Effects of Thermal Treatment on Physical Properties of Teak Veneer (*Tectona grandis*)

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Thermo treatment on veneer has been recognized as environmentally friendly and can modify wood properties. The objectives of this study were to investigate mass loss of thermo-teak veneer, to assess the density changes, and to examine shrinkage based on different levels of temperature at different time lengths. The temperatures were 180, 200, 220, and 240 °C applied at three different lengths of time, *i.e.,* 4, 8, and 12 min on teak veneer sheets. The results showed that the mass loss at the temperature of 180, 200, 220, and 240 °C were not significantly different. Density changes were significant depending on the level of temperatures. Percentage of density decrease changed from 3.85% to 15.69% at temperatures ranging from 180 to 240 °C but the length of time (4, 8, and 12 min of thermal treatment) did not have a significant effect. The mass loss ranged from 5.90% to 17.66%.

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INTRODUCTION

The European zone has high restricted use of wood chemical preservatives that are considered toxic, as the market requirement for durable products from modified wood has been increased recently (Sandberg *et al.* 2017). As a solution, the thermal wood modification method is environmentally friendly; it was introduced by the Forest Product Research Laboratory (FPRL) in the early 20th century (International Thermo-wood Association 2003).

Teak veneer is one of the most famous of wooden products, *i.e.* the teak veneer market has been increased by 1.5 times from 2006 to 2021, thus contributing to an economic growth of 36% (Cabuk *et al.* 2011). However, the production of teak veneer in Laos is low due to a lack of plywood manufacturers that are currently focusing on the export market. Thus the production of engineered wood products may add value to small-diameter teak logs in Laos that are grown by smallholders. The main product of teak veneer is wood base panel such as plywood, LVL, and decorations (Wiedenbeck 2004).

Teak woods grown in Malaysia and Myanmar are very durable against termites. For example, Wong *et al.* (1998) visually rated termite attached teak in Malaysia as 0, with a mass gain of 1%. In addition, Myanmar teak had a visual rating of 0, with a mass gain of 8%, and Lao teak was rated very resistant to *Coptotermes formosanus* (Wong *et al.* 1998). May (2003) reported that natural durability, dimensional stability, cellulose, and lignin content in the teak wood were different in volume depending on teak age.

Heat treatment results showed significant changes in the properties of wood (Bal and Bektaş 2012). The thermo-wood at temperatures higher than 150 °C from 2 to 10 h can reach 3% of the mass loss for solid wood (Esteves and Pereira 2009). The mass loss value of earlywood is greater than those heartwood, and the highest mass loss in wood that was treated at 180 °C for 8 h for *Eucalyptus grandis* at sapwood was higher than heartwood by 0.23% (Bal and Bektaş 2012). Another timber species, teak wood, showed increasing mass loss with the increase of temperature level. For example, mass loss ranged between 1.6 to 5.9% as per the increase of the temperature from 170 to 210 °C. However, treated with the temperature at 180 °C for 3 to 5 h, the mass loss was 4.3% (Cuccui *et al.* 2017). Other studies on beech, poplar, and spruce species showed that for treatment at 200 °C for 3 h, the mass loss was 6.9%, 10.4%, and 4.5%, respectively (Čermák *et al.* 2015).

Thermo-wood treatment is affected directly by the moisture content in wood. The length of time and temperature are the two key parameters that affect the mass loss in wood (Holger 2002; Esteves and Pereira 2009; Ignazia *et al.* 2017). Thermo-wood in the lower temperature reduces the amount of moisture content. In addition, the mass loss is lower than that at the higher temperature.

The density of teak wood through thermal treatment at different temperatures can be decreased by 12% at 210 °C and 9% at (215 °C and 220 °C) for the 25-mm thick veneer when heated for 3 h (Méndez-Mejías and Roque 2016). Teak dimensions of 2 x 2 x 5 cm have been treated at 120, 150, and 180 °C for 2 and 6 h; the density average was decreased by 3.58% which indicated no significant difference due to temperature (Priadi *et al.* 2019). This work was done considering the estimation method suggested by Simpson (2006), that when applying a temperature of 180 °C on 20-mm thick board, it takes 18 min to reach the core of the board. Heat modification is expected to improve the physical properties of young (15-year-old) teak wood. The density of the teak wood slightly decreases after heat treatment. Its dimensional stability improves substantially, and it exhibits reduced water absorption (Kačíková *et al.* 2020). However, thermal wood has decreased density.

