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Review of Heat Effect for wood Properties

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Abstract

This study aimed to analyse the effect of physical and mechanical properties of thermally wood. The study compiled information from review of literature that related to the thermo wood. One-way and two factors ANOVA table were used to analyses data. The result showed that thermo wood property was affected based on physical and mechanical. Physical property effective was density decreasing but improved biological durability. Mechanical property like hardness was increasing, but tension, MOR, compression was decreasing and MOE was not change.

Keyword: Thermo wood, Affection and wood durability, physical, mechanical

1. Introduction

The worldwide is concerning environmental effect, especially, European zone is being exposed to high restrict use of toxic preservation. The market for new durable products like modified wood has increased substantially during the last few years (Dick, Andreja, & George, 2017). Thermo wood modification established since early part of the 20th century which Forest Product Research Laboratory (FPRL) (Callum, 2011). Even though the method of thermal modification of wood has been found for long time ago, considerable amount of researches that focused on this method has yet responded to all wood products in market share (Kantay and Kartal, 2007). The thermally wood can increase dimensional stability and it is environmentally friendly than the methods that used chemical treatment. Heat treatment results in significant change properties of wood (Bal & Bektaş, 2012). Heat treatment, the chemical composition of wood is altered; the hemicelluloses are most affected, and cellulose is somewhat resistant to chemical alterations (Esteves & Pereira, 2009). The temperature during burned of wood charcoal were about 677.67,649.57, 557.86, and 647.02 (DONSAVANH *et.al*, 2023). The wood drying by high temperature and densification by the hot press the wood the equilibrium, swelling and shrinkage decreased with heating in several gasses.

There are three properties of wood include physical, mechanical and chemical properties that Wood has two parts separation; sapwood is outer part and heartwood is inner part. Each wood species has different properties. For instance, solid wood of teak has density in sapwood of 584 kg/m^3 is at the moisture content (MC)of 0%, 597 kg/m^3 at MC of 30% and 610 kg/m^3 at MC (65%). But heartwood density of 597 kg/m^3 at MC (0%), 609 kg/m^3 at MC(30%) and 623 kg/m^3 at MC (0%) (Cuccui, Negro, Zanuttini, Espinoza, & Allegretti, 2017). *Eucalyptus grandis* density in juvenile wood was lower than mature wood were 554.5 and 725.1 kg/m^3 at humidity 0% because juvenile wood has more gave air (Bal & Bektaş, 2012). *Eucalyptus*

camaldulensis Dehn has average density of 680 kg/m^3 at humidity 0% (Unsal, Korkut, & Atik, 2003). The density of Turkey Hezel *Corylus colurna* L was 699 kg/m^3 at MC 0% and air dry 735 kg/m^3 (Derya et al., 2008). Modified Teak wood by heat treatment could change its density at the temperature of 180°C for 5 hours. density of teak to maximin number in three different condition such as 595 kg/m^3 at humidity 0%, 606 kg/m^3 at humidity 30% and 616 kg/m^3 (Cuccui et al., 2017). After thermo wood of *Eucalyptus grandis* the sapwood density was higher control density of 9.3% for 120°C at 8 hours while temperature increased up 180°C for 8 hours but density was 6.2% decreasing (Bal & Bektaş, 2012). Beech, Polar, and Spruce density control were 723 kg/m^3, 395 kg/m^3 and 405 kg/m^{3}while thermo by temperature at 200°C for 3 hours those species densities decreased were 3.01% of beech, 10.37% of Polar and 4.44% of Spruce (Čermák et al., 2015). Thermo wood was affected to wood densities of wood species but it was different humidity condition.

The thermo-wood established in a humid atmosphere at the temperature that is higher than 150 °C for 2 to 10 hours to reach at least 3% of mass loss (Esteves & Pereira, 2009). The treatment is made with vapors, with less than 3 to 5% of oxygen, without air pressure, and with an air speed of at least 10 m/s (Syrjänen & Kangas, 2000). In the oven dry, the temperature increased up 130°C inside with oven dry humidity was at 0% (Militz, 2002). The mass loss value of early wood is greater than later wood , the highest mass loss was found at 180°C for 8 hours, (Bal & Bektaş, 2012). Teak mass loss was increased at high temperature, mass loss is in the range from 1.6 to 5.9 % at 170 to 210 ° C but at the temperature of 180 °C for 5 and 3 hours there were a little different (Cuccui et al., 2017). The mass loss in sapwood of *Eucalyptus grandis* was 0.23% higher than in heartwood? (Bal & Bektaş, 2012). Beech, Polar, and Spruce species thermo at 200°C for 3 hours the mass loss were 6.9%, 10.4% and 4.5%, respectively (Čermák et al., 2015). This could imply that the change of mass loss of wood is affected by high temperature and times.

