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THE EFFECTS OF HOT OIL TREATMENT PROCESS ON THE CHEMICAL, COLOUR AND STRENGTH PROPERTIES ON 15-YEAR-OLD CULTIVATED *ACACIA* HYBRID

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ABSTRACT

The effects of hot oil treatment on the chemical, colour and strength properties of 15-year-old cultivated *Acacia* hybrid were investigated. Logs of *A.* hybrid were harvested and cut at the bottom, middle and top sections. The wood sections were treated in the hot oil treatment process using palm oil at temperatures of 180, 200 and 220°C for durations of 30, 60 and 90 min. The hot oil treatment process causes some modification in the wood features especially in the chemical constituents, colour appearances and strength properties of *A.* hybrid. Parameters such as temperatures and treatment time were closely monitored as they influence the chemical, colour and strength changes in the treated wood. The degradation in holocellulose, cellulose, and hemicellulose contents was recognized when acacia woods were exposed to oil thermally modified process. Holocellulose and celulose degraded with the increasing of treatment temperature and duration of heating exposure, while lignin showed the increment in content through this treatment. The colour changes in the sap and heartwood were measured using a Minolta Chroma-meter CR-310 and the results are presented in the CIE L*a*b* colour co-ordinates system. The results show that the colour of the treated sapwood can be improve to match the colour of the natural *A.* hybrid heartwood. The strength properties of the oil heat treated *A.* hybrid wood decreases in values of both MOR and MOE throughout the treatment process. The decreases in values were influenced by temperature and duration of the treatment.

Keywords: Cultivated *Acacia* hybrid**,** hot oil treatment process, chemical changes, colour changes, strength reductions.

INTRODUCTION

Declining of timbers from the natural forests has pressured the wood-based industry to shift to forest plantation for consistent supply of wood. The sensitivity of the consumers in Europe and North America about logging activities of naturally grown species from tropical rainforest has further aggregate the problem. Plantation forestry rotations which are shorter than of natural stands provide attractive investments for government and private sectors to fulfill the needs of the timber industries and, at the same time, conserve the natural forest from continuously being depleted by logging activities. *Acacia* which can easily adapted itself to the local soil condition, having high growth rate and possess high wood quality make them most suitable for used as a plantation species.

The hot oil thermal process seems to be a suitable modification because of its competitive advantage as an environment friendly process, since it does not require the uses of chemicals preservative (Razak *et al*., 2011, 2005). Most of current woods treatment techniques uses preservative which are harmful and has negative effect to the environment. Corome Copper Arsenic (CCA) treated wood which has heavy metals and can discharge toxin to the environment has totally been banned by many developed countries (Berard *et al*., 2006). The advances in environmental awareness and the implementation of policies which support the use of renewable resources and environment-friendly chemicals have resulted in high interest in the uses of non-biocides. Effort has been put forward in developing new chemical wood preservatives with no or little impact to the environment (Hyvonen *et al*., 2006).

The present study investigated on the changes that occurred in the main chemical components of an oil heat treated cultivated *A.* hybrid, their effects on the colour appearances and strength of the wood. Chemical constituents, colour changes and strength properties are parameters that influenced durability, appearances and stability of the wood. The results of this study will be beneficial in improving the technologies in treating acacia wood for the industry.

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MATERIALS AND METHODS

Materials

A. hybrid wood was cut from the 15-year-old *A.* hybrid trees obtained from the Sabah Forest Development Authority in Kinarut, Kota Kinabalu, Sabah, Malaysia. The trees were selected based on their long straight bole with minimum branches, good physical appearances and diameter ranging from between 250 to 300 mm. The logs were cut and segregated into different height, namely, bottom, middle and top sections, corresponding to 50, 30 and 20% of the merchantable height respectively. Blocks of 600 mm long were cut from the middle of each section. The wood blocks were then transported to Universiti Malaysia Sabah (UMS) for further processing and subsequent testing. The study was conducted in UMS from Jan. 2009 to Oct 2010.