Méndez-Mejías and Roque (2016) reported that the shrinkage was decreased based on the increase of temperature. The study found that the shrinkage of teak veneer was 11.05% when thermal wood was treated at 210 to 215 °C, and shrinkage was 7.89% when treatment was at 220 °C for 6 h. However, in contrast, other studies found that the shrinkage was increased based on the increase of temperature. For instance, the shrinkage was 2% at 130 °C, 2.27% (150 °C), 2.36% (180 °C), and 2.80 at 210 °C (Uribe and Ayala 2015). Higher temperature increases shrinkage (Uribe and Ayala 2015; Méndez-Mejías and Roque 2016).

Thermo-wood products can also give dimensional stability, so this study supports improving the quality of the wooden products for further manufacturing and other construction purposes. The objectives of this study were to investigate mass loss of thermo-teak veneer, to assess the density changes, and to examine shrinkage based on the different level of temperature at different applied time lengths.

EXPERIMENTAL

Materials

Teak plantation logs of 18 years old from the first thinning practice plantation were used in this study. The plantation teak was located at 18°08’02.66” N, 102°45’44.51” E at Napork village, Xaythany District, which is 24 km from Vientiane, the Capital City, Laos. A spindleless peeling lathe machine (model 1350/3, BSY Industry China, Weihai City, China) was used for peeling veneer. A Quintix5101-1S digital balance was supplied by Scientific Construction Co. Ltd (Goettinggen, Germany). A small wood hot pressure machiner (model STK No. 44-275, DAKE, Grand Haven, MI, USA) and dial thickness gauge digital calipers (code 34-506, Measumax, Melbourne, Australia) were used. The experiments were conducted at the laboratory of Department of Forest Economics and Wood Technology, Faculty of Forest Sciences, National University of Laos.

Methods

The veneer was cut into pieces measuring 2 mm x 400 mm x 400 mm with a total of 60 pieces of peeled veneer; the moisture content of veneer ranged from 6 to 12% based on air-dry weight. The thickness of veneer was measured using a digital caliper and weighing the samples on a digital balance. The thermo processes were based on the factorial design as 4 x 3 x 5 = 60 (four different temperatures, *i.e.*, 180, 200, 220, and 240 °C; three different times, *i.e.*, 4, 8, and 12 min for the treatment of five peeling veneer at a time) and re-weighing and measuring the thickness of samples.

Mass loss is used as the main parameter for denoting the modification intensity of treatment (Cuccui *et al.* 2017). Mass loss (ML, %) was determined by weighing the veneer sample before and after thermal treatment, one by one peeling veneer with the pressure of 5 metric tons. The calculation is shown as Eq. 1,

$$ML = \frac{(M_d - M_{hp})}{M_d} x100 \tag{1}$$

where M_d is the mass of veneer after drying (g) at MC (6 to 12%), and M_{hp} is the mass after thermo by a hot press machine (g).

The change in density (D_{change}) after thermo treatment was calculated using Eq. 2 (Méndez-Mejías and Roque 2016),

$$D_{change} = \frac{(D_{dry} - D_{hp})}{D_{dry}} x100 \tag{2}$$

where D_{dry} is the veneer density before thermo (g/cm^3), and D_{hp} is the veneer density after thermo (g/cm^3). Veneer shrinkage was estimated from the changes of dimension before and after thermo calculated using Eq. 3.

$$Shrinking = \frac{[(thickness\ before\ thermo\ (mm) - thickness\ after\ themo\ (mm))]}{thickness\ before\ thermo\ (mm)} x100 \tag{3}$$

Analysis of variance (ANOVA) was used to compare between groups of samples based on temperature levels and length of pressing time on the mass loss, shrinkage, and density. Linear regression analysis was also used to see the relationship between the temperature level on the shrinkage of veneers. In addition, the multiple regression analysis was used to see the influenced parameters on the mass loss of veneer.

