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Physical and Mechanical Properties of Teak (Tectona Grandis L.Fil.) Thermo-Plywood from Plantations in Lao P.D.R

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Keywords: thermo, plywood, density, absorption, swelling, MOR, MOE, shearing, hardness.

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Strictly as per the compliance and regulations of:

Physical and Mechanical Properties of Teak (Tectona Grandis L.Fil.) Thermo-Plywood from Plantations in Lao P.D.R

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Abstract- The aim of this research to investigated physical and mechanical properties of thermal plywood of PF adhesive. Physical property focused on density, water absorption and swelling. And mechanical property was MOR, MOE, shearing strength and hardness. The Teak veneer was the main raw material the size was 2 mm in thickness, and 400 mm in width and length. The veneer was divided into five groups as were control, thermos-veneer, at 180°C, at 200°C, 220°C and 240°C and 4 min, 8 min and 12 min, the spread 150 g/m2 and five layers. Plywood products used PF adhesive products were cool pressing in 10 min and hot pressing in 15 min. density test followed with AS/ANZ 2098.7, 2012, WA and swelling thickness were followed ASTM D 3502-76, The dimension sample design was 10x25x300 mm for MOR and MOE, 10x50x100 mm for shearing strength and 10x50x50 for harness and testing by Fast Test software. Data analyses were One-way ANOVA and multiple linear regression. *As the result, the density of* thermal treatment was decreased density of teak plywood. A control was significant different on thermal treatment of different level of temperature and length of time the control was no significant different. WA in the different level of temperature and length of time the WA increases. The control was significant different with thermally. Swelling thickness of thermal treatment at 180, 220, 240 °C was increased to significant different with control, and length of time the control was no significant different. The MOR in different level of temperature the control was only significant with at 180°C and but another group at 200, 220, and 240°C was no significant. The length of time on 4, 8, and 12 min was no significant different. MOE was decreased in different level of temperature at 180, 200, 220, and 240°C significant different and length of time on 4, 8, and 12 min was no significant different. The different level of temperature effected MOE of teak plywood. The shearing strength in different level of temperature at 180, 200, 220, and 240°C and length of time on 4, 8, and 12 min were no significant different. And the hardness in thermal treatment at 180, 200, 220, and 240°C and length of time on 4, 8, and 12 min was fluctuated. And it was no significant different.

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I. Introduction

Teak plantation quality is most important for sawmilling where processors acquired high volume from the processing. Lao teak plantations were abandoned naturally but Luang Prabang Teak Program (LPTP) provided technical skills in maintenance like thinning and pruning for local farmers (Fondation Ensemble, 2014).,(Bouaphavong *et al.*, 2016) confirmed that planted teak in Laos had many knots which affected log grad compared to grown teak in Thailand. GPérez and Kanninen (2005) confirmed that Teak wood quality is of considerable importance when classified according to international grading rules. Since teak is a light-demanding tree light-demanding does grow not grown well in dense stands (Budiadi. *et al.*, 2017).

DJATI *et al.* (2015) also has done research on mechanical property and characteristic of young teak for making products in Indonesia. The teak wood contains different proportion of sapwood and heartwood depend on ages, such as young teak wood has lots of sapwood but rich of heartwood in old trees. Proportion of heartwood teak was 91% during 50 to 70 years old in the East Timor (Miranda *et al.*, 2011). Izekor *et al.* (2010)confirmed that teakwood density and mechanical properties increased with increase in ages. The research comparison between heartwood and sapwood in density and MOR, which density of teak ages for 1-10 years old the sapwood and heartwood were 0.61 and 0.63 g/cm^3, 11-20 years old were 0.65 and 0.61 g/cm^3, 21-30 years old were 0.62 and 0.72 g/cm^3, and 31-40 years old the size of sapwood less than minimum standard and heartwood was 0.75 g/cm^3. For MOR testing between sapwood and heartwood in 1-10 years old were 52.70 and 80.26 MPa, 21-30 years old were 91.41 and 81.45 MPa, and 31-40 years old the sapwood less than standard and heartwood was 101.10 MPa. The conclusion teak ages to most important with properties of teak.