Sample preparation

The wood blocks were air dried at room temperature for about a month to reduce the moisture to equivalent moisture content (15%) and to remove stresses in them. After drying, the wood blocks were planed into sizes of 300 mm × 100 mm x 25 mm (length × width × thickness) for the oil heat treatment process. These samples were mixture of sapwood and heartwood. They were then oil heat treated using palm oil as the heating medium. Untreated wood were used as control for comparison purposes.

Hot oil thermal modification process

A. Hybrid samples were hot oil treated in a stainless steel tank connected to a locally designed heat treatment machine. Palm oil was used as the heating medium. The temperatures of the oil and the wood samples were control through a control panel located on the out-side of the tank. An electric generator was used to generate heat. The wood samples moisture were stabilized to 12% in a conditional chamber set at 65% relative humidity and temperature 25 °C before they were put into the tank. Eighty woods were prepared prior to the treatment. The weights of the woods were recorded before and after treatment to determine weight loss caused by the treatment. The tank was filled with the oil until it reached three quarters full. The treatment temperature and duration were set at 180°C, 200°C and 220°C for 30, 60 and 90 min. respectively. The wood samples were initially placed into hot oil at 80°C and the real treatment time started only when the oil bath reached the targeted temperature. The temperatures were recorded every 10 min respectively. At the end of each treatment period, the wood samples were taken out from the tank and wiped clean with cloth to avoid oil seeping into the wood tissues. The wood samples were later cooled and conditioned in a conditioning chamber set at 20 ± 2 ºC and 65 ± 5% relative humidity before reweighing. The wood samples were later cut into various sizes for respective testing for chemical analysis and strength tests. The procedure Razak *et al*. (2005) were followed for the wood treatment and testing.

Chemical Properties

Chemical Analysis

The main chemical components evaluated in the oil heat treated wood were the alcohol-toluene solubility, holocellulose, alpha-cellulose and klason lignin. Separated chemical analysis was done each for the sapwood and heartwood respectively. The amount of chemical constituents presents were calculated based on their ratios. Tests were conducted in accordance with using TAPPI T203 om-99 (1999) and TAPPI T222 om-02 (2002) standards.

Wood Sample Preparation

In the study of the chemical constituents the wood were divided into 2 groups namely the sapwood and heartwood. The woods were chipped before undergoing grinding process. Willey's mill was used in turning the wood into powdery form in order to pass BS 40-mesh sieve and retained on a BS 60-mesh sieved. The grinded samples were then dried for 7 days until their moisture is in equilibrium with the atmosphere before undergoing chemical analysis process. 2g air-dried sawdust was placed in the weighing bottle and weigh to the nearest 0.01 g. The sawdust was later dried in an oven set at 103±2°C for 3 hours with the cover off. The bottle was then taken out and placed in a desiccators for 15min. Moisture content of the sawdust was later determined.

Colour Measurement of Hot Oil Heat Treated Wood

Measurement for colour were taken before and after the wood samples had completed the hot oil treatment process at temperatures 180, 200, 220ºC for treatment time of 30, 60, and 90 minutes respectively. The surfaces on the woods to be measured were marked before undergoing the hot oil heat treatment process. This was to ensure the wood surface measured were consistent throughout the process. Marked point was made using a sharp pencil on the wood surfaces measuring 2 x 2 cm at the cross-sectional surface of each sapwood and heartwood. This section in the wood was the most representative area for revealing the colour difference (Unsal *et al*., 2003). Measurement for the colour appearances were done at the middle of each sapwood and heartwood in the cross sections of the *A.* hybrid at each section height. The samples were sanded slightly for about 3 mm using P100 sandpaper and brushed cleanly to minimize the risk of colour variation values cause by differences in surface structure. Measurements of colour appearances were done in accordance to the CIE L*a*b* (1986) system using a Minolta Chroma Meter CR-10. The colour reader measures the colour difference on the surface of wood specimens between two colours which that before and after treatment. The results were presented following the

CIE L* a* b* colour co-ordinates system base on the D65 light source with the reflection spectrum measured in the 400 – 700 nm regions. The values were used to calculate the colour change as a function of thermal treatment.

