Physical and mechanical properties of Tectona grandis wood after oil heat treatment process

R Wahab1,2, R Kamarulzaman1,2, S M Razali1, M S Sulaiman1,2, N Mokhtar1,2, T Edin1,2 and M H Razak3

1Centre of Excellence in Wood Engineered Products, 96000 Sibu, Sarawak, Malaysia
2University of Technology Sarawak (UTS), 96000 Sibu, Sarawak, Malaysia
3Universiti Sains Malaysia (USM), 11800 USM Penang, Malaysia

* Corresponding author: drrazakw5181@uts.edu.my

Abstract. A study was carried out to investigate the effect of an oil heat treatment process on the physical and mechanical properties of the 10 and 15-year-old cultivated Tectona grandis wood. All the wood specimens typically possess the sapwood having lighter colour than the dark colour heartwood, and turning these woods into products at this stage results in uneven colour due to the combination of sapwood and heartwood. The situation was to decrease the aesthetic value of the product. Therefore, the oil heat-treatment process enhanced and improved the physical and mechanical properties of the wood in the long run. In designing this study, factors such as the wood height, wood portion, temperatures applied, and treatment duration are considered. The sapwood and heartwood of wood underwent the hot oil treatment process using oil palm crude oil at 160°C, 200°C, and 240°C for 2 hours., respectively. The physical and mechanical properties of the treated wood were determined following the ASTM standards. The relationship between the physical and mechanical properties and treatment variables was determined using the correlation analysis. The results showed that temp. is one of the main variables affecting the properties of treated wood.

Keywords: Cultivated Tectona grandis; oil heat-treatment; temperature; duration; properties.

1. Introduction
Tectona grandis, commonly known as teak, is a tropical hardwood native to India, Sri Lanka, and Southeast Asia. Teak wood is recognized as one of the most durable wood favoured for furniture, especially for outdoor use. It is known to withstand sun, rain, snow and frost. After years of exposure to these harsh conditions, the furniture made from teak can remain dimensional stable, though with slight changes in its colour. Still, the natural beauty of the colour change is considered by some to be aesthetic [1]. Tectona grandis contains natural oils that repel water [2] and silica, preventing warping, deforming, and rottin [3]. The teak wood is also known to have great flexibility, enabling it to withstand high pressure without cracking. Apart from that, the dense fibres of teak wood make it relatively easy to cut and graft, popularizing it as one of the finest wood for outdoor furniture [4]. It also have high resistance towards insects and fungi attacks. Still, they are not entirely immune to the insect attacks and rots, especially at the sapwood part, due to fewer extractives or deciduous oil in it. Late formed heartwood is also less durable than the heartwood from mature trees. Consequently, plantation teak wood quality at a young age will differ from forest harvested old teak trees [5].

Low timber supply due to high demand will also encourage wood industries to fully utilize the sapwood portion and the juvenile heartwood portion of teak wood even if they are less durable, making it more susceptible to decay. Hence, heat treatment can be applied to increase the resistance of the wood towards insect and fungi attacks, thus enhancing the lifespan of these wood products. The heat treatment is one of the wood modification processes used in the wood industry [6,7]. The oil-curing treatment is considered an environmental-friendly process as it does not use chemicals [6]. The objectives of this study were to investigate the physical and mechanical properties of the oil heat treatment process on the cultivated Tectona grandis wood. The results of this study will be beneficial to the Malaysian wood-based industry.
2. Methodology
Three *T. grandis* logs (10 and 15 years) were selected randomly from a private forest plantation owned in Ranau, Sabah. The middle portion of the *T. grandis* log was prepared according to [6]. The tree cutting process was done using a chainsaw. The middle portions of the trees were then subsequently cut into sizes of 2 cm x 6 cm x 75 cm. A total of 24 wood samples from the 10-year-old *T. grandis* tree and 24 representatives from the 15 years old *T. grandis* tree were prepared. The prepared samples were directly vacuumed in plastic packaging and then immediately delivered to the laboratory to be heat treated. The parameters tested include the wood portion, age of the tree, and duration of heat treatment.

2.1 Heat treatment process
Heat treatment was performed using the oil curing method [6]. The treatment carried out using an electrical heat treatment machine, and crude oil palm oil used as the heating medium. The study conducted at 160, 200, and 240°C for 2 hours [7]. Firstly, the crude palm oil heated up to 80°C, the teak wood samples were put into a metal cage and then submerged into the heated oil. A control panel was set up to control the temperature and treatment duration. The treatment process continued for 2 hours [6]. Once completed the wood removed while the oil is still hot. The wood wiped with a cloth to prevent oil absorbed into the wood. The weight and volume were recorded before and after the treatment. The untreated *T. grandis* wood was used as the control samples.