Thermo wood could also protect wood from swelling. For example, *Eucalyptus grandis* was decreased its percentage of volumetric swelling when wood dried in high temperature at 180 °C for 8 hours was 2.3% in juvenile wood and 3.3% in mature wood (Bal & Bektaş, 2012). *Eucalyptus camaldulensis* heat treatment was declining swelling as well, in general sample wood control or non-treating were 6.59% in redial and 7.67% in tangential sides after thermo by different degree and times at 180°C for 10 hours sample swelling decreased remain of 5.66% in redial and 6.02% in tangential (Unsal et al., 2003). Swelling of Turkish Hazel (*Corylus colurna* L.) was 5.51 % in redial, 9.37% in tangential, 1.26% in longitudinal of the control sample, after it was treated at the temperature of 180°C for 10 hours the volumetric swelling of wood was decreased by 4.93% in redial, 7.16% in tangential and 0.56% in longitudinal (Derya et al., 2008). Wood swelling of Back pine in control sample in compression wood was 3.75% in redial, 4.86% in tangential and 1.77% in longitudinal and 10.39% in volumetric. Thermo wood at 180 and 210°C for 3 hours the wood swelling was decreased differently, for instance, at the temperature of 180°C the redial direction was 2.87%, tangential (3.84%) in, ongitudinal (1.20%) in l and 7.90% in volumetric. At 210 °C treatment the radial was (2.44%) , tangential (3.18%) , longitudinal (0.86%) and 6.48% in volumetric (Dündar *et.al,* 2012). Physical property wood of nine research depend on length of time and high temperature level (Khonxai *et.al,* 2023). In summary, thermo wood has affected to wood swelling.

The hardness property of thermally *Eucalyptus camaldulensis* decreased. For instanc, the comparison of different temperature conditions for *Eucalyptus camaldulensis,* hardness in control sample were 73.6 N/mm^2 of cross section, 36.2 N/mm^2 of radial and 42.3 N/mm^2 of tangential (Unsal et al., 2003). The wood heating temperature at 120°C for 10 hours

were 61.3 N/mm^2 of cross section, 24.5 N/mm^2 of radial and 31.1 N/mm^2 of tangent, the increase temperature at 150°C for 10 hours the property were decreased to 58.9 N/mm^2 of cross section, 22.4 N/mm^2 of radial and 29.6 N/mm^2 of tangent, the increased temperature at 180°C hardness property were decreased to 56 N/mm^2 of cross section, 20.2 N/mm^2 of radial and 28.1 N/mm^2 of tangent. Similar with (Korkut, 2008) the studied by Suleyman Korkut (2008) concluded that heat treatment decreased hardness properties of wood. Uludagˇ fir *Abies bornmuellerinana* Mattf the hardness properties of control sample were 41.6 N/mm^2 of cross section, 22.57 N/mm^2 of radial and 24.23 N/mm^2 of tangent, sample heat treatment at 120°C for 10 hours the hardness property was decreased by 40.38 N/mm^2, 19.28 N/mm^2 of radial and 22.61 N/mm^2 of tangent, the treatment at 150° for 10 hours decreased hardness property by 38.41 N/mm^2 of cross section, 18.22 N/mm^2 of radial and 21.36 N/mm^2 of tangent, when increasing temperature at 180°C for 10 hours the property of hardness decreased by 32.35 N/mm^{2}of cross section, 17.32 N/mm2 radial and 20.31 N/mm^2 tangential. The Scots pine *Pinus sylvestris* L the hardness properties of control sample were 66.64 N/mm^2 of cross section, 30.47 N/mm^2 of radial and 32.07 N/mm^2 of tangential, while increasing temperature at 120°C the hardness property was decreased by 52.38 N/mm^2 of cross section, 25.12 N/mm^2 of radial and 26 N/mm^2 of tangent, at 180 °C for 10 hours the hardness affective decreased by 39.32 N/mm^2 of cross section, 22.12 N/mm^2 of radial and 19.57 N/mm^2 (Su¨leyman, Mehmet, & Turker, 2008). Thermally heat treatment of wood exposed in increasing of temperature level confirmed that affected to decrease hardness property.