Strength Properties (Modulus of Rupture and Modulus of Elasticity in Static Bending)

Evaluation of the modulus of rupture (MOR) and modulus of elasticity (MOE) in Static Bending static bending of the wood was conducted in accordance with ASTM D4761 (1999) standard. A Universal Testing Machine located in Forest Research Center, Sandakan, Sabah, was used for bending testing. The dimensions of wood samples for static bending test were 20 x 20 x 300 mm. The specimen was supported on a span of 280 mm and the force applied at mid-span using a loading head. The rate of loading was 6.6 mm/min. Wood were loaded on the radial surface. The tests were stopped when the wood started to break. The proportional limit and ultimate load and deflection were recorded, and the MOE and MOR were calculated automatically by the computer connected to the machine.

RESULTS AND DISCUSSION

Chemical Properties

Table 1 shows the chemical composition of the treated acacia wood before and after undergoing the hot oil treatment process. Both the control sapwood and heartwood had the highest chemical compositions of holocellulose and cellulose compared to the hot oil heat treated wood at various treatment temperature and time. The results clearly showed that the changes of chemical components compositions occurred when the wood were treated at higher temperature and duration (Razak *et al*., 2011; Izyan *et al*., 2010). At temperature above 180°C, the hot oil treated wood experiences the loss of polysaccharide material (Hill, 2006). The holocellulose contents varied between 63.1% and 70.8% for the hot oil treated sapwood. The cellulose contents between 37.7% and 46.2%, with hemicelluloses contents varied between 23% and 26.1% and lignin between 19.2% and 24.9% at 180-220°C with 30 to 90 minutes treatments. For the heartwood, the holocellulose contents for treated varied between 64% and 71.7%, cellulose between 38.1% and 47.8%, hemicelluloses contents varied between 23.2% and 26.2% with and the lignin between 22.4% and 27.0% at 180 - 220°C with 30 to 90 minutes treatments.

***Holocellulose*:** Slight reduction on the holocellulose contents in the treated sapwood and heartwood occurred with the increment in of treatment temperature and time in comparison to both untreated sapwood and heartwood. The holocellulose contents for sapwood ranged between 63.1 to 70.8 % and for heartwood from 64.0 to 71.7% depending on the temperature and duration applied. Studies by Inari *et al.* (2007) and Boonstra and Tjeerdsma

Table 1. Average values of chemical changes of 15-year-old oil heat-treated *A.* hybrid wood.

