# Relationship between Wood Properties and Developed Drying Schedule of Inferior Teak (*Tectona grandis* L.F) and Mahogany (*Swietenia macrophylla* King)

Tomy Listyanto, Ganis Lukmandaru, Chandra Pramadya, Dwi Siswanto, and Nobuaki Hattori

**Abstract**

Development of drying schedule has been a critical issue on a drying process concerning the changing of material condition, especially in Java. Established drying schedule used to be purposed for a high quality timber. The aims of this study were to develop drying schedule of inferior teak and mahogany, and to analyze the relationship between the drying schedule and its wood properties.

The specimens were taken from 25 years old teak and 20 years-old mahogany. Wood density, sapwood percentage and extractive contents were determined as wood properties. Four types of specimen's dimensions (25 x 30 mm; 25 x 50 mm; 25 x 100 mm; and 50 x 50 mm) were dried in the oven with temperature of 103$^{o}$ C until reach oven dried conditions. Levels of checks, collapse, and honeycomb were observed to develop drying schedule. A Chi square analysis was used to analyze the relationship between wood properties and the drying schedule.

The results showed that there were four types of drying schedule are applicable for teak and five types for mahogany. The most recommended schedule for teak sample was the schedule with an initial temperature (IT) was 70$^{o}$ C, relative humidity (RH) was 71%, and the final temperature (FT) was 90$^{o}$ C, while the mahogany wood was the schedule with an IT 60$^{o}$ C, RH 81%, and the FT 85$^{o}$ C, respectively. Chi square analysis indicated that the mahogany lumber dimension was significantly related to the schedule development while specific gravity, heartwood percentage, and extractive content had no significant relationship with the drying schedule development.

**Key words:** wood properties, lumber dimension, teak, mahogany, drying schedule.

## Introduction

Drying timber is important for many end use applications that require the timber to be in a stable state. Drying schedule can be defined as a series of dry and wet-bulb temperatures that establish the temperature and relative humidity in a kiln and are applied at various stages of the drying process. The schedules should be developed so that the drying stresses do not exceed the strength of the wood at any given temperature and moisture content, otherwise, the wood will crack either on the surface or internally, or be crushed by forces that collapse the wood cells (Simpson 1991). Drying schedule development was recommended by Wood Drying Working Party to improve better drying quality (Vermaas 1983) especially in tropical countries which have many species variation (Simpson 1992). Developing drying schedule by trial and error is very slow and costly. A quick method which initiated by Terazawa (1965) showed the satisfaction results to select proper drying schedule (Ilic and Hillis 1986; Jankowsky 1992).

Developing drying schedule in tropical country, including Indonesia should consider two problems. First, several species do not have any drying schedule, though the schedules were developed based on good quality lumber and conducted long years ago. In addition the drying schedules were developed and recommended as conservative starting points (Simpson 1996). A second problem is that might not a practice to dry one species in dry kiln due to the abundant and the heterogeneous supplied species lumber. Therefore, it is required to develop drying schedule for a group of species. It is important to investigate a suitable drying schedule for differences in kilns and with wood property variations within a species (Boone *et al*. 1988). Density, heartwood percentage, and extractives play important role in developing drying schedule as well as lumber dimension (Meyer and Barton 1971; Hisada and Sato 1976; Durand 1985; Simpson 1996).

Recently, supply of high quality (old grown timber) as the raw material for furniture in Java from plantation forest mainly in teak and mahogany is significantly decreasing. The timber which is available now and will be the source of the future supply is mainly young one which is of inferior quality harvested from community forests. These inferior quality might be due to much shorter rotations and lack of proper silviculture practices and thus trees from these plantations have shorter clear stems, inferior wood properties, including physical and mechanical properties, very high growth stresses, and low dimensional stability (due to the absence and/or lower proportion of heartwood) (Listyanto and Nichols 2009). These inferior properties and characteristics become major constraints for producing high quality furniture for more competitive international markets. Unfortunately, drying process of teak and mahogany lumber has been known as the bottleneck of the processing due to its low permeability. This might be due to its anatomical features which has short and wide vessel, small inter-vessel pits, and short fiber (Ahmed and Chun 2010). Moreover, pits of teak have been known to be heavily encrusted such as by tylosis.

Taking into consideration the above described problems, it is important to developed new drying schedule of inferior teak and mahogany from community plantation forest. The aims of this study were to develop drying schedule of inferior teak and mahogany, and to analyze the relationship between the developed drying schedule and its wood properties.