According to Sedliacik *et al.* (2010) studied that compared low temperature pressing of 100 °C in 6 min, glue spread of 140 g/m² with plywood pressed by high temperature (120 and 150°C) by phenol formaldehyde condensation. The results showed that lower temperature pressing was significant without worsening of mechanical properties of plywood. Moisture content of veneer was 10-12%, 2 mm thick, it used cornstarch-tannin-phenol formaldehyde amount 225 g/m², at 125°C in 6 min, loading presser was 12 bars as the result of MOR was 41 N/mm² of the control, 70 N/mm² of the cornstarch PF, MOE was 2,958 N/mm² of the control, 4,271 N/mm² of the cornstarch PF, strength tension in 8 hours boiling water was 0.5 N/mm² of the control, 1.75 N/mm² of the cornstarch PF, wood failure was 11% of the control, 72% of the cornstarch PF and formaldehyde emission was 2.62 mg/m²/h of the control, 1.92 mg/m² /h (Moubarik *et al.*, 2009). Lignin phenol formaldehyde resolves were prepared different of lignin at both 20 and 40% phenol replacement (Ghorbani *et al.*, 2016). Phenol formaldehyde was low formaldehydes effectives with products and user, high water resistance, it was developed for outdoor plywood and PF was used improve teak plywood in Laos and supporting information to Lao industry.

Thermo wood modification method has been found since early part of the 20th century (Callum, 2011). Wood modification could be the best option for improving teak plantation in Laos. For instance, thermo-plywood can increase durability and dimensional properties of the product and it can also reduce chemical use for wood preservation. For example, worldwide is concerning environmental effect, especially, European zone is high restricted use of toxic preservation and the market for new durable products of modified wood during the last few years(Sandberg *et al.*, 2017). Even though thermal modification is long-known method, considerable amount of research has recently focused on this method and heat-modified wood has an important market share (Kantay & KARTAL, 2007). Thermo-wood modification can be performed in special thermal treatment kilns as well as under pressure and heat using special press equipment. Considering special thermal treatment kilns, five processes have been developed and are currently available at industrial scale. Thermo-plywood products can extend young teak duration, safe for users and environmentally friendly because thermo-veneer to be able chemical composition of teak veneer, thermo-plywood never use chemical elements (toxic) which only using glue ability and the product high resistances with insect destroying such termites, beetles, and others.

Generally, Teak log thinned from plantation is less utilization in Laos, which has small diameter and more proportion of sapwood. Famers have been using it for fence, poles, firewood, discard on the ground plantation site and some burning. Young lumber teak is low insect resistance especially termites, fungus, and beetles. The modern alternative to improve wood products needs to be modernized wood technology into wood industrial in Laos. Thermo-plywood method is believed to be able to increase smart teak products without chemical and high insect resistance through removing chemical composition of the wood, thermo-wood is thermal modification. According to Mohamed *et al.* (2018) found that thermo wood, whenincreasing temperature in the range of 160-220 °C. Thermo-Wood® method for about 1 and 2 hours at temperatures of 190 and 212 °C in an industrial business (Aytin *et al.*, 2015). Both research article confirms that thermal domification to be change chemical composition of the wood by temperature increasing rang in the range more 160°C.

This study objectives to investigated physical and mechanical properties of thermal plywood of PF adhesive. Physical property focused on density, water absorption and swelling. And mechanical property was MOR, MOE, shearing strength and hardness.

II. Material

Teak veneer was peeled insplindleless rotary at the Faculty of Forest Science, National University of Laos, Vientiane Capital, Lao.P.DR. A small wood hot pressure machiner (model STK No. 44-275, DAKE, Grand Haven, MI, USA), A Cole pressure machiner (model No BY 814*4/2B, Production code 7265, Made in China), a hot pressure machiner (model, No BY 214*4/2A-1, Production code 7276 Mad in China), a circular saw cutter (model, No BJ 6116-4B, Production code 180401), dial thickness gaugedigital calipers (code 34-506, Measumax, Melbourne, Australia) were used. And Horizontal Flow Oven (Model WOF-050, serial No WOF050071018002, Made by Daihan Scientific Co., Ltd).

III. Methodology

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 thermal treatment processes were based on the factorial design as 5 x 13 x 30 = 1,950 (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).

The adhesive to apply on teak veneer for teak plywood products is phenol formaldehyde based on Standard (2012). Plywood product consists of 5 layers or 10 mm of thickness, veneer laying should be placed over to another with perpendicular grain. PF glue should be speeded on the veneer by passing them through the roller of a glue transfer spreader between 150 g/m².

Dimension of teak plywood product is 40x40 cm which it is hot press machinery. The hot press rate used as 1mm thick per 1 min, thermo-teak plywood and teak plywood has 10 mm of average, time for pressing at 10 min for 130 °C. The press loading is 2.5 MPa/mm^2.

A. Density testing: According to the Standard (AS/ANZ 2098.7, 2012), the specimen should be cut into 10x25x50 mm (30 specimens), formula calculation as Eq1.

$$\text{Density } \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

Where: Density is mass divided by volume of a specimen (g/cm^3), Mass is the weight of a specimen (g), Volume is the multiple of thickness, width, and the length of a specimen (cm^3).

B. Water Resistant or Absorption Testing: method for testing was using ASTM D 3502-76 as the method recorded by Somwang (1995). Method testing specimen was placed in a conditioning chamber for 24 h in the temperature at 50±2°C. Next, Specimen should be soak in the distilled water at 25±2 °C in for 24 hours, then using dry cloth to support for taking of water from the surface and immediately weigh it and recording data. Water absorption (WA) calculation as Eq 2.

$$\text{WA} = \frac{W_2 - W_1}{W_1} \text{x} 100 \quad (2)$$

Where: WA water absorption (%), W_1 Weight of a specimen before soaking distilled water (g), W2 weight of a specimen after soaking distilled water (g)

C. Thickness swelling: the method was following up point B mention above, thickness was measuring by digital caliper and swelling changes as calculated in Eq 3.

$$\text{Swelling (\%)} = \frac{(T_2 - T_1)}{T_1} \text{x} 100 \quad (3)$$

Where: T_1 thickness before soaking in distilled water and T_2 Thickness after soaking distilled water.

MOR and MOE were testing the same specimen which it's dimension of 10x20x300 mm accordance with D1037-12 for test specimen shall be less than 12 mm of thickness and speed loading rate is 3mm/min. formula of rate as calculation in the Eq 4.

$$MOR = \frac{3xP_{max}\,xL}{2xbx\,d^2} \quad \text{(Eq4)}$$

Where: P_{max}=maximum load (N), L= Length of span (mm), b= width of specimen measured in dry condition (mm), d=thickness (depth) of specimen measured dry condition (mm)

MOE was calculating by formula as Eq 5.

$$MOE = \frac{L^3}{4xbx\,d^3}\,x\,\frac{\Delta P}{\Delta Y} \quad \text{(Eq 5)}$$

Where: L= Length of span (mm), d=thickness (depth) of specimen measured dry condition (mm), b= width of specimen measured in dry condition (mm), $\frac{\Delta P}{\Delta Y}$ =slope of the straight-line portion of the load deflection curve (N/mm)

The shearing strength was following D143. The load applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine of 0.6 mm/min, the calculation as Eq 6.

$$Shearing = \frac{P_{max}}{bd} \quad (6)$$

Where: d=thickness (depth) of specimen measured dry condition (mm), b= width of specimen measured in dry condition (mm), and P_{max}=maximum load (N)

The diameter of head pressor is 10 mm, and load applied continuously throughout the test at a uniform rate of motion of the movable crosshead of testing of 1.3 mm/min (ASTM, 20112). The calculation hardness as Eq 7.

$$Hardness\ (MPa) = \frac{P}{2\P rh} \quad (5)$$

Where: P=loading selected is to be in calculation (N), r=radian of penetrating ball (mm), and h=depth of penetrating in specimen (mm)

Data Analysis: All properties of teak plywood analysis conducted by One-way ANOVA table of statistic in relativity 95 %. Whole study was use multiple comparison. If Significant (sig) differences start from sig equated 0.05 (p=0.05) and high significant differences of three techniques and wood machineries in recovery is 0.00 (p=0.00). The multiple regression model analyzed only mechanical property.

IV. Result and Discussion

Table 1 showed that average and standard deviation of physical and mechanical property of thermo-treatment teak plywood. The length of time was showed in Table 2, the physical property investigated density, thickness swelling and water absorption. The mechanical property investigated MOR, MOE, Shearing, and hardness.