Wood type	Temp. (°C)	Treatment duration (min)	Chemical Composition (%)			
			Holocellulose	Cellulose	Hemicellulose	Lignin
Sapwood	Control	Control	71.5 (0.00)	47.1 (0.00)	24.4 (0.00)	20.8 (0.00)
	180	30	70.8 (-1.0)	46.2 (-1.9)	24.6 (0.8)	20.7 (-0.5)
		60	69.7 (-2.5)	45.1 (-4.2)	24.6 (0.8)	22.0 (5.8)
		90	66.6 (-6.9)	43.6 (-7.4	23.0 (-5.7)	22.1 (6.3)
	200	30	68.6 (-4.1)	42.5 (-9.8)	26.1 (7.0)	23.9 (14.9)
		60	65.3 (-8.7)	39.2 (-16.8)	26.0 (6.6)	23.8 (14.4)
		90	64.5 (-9.8)	38.5 (-18.3)	26.0 (6.6)	24.7 (18.8)
	220	30	66.4 (-7.1)	41.6 (-11.7)	24.8 (1.6)	23.7 (13.9)
		60	64.9 (-9.2)	38.9 (-17.4)	26.0 (6.6)	24.3 (16.8)
		90	63.1 (-11.7)	37.7 (-20.0)	25.4 (4.1)	24.0 (15.4)
Heartwood	Control	Control	73.4 (0.00)	48.9 (0.00)	24.5 (0.00)	22.4 (0.00)
	180	30	71.7 (-2.3)	47.8 (-2.3)	23.9 (-2.5)	21.7 (-3.1)
		60	70.6 (-3.8)	46.3 (-5.3)	24.3 (-0.8)	22.9 (2.2)
		90	67.9 (7.5)	44.7 (-8.6)	23.2 (-5.3)	23.0 (2.7)
	200	30	68.8 (-6.3)	42.6 (-12.9)	25.9 (5.7)	24.5 (9.4)
		60	68.3 (-6.9)	42.1 (-14.0)	26.2 (6.9)	24.9 (11.2)
		90	66.5 (-9.4)	40.9 (-16.4)	25.6 (4.5)	25.0 (11.6)
	220	30	67.1 (-8.6)	42.0 (-14.1)	25.7 (4.9)	24.7 (10.3)
		60	65.1 (-11.3)	39.7 (-18.8)	25.4 (3.7)	24.8 (10.7)
		90	64.0 (-12.8)	38.1 (-22.1)	25.9 (5.7)	24.9 (11.2)

( ) = % change from control,

Holocellulose is the total polysaccharide fraction of wood that is composed of cellulose and all of the hemicelluloses and what is obtained when the extractives and lignin are removed from the natural material.

(2005) also reported similar observations. The holocellulose content of beech and pine decreases between 50% and 60% after heat treatment (Inari *et al*., 2007). Boonstra and Tjeerdsma (2005) noted that holocellulose content of heat treated Scots pine decreased between 79.7% and 63.3%. The decreases occurred when the wood were heated at a temperature above 100°C (Hill, 2006). The content decrease is associated with the loss of cellulose and hemicellulose chains during the process.

***Cellulose*:** The cellulose content determined for the hot oil treated sapwood was between 80 - 98% and heartwood between 78-97%. The results showed occurrence of minor degradation in celluloses content when the wood were treated at 180°C for 30 min and continue to decrease with the increase in treatment temperature. From the analysis of molecule size of cellulose in heat treatment by using intrinsic viscosity measurement, it showed that heat treatment results in a considerable reduction in molecule size of cellulose. Different process conditions and treatment time applied during the heat treatment can influence the degradation rate of cellulose content (Boonstra and Tjeerdsma, 2005). The degree of polymerization of cellulose is already decreased in thermally treated spruce at temperatures above 120°C due to cleavage of the glucosidic bonding that is accelerated by the presence of acids that catalyzed the reaction (Fengel and Wegener, 1989). Chain scission of the cellulose occurred with extended heating, producing alkaline soluble oligosaccharides, with a concomitant decrease in the cellulose degree of polymerization (DP) and degree of cyrstallinity (Hill, 2006).

***Hemicellulose*:** Hemicelluloses content for both heat treated sapwood and heartwood showed fluctuation values, but with no specific trend. The hemicelluloses for sapwood experiences changes in content from 24.4% in control to 26.1% in heat treated samples. While in the heartwood the content changes from 24.5% to 26.2%. Both wood experiences an increases in the hemicelluloses contents. A study by on *Grevillea robusta* wood found that the increment in lignin content with treatment time confirming higher susceptibility of hemicelluloses to thermal treatment (Mburu *et al.,* 2008). Rowell *et al.,* (2005), stated that the hemicelluloses change is predominate at temperatures below 200°C. When wood undergo a heat treatment process, most of the heat labile hemicelluloses begins to deteriorate, resulting in the output of methanol, acetic acid and other volatile heterocyclic compounds (Hill, 2006). Acetic acid is produced when the acetylated hydroxyl groups of the hemicellulose chains are split off during the heating (Johansson, 2008). Volatile organic acids formed during to the heating of wood are trapped and promote the degradation rate (Viitaