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# Investigation of Drying Characteristics and Proposed Kiln Schedules of Plantation Teak from Provenance Trial


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# Investigation of Drying Characteristics and Proposed Kiln Schedules of Plantation Teak from Provenance Trial

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## Abstract

This research investigated the drying characteristics and proposed kiln schedules of 15 years old plantation teak from the eight provenances (Nattalin, Paukkhaung, Kanbalu, Oaktwin, Taungoo, Phyu, Bago, Thabeikkyin) in Provenance Trial in compartment No.(9), Ngalaik Reserved Forest, Ottarathiri Township, Naypyitaw. Drying characteristics were investigated using the Quick Drying Test method of Terazawa (1965) modified by Jonkosky (1992), and the proposed kiln schedules were determined based on these drying characteristics. For this study, two thinning poles of different sizes and lengths of 5.49 m (18 ft) were used for each provenance, and wood samples were prepared according to the standard of Quick Drying Test method (1965). According to the observations, the results showed that initial moisture content of plantation teak from Kanbalu provenance was the highest at 114.97%, followed by Phyu provenance (112.77%), Thabeikkyin provenance (112.34%), Taungoo provenance (100.64%), Paukkaung provenance (99.71%), Oaktwin provenance (96.99%), Nattalin provenance (96.85%), and Bago provenance (82.23%), respectively. In observation of the drying characteristics, it was found that no internal checks with the class 1, end checks with the class 3, and deformations with the class 2 were occurred in all plantation teak from eight provenances tested. Based on the results, two proposed kiln schedules were developed. The first, kiln schedule ($D_{34}W_{34}$) with dry bulb temperature range of 55-80˚C, wet bulb depression range of 4-30˚C, and relative humidity range of 81-22 % was recommended for 25 mm thick lumber from Nattalin, Oaktwin and Bago provenances. The second, kiln schedule ($D_{35}W_{35}$) with dry bulb temperature range of 55-80˚C, wet bulb depression range of 4-30˚C, and relative humidity range of 81-22 % was recommended for 25 mm thick lumber from Paukkhaung, Kanbalu, Taungoo, Phyu and Thabeikkyin provenances. Although the plantation teaks from all eight provenances were of the same age and species, and drying characteristics were not significantly different, the two kiln schedules were slightly different due to variations in moisture content. However, both kiln schedules were designed to minimize undesirable drying defects by starting with moderate temperature and moderately high relative humidity, based on the worst defects observed.

Key Words: drying characteristics, proposed kiln schedule, plantation teak, provenance trial, quick drying test

# အနယ်နယ်ကျွန်းစမ်းသပ်ကွက်မှ စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများနှင့် အဆိုပြုသစ်ပေါင်းဖိုဇယားများအား လေ့လာဖော်ထုတ်ခြင်း

