table 6. Severe drying schedule can be used if the wood is insusceptible to check and deformation. Conversely, it must be carried out at a milder schedule if the wood is susceptible to check and deformation (Terazawa, S.1965). In view of the 40-year-old plantation teak, the determination of drying condition should consider the occurrence of deformation and not only initial check. Split and checks are aggravated by rapid drying or extremely fast, hot drying; slower drying will reduce these defects, expect when they are a result of logging damage (Wengert, 1991). Initial checking is strictly related to initial relative humidity, and less so to initial temperature (J.Ofori, 2010). Therefore, to prevent the initial check, the temperature depression should not be too big in early stage of drying and drying condition should be slow. According to Terazawa, S.(1965), deformation is related to the initial temperature and less related to final temperature and also related to the initial relative humidity, but not to the final relative humidity. Therefore, moderate schedule should be used and this drying condition with moderate initial temperature and high initial humidity would be better to prevent checking and deformation for 40-year-old plantation teak.

Table 9. Proposed drying schedule ($D_{44}W_{44}$) for 37- and 32-year-old plantation teak

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

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

According to schedule $D_{44}W_{44}$, 25 mm thick lumber of 37- and 32-year-old plantation teak should be dried with moderately higher initial-final dry bulb temperature range of 60-85˚C, initial-final wet bulb depression range of 5-30˚C, the initial-final humidity range of 77-23% to get below 10% moisture content. This drying condition in this schedule is milder than the estimated drying condition (initial-final temperature range of 66-88˚C, initial wet bulb depression of 6˚C) shown in Table 6. The grade of deformation is high, indicating the wood tends to collapse, so the drying temperature should not be high (Terazawa. S, 1965). In view of 37- and 32-year-old plantation teak, these two ages indicated low class in deformation. Therefore, moderate schedule should be used and this drying condition would be better to be applied to prevent deformation.

Table 10. Proposed drying schedule ($D_{44}W_{45}$) for 20-year-old plantation teak

Step No.	Moisture content Range (%)	DBT(˚C)	WBD(˚C)	RH(%)
1	Above 75	60	5	77
2	75 ~ 65	60	6	73
3	65 ~ 55	60	8	66
4	55 ~ 45	60	11	55
5	45 ~ 35	65	14	48
6	35 ~ 25	70	19	38
7	25~ 20	75	25	28
8	20 ~ 15	80	25	30
9	15 to Final	85	30	23

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

According to schedule $D_{44}W_{45}$, similarly moderately higher initial-final temperature range of 60-85˚C, initial-final wet bulb depression range of 5-30˚C, initial-final humidity range of 77-23% with the moisture content changes should be used in the drying of 25 mm thick lumber from 20-year- old plantation teak. Initial-final temperature range 60-85˚C in this drying condition was a little bit higher than the estimated drying condition (initial-final temperature range of 55-83˚C) but, wet bulb depression value 5˚C was nearly a similar value with 4.5˚C in estimated condition shown in Table 6. 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, S.1965). A study carried out by Yusuf Sudo & Terazawa.S.(1984) has shown that in some cases, inferred initial dry bulb temperature could be raised a little bit if the species was indicated the low grades of honeycombing and deformation in Quick drying Test. In this study, 20-year-old plantation teak indicated the same low grade (class 2) in deformation and honeycombing. Therefore, moderate schedule should be used to prevent deformation and honeycomb for 20-year-old plantation teak.

Moreover, drying condition in this study was similar to the result of 20-year-old plantation teak from Oaktwin Township although drying defects were little different in the previous studied by Aung Soe,et.al. (2009). He mentioned that 25 mm thick lumber of 20-year-old-plantation teak could be dried without any defects from initial moisture 38.8% to final moisture content 8.8% by this schedule. For that reason, application with this proposed drying schedule would be caused more rapid drying without objectionable drying defects or with as little defects as possible to reduce production cost, energy consumption which increases economic benefit. Summary of Quick Dry Test results are shown in Table 11.

Table (11). Summary of Quick Dry Test results

Age group (year)	Initial moisture content (%)	Classification of drying defects			Proposed Drying Condition(ºC)			Schedule codes
		Initial Checks	Defor-mation	Honey comb	Initial DBT	Initial WBD	Final DBT	
40-year-old	96.22	3	2	1	55	4	81	$D_{34}W_{34}$
37-year-old	87.27	1	2	1	60	5	85	$D_{44}W_{44}$
32-year-old	98.34	1	2	1	60	5	85	$D_{44}W_{44}$
20-year-old	102.67	1	2	2	60	5	85	$D_{44}W_{45}$

5. Conclusion

According to the results obtained from the test, it can be concluded that even though they are plantation teak of the same species, drying characteristics and drying schedules are different because of different ages. Based on the drying characteristics, three proposed drying schedules were developed altogether, the drying schedule ($D_{34}W_{34}$) with the moderate initial-final temperature range of 55-80˚C, initial-final wet bulb depression range of 4-30˚C, the high initial-final humidity range of 81-22 % for 40-year-old-plantation teak, the drying schedule ($D_{44}W_{45}$) with the moderately higher initial-final temperature range of 60-85˚C, initial-final wet bulb depression range of 5-30˚C, initial-final relative humidity range of 77-23% for 20-year-old-plantation teak and the drying schedule of ($D_{44}W_{44}$) 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 % for 37- and 32-year-old-plantation teak. These drying schedules are intended for 25 mm thick lumber drying. So, it is still possible need to be modified based on the kiln drying condition and dimensional sizes of lumber.

These research findings would be useful not only for knowledge of wood properties related to drying but also for 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 be present satisfactory behavior when subject to these schedules.

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