2.2 Physical properties
The physical properties of oil heat-treated *T. grandis* wood samples and the subsequent testing were conducted following [7,8] methods and the American Society for Testing Materials (ASTM) (1990) [9].

2.3 Moisture content
The method used to determine the moisture content (MC) of the *T. grandis* is based on oven-dry weight [10]. The samples were cut to sizes of 30 mm x 30 mm x 30 mm. The ASTM D143 (1990) was applied to determine the moisture content values that determine MC’s determination at the green condition. The weight of samples was recorded, then placed in an oven at 60°C for 24 hours and later reset at 102°C for 24 hours. The sample was then removed from the oven and cooled in a desiccator for 30 minutes. Samples were taken out and weighed for the second time before being recorded.

2.4 Density and basic density
The density of wood defined as the mass per unit volume, is measured at 12% moisture content. Basic density on the other hand is defined as the mass per unit volume in oven-dry conditions [10]. In this study, each sample was cut to 30 mm x 30 mm x 30 mm. The samples were oven-dried for 48 hours at 105±2°C until a constant weight was attained. According to the previous report from [7], the dried weight was taken and placed into water under a vacuum at 700 mm Hg for 24 hours until saturated to attain green volume condition. The volume of fully saturated samples was obtained using the water displacement method. The weight displaced was then converted to the volume green.

2.5 Shrinkage
The volumetric, radial, and tangential shrinkage of the *T. grandis* samples measured based on the ASTM (1990) standard and Wahab et al. of testing small smooth specimens of timber [7,9].

2.6 Mechanical properties
The strength tests carried out were according to the ASTM D143 [9] for the standard testing of small clear specimens’ timber. The research was conducted using the Instron Testing Machine (with 100 kN max. load). The modulus of rupture (MOR) and modulus of elasticity (MOE) in the tensile test were investigated. The samples’ sizes were 300 (L) x 20 (W) x 5 mm (T) following the standard [9].
3. Results and discussion

3.1 Physical properties

3.1.1 Moisture content. Figure 1 shows the results of moisture contents (MC) for 10 and 15 years old cultivated *T. grandis* (sapwood and heartwood) under different heat treatment temperatures. Figure showed a decrease in all the MC values with the temperature of the heating medium. The wood initially shows high values in MC at 61.52% for 10 years old *T. grandis* sapwood and 60.14% for the heartwood. For the 15-year-old *T. grandis*, the MC was at 60.03% and 59.20% for sapwood and heartwood, respectively. The initial MC for the 15 years old was slightly lower than ten years old *T. grandis* wood, at 2.24% for sapwood and 1.38% for heartwood. The highest moisture content in 10-year-old wood was 87.74% (sapwood) and 89.66% (heartwood). The 15-year-old wood was 90.99% for sapwood and 91.64% for heartwood when wood treated at 240°C. Decreases in water moisture content by up to 50% for wood treated at temp. above 200°C [11]. In addition, the oil absorbed by the wood benefits the treated wood, significantly reducing water absorption [11]. The rate of decrease in moisture content is highly dependent on wood specimens, the maximum temp. achieved, and the duration of treatment [12]. The moisture content found in cell walls could affect density, strength, and dimensions of wood [13]. Wood with high moisture content have high density as the weight and volume increases. The results show the treated wood has a lower density than the untreated wood. This condition occurs due to pits in the wood undergo expansion and open during treatment at high temp. It causes the water moisture in the pits to evaporate. The moisture content in wooden vessels disappear during treatment due to higher pressure in the environment [14].

![Figure 1](image.png)

*Figure 1. Moisture contents for 10 & 15 years old cultivated *T. grandis* (sapwood & heartwood) under different heat treatment temperatures.*