Mechanical property for the modulus of rupture (MOR) and modulus of elasticity (MOE) effected from thermo wood was decreasing depend on the different times and temperature condition. In general, the Uludagˇ fir *Abies bornmuellerinana* Mattfˇs MOR was 85.64 N/mm^{2,} MOE was 1064.82 N/mm^2, Compression strength was 36.62 N/mm^2, tension strength perpendicular to grain was 2.06 N/mm^2, while increasing temperature at 120°C for 10 hours in properties of MOR was decreased by 9.02% and the MOE was 30.34%, compression strength was 7.72% and tension strength perpendicular to grain was 13.32%. The temperature at 150°C for 10 hours in properties of MOR decreased by 14.8%MOE was 35.46%, compression strength was 9.92%, and the tension strength perpendicular to grain was 18.50%. The maximal percentage of property decreased while temperature increased at 180°C for 10 hours, i.e. the MOR was 29.28% decreased, MOE was 40.08% decreased, compression strength was 29.41% and tension strength perpendicular to grain was 28.14% (Korkut, 2008). Wood treatment with Scot pine *Pinus sylvestris* L was decreased mechanical properties, MOR in control was 138.02 N/mm^2, MOE was 1,472.77 N/mm^2, compression strength was 59.71 N/mm^2, tension strength perpendicular to grain was 3.43 N/mm^2, while increasing temperature for treatment at 120°C for 10 hours the MOR decreased by 124.79 N/mm^2, MOE was 1,267,59 N/mm^2, compression strength was 55.99 N/mm^2, tension strength perpendicular to grain was2.65 N/mm^2, temperature continuous increasing at 150°C for 10 hours the wood decreased its properties in MOR by 120.47 N/mm^2, MOE was 1,060.49 N/mm^2, compression strength was 54.02 N/mm^2, tension strength perpendicular to grain was 2.14N/mm^2, maximin temperature at 180°C for 10 hours in MOR decreased of 92.91 N/mm^2, MOE was 999.63 N/mm^2, compression strength was 44.54 N/mm^2, tension strength perpendicular to grain was 1.84 N/mm^2 (Su¨leyman et al., 2008). Mechanical property of wood from heating were decreased and MOR and MOE (*Black pine*), control wood sample were 64.4 N/mm^2 of MOR, 50606.8 N/mm^2 of MOE, the sample used compression wood method in thigh temperature at 180°C for 3 hours, MOR decreased of 43 N/mm^2 and 210 °C was 39.3 N/mm^2, MOE at 180°C decreased of 4,738.5 N/mm^2 and at 210°C was 4,537.5 N/mm^2

(Dündar et al., 2012). All wood treatment by high temperature and time length of heating affected to mechanical properties of wood, from the document review could imply that high temperature was significantly decrease mechanical properties of wood.

This research objectives focus on heat thermal to effected wood species. The physical and mechanical changing at high temperature and time length wood treatment in each species.

2. Methodology

This study to focus on wood thermal treatment from article papers which was included wet and dry thermally. The temperature selected from 120 °C to 220 °C, and length of time was 2 hours to 10 hours. The wood species were *Eucalyptus grandis, Teak Tectona grandis, Eucalyptus camaldulensis* DEHN, and Turkish Hazel (*Corylus colurna L.).* Wet thermal treatment always use vacuums technology to took long time and dry thermal used heat direct on wood surface to took sorter time but it was limited volume. The wood thermal with different temperature and length of time impacted wood physical and mechanical properties as this study of physical as density, mass loss, and mechanical property was modulus of rupture MOR and modulus of elasticity MOE.

This study was only used secondary data from journals for re-analysis in finding gave effecting from thermo-wood, all paper for only focus two properties of wood include physical and mechanical properties. The physical property was focus on density changing, mass loss. Mechanical property was focus on hardness, compression, MOR, MOE, tension perpendicular to grain, one-way ANOVA table analysis.

3. Results

The densities of wood to effected from thermal wood different method, the *Eucalyptus grandis* used temperature at 120, 150 and 180 °C for different times 4, 6 and 8 hours to compared with control density was 554.5 kg/m^3 when temperature heat at 120 °C and 150°C for 6 and 8 hours densities were increase more control density of 1.11% for 120 °C, 0.10% for 150°C and for 6 and 8 hours increased 0.29% and 0.50 % and two-way ANOVA analysis no significant (P-value=0.17). Teak (*Tectona grandis*) modified four different temperature at 170, 180, 190 and 200°C for 5 and 3 hours the control density was 597 kg/m^3, temperature increasing the density was decrease alitle follow up high level temperature but no significant for 5 and 3 hours (p-value=0.66). *Eucalyptus camaldulensis* was significant by the time and temperature thermally, control density was 680 kg/m^3 density was decrease at level high temperature and times, the maximin temperature at 180 °C for 10 hours were high decreased density of 8.63% (p-value=0.001). the Turkish hazel *Corylus colurna* L was high significant the temperature increasing and took long time heating to effected with density decreasing as well (p-value=0.001)

Three wood species in table 1 show that thermo wood effecting include as spruce, porla and beech. The average temperature was 190 °C for 4 hours to effected with density was high significant decreased of 3.58% in spruce one-way ANOVA (p-value=0.002), the polar average density was 6.8% to high significant (P-value=0.003) and Beech average density was 5.39% to high significant (P-value=0.002).

Comparison mass loss of fives wood species on wood heat treatment as include *eucalyptus grandis, Beerch, Poplar, Spruce* and *Paulownia*. Temperature and times were high significant effecting wood mass loss. Table 3 show that high temperature was significant different wood mass loss, 160 and 180 °C were similar group mass loss, 120 and 150 °C were same group mass loss and 200°C was high different.

Mechanical properties of Thermo-wood effected wood hardness, compression, MOR, MOE, impact bending and tension perpendicular to grain in tree species as Fir, *Eucalyptus camaldulensis* and Scot pine (*Pinus sylvestris* L.) were used the same technical as result the

thermo-wood were affected with hardness properties. The one-way ANOVA analysis three sides of each species were high significant in table 3 and 4. The technical

4. Discussion

Two species no significant in thermo-wood, *Eucalyptus grandis* and teak *Tectona grandis* temperature start since 120 °C until 180° C for 8 hours in *Eucalyptus grandis* was insufficient for changing density, wood property change rapidly in temperature at 200°C (Association, 2003). Teak *Tectona grandis* heat treat at 200°C for 3 hours density was decreasing a little and it was not different when compared with different temperature. Base one Bouaphavong *et.al* (2022) confirm that heat factors effected density of teak veneer thermally in multiple regression model analysis is $D = -27.7225 + 0.1679 * T + 0.1790 * t$ (D is the density; T is the temperature level (ºC) and t is time (min).

Thermo-wood can improve durability and stability of wood from table 1 show that wood physical properties were decreased density but teak was increasing a little, mechanical properties affected from thermo-wood can improved duration time of wood. According to Wood Treatment Technology (2008) confirm that wood durability classification (DC) as DC1 was very durable over 25 years, DC2 durable 15-25 years, DC3 was moderately durable up to 15 years DC4 slightly durable 5-10 years and DC5 durable less than 5 years. The weight loss (WL) of beech species natural duration with fungi resistance in natural durable in DC5 which it was treatment heating at 160°C and 180 °C follow up CEN/TS 15083-1 upgrade durability to DC3 and DC2 and follow up EN 113/EN 350-1 upgraded durability of wood DC2 and DC1. Ash wood species fungi resistant in D5 which it was thermo-wood at 160 and 180°C to improving DC3 in temperature at160°C and DC1 in temperature at 180°C follow up CEN/TS 15083-1. the follow up EN 113/EN 350-1 standard was DC4 in control but at 160°C was DC2 and DC1 at 180° C. the Oak wood species in the durability classification control was DC5 in CEN/TS 15083-1 and DC4 in EN 113/EN 350-1 after heat treatment at 160°C upgraded to DC2 and DC1 at 180°C in CEN/TS 15083-1 and EN 113/EN 350-1 standards. The scot pine wood species of wood durability in control was DC5 to be able upgraded duration to DC2 in CEN/TS 15083-1 at 160 and 180°C and DC1 and DC2 in EN 113/EN 350-1. Base on International Association Thermo-wood (2003) confirm that thermo-wood has a lower density than untreated wood, the selling and shrinkage were significant reduces the tangential and radial, the weight-to-strength ratio can remain practically unchanged, the bending strength has loss after temperature more 220 °C and MOE was not significant change of wood, the compression strength perpendicular to grain treated at 190°C for 3 hours was higher timber untreated about 30%, the impact bending of thermo-wood was decreased 25%, the hardness was highly dependent on the density. Finally, thermo-wood to be able improving timbers product and the first reason thermo wood was improving fungi resistance better timber was not treatment. Second reason of thermo wood was affected timber some properties of wood as density, strength, weigh loss decreasing but thermo wood can increased wood durability classification or dabble times utilization of wood. Third reason thermo wood were innovation technical and technology for improving wood in green product and green environment because this technical never used toxic or other chemical to environmental impact and human.

5.Conclusion

Temperature and time were significant timbers treatment, high temperature and took long time wood treatment were impact with density, mass loss decreasing directly depend on species density. Temperature during 120-150°C was mass loss in the same group, 160-180°C was higher mass loss than lower temperature using and maximin mass loss was 200°C which it compared three group was high significant different. Thermo wood to affected and improved

with mechanical properties as well the temperature used higher 220°C the strength bending was decreasing, wood treatment at 190°C for 3 hours compression strength has improving than wood untreated 30%. The appropriate temperature of thermo-wood from 180°C to 220°C was best thermo wood.

6. Conflict of Interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Table 1. comparison of three species for wood density decreasing effected from thermo wood by one-way ANOVA analysis

Species	**Temperature °C**	***Sum***	***Average (%)***	***Variance***
Spruce	180 and 200	380	190	200
		7.16	3.58	1.49
P-value				0.002**
Poplar	180 and 200	380	190	200
		13.67	6.84	25.12
P-value				0.003**
Beech	180 and 200	380	190	200
		10.79	5.39	4.63
P-value				0.002**

*Note: (-) density was higher control density or wood density increasing, * significant (p-value=0.05), ** high significant (P-value=0.00).*

Table 2. High temperatures different affected to wood mass loss

Temperature	N	Mean (%)	Duncan grouping
120	3	0.24	a
150	3	0.72	a
180	7	3.68	b
160	6	5.60	b
200	5	7.64	c

Table 4. Thermo-wood affected hardness

Wood Sections Hardness		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Radial	Between Groups	511.75	2	255.87	3.69	0.04*
	Within Groups	1663.77	24	69.32		
	Total	2175.52	26			
Tangential	Between Groups	2623.19	2	1311.59	21.05	0.00**
	Within Groups	1494.75	24	62.281		
	Total	4117.94	26			
Cross section	Between Groups	15073.64	2	7536.82	168.80	0.00**
	Within Groups	1071.56	24	44.64		
	Total	**16145.21**	**26**			

*Note: NA is not Available, * significant (sig=0.05), ** high significant (sig=0.00).*

Table 3. Mechanical properties significant different of heat treatment to wood species

Mechanical properties		Sum of Squares	df	Mean Square	F	Sig.
compression	Between Groups	421.87	2	210.93	9.13	0.003**
	Within Groups	346.33	15	23.08		
	Total	768.21	17			
MOR	Between Groups	951.24	2	475.62	20.62	0.000**
	Within Groups	345.86	15	23.05		
	Total	1297.10	17			
MOE	Between Groups	770.65	2	385.32	8.67	0.003**
	Within Groups	666.35	15	44.42		
	Total	1437.00	17			
Impact bending	Between Groups	1973.45	2	986.72	23.33	0.000**
	Within Groups	634.38	15	42.29		
	Total	2607.84	17			
Tension	Between Groups	955.82	2	477.91	6.54	0.009**
	Within Groups	1094.93	15	72.99		
	Total	2050.75	17			

*Note: NA is not Available, * significant (sig=0.05), ** high significant (sig=0.00).*

Table 4. comparison of four species for wood densities decreasing effected from thermal wood by ANOVA-Two-Factor Without Replication analysis

Species			*Sum*	*Average (%)*	*Variance*
Eucalyptus grandis	Temperature °C	120	(-3.32)	(-1.11)	0.68
		150	(-0.31)	(-0.10)	2.33
		180	3.05	1.02	0.47
	Times (hours)	4	1.82	0.61	3.26
		6	(0.88)	(-0.29)	0.43
		8	(-1.51)	(-0.50)	2.11
	P-value				0.17
Teak Tectona grandis	Temperature °C	170	2.51	1.26	1.14
		180	0.34	0.17	0.06
		190	2.68	1.34	3.59
		200	0.17	0.08	0.01
	Times (hours)	5.00	2.35	0.59	0.93
		3.00	3.35	0.84	1.55
	P-value				0.66
	Temperature °C	120.00	11.91	3.97	0.54
		150.00	16.32	5.44	2.75

Species			*Sum*	*Average (%)*	*Variance*
***Eucalyptus camaldulensis* DEHN**		180.00	25.88	8.63	7.38
	Times (hours)	2.00	14.71	4.90	3.84
		6.00	15.59	5.20	2.69
		10.00	23.82	7.94	12.72
	P-value				0.01 *
Turkish Hazel (*Corylus colurna L.*)	Temperature °C	120.00	55.65	18.55	4.84
		150.00	64.66	21.55	1.69
		180.00	76.97	25.66	3.20
	Times (hours)	2.00	60.23	20.08	14.58
		6.00	67.10	22.37	13.13
		10.00	69.96	23.32	11.85
	P-value				0.001**

Note: (-) density was higher control density or wood density increasing, * significant (p-value=0.05), ** high significant (P-value=0.00).