စုစုလှိုင်၊ လက်ထောက်သုတေသနအရာရှိ

သစ်တောသုတေသနဌာန

## စာတမ်းအကျဉ်းချုပ်

ဤစာတမ်းသည် နေပြည်တော်ကောင်စီနယ်မြေ၊ ဥတ္တရသီရိမြို့နယ်၊ ငါးလိုက်ကြိုးဝိုင်း အကွက်အမှတ် (၉) တွင် ဒေသရှစ်ခု (နတ်တလင်း၊ ပေါက်ခေါင်း၊ ကန့်ဘလူ၊ အုတ်တွင်း၊ တောင်ငူ၊ ဖြူး၊ ပဲခူး၊ သပိတ်ကျင်း) မှ တည်ထောင်ထားသည့် အနယ်နယ်ကျွန်းစမ်းသပ်ကွက်မှ သက်တမ်း ၁၅ နှစ်ရှိသော စိုက်ခင်းကျွန်းများ၏ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာ များနှင့် အဆိုပြုပေါင်းဖိုဇယားများအား လေ့လာထားခြင်းဖြစ်ပါသည်။ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများကို Jonkosky (1992) မှ ပြုပြင်ထားသော Terazawa (1965) ၏ Quick Drying Test method ကို အသုံးပြု၍ လေ့လာခဲ့ပြီး ယင်းလက္ခဏာများအပေါ် အခြေခံ၍ အဆိုပြုပေါင်းဖိုဇယားများကို ဖော်ထုတ်ခဲ့ပါသည်။ လေ့လာမှုအတွက် ၅.၄၉ မီတာ အရှည်ရှိပြီး အရွယ်အစား မတူညီသည့် ကျွန်းပင်ကျပ်တိုင် ၂ လုံးအား ဒေသတစ်ခုစီအတွက် အသုံးပြုခဲ့ပြီး အမျက်နှင့် အပြစ်အနာအဆာများ လွတ်ကင်းသည့် သစ်နမူနာများအား Quick Drying Test method ၏ စံသတ်မှတ်ချက်များနှင့်အညီ ခွဲစိတ်ပြင်ဆင်ခဲ့ပါသည်။ လေ့လာ တွေ့ရှိချက်များအရ ကန့်ဘလူကျွန်း၏ ကနဦးအစိုဓာတ်ပါဝင်မှုသည် (၁၁၄.၉၇ ရာခိုင်နှုန်း) အများဆုံးဖြစ်ပြီး၊ ဖြူးကျွန်းသည် ၁၁၂.၇၇ ရာခိုင်နှုန်း၊ သပိတ်ကျင်းကျွန်းသည် ၁၁၂.၃၄ ရာခိုင်နှုန်း၊ တောင်ငူကျွန်းသည် ၁၀၀.၆၄ ရာခိုင်နှုန်း၊ ပေါက်ခေါင်းကျွန်းသည် ၉၉.၇၁ ရာခိုင်နှုန်း၊ အုတ်တွင်းကျွန်းသည် ၉၆.၉၉ ရာခိုင်နှုန်း၊ နတ်တလင်းကျွန်းသည် ၉၆.၈၅ ရာခိုင်နှုန်းနှင့် ပဲခူးကျွန်းသည် ၈၂.၂၃ ရာခိုင်နှုန်း အသီးသီး ရှိသည်ကို တွေ့ရှိခဲ့ရပါသည်။ အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများ ရှာဖွေရာ၌ စမ်းသပ်ခဲ့သော ကျွန်းများတွင် ထိပ်ကွဲအက်မှုများ (အဆင့် ၃) နှင့် ပုံပျက်မှုများ အတော်အတန် (အဆင့် ၂) ဖြစ်ပေါ်ပြီး အတွင်းပိုင်း အက်ကွဲမှုများ ဖြစ်ပေါ်ခြင်းမရှိ (အဆင့် ၁) သည်ကို တွေ့ရှိခဲ့ရပါသည်။. စမ်းသပ်မှုမှ ရရှိခဲ့သော ရလဒ်များအရ ပေါင်းဖိုဇယားနှစ်ခုကို ဖော်ထုတ် ရရှိခဲ့ပါသည်။ 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 ရာခိုင်နှုန်းသည် ပဲခူး၊ အုတ်တွင်းနှင့် နတ်တလင်း ကျွန်းများမှ ၂၅ မီလီမီတာထုသစ်များအတွက်ဖြစ်ပြီး ပေါင်းဖိုဇယား ($D_{35}W_{35}$)၊ အပူချိန် ၅၅–၈၀ ဒီဂရီ စင်တီဂရိတ်၊ အခြောက်သာမိုမီတာ (dry bulb)နှင့် အစိုသာမိုမီတာ (wet bulb) တို့၏ အပူချိန်ခြားနားမှု (wet bulb depression) ၄–၃၀ ဒီဂရီစင်တီဂရိတ်၊ စိုထိုင်းဆ ၈၁–၂၂ ရာခိုင်နှုန်းသည် ပေါက်ခေါင်း၊ ကန့်ဘလူ၊ တောင်ငူ၊ ဖြူးနှင့် သပိတ်ကျင်းကျွန်းများမှ ၂၅ မီလီမီတာထုသစ်များအတွက် ဖြစ်ပါသည်။ စမ်းသပ်ခဲ့သော ဒေသရစ်ခုမှ ကျွန်းများသည် သက်တမ်းနှင့် မျိုးစိတ်တူကြပြီး အခြောက်ခံမှုဆိုင်ရာ သွင်ပြင်လက္ခဏာများသည် သိသာ ထင်ရှားစွာ ကွဲပြားခြင်းမရှိကြသော်လည်း အစိုဓာတ်ပါဝင်မှု ကွာခြားခြင်းကြောင့် ရရှိခဲ့သော ပေါင်းဖိုဇယားနှစ်ခုသည် အနည်းငယ် ကွဲပြားသည်ကို တွေ့ရှိခဲ့ရပါသည်။ သို့သော်လည်း ဤပေါင်းဖိုဇယားနှစ်ခုသည် အပြစ်အနာအဆာ အဖြစ်အများဆုံးမှ အခြေခံထားသည်ဖြစ်၍ အလယ်အလတ်ဖြစ်သော အပူချိန်နှင့် အတန်အသင့် မြင့်မားသော နှိုင်းရစိုထိုင်းဆဖြင့် စတင်ထားခြင်းကြောင့် ပေါင်းဖိုဖြင့် အခြောက်ခံရာတွင် မလိုလားအပ်သော အပြစ်အနာ အဆာများကို လျော့နည်းစေမည် ဖြစ်ပါသည်။

# Investigation of Drying Characteristics and Proposed Kiln Schedules of Plantation Teak from Provenance Trial

## 1. Introduction

Teak (*Tectona grandis* Linn.f.) is one of the most well-known and valuable commercial tropical timber species. It is renowned for its durability and beauty, making it extremely valuable in the market. Myanmar is one of the major natural teak-growing countries in the world. All kinds of furniture and many other products are usually made of teak wood due to its many favorable properties, which have been used for hundreds of years and continue to be used today. Nowadays, the availability of wood from mature teak is obviously decreasing, due to the rapid depletion of natural teak forests, and the market price of mature teak wood is also increasing. As a result, efforts to increase the availability of teak wood have been made through the establishment of teak plantations. These plantations are playing an important role in the local and national economic development of tropical countries, including natural teak growing countries, and will continue to be in the future.