3.1.2 Maximum density and basic density. The maximum density for 10 and 15 years old cultivated *T. grandis* (sapwood and heartwood) at different heat treatment temperatures, shown in Figure 2. The value was higher in the 15- than the 10-year-old for both wood types. The maximum density decreases for both sapwood and heartwood. The maximum densities of the 10- and 15-year-old sapwood were initially at 0.73 g/cm$^3$ and 0.75 g/cm$^3$, respectively. Then, the values decrease to 0.55 g/cm$^3$, 0.52 g/cm$^3$ and 0.47 g/cm$^3$ at 160°C, 200°C and 240°C for the 10-year old sapwood. For 15-year old sapwood, values decrease to 0.60 g/cm$^3$, 0.57 g/cm$^3$ and 0.55 g/cm$^3$ at 160°C, 200°C and 240°C. The maximum densities of the 10- and 15-year-old (heartwood), the values are at 0.75 g/cm$^3$ and 0.77 g/cm$^3$, respectively. The values decrease to 0.58 g/cm$^3$, 0.55 g/cm$^3$ and 0.50 g/cm$^3$ at 160°C, 200°C and 240°C for 10-year old. The value also decrease for the 15-year old wood with 0.72 g/cm$^3$, 0.60 g/cm$^3$ and 0.56 g/cm$^3$ at 160°C, 200°C and 240°C.
Figure 2. Maximum density for 10 & 15 years old cultivated *T. grandis* (sapwood & heartwood) under different heat treatment temperatures.

Figure 3 shows the results of the basic density for 10 and 15 years old cultivated *T. grandis* (sapwood and heartwood) under different heat temperatures. The results show that the basic density of 15-year-old was higher than those of the 10-year-old in both types of wood. Thus, the heartwood possesses a higher basic density than the sapwood for both wood ages. The results showed an increase in the basic results for treated logs and cores for both tree ages compared to untreated wood samples. It is because the oil molecule has penetrated the lumen or cell wall. Density increases when the oil absorbed into the cell wall and affected the wood resistance [15]. In comparison, Li reported that the increase in density is due to the cell wall thickness [16].

Figure 3. Basic density for 10 & 15 years old cultivated *T. grandis* (sapwood & heartwood) under different heat treatment temperatures.

3.1.3 Volumetric shrinkage. The results for volumetric shrinkage on samples of *T. grandis* wood aged 10 and 15 years are shown in Figure 4. The untreated *T. grandis* wood samples had the highest percentage of volume matric of shrinkage compared to treated wood for both wood type and age-group. Figure shows the percentage of volumetric shrinkage for both wood types and age groups. Again, the untreated wood experiences a high rate of shrinkage. In contrast, the oil heat-treated wood shows lower shrinkage when treated at 160°C and continued to decline when the treatment temp. was 200°C and 240°C. In addition, the percentage for volume matric of shrinkage on 10-year-old *T. grandis* wood was
higher than 15-year-old *T. grandis* wood. Sapwood also has a higher volume matric of shrinkage percentage than heartwood for both wood ages. The volume shrinkage of treated wood was lower with untreated wood samples. A complete sample of wood into the oven, the moisture content has flowed out of the wall as wide as fibre saturated intoxication. Thus, the volume of wood shrunk and achieved a dimension of stability.

![Figure 4](image)

**Figure 4.** Volumetric shrinkage for 10 and 15 years old cultivated *T. grandis* (sapwood & heartwood) under different heat treatment temperatures.

### 3.2 Mechanical properties

The results for the Modulus of Rupture (MOR) test for *T. grandis* wood treated with heat treatment are shown in Figure 5. Based on the results, wood samples that were not treated with the heat treatment process still had the highest strength values compared to the wood samples treated for all treatment temperatures. There was an increase in MOR for 15-year-old wood, which was 51.83% for sapwood and 25.73% for heartwood compared to the MOR value of 10-year old wood. Based on both types of wood, untreated wood has the highest MOR, and the value of MOR starts to decrease when the wood is treated at heat temperatures of 160°C, 200°C, and 240°C. Therefore, 15-year-old *T. grandis* wood has a high MOR value compared to 10-year-old *T. grandis* wood.

The MOE values of 10 and 15-year-old *T. grandis* (sapwood and heartwood) showed in Figure 6. The results of the MOE values for untreated 10-year-old *T. grandis* (sapwood and heartwood) were 10545.95 N/mm² and 11497.06 N/mm², and the MOE values for untreated 15-year-old *T. grandis* (sapwood and heartwood) were 14643.88 N/mm² and 12156.94 N/mm². The MOE increase for 15-year-old *T. grandis* wood was 38.86% for sapwood and 5.47% for heartwood compared to 10-year-old *T. grandis* wood. Figure show that untreated wood's MOE value was the highest for both wood type and age. MOE values decreased as treatment temperatures were 160°C, 200°C, and 240°C for both wood type and age. Therefore, 15-year-old *T. grandis* wood has a higher MOE value than 10-year-old *T. grandis* wood. The recorded results show the heat-treated wood have a lower tensile strength value compared to the untreated wood samples. The mechanical properties of heat-treated wood decreases with increasing temp. and increase with decrease with temp. [17]. Treatment exceeding 200°C, can reduced up to 50% in MOR and MOE [18]. However, the dimensional stability and biological durability of wood increase without the use of certain chemicals [19]. Decreases in wood strength is due to depolymerization reactions to wood polymers [20]. At high temp., changes in the mechanical properties of wood occur due to damage to the structure of hemicelluloses [21]. The treated wood has a lower molecular weight than other wood polymers and causes the wood to be damaged more quickly. Thus, cellulose crystallization and modification of lignin will replace that place [22].
Figure 5. MOR for 10 and 15 years old cultivated *T. grandis* (sapwood & heartwood) after heat treatment.

Figure 6. MOE for 10 and 15 years old cultivated *T. grandis* (sapwood & heartwood) after heat treatment.

Moisture content, temp., presence and absence of oxygen, and duration of treatment are the factors that most influence the hydrolysis reaction and mechanical properties. However, the effect on strength reduction is different for each sepsis, anatomical features, and treatment method [21]. The MOE decreases when treated at temp. above 100°C. Treatment at lower temp. up to about 100°C only cause slight changes in wood's mechanical properties [21]. The strength begins to weaken and brittle when treatment exceeded 200°C. The strength properties of wood suffered failure in compression due to the low density of the wood [21]. The heat-treated wood is unsuitable for construction due to the decreases in strength especially bending and tensile between 10% to 30% [23].

3.3 Correlation between physical and mechanical properties
The Pearson correlation between each pair of variables in physical and mechanical properties of *T. grandis* was shown in Table 1. The correlation coefficients range between -1 and +1 and measure the strength of the linear relationship between the variables. The parentheses showed the number of data values used to compute each coefficient. The third number in each table's was P-value that tests the
estimated correlations' statistical significance with P-values less than/equal to 0.05 (p ≤ 0.05), indicate statistically significant non-zero correlations at 95% confidence level. Highlighted there was a correlation between the physical properties of samples made from Teak with different factors. All physical properties show a positive correlation with varying factors except for basic density and dimensional change in a tangential direction. All mechanical properties show a positive correlation with varying factors except for basic density from physical properties.

| Table 1. Correlation Analysis between physical and mechanical properties of 10-year-old T. grandis. |
|---------------------------------------------------------------|
| | MC | BD | DCt | DCl | TsMor | TsMoe | Comp |
| MC | -0.5196 | -0.0973 | 0.4176 | 0.7583 | 0.7917 | 0.3623 | 0.7678 |
| BD | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.1540 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| DCt | -0.0973 | -0.2956 | 0.2786 | 0.0043 | 0.1685 | 0.0663 | 0.0687 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.1540 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| DCr | 0.4176 | -0.5098 | 0.2786 | 0.3983 | 0.5046 | 0.3102 | 0.4234 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| DCl | 0.7583 | -0.4931 | -0.0043 | 0.3983 | 0.6310 | 0.3996 | 0.5883 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.0000 | 0.9504 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| TsMor | 0.7917 | -0.6811 | 0.1685 | 0.5046 | 0.6310 | 0.0000 | 0.3485 | 0.7638 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.0000 | 0.0131 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| TsMoe | 0.3623 | -0.3991 | 0.0663 | 0.3102 | 0.3996 | 0.3485 | 0.2430 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.0000 | 0.3323 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| Comp | 0.7678 | -0.5324 | 0.0687 | 0.4234 | 0.5883 | 0.7638 | 0.2430 |
| (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) | (216) |
| | 0.0000 | 0.0000 | 0.3147 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |

Note: Correlation, (Sample Size), P-Value at either 95% or 99%. MC = moisture content, BD = basic density, DCt = dimensional changes in tangential direction, DCl = dimensional changes in the longitudinal direction, TsMor = tensile strength modulus of rupture, TsMoe = tensile strength modulus of elasticity, Comp = compression strength.

4. Conclusion

The oil heat-treatment process enhanced and improved both the 10- and 15-year-old cultivated Tectona grandis in the physical characterization of the wood by both sapwood and heartwood. The modulus of elasticity (MOE) and modulus of rupture (MOR) in the tensile and MOR in the compression tests decrease in the oil heat-treated wood compared to untreated wood. However, the reduction does not affect the overall strength properties of the oil heat-treated Tectona grandis wood.

5. References

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