The density was highest (0.705±0.04 g/cm^3) which it was thermo-treatment in different level of temperature for percentage of density decreased in 3.12% at 180°C, 5.39 % at 200 °C, 3.12% at 220 °C, and 3.40 % at 240 °C compared with control CL. This study the age of teak plywood 18 year old to less than May (2003) study teak age was 20 year old in 0.26 g/cm^3.This study to compared with Cuccui *et al.* (2017) treated solid wood at temperature of 180°C for 5 hours, the PF density of this study was higher 12.88% in condition of humidity at 0%, 11.27% in condition of humidity at 30 %, and 9.80 % in condition of humidity at 60%.

One-way ANOVA analysis to compared between significant different from each temperature level, result showed that PF plywood product compared between control with thermal at 180-240°C was high significant different P <0.05. While compared temperature between 180°C with 200-240°C was only

200°C was high significant different but 220 °C and 240 °C were not significant different. The length of time of PF density was 0.705±0.040 g/cm^3 in CL, 0.676 ±0.041 g/cm^3 in4 min, 0.679±0.038 g/cm^{3}in 8 min, and 0.681 0.±033 g/cm^3 in 12min. One-way ANOVA analysis. the result illustrated that different length of times thermal treatment as the control compared between group (4 min, 8 min and 12 min) were significant different, as P<0.05 (P=0.000, P=0.001 and P=0.002) respectively. To compared 4 min with 8 min and 12 min were no significant and 8 min with 12 min was no significant different.

The water absorption (WA)of plywood showed that it was 31.07±4.60, to compared control with different level of temperature at 180 °C for PF was increased 6.05%,thermo-treatment at 200°C was increased 1 %, thermo-treatment at 220°C was increased 4.9 %, and thermo-treatment at 240°C increased 2.55 %, According to Uribe and Ayala (2015) confirm that WA of treatment solid teak has 25 mm thick for 2 hour in different level of temperature, it was 4 % at 180°C, 3.6 % at 200 °C, and 2 % at 210 °C as much different of this study. In contrast, this study was similar with Islam *et al.* (2012) studied WA in plywood of *Eucalyptus camaldulensis*, the WA was 36.9±3.82 %. DEL MENEZZI *et al.* (2017) studied that the WA of teak plywood absorption were improved depend on volume of gluing speed as 0.96 g/m^2, 1.92 g/m^2, and 2.88 g/m^2, the WA were 36.08 %, 30.26 %, and 25.20 %. Thermo-teak plywood in this study used gluing speed was 150 g/m^2 the WA range from 31.07-37.12 % for PF, 31.49-37.26 %. In conclusion, thermal treatment was not improved WA, but volume of gluing speed was significant for plywood.

One-way ANOVA in Duncan analysis the water absorption which it groups a was significant different with b (a=180°C, 220°C and b=control, 200°C, 240°C). One-way ANOVA analysis the variable multiple comparison of times length different for teak thermal plywood, The between group to compared control with 4 min was high significant different (P=0.00), to compared control with 8 min was significant different (P=0.02), to compared control with 12 min was no significant different (P=0.45), to compared 4 min with 8 min was high significant different (P=0.00), to compared 4 min with 12 min was high significant different (P=0.00) and to compared 8 min with 12 min was significant different (P=0.01).

The swelling thickness of thermo-teak plywood showed that the control was 3.08±1.12 %, the thermo-treatment at 180, 220, 240°C was increased from a control of 1.48,0.46, 0.51 % respectively. But at 200 °C the swelling thickness comparison with control was decreased 1.36 %. Bas on Uribe and Ayala (2015) showed the swelling thickness of teak treatment at 180 °C was0.8 %, at 200 °C was 0.6 %, and 210 °C was 0.5 % which it was decreased in different level of temperature but teak thermo-plywood of this study was not change. The mean value of eucalyptus plywood (1.5%) was evidently lower than that of simul plywood (2.9%) (Islam *et al.*, 2012). This study was higher Ayala (2015), and Islam *et al.* (2012) because the high temperature was changed physical property of thin veneer. However, water has been absorbed as well.

Base on Duncan in One-way ANOVA analysis grouping significant different, the thickness swelling thermal treatment at 200°C was significant different with control, 220°C and 240°C (P=0.00) and 180°C, but control compared with at 220, and 240°C was no significant different (P=0.41, 0.36) respectively. And to compared 180°C with control sample was significant different (P=0.01), at 200°C was significant (P=0.01) and at 240°C was significant different (P=0.01). The length of time illustrated that the control compared with 4, 8, and 12 min was no significant different (P>0.0.05), to compared 4 min 8 min sample was significant different (P≤0.05), but on 4 min compared with 12 min was no significant different (P>0.05), and 8 min with 12 min was high significant different(P<0.05).

Base on this study found that the PF average MOR of control sample was 68.33±20.59 MPa, it was higher than SOUKPHAXAY *et al.* (2021) studied teak LVL in 6.79 MPa. According to Sutiawan *et al.* (2021)studied that the influence of different hot pressing condition of Jabon plywood, the MOR perpendicular parallel to grain was increased at high hot pressing i,e., 34.78 MPa at180 °C, 57.51 at 190 °C, and 58.60 MPa at 200°C. This study discussed at 180 °C, and 200 °C was increased in 8.55 MPa of different. But Sutiawan *et al.* (2021) confirmed that the MOR different between 180 °C to 200 °C was increased 23.82 MPa. The thermo-treatment at different level of temperature was unchanged MOR of the plywood. The MOR of teak LVL used volume of gluing speed in 0.96 g/m^2, 1.92 g/m^2, and 2.88 g/m^2 the result was 49.3 MPa, 53.6 MPa, and 74.1 MPa respectively(DEL MENEZZI *et al.*, 2017). However,The MOR of thermal treatment in different level of temperature were not reduced force loading in the plywood, types and volume spread of adhesives were significant to static bending.

MOR in control sample with 180°C was significantly different (P<0.05), to compared control with 200°C, 220°C, and 240°C samples were no significant differences (P>0.05), to compared 180°C samples with 200°C220°C and 240°C samples were significantly different (P<0.05), to compared 200°C with 220°C was no significant different (P>0.05), to compared 200°C with 240°C was significantly different (P<0.05) and to compared 22°C with 240°C was no significant different (P>0.05). MOR of PF group confirm that heat treatment with high temperature was impacted with MOR of teak plywood. The length of time on control compared with 4, 8, and 12 min the result was not significantly different (P>0.05).

The modulus of elasticity MOE of teak plywood thermal treatment of control was 12,734.54± 2,246.33 MPa, the thermal treatment was reduced MOE on high different level of temperature as to compared control with at 180 °C, 200°C, 220 °C, and 240 °C the MOE. According to DEL MENEZZI *et al.* (2017) studied that the teak LVL of MOE in different volume of spread was 8,469.8 MPa, 8,872.4 MPa, and 9,132.6 MPa to lower than this study. SOUKPHAXAY *et al.* (2021) studied that the MOE of teak LVL was lowest in 2,609.97 MPa. DEL MENEZZI *et al.* (2017) and SOUKPHAXAY *et al.* (2021) confirm that the MOE of LVL was lower than teak thermal treatment of plywood. The different level of temperature thermal treatment decreased MOE of teak thermal treatment plywood.

Based on multiple comparisons by One-way ANOVA analysis showed that the results of PF groups to compared a control with 180°C, 200°C, 220°C, and 240°C were high significantly different (sig<0.05), to compared 180°C with 200°C was not significantly different (sig>0.05), to compared 180°C with 220°C and 240°C were high significantly different (sig<0.05), to compared 200°C with 220°C and 240°C were high significantly different (sig<0.05), and to compared 220°C with 240°C was not significantly different (sig>0.05). The multiple comparisons of times length thermal on different times of two plywood adhesives. To compared a control sample with 4 min, 8 min and 12 min were high significant different (sig<0.05), and its MOE were high than other times thermal treatment. Comparing 4 min with 8 min and 12 min was not significantly different (sig>0.05) and to compared 8 min with 12 min was not significantly different (sig>0.05).

The shearing strength value of teak plywood thermal treatment of control in PF was13.55±2.97 MPa. This study was similar Nautiyal (2015) studied that shear strength of *Melia composita and Populus deltoides* in 5 ply, to applied PF condensation and result showed that the shear strength in dry condition ranged from 13.82 to 14.7 MPa, and 9.4 to 11.57 MPa in wet condition. According to International Thermowood Association (2003) reported that the higher-temperature treatments (at 230 °C for 4 hours) the strength properties were reduced in radial tests from 1 to 25%. This study was similar with theory of International Thermowood Association (2003). But this study shear strength was higher Bekhta *et al.* (2016) in 8.39 MPa because this study used PF glue spread more 150 g/m^2. The shearing strength was depended on volume of glue spread in layer plywood.

One-way ANOVA analysis showed that the multiple comparison of significant different for PF. The PF group, to compared control sample with at 180 °C, 200 °C, 240 °C were no significant different (P>0.05), to compared control sample with at 220 °C was high significant different (P<0.05), to compared at 180 °C with at 200 °C was no significant different (P>0.05), to compared 180°C with at 220°C, and 240°C were significant different (P<0.05), to compared at 200°C with at 220°C was high significant different (P<0.05), to compared at 200°C with at 240°C was not significant (P> 0.05), and to compared at 220°C with at 240°C was high significant different (P<0.05). The length of time thermal treatment on 4, 8, and 12 min was not significant different.

The hardness of this study was showed in Table 1, and 2 show the average and standard deviation of teak plywood thermal treatment. The control was 22.09±6.35 MPa the percentage of hardness compared with control showed that the hardness increased at 200°C, and 240°C in 11.18 %, and 0.95 (PF) respectively. In contrast, the different level of temperature at 180°C, 220°C the hardness decreased in 14.21 %, 0.22 % (PF) respectively. The length of time illustrated that the thermal treatment on 4, 8, and 12 min was a little fluctuation. According to Lengowski *et al.* (2021)confirm that teak thermal treatment was significant declines of hardness occurred in the longitudinal and tangential section. Pelit *et al.* (2015) confirm that the higher in Eastern beech samples (36.30 N/mm^2) than in Scots pine samples (27.27 N/mm^2), and the hardness was increased as treatment temperature increases. Base on International Thermowood Association (2003) recorded that the thermo-solid wood treatment at 180°C to 240°C the hardness increased as the treatment temperature increases, the Brinell hardness was highly dependent on the density as bout 17.64 %. This study was similar with Lengowski *et al.* (2021) at 180°C, 220°C (PF), and similar with Pelit *et al.* (2015) and International Thermowood Association (2003) at 200°C, and 240°C (PF).

The multiple comparison analysis of the PF group, to compared control with at 180°C and 200°C were significant different (P<0.05), to compared control with at 220°C and 240°C were no significant different (P>0.05). The significant point is that compared at 180°C with at 220°C 220°C and 240°C were high significant different (P<0.05), but to compared at 200 °C with at 220°C, 240°C were no significant different (P>0.05), and to compared at 220 °C with at 240°C was no significant different (P>0.05). The length of time thermal treatment on 4, 8, and 12 min. To compared control with 4 min, 8 min and 12 min were no significant different (P>0.05), but to compared 4 min with 8 min was high significant (P<0.05), to compared 4 min with 12 min was no significant different (P>0.05), and to compared 8 min with 12 min was significant different (P<0.05).

PF multiple regression model (Eq 5X) considered as high (R^2=0.83)

$$MOR(PF)=0+0.3103*T+(-0.1603)*t \qquad (Eq\ 5x)$$

Where: MOR= Modulus of rupture (MPa), T= Temperatures requirement thermally (°C), t= Times requirement thermally (min), (PF)=Phenol formaldehyde UF multiple regression model (Eq 5x) considered above average (R^2=0.79)

$$MOR(UF)=0+0.3253*T+(-1.5801)*t \quad \text{(Eq 5x)}$$

Where: MOR= Modulus of rupture (MPa), T= Temperatures requirement thermally (°C), t= Times requirement thermally (min), (UF)= Urea formaldehyde,

PF multiple regression model (Eq 5X) considered as high (R^2=0.85)

$$MOE(PF)=0+51.2504*T+(-43.7003)*t \quad \text{(Eq 5x)}$$

Where: MOE= Modulus of Elasticity (MPa), T= Temperatures requirement thermally (°C), t= Times requirement thermally (min), (PF)=Phenol formaldehyde UF multiple regression model (Eq 5x) considered above average (R^2=0.88)

$$MOE(UF)=0+50.5502*T+(-56.3688)*t \quad \text{(Eq 5x)}$$

Where: MOE= Modulus of Elasticity (MPa), T= Temperatures requirement thermally (°C), t= Times requirement thermally (min), (UF)=Urea formaldehyde,