The wood from older natural teak is of good quality because it was harvested at approximately 80 years old (Damayanti et.al, 2018). On the other hand, teak trees from plantations are harvested at different ages, ranging from 20-30 years old or even 10-20 years old (Ball et al., 2000). Wood from young plantations with fast-growing species is commonly dominated by lower quality wood (Hadiyane et al., 2018). Therefore, it is necessary to enhance and maintain the quality of wood from teak plantations. Drying of wood is a valuable method for enhancing the quality of sawn products in the primary wood processing industries (Attah et al., 2005 as cited in Bernard, 2012). It also promotes long-term economic benefits by optimizing the use of timber resources (Wengert, 2006). In determining the success of the drying process, kiln schedule that controls temperature and relative humidity, is an important factor that can reduce energy consumption, drying time and costs, and improve wood quality.

Nowadays, wood from young teak trees and thinning operations is being utilized in the production of teak wood products. However, there is limited information on its drying characteristics, which is one of the drying properties. Drying properties are important wood processing properties (Bernard, 2014). Information about the properties and characteristics of teak wood primary applies to the heartwood of the mature trees. However, the drying characteristics of wood from young teak plantations may differ due to the presence of sapwood. Therefore, it is necessary to investigate the drying characteristics of wood from young teak plantations because drying characteristics reduce the grade and value of intended products. If wood from young teak plantations is properly processed, it can result in high-quality furniture products that meet domestic demand. This can also make industrial production profitable for wood-based industries and optimize the use of resources.

## 2. Objectives

The objectives of this study are:

(1) to investigate the drying characteristics of plantation teaks,

(2) to formulate the proper kiln schedules based on the drying characteristics,

(3) to improve the efficiency of the wood drying process by using these kiln schedules.

## 3. Materials and Method

### 3.1. Materials

#### 3.1.1. Sample collection and preparation

Fifteen years old plantation teak from the thinning operation of the provenance trial was studied in this research. This trial site was established in 2007 to conserve the Teak genetic resources and to study the growth performances among the eight provenances namely Nattalin, Paukkhaung, Kanbalu, Oaktwin, Taungoo, Phyu, Bago, Thabeikkyin where natural teak grows. It was located in compartment No. (9), Ngalaik Reserved Forest, Ottarathiri Township, Naypyitaw.

Two thinning poles of different sizes and lengths of 5.49 m (18-ft) were collected for each provenance. Each pole was cut into three 6-ft (1.83 m) parts and flat-sawn wood specimens, which were free from defects such as knots, checks, and decay, were prepared into 20 mm thickness x 100 mm width x 200 mm length according to the standard of the Quick Drying Test (1965). The presence of sapwood and heartwood was not considered in this study because the understanding of general drying characteristics was the main objective. After preparation of the required size, saw dust 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. Drying processes was carried out in Timber seasoning section.

The equipment used in this research included: laboratory oven, electric balance, and digital caliper to measure length and width of defects and deformation.

### 3.2. Method

Quick Drying Test developed by Terazawa (1965) which was modified and adjusted by Jankowski (1992) and Hisada et.al. (1986) was used in this research. This method was originally designed and developed at the Forestry & Forest Product Research Institute of Japan (FFPRI). Research 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. Eight 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 $103 \pm 2^{\circ}$C. During the drying process, at the first eight hours, the test specimens were weighed to get the change in sample masses, and initial checks (expressed as Defect 1-$D_1$) including surface checks, end checks, and end-to-surface checks were critically observed, measured, and recorded. After that, re-weighing, observations and measurement were made once a day until oven-dry condition was reached. During drying and monitoring processes, occurrences of checks, 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 or internal checks (expressed as

Defect 3- $D_3$) and to measure the deformation (expressed as Defect 2-$D_2$). Deformation was determined by the mean value. 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 initial 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). The highest score is the worst defect.