## Materials and Methods

The samples were taken from 25 years old teak (*Tectona grandis* L.F.) and 20 years old mahogany (*Swietenia macrophylla* King) harvested from community plantation forest in Purworejo, Central Java Province. A total of 96 samples in four different dimensions (25 x 30 mm; 25 x 50 mm; 25 x 100 mm; and 50 x 50 mm; in width and thickness, and 200 mm in length) were cut from both species. Both two ends of the samples were sealed with wax to avoid excessive evaporation in longitudinal direction. All specimens were dried in the oven with temperature of 103°C until reach oven dried conditions followed the method initiated by Terazawa (1965). The specimens were weighed and measured in level of checks and collapse (Table 1). Afterwards, the samples were cut in the middle and evaluated in honeycombing level. The most severe defect then used as primary key to select proper schedule (Table 2). The detailed procedure can be seen in Terazawa (1965) which was modified and adjusted by Jankowski (1992).

Heartwood percentages of each sample were also calculated. Wood specific gravity and extractive content of the sample were taken from the near part of the drying schedule sample in the certain select one. Determining of wood density was following the standard of BS 373 (1957) while extractive contents were measured based on alcohol-benzene method. A Chi square analysis was used to analyze the relationship between wood properties and the drying schedule. Specific gravity, heartwood percentage and extractive content were divided into classes based on statistical method in which equation $N = 1+3.3 \log n$, where N is number of class and n is total used sample. The length of class was determined by dividing the distance between maximum and minimum value of parameters by the number of class.

Commercial test was conducted for both teak and lumber with dimension in 25 mm thickness and 2000 mm length by applying the schedule with an initial temperature (IT) 60°C, relative humidity (RH) 81%, and the final temperature (FT) 80°C. The level of checks, collapse, honeycomb and warping were observed as parameters of drying quality.

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

| Level of defects | Checks | | Collapse | Honeycomb |
|---|---|---|---|---|
| | End checks (mm) | Surface check (mm) | (A-B) (mm) | |
| 1 | No check | No check | 0~0.3 | No |
| 2 | P<10<br>L<0.8 | P<50<br>L<0.5 | 0.3~0.5 | 1~2 |
| 3 | P>10<br>L<0.8 | 5 < P<100<br>1 <L<1.5 | 0.5~0.8 | 3~4 |
| 4 | P<10<br>0.8 <L<1.5 | P<150<br>L<1.5 | 0.8~1.2 | 5~7 |
| 5 | P>10<br>0.8 <L<1.5 | P>150<br>L>1.5 | 1.2~1.8 | 8~10 |
| 6 | P>10<br>L<0.8 | P>150<br>L>1.5 | 1.8~2.5 | >10 |
| 7 | P>10<br>L<0.8 | P>150<br>L>1.5 | 2.5~3.5 | |
| 8 | P>10<br>L<0.8 | P>150<br>L>1.5 | > 3.5 | |

Table 2. Drying schedules based on level of checks, collapse and honeycombing based on Terazawa (1965).

| Type of defects | Drying schedule | Grade of defects | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (°C) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Checks | Initial temperature | 70 | 65 | 60 | 55 | 53 | 50 | 47 | 45 |
| | Wet bulb depression | 6.5 | 5.5 | 4.3 | 3.6 | 3.0 | 2.3 | 2.0 | 1.8 |
| | Final temperature | 95 | 90 | 85 | 83 | 82 | 81 | 80 | 70 |
| Collapse | Initial temperature | 70 | 66 | 58 | 54 | 50 | 49 | 48 | 47 |
| | Wet bulb depression | 6.5 | 6.0 | 4.7 | 4.0 | 3.6 | 3.3 | 2.8 | 2,5 |
| | Final temperature | 95 | 88 | 83 | 80 | 77 | 75 | 73 | 70 |
| Honeycombing | Initial temperature | 70 | 55 | 50 | 49 | 48 | 45 | - | - |
| | Wet bulb depression | 6.5 | 4.5 | 3.8 | 3.3 | 3.0 | 2.5 | - | - |
| | Final temperature | 95 | 83 | 77 | 73 | 71 | 70 | - | - |

## Results and Discussion

Grade of checks, collapse, and honeycomb for four different dimensions of teak and mahogany lumber are presented in Table 3. Checks have dominated the defect types of teak and mahogany lumber, except in teak samples which have dimension 25 by 30 mm. Based on the Table 3, drying schedules of teak and mahogany lumber can be developed as can be seen in Table 4. There were four variations of drying schedule for teak lumber and five variations for mahogany lumber. However, the most recommended drying schedule for teak lumber was the schedule with an IT in 70ºC, RH in 71% and the FT in 90ºC (Sch. 4), while for the mahogany lumber was the schedule with an IT in 60ºC, RH in 81%, and the FT in 85ºC (Sch. 3). The both detailed scheduled are presented in Table 5 and Table 6. This schedule was more severe than developed drying schedule by Boone (1988). The drying schedule can be set up more severe because the lumber showed insusceptibility from checks and collapse to obtain more drying rate and to reduce required energy. The insusceptibility might be due to the better moisture diffusion during drying process which reduces the different moisture distribution between surface and inside part.