Table 1: Physical and mechanical properties of teak plywood in the thermal treatment of different level of temperature in PF adhesive

Properties	Temperature (°C)				
	CL±Std	180±Std	200±Std	220±Std	240±Std
Density (g/cm³)	0.705±0.04	0.683±0.03	0.667±0.03	0.683±0.04	0.681±0.04
Water absorption (%)	31.07±4.60	37.12±6.59	32.07±11.44	35.97±5.54	33.62±5.37
Thickness swelling (%)	3.08±1.12	4.56±2.70	1.72±3.34	3.54±2.85	3.59±2.11
MOR (MPa)	63.33±20.59	58.10±22.85	66.65±20.55	64.55±21.02	65.81±18.06
MOE (MPa)	12,734.54±2,246.33	11,383.85±2,265.14	10,945.29±1,634.48	9,673.65±2,407.91	9,948.38±2,229.25
Shearing (MPa)	13.55±2.97	12.53±3.20	12.76±3.22	11.39±3.58	13.51±3.46
Hardness (MPa)	22.09±6.35	18.95±5.11	24.56±6.01	22.04±6.15	22.30±6.78

Table 2: Physical and mechanical properties of teak plywood in the thermal treatment of length of time in PF adhesive

Properties	Time (min)			
	CL±Std	4±Std	8±Std	12±Std
Density (g/cm³)	0.705±0.040	0.676±0.041	0.679±0.038	0.681±0.033
Water absorption (%)	31.07±4.60	37.56±7.16	34.59±7.04	32.25±9.25
Thickness swelling (%)	3.08±1.12	3.29±2.97	4.00±2.45	2.77±3.28
MOR (MPa)	68.33±20.59	62.93±19.52	66.09±21.90	62.32±21.12
MOE (MPa)	12,734.54±2,246.33	10,887.21±2,000.07	10,487.39±2,331.09	10,088.77±2,370.60
Shearing (MPa)	13.55±2.97	12.74±2.74	12.50±3.87	12.40±3.63
Hardness (MPa)	22.09±6.35	21.09±6.00	23.49±6.54	21.79±6.31

V. Conclusion

1. Density of teak plywood thermal treatment in control, at 180, 200, 220, and 240°C in the length of time in control, 4, 8 and 12 min ranged from 0.667-0.705 g/cm³, thermal treatment decreased density of teak plywood. A control was significant different on thermal treatment of different level of temperature and length of time.
2. Water absorption of teak thermal treatment in control, at 180, 200, 220, and 240°C in the length of time in control, 4, 8 and 12 min range from 31.07-37.12%. The different level of temperature and length of time the WA increases. The control was significant different with thermally.
3. Swelling thickness of plywood thermal treatment in different level of temperature as control, at 180, 200, 220, and 240°C base on length of time 4, 8, and min was range from 1.72-4.56%. The thermal treatment at 180, 220, 240 °C was increased to significant different with control, and length of time the control was no significant different.
4. The MOR of control sample was 68.33±20.59 MPa the thermal treatment plywood was fluctuated. The different level of temperature the control was only significant with at 180°C and but another group at 200, 220, and 240 °C was no significant. The length of time on 4, 8, and 12 min was no significant different.

5. The MOE of teak plywood, the control was 12,734.54 MPa, it was decreased in different level of temperature at 180, 200, 220, and 240°C significant different and length of time on 4, 8, and 12 min was no significant different. The different level of temperature effected MOE of teak plywood.
6. The shearing strength value of teak plywood in control 13.55 MPa, thermal treatment in different level of temperature at 180, 200, 220, and 240 °C and length of time on 4, 8, and 12 min was decreased. A control and at 200 °C, 220 and 240 °C were significant different, but thermal treatment at 180, 200, and 240°C on 4, 8, and 12 min was no significant different. The shearing strength was a little decreased.
7. The hardness a control average was 22.09 MPa, thermal treatment at 180, 200, 220, and 240°C and length of time on 4, 8, and 12 min was fluctuated. And it was no significant different.

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