**Table1. Classification of initial checks based on Terazawa (1965) and modified by Jankowski (1992) and honeycombing**

| Class no. | Initial Checks -$D_1$ | | Honeycombing (internal checks) - $D_3$ |
|---|---|---|---|
| | End check(mm) | Surface check(mm) | |
| 1 | No check | No check | No check |
| 2 | Small checks<br>L<10 W< 0.8 | Small checks<br>L<50 W<0.5 | Large 1 , Small 2 |
| 3 | Small checks<br>L >10 W< 0.8 | Small to medium checks<br>5<L<100 1<W<1 | Large 2, Small 4-5<br>Large 1 & small 3 |
| 4 | Medium checks<br>L<10 0.8<W<1.5 | Medium to large checks<br>L<150 W<1.5 | Large 4 , Small 7-9<br>Large 1 & small 4-6 |
| 5 | Medium to large checks<br>L>10 0.8<W<1.5 | Large checks<br>L >150 W>1.5 | Large 6-8, Small 15<br>Large 4 & small 6-8 |
| 6 | Large checks<br>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 – $D_2$**

| 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

Patternized kiln schedule codes of Dry Bulb Temperature (DBT) and Wet Bulb Depression (WBD) were then determined by using the degree of initial check-$D_1$, deformation-$D_2$, honeycombing-$D_3$ and initial moisture content-Ua,. These steps were done by Figure 1 and 2.

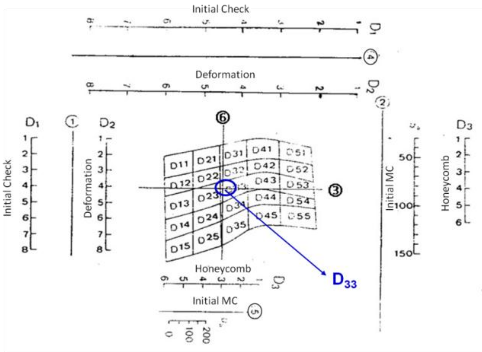


Figure 1. Chart for the code number of patternized dry-bulb temperature schedule (Hisadaet.al, 1986)

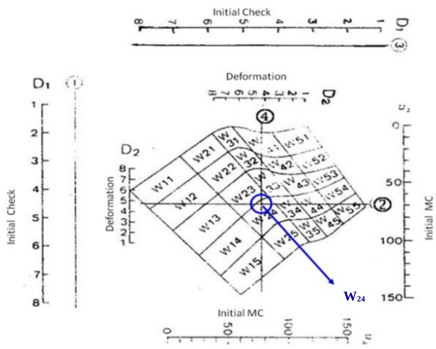


Figure 2.Chart for the code number of patternized wet-bulb depression schedule (Hisadaet.al, 1986)

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 (for maximum thickness of 25 mm).

**Table 3. Patternized dry bulb temperature Schedule**

| Schedule type | Dry bulb temperature for each schedule type (°C ) (Moisture content (%) from 60 down to 10) |
|---|---|
| D11 | 45, 50, 55, 60, 70 |
| D12 | 45, 50, 55, 60, 65, 70 |
| D13 | 45, 50, 55, 60, 65, 70 |
| D14 | 45, 50, 55, 60, 65, 70 |
| D15 | 45, 50, 55, 60, 65, 70 |
| D21 | 50, 55, 60, 65, 75 |
| D22 | 50, 55, 60, 65, 70, 75 |
| D23 | 50, 55, 60, 65, 70, 75 |
| D24 | 50, 55, 60, 65, 70, 75 |
| D25 | 50, 55, 60, 65, 70, 75 |
| D31 | 55, 60, 65, 70, 80 |
| D32 | 55, 60, 65, 70, 75, 80 |
| D33 | 55, 60, 65, 70, 75, 80 |
| D34 | 55, 60, 65, 70, 75, 80 |
| D35 | 55, 60, 65, 70, 75, 80 |
| D41 | 60, 65, 70, 75, 85 |
| D42 | 60, 65, 70, 75, 80, 85 |
| D43 | 60, 65, 70, 75, 80, 85 |
| D44 | 60, 65, 70, 75, 80, 85 |
| D45 | 60, 65, 70, 75, 80, 85 |
| D51 | 70, 75, 80, 85, 90 |
| D52 | 70, 75, 80, 85, 90 |
| D53 | 70, 75, 80, 85, 90 |
| D54 | 70, 75, 80, 85, 90 |
| D55 | 70, 75, 80, 85, 90 |

Source: Hisada et.al. (1986)

**Table 4. Patternized wet bulb depression schedule**

| Schedule type | Wet Bulb Depression for each schedule type ( °C ) (MC (%) from 80 down to 10) |
|---|---|
| W11 | 2, 3, 4, 5, 7, 10, 17, 20 |
| W12 | 2, 3, 6, 9, 15, 25 |
| W13 | 2, 3, 5, 7, 10, 16, 25 |
| W14 | 2, 3, 4, 6, 8, 11, 16, 25 |
| W15 | 2, 3, 5, 8, 12, 18, 25 |
| W21 | 3, 5, 8, 13, 21, 30 |
| W22 | 3, 4, 6, 10, 15, 22, 30 |
| W23 | 3, 4, 6, 8, 11, 16, 22, 30 |
| W24 | 3, 4.5, 7, 9, 12, 16, 21, 30 |
| W25 | 3, 4, 6, 9, 14, 20, 30 |
| W31 | 4, 6, 9, 13, 20, 30 |
| W32 | 4, 5, 7, 10, 15, 21, 30 |
| W33 | 4, 5, 7, 9, 12, 16, 21, 30 |
| W34 | 4, 5, 8, 12, 18, 25, 30 |
| W35 | 4, 5, 7, 10, 13, 18, 23, 30 |
| W41 | 5, 7, 10, 14, 20, 25, 30 |
| W42 | 5, 7, 9, 12, 15, 20, 25, 30 |
| W43 | 5, 7, 10, 13, 16, 20, 25, 30 |
| W44 | 5, 7, 9, 13, 18, 24, 30 |
| W45 | 5, 6, 8, 11, 14, 19, 25, 30 |
| W51 | 7, 9, 12, 16, 20, 25, 30 |
| W52 | 7, 10, 15, 20, 25, 30 |
| W53 | 7, 9, 13, 19, 25, 30 |
| W54 | 7, 9, 12, 15, 20, 25, 30 |
| W55 | 7, 8, 10, 13, 16, 20, 25, 30 |

Source: Hisada et.al. (1986)

Differences in drying characteristics based on the measurements of the end checks and deformations of each sample and moisture content of 15 years old plantation teak from provenance trial were analysed using one-way ANOVA and continued by Tukey's post-hoc test if data were statistically different. All analysis was conducted using SPSS window 20.

## 4. Results and Discussion

The results of the Quick drying test for 15 years old plantation teak from the provenance trial are presented in the form of graphs and tables below.

### 4.1. Moisture content

The average moisture contents were investigated for use in developing the proposed kiln schedules and presented in Table 5 and Fig 3.

**Table 5. Moisture content of 15 years old plantation teak from provenance trail**

| Sr No. | Provenances | Moisture content (%) | | | |
|---|---|---|---|---|---|
| | | Mean | Minimum | Maximum | Standard deviation |
| 1 | Natalin | 96.85 | 89.71 | 107.79 | 5.97 |
| 2 | Paukkaung | 99.71 | 91.53 | 125.78 | 11.93 |
| 3 | Kanbalu | 114.97 | 105.90 | 128.61 | 7.15 |
| 4 | Oaktwin | 96.99 | 85.09 | 110.38 | 6.64 |
| 5 | Taungoo | 100.64 | 97.09 | 106.99 | 3.44 |
| 6 | Phyu | 112.77 | 103.07 | 122.16 | 5.64 |
| 7 | Bago | 82.23 | 73.92 | 88.80 | 5.36 |
| 8 | Tabaikyin | 112.34 | 101.30 | 120.54 | 6.49 |

It was revealed that, the average moisture contents of the 15 years old plantation teak from the provenance trail ranged from 82.23% to 114.97%. Plantation teak from Kanbalu provenance had the highest moisture content at 114.97%, followed by Phyu (112.77%), Thabeikkyin (112.34%), Taungoo (100.64%), Paukkaung (99.71%), Oaktwin (96.99%), Nattalin (96.85%), and Bago provenance 82.23%, respectively (Figure 3). The high variability in moisture content at wood may be caused by its anatomical structure, heartwood content and wood density (Panshin, 1980). Drying rate and susceptibility to drying defects are related to the moisture content of lumber, so kiln schedules are usually based on moisture content (Simpson, 1991).

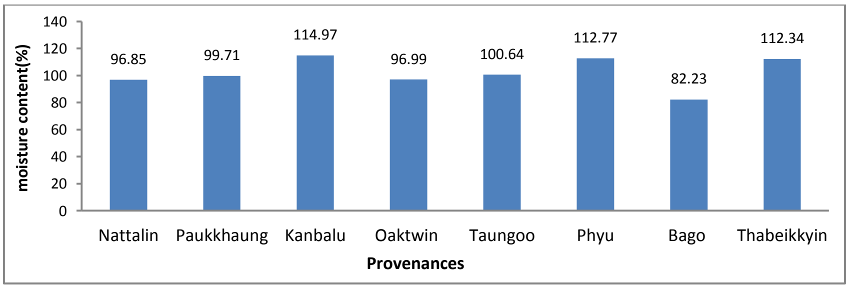


Fig 3. Moisture contents of 15 years old plantation teak from provenance trail

### 4.2. Observation and classification of drying characteristics

The drying characteristics were observed in the form of end checks and deformation as follows.

End checks were observed in all plantation teak from eight provenances in the early stage of drying. The maximum length of the end checks ranged from 20.91 mm to 23.53 mm (Fig 4), with widths ranging from 0.25 to 0.53mm. The occurrence of end checks is most likely due to the combination of low relative humidity and high temperature conditions (Aileen et.al, 2008). This is because moisture moves faster in the longitudinal direction than in transverse direction, causing the ends of boards to dry faster and develop stresses. To minimize this, it is recommended to use high relative humidity (Simpson, 1991). End checks of 15 years old plantation teak from provenances trial were shown in Figure 5 below.

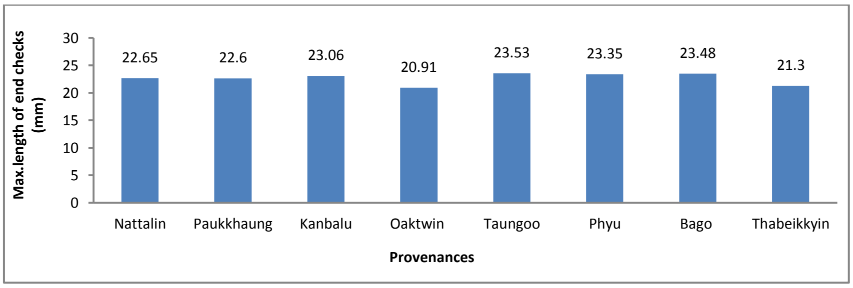


Fig 4. Maximum length of end checks of 15 years old plantation teak from provenance trail

Nattalin provenance

Paukkhaung provenance

Kanbalu provenance

Oaktwin provenance

Taungoo provenance

Phyu provenance

Bago provenance

Thabeikkyin provenance

Fig 5. End checks in 15 years old plantation teak from provenance trial

Further observation showed that although there was no occurrence of internal checks or honeycombing ($D_3$), deformations ($D_2$) were observed in all plantation teak from eight provenances studied. The maximum average values of deformation ranged from 0.4 mm to 0.5 mm (Fig 6). Deformation occurs due to high moisture content. In general, higher moisture content causes the wood sample to warp (Ofori, J. et. al, 2005 and Basri, E. et al., 2015).

Simpson (1991) stated that deformation can be caused by differences between radial and tangential shrinkage in the wood when it dries. At the same species, the wetter the wood is, the higher the difference between tangential and radial shrinkage (Basri, E. 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). Figure 6 show the deformation that occurred in 15 years old plantation from provenance trial.

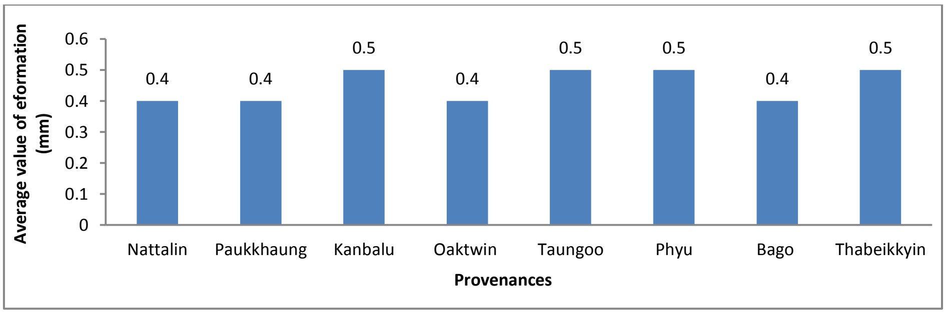


Fig 6. Measurements of deformation of 15 years old plantation teak from provenance trail

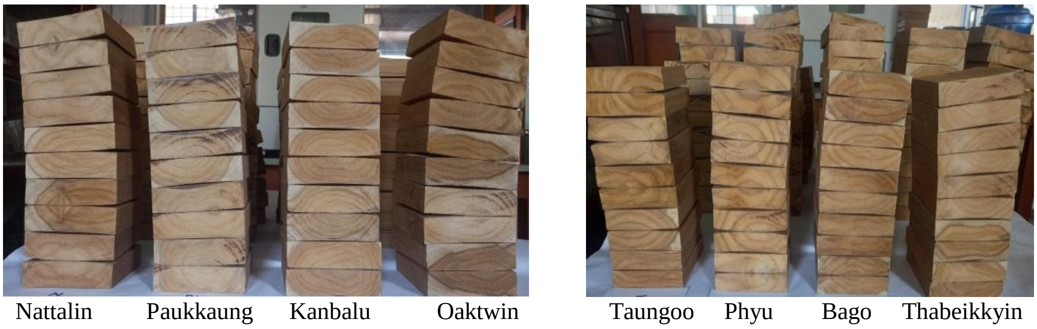


Fig 7. Deformation of 15 years old plantation teak from Provenance Trial

According to the above figures, based on the classification of the drying characteristics showed in Table 1 and 2, 15 years old plantation teak from provenance trial were classified into class 3 for initial check ($D_1$), class 2 for deformation ($D_2$), and class 1 for internal checks or honeycombing ($D_3$).

One-way ANOVA based on a significance level of 0.05 was conducted to check the differences among drying characteristics and moisture content between provenances. The results showed that, drying characteristics were not significantly different ($F(7,69)=0.402$; $P=0.898$ in deformation, $F(7,51)=1.347$; $P=0.248$ in initial checks) between provenances. On the other hand, moisture contents were significantly different ($F(7,77)=29.353$; $P=0.000$) between provenances. According to Tukey's test for multiple comparisons shown in Table 6, in terms of moisture content, Bago provenance (82.23%) was significantly different from the rest of the provenances, while Nattalin (96.85%), Paukkhaung (99.71%), Oaktwin (96.99%), and Taungoo (100.64%) provenance were significantly different from Kanbalu, Phyu, Bago and Thabeikkyin provenances ($p<0.05$), and Kanbalu (114.97%), Phyu (112.77%) and Thabeikkyin (112.34%) provenance were significantly different from Nattalin, Paukkhaung, Oaktwin, Taungoo and Bago provenance ($p<0.05$).