RESULTS AND DISCUSSION

Table 1 shows the average mass loss from air drying before thermo treatment and after the treatment, which was affected by the different temperatures (180 °C, 200 °C, 220 °C, and 240 °C) and time length (4, 8, and 12 min). The results showed no significant difference between 4, 8, and 12 min, *i.e.*, p=0.89. The average mass loss was 9.79 ± 0.67%, 9.70 ± 1.14%, and 9.90 ± 0.4% for the group of 4, 8, and 12 min, respectively. Because there was no significant difference in mass loss, the average mass loss for this experiment was 9.80 ±0.7%. Due to the limitation of study on teak veneer of 2-mm thickness, the authors attempted to compare with previously published results (Cuccui *et al.* 2017) where solid wood of 28-, 33-, and 40-mm thickness was treated for 3 h but with a vacuum dryer. The comparison found that the mass loss was 5.3% higher than this current study at the temperature of 200 °C. Mass loss ranged from 8.29% to 10.78% at four different temperatures of 180 °C, 200 °C, 220 °C, and 240 °C with three times (4 min, 8 min, and 12 min).

The value of teak mass loss was higher than the findings by Ignazia *et al*. (2017), which ranged between 1.6 to 5.9% as per the increase of the temperature at 170 to 210 °C for the solid wood of thickness, 28 mm, 33 mm, and 40 mm. The veneer thickness was 2 mm, which had a quicker effect on mass loss (0.75%/min) compared with the 15-mm beech board (0.02%/min) (Čermák *et al.* 2015) and 0.04%/min for 25-mm pine wood (ITA 2003). Times for this study were shorter than others (Esteves and Pereira 2009; Cihad and İbrahim 2012; Čermák *et al.* 2015; Ignazia *et al.* 2017); time was not a significant factor at p = 0.42 (p>0.05). Because the thinner layer of veneer can receive heat quicker than thicker wood (Simpson 2006), mass loss was greater in thinner wood.

Table 1. Influence of Temperature and Time on Mass Loss

Temperature (°C)	Mass Loss (%)		
	4 min	8 min	12 min
180	8.90±1.68	9.31±1.11	9.55±0.52
200	9.82±0.52	8.29±2.82	9.49±0.44
220	9.79±0.54	10.34±0.98	10.34±0.77
240	10.58±0.54	10.87±0.74	10.21±0.57

Note: Values shown are averages ± standard deviation

Different temperatures had an impact on teak veneer mass loss (p= 0.0006) at 180 to 240 °C. The mass loss for 4 min at 180 °C (8.95%) increased to 0.87% at 200 °C and 220 °C and 1.63% at 240 °C. The mass loss for 8 min was 8.28% at 200 °C and increased to 1.02% at 180 °C and 2.68% at 240 °C. The mass loss for 12 min of any temperature was less than 1% different. However, the multiple regression model was expressed in Eq. 4 with R^2=0.18. The experiments used a short time for heat treatment (4, 8, and 12 min). Thus, to detect a significant difference of mass loss, the treatment time should be extended.

$$ML = 4.6333 + 0.0241 * T + 0.0135 * t \quad (4)$$

where *ML* is the mass loss, *T* is the temperature (ºC), and *t* is time (min).

Table 2 shows average density decrease after thermal treatment that was affected by different temperatures (180, 200, 220, and 240 °C) with time length (4, 8, and 12 min) with each temperature level. For the treatment of different temperatures at 4, 8, and 12 min, there was no significant difference from one-way ANOVA analysis between groups, *i.e.*, p=0.54 (p>0.05). The average percentage density decrease was 7.74±5.82%, 9.998±7.02%, and 9.77±7.02% for 4, 8, and 12 min, respectively. This result was similar to a previous report (Méndez-Mejías and Roque 2016) that treated for 3 h but different from another study (Priadi *et al.* 2019) which reported that the percentage density was decreased by 5%.

Different temperatures had a significant impact on teak veneer density; the p-value between groups was 0.00 (p<0.05). The different groups of density for 180 and 240 °C are shown in Table 3.

Table 2. Average Density Decrease in Teak Veneer after Hot Press Thermal Treatment with Different Times and Temperatures

Temperature (°C)	Density Decrease (%)		
	4 min	8 min	12 min
180	3.85±2.77	4.08±1.74	3.67±2.39
200	5.93±2.59	8.37±4.74	9.22±4.45
220	5.48±2.05	11.77±5.41	11.81±9.93
240	15.68±5.87	15.69±9.36	11.97±8.87

Note: Values shown are averages ± standard deviation.