Chi square analysis indicate that drying schedule between teak and mahogany lumber is significantly correlated (λ = 21.36, df = 4, α = 0.05). The percentage of the drying samples that distribute in different level of the drying schedule can be seen in Figure 1a. Generally, drying schedule of teak lumber was quite harder than mahogany. Therefore, mahogany lumber was not allowed to be set up more severe than teak lumber because the higher percentage of the sample susceptible with checks and collapse (Terazawa *et al*. 1984).

The commercial test showed that drying rate of mahogany was higher than teak lumber (Figure 1b). The level of checks, collapse, honeycomb and warping were also fine. This result indicates that there were some wood properties of teak that play important role on affecting drying schedule. Some of wood properties were examined in later part in this paper. Subsequently, it was suggested that mahogany and teak lumber should not be mixed up in the one batch drying.

Chi square analysis showed that variation of teak lumber dimension was not significantly related (λ = 15.36, df = 9, α = 0.05) to the development of drying schedule. This result indicated that the different of lumber dimension was not enough to segregate drying schedule and lumber dimension of teak. However, the significant relationship (λ = 55.94, df = 12, α = 0.05) occurred between lumber dimension and drying schedule in mahogany. Therefore, it can be stated that mahogany lumber dimension between 25 x 30 mm and 25 x 100 mm were allowed to put in one kiln drying with the schedule level of 5 while lumber dimension 50 x 50 mm should be put single-handedly in drying schedule level 4 (Figure 2). Interestingly, mahogany lumber dimensions 25 x 50 mm was recommended to dry in kiln drying with schedule level 3 which was lower than two other specimens though both have an equal thickness. This result indicated unconformity with the idea that similar thickness has similar characters in drying (Langrish and Walker 2006). This might be due to some wood properties of the lumber that the drying characteristics were affected than the thickness factor. This phenomena was supported by Pang (2002) as that thickness factors might not directly affected the drying process due to other wood properties which influencing simultaneously.

As a stated in the previous discussion, it was important to investigate the relationship of wood properties on developed drying schedule. The wood properties that might have important role on drying schedule are specific gravity, heartwood and extractive contents. However, this study showed that those three wood properties have no significant relationships with developed drying schedule. The specific gravity of the teak samples were in the range of 0.43~0.84 which distributed in 4 classes while mahogany samples were the range of 0.40~0.67 which distributed into 7 classes. The relationship between drying schedule and specific gravity was not significant for both teak lumber (λ = 9.20, df = 9, α = 0.05) and mahogany one (λ = 24.9, df = 24, α = 0.05). The changing of drying schedule responded randomly to the changing of specific gravity. This result showed contrary with the study of Zhang *et al*. (1996) that higher density should be separated with the lower density in drying process because of different level of drying rate and defects. This might due to the changing of specific gravity which was not enough as important factor affecting developing drying schedule. The response of drying schedule might not consistent because the denser wood showed more favorable for heat conduction compare to lighter one but denser wood was less permeable than lighter wood (Pang 2002).

Chi square analysis also indicated that there was no significant relationship between heartwood percentage and developed drying schedule for both teak lumber (λ = 12.84, df = 18, α = 0.05) and mahogany lumber (λ = 25.92, df = 24, α = 0.05), respectively. The higher heartwood percentage sample in which showed lower level of drying schedule because of higher proportion of juvenile wood since the sample cut from young age. The juvenile wood was part of the wood that shows higher risk of checks, honeycomb and collapse compare to mature wood. Another reason was that heartwood percentage acts simultaneously with thickness and initial moisture content in which the samples condition in this study might not enough strength to segregate the drying schedule (Pang 2000).

Extractive contents of teak sample were in the range of 3.12~9.69% which divided into 7 classes while extractives contents in mahogany lumber were in the range of 9.89~18.38% which divided into 5 classes. According to Chi Square analysis, the relationship between extractive content and drying schedule was not significant for both teak samples (λ = 19.72, df = 18, α = 0.05) and mahogany samples (λ = 18.49, df = 24, α = 0.05). It appear that in this study, extractives did not act primarily as bulking agents or increase the plasticity of cell wall causing increased shrinkage and collapse during free water movement (Meyer and Barton 1971).