**Table 6. Results of Tukey test in terms of moisture content between provenances**

| Provenances | Nattalin | Paukkhaung | Kanbalu | Oaktwin | Taungoo | Phyu | Bago | Thabeikkyin |
|---|---|---|---|---|---|---|---|---|
| Nattalin | - | ns | * | ns | ns | * | * | * |
| Paukkhaung | ns | - | * | ns | ns | * | * | * |
| Kanbalu | * | * | - | * | * | ns | * | ns |
| Oakwin | ns | ns | * | - | ns | * | * | * |
| Taungoo | ns | ns | * | ns | - | * | * | * |
| Phyu | * | * | ns | * | * | - | * | ns |
| Bago | * | * | * | * | * | * | - | * |
| Thabeikkyin | * | * | ns | * | * | ns | * | - |

*significant at the 0.05 level; ns=not significant

### 4.3. 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 the mildest schedule $W_{11}$-$W_{15,}$ to the highest schedule $W_{51}$ - $W_{55}$ for Wet-bulb depression (WBD).

Based on the grade of drying characteristics and initial moisture content, a kiln schedule ($D_{34}W_{34}$) for plantation teak from Nattalin, Oaktwin and Bago provenance and a kiln schedule ($D_{35}W_{35}$) for the rest of provenances; Paukkaung, Kanbalu, Taungoo, Phyu and Thabeikkyin were developed.

### 4.4. Formulation of proposed kiln schedules

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 $D_{34}W_{34}$, the step of dry bulb temperature changes were 55; 60; 65; 70; 75; 80˚C and wet bub depression values were 4;5;8;12;18;25;30˚C. The dry bulb temperature changes 55; 60; 65; 70; 75; 80˚C and wet bub depression values 4; 5; 7; 10; 13; 18; 23; 30˚C were for schedule code $D_{35}W_{35}$.

The classification of moisture content levels with adjustments; above 60; 60~50; 50~ 40; 40 ~30; 30 ~ 20, 20 ~ 15 and 15% to final step was for schedule code $D_{34}W_{34,}$ and above 70; 70~ 60; 60 ~ 50; 50 ~ 40; 40 ~ 30; 30 ~ 20; 20 ~ 15 and less than 15% was for schedule code $D_{35}W_{35}$. By combining these results (dry bulb temperature changes, wet bub depression values, and moisture content levels) obtained, the complete proposed kiln schedules were formulated as shown in Tables 7 and 8. The values of relative humidity were determined by dry-bulb temperature and the wet-bulb depression.

**Table 7. Proposed kiln schedule ($D_{34}W_{34}$) for 15 years old plantation teak from Nattalin, Oaktwin and Bago provenances**

| Step No. | Moisture content (%) | 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

Kiln schedule $D_{34}W_{34}$ is described by moderate dry bulb temperature and moderately high relative humidity at the start of drying to effect faster moisture diffusion and surface evaporation. The initial temperature of 55°C is held constant until the moisture content is reduced to 50%. The relative humidity (RH) is gradually reduced to maintain a fast drying rate. 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 80°C until to reach the desired moisture content.

**Table 8. Proposed kiln schedule ($D_{35}W_{35}$) for 15 years old plantation teak from Paukkaung, Kantbalu, Taungoo, Phyu and Thabeikkyin provenances**

| Step. No. | Moisture content (%) | DBT(˚C) | WBD(˚C) | R.H(%) |
|---|---|---|---|---|
| 1 | Above 70 | 55 | 4 | 81 |
| 2 | 70 – 60 | 55 | 5 | 76 |
| 3 | 60 -50 | 55 | 7 | 68 |
| 4 | 50 – 40 | 60 | 10 | 59 |
| 5 | 40 – 30 | 65 | 13 | 51 |
| 6 | 30 – 20 | 70 | 18 | 40 |
| 7 | 20 – 15 | 75 | 23 | 31 |
| 8 | 15 to final | 80 | 30 | 22 |

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

In this kiln Schedule $D_{35}W_{35}$, initial temperature of 55°C is also held constant until the moisture content is reduced to 50%, while the relative humidity (RH) is gradually reduced to maintain a fast drying rate. From moisture content 50% to the target final moisture content, dry bulb temperature is gradually increased from 60°C to 80°C for faster moisture diffusion from the interior to the surface of the wood.

In these two kiln schedules ($D_{35}W_{35}$) and ($D_{34}W_{34}$), the wet bulb depression in schedule $D_{35}W_{35}$ is slightly larger, and humidity range is lower than those of schedule $D_{34}W_{34}$ until the moisture content reaches 30%. The drying conditions are the same until the moisture content reaches 20%. Then, different drying condition is applied until the moisture content reaches 15%, and the final drying conditions are the same.

Even if the initial dry bulb temperature of 55˚C is held constant until the moisture content is reduced to 50%, lowering the relative humidity in ($D_{35}W_{35}$) would lead to faster moisture absorption from the wood surface, resulting in a faster drying process. As a result, kiln schedule ($D_{34}W_{34}$) is milder than kiln schedule ($D_{35}W_{35}$). It may be due to the difference in moisture content.

According to the results above, in determining the drying condition for 15 years old plantation teak, not only the initial check, but also the occurrence of deformation should be considered. Initial checking is strictly related to initial relative humidity, and less so to initial temperature (Ofori.J, 2010). Deformation is generally 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 (Terazawa. 1965). Bergman (2012) stated that if relative humidity is too low in the early stages of drying, excessive shrinkage may occur, resulting in surface and end checking. If the temperature is too high, collapse, honeycomb, or strength reduction can occur. Rasmussen (1961) also indicated that, drying hardwood lumber requires a gentle process with lower temperature and higher relative humidity. For that reason, if 25 mm thick lumbers of 15 years old plantation teak from eight provenances studied are to be kiln-dried, a higher relative humidity needs to be used, and the drying temperature should not be too high in the early stages of drying, to prevent deformation and initial checks. Therefore, a moderate dry bulb temperature of 55-80˚C and a moderately high relative humidity of 81-22% from these two kiln schedules would result in moderately rapid drying without defects or with as few defects as possible in kiln drying. Quick dry test results of 15 years old plantation teak from provenances trial were summarized and shown in Table 9.

**Table 9. Summary of Quick dry test results of 15 years old plantation teak from provenance trial**

| Sr. No. | Provenances | Moisture content (%) | Grade of drying characteristics | | | Proposed Drying Condition(ºC) | | | Patternized schedule codes |
|---|---|---|---|---|---|---|---|---|---|
| | | | Initial check | Defor mation | Honey comb | Initial DBT | Initial WBD | Final DBT | |
| 1 | Natalin | 96.84 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{34}W_{34}$ |
| 2 | Paukkaung | 99.71 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{35}W_{35}$ |
| 3 | Kanbalu | 114.97 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{35}W_{35}$ |
| 4 | Oaktwin | 97.00 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{34}W_{34}$ |
| 5 | Taungoo | 100.64 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{35}W_{35}$ |
| 6 | Phyu | 112.77 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{35}W_{35}$ |
| 7 | Bago | 82.22 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{34}W_{34}$ |
| 8 | Tabaikyin | 112.34 | 3 | 2 | 1 | 55 | 4 | 81 | $D_{35}W_{35}$ |

DBT= Dry bulb temperature, WBD= Wet bulb depression

## 5. Conclusion

Based on the results of 15 years old plantation teak from provenance trial, the following conclusions were made as follows:

All of the plantation teak studied were prone to end checking (class 3) and deformation (class 2), but internal checking (class 1) did not occur. The moisture contents ranged from 82.23% to 114.97%. There were no significant differences in drying characteristics, but moisture content differed significantly between regions.

Based on the drying characteristics and moisture content, two proposed kiln schedule, ($D_{34}W_{34}$) with dry bulb temperature range of 55-80˚C, wet bulb depression range of 4-30˚C, and relative humidity range of 81-22 % for 25 mm thick lumber from Nattalin, Oaktwin and Bago provenances, and ($D_{35}W_{35}$) with dry bulb temperature range of 55-80˚C, wet bulb depression range of 4-30˚C, and relative humidity range of 81-22 % for 25 mm thick lumber from Paukkhaung, Kanbalu, Taungoo, Phyu and Thabeikkyin provenances were developed.

It is recommended that, if the dried wood does not develop checks and deformation in using the kiln schedule $D_{34}W_{34}$ (milder drying condition), kiln schedule ($D_{35}W_{35}$) with a larger wet bulb depression value (low relative humidity) should be used to reduce the production cost and energy consumption. If the dried wood develops checks and deformation, in using the kiln schedule $D_{35}W_{35}$, kiln schedule $D_{34}W_{34,}$ drying condition with a low wet bulb depression value (high relative humidity) should be used to prevent the initial checks and deformations. Being plantation teak of the same species and age, if the density is approximately the same, the wood from the eight provenances can be dried together with the milder drying condition first.

These two drying schedules are inferred from the most severe defects, so it would be minimize surface and end checking, and deformation in kiln drying because starting with a moderate temperature and moderately high relative humidity.

These research findings can be applied to the early estimation of possible development of drying characteristics during the kiln drying process of 25 mm thick lumbers from 15 years old plantation teak. It is expected that this information will be useful for wood-based industries in order to make industrial production profitable and to optimize resource use.

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