Table 3. Multiple Comparison of Thermo-teak Veneer and Different Temperature Levels

Temperature I (°C)	Temperature J (°C)	Mean Different (I-J)	p-value	sig
180	200	-3.97	0.05	*
	220	-6.67	0.00	**
	240	-10.57	0.00	**
200	220	-2.70	0.18	NS
	240	-6.60	0.00	**
220	240	-3.90	0.06	NS

*, Significant; **, highly significant; NS, not significant

The multiple regression model (Eq. 5) was considered as low (R^2=0.33),

$$D = -27.7225 + 0.1679 * T + 0.1790 * t \quad (5)$$

where *D* is the density change in percentage (%), *T* is the temperature (ºC), and *t* is time (min).

High temperature level significantly affected the density of teak veneer, which was similar to previous results (Méndez-Mejías and Roque 2016). For instance, after thermal treatment at 210 °C, the density of teak decreased by 12%, and it decreased 9% at 215 °C (ITA 2003).

Linear regression analysis was plotted for the thermal treatment at 8 min at the different levels of temperature (180, 200, 220, and 240 °C). The shrinkage change depended on temperature (R^2=0.92). As shown in Fig. 1, the low temperature shrinkage change was lower than high temperature (11.42%, 11.78%, 15.40%, and 17.66% at 180, 200, 220, and 240 °C, respectively). The results at 4 and 8 min were significantly lower (R^2=0.07 and R^2=0.02, respectively).

One-way ANOVA analysis compared between group results showed that times and temperatures were not significant (p=0.81 and p=0.12), but the temperature at 180 °C for

4 min gave 12.27% of shrinkage, for 8 min was less than 0.85%, and 12 min was less than 2.49%; when the temperature increased to 200 °C, the shrinkage was 5.90%, 5.88%, and 11.27% for 4, 8, and 12 min, respectively; then at 220 °C, the shrinkage was 8.76%, 6.64%, and 4.04% at 4, 8, and 12 min, respectively; at 240 °C, the shrinkage was 13.77%, 3.89%, and 3.79% for 4, 8, and 12 min, respectively. This 4 min result was similar to a previous study that treated teak wood (7.89% at 220 °C) (Méndez-Mejías and Roque 2016). The veneer surface of 1600 cm^2 had 4 to 7 knots, representing 30 to 60% of the total surface area. The knots could be the reason for the abnormal shrinkage.

One-way ANOVA of temperature differences and time showed that the shrinkage values were not significantly different. The multiple regression model (Eq. 6) was considered as low (R^2=0.03),

$$Shr = 1.1307 + 0.2768 * T + 0.0422 * t \quad (6)$$

where *Shr* is shrinkage (%), *T* is temperature (ºC), and *t* is time (min).

Méndez-Mejías and Roque (2016) showed that shrinkage was based on the different temperature levels, such as 7.89% at 220 °C and 11.05% at 210 °C. However, results in Table 4 show that time length of thermos for 4, 8, and 12 min was not significant.

Table 4. Thickness Shrinkage after Thermal Treatment with Different Length of Times and Temperature

Temperatures (°C)	Thickness Shrinkage (%)		
	4 min ±SD	8 min ±SD	12 min ±SD
180	12.27±6.31	11.42±5.91	9.78±6.64
200	5.90±5.92	11.78±5.59	17.17±6.82
220	8.76±3.70	15.40±8.83	12.80±8.20
240	13.77±7.41	17.66±5.57	9.80±4.34

CONCLUSIONS

1. Mass loss depended on the temperature. The time length of thermal treatment for 4, 8 and 12 min did not show a significant difference. The mean mass loss was 9.80 ± 0.7%.
2. Density changes were significant at different temperatures. Percentage density decrease changed from 3.85% to 15.69% at temperatures ranging from 180 °C to 240 °C, but different times of 4, 8, and 12 min of thermal treatment did not produce significant changes.
3. Shrinking thickness temperatures and times were not significantly different. The results ranged from 5.90% to 17.66%.
4. Applying the length of time for thermal treatment for 4, 8, and 12 min at 180, 200, 220, and 240 °C on a 2-mm thick teak veneer resulted in no significant difference in the teak veneer properties. Thus, it is suggested to find out whether expanding the time length of thermal treatment more than 12 min would significantly change veneer properties.

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