Table 3. Value of defect level of four different dimension lumber of teak and mahogany.

| Sample dimension (mm) | Species | Level of defects | | |
|---|---|---|---|---|
| | | Checks | Collapse | Honeycomb |
| 25 x 30 | Teak | Level 1 | Level 1 | Level 1 |
| | Mahogany | Level 1;2;3 | Level 1;6 | Level 1 |
| 25 x 50 | Teak | Level 1;2 | Level 1 | Level 1 |
| | Mahogany | Level 1; 2; 3; 4 | Level 1 | Level 1 |
| 25 x 100 | Teak | Level 2;4 | Level 1 | Level 1 |
| | Mahogany | Level 1; 3; 4 | Level 1 | Level 1 |
| 50 x 50 | Teak | Level 3 | Level 1 | Level 1 |
| | Mahogany | Level 1;3 | Level 1 | Level 1 |

Table 4. Classification of drying schedule of teak and mahogany.

| No | Schedule Code | Initial temperature (ºC) | Wet bulb depression (ºC) | Final temperature (ºC) | Species |
|---|---|---|---|---|---|
| 1 | Sch. 1 | 49 | 3.3 | 70~80 | Mahogany |
| 2 | Sch. 2 | 55 | 3.6 | 70~80 | Teak, Mahogany |
| 3 | Sch. 3 | 60 | 4.3 | 70~80 | Teak, Mahogany |
| 4 | Sch. 4 | 65 | 5.5 | 90~105 | Teak, Mahogany |
| 5 | Sch. 5 | 70 | 6.5 | 95~105 | Teak, Mahogany |

Table 5. Recommended drying schedule for teak.

| MC (%) | Dry Bulb (°C) | Wet bulb depression (°C) | Relative Humidity (%) | EMC (%) |
|---|---|---|---|---|
| 60~40 | 70 | 6.5 | 71 | 10.5 |
| 40~35 | 75 | 10 | 63 | 8.5 |
| 35~31 | 80 | 14 | 53 | 6.5 |
| 31~27 | 85 | 20 | 41 | 5 |
| 27~24 | 85 | 25 | 32 | 4 |
| 24~21 | 95 | 30 | 27 | 3 |
| <21 | 90~105 | 30 | 30 | 3 |
| Equalizing and conditioning | | | | |

Table 6. Recommended drying schedule for mahogany.

| MC (%) | Dry Bulb (ºC) | Wet bulb depression (ºC) | Relative Humidity (%) | EMC (%) |
|---|---|---|---|---|
| 60~40 | 60 | 4.3 | 81 | 13.5 |
| 40~35 | 60 | 5.5 | 77 | 12.5 |
| 35~31 | 65 | 8 | 66 | 10 |
| 31~27 | 70 | 13 | 55 | 7.5 |
| 27~24 | 70 | 17 | 44 | 6 |
| 24~21 | 75 | 21 | 38 | 5 |
| <21 | 80~90 | 25~30 | 30 | 4 |
| Equalizing and conditioning | | | | |

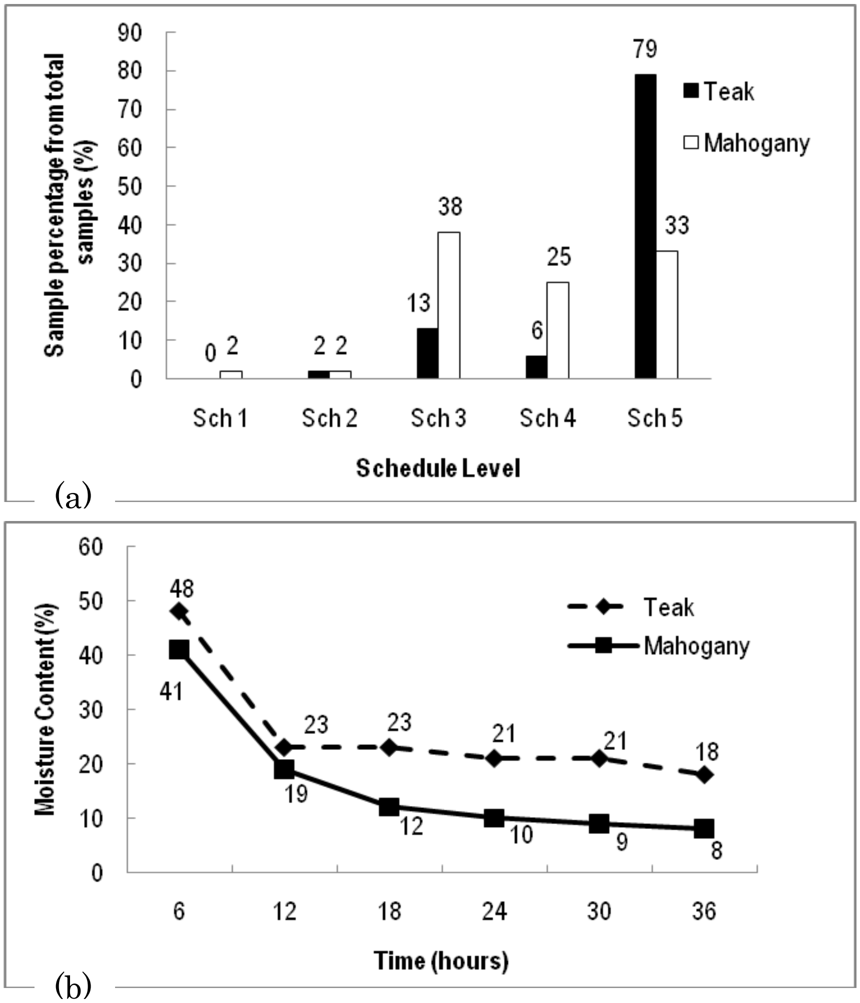


Figure 1. (a) Sample percentage of teak and mahogany specimens in different level of drying schedule;
(b) Drying rate of teak and mahogany by applying the schedule with an IT 60°C, RH 81%, and the FT 80°C.

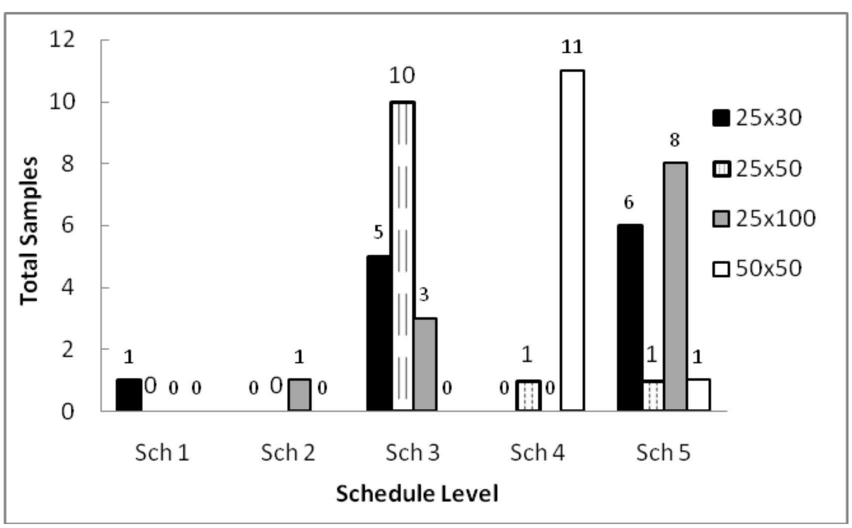


Figure 2. The distribution of mahogany lumber dimension in different level of drying schedule.

## Conclusions

Optimum drying schedule in this study, for teak sample was found that an initial temperature (IT), Relative Humidity (RH), and the final temperature(FT) were 70ºC, 71%, 90ºC, respectively, while the mahogany wood was the schedule with an IT 60ºC, RH 81%, and the FT 80ºC. Lumber dimension had significantly relationship with the schedule development for mahogany. In contrast, specific gravity, heartwood percentage, and extractive content had no significant relationship with the drying schedule developed. However, it should be considered that the tendency of the response of the drying schedule on specific gravity, heartwood percentage and extractive contents only in this samples condition of teak and mahogany lumber. It was suggested to conduct more research which uses other species which have wider difference in density, heartwood percentage and extractive content. Relationship between drying schedule and anatomical properties might be also important to be investigated.


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Tomy Listyanto, Ganis Lukmandaru,
Candra Pramadya and Dwi Siswanto
Faculty of Forestry, Gadjah Mada University,
Jl. Agro No 1. Bulaksumur, Yogyakarta, Indonesia
Tel./Fax. : +62 274 550541
Corresponding : tomy.listyanto@gadjahmada.edu

Tomy Listyanto and Nobuaki Hattori
United Graduate School of Agriculture Science,
Tokyo University of Agriculture and Technology,
3-8-1 Harumi-cho, Fuchu-shi, Tokyo, 183-8538, Japan
Tel./Fax. : +81 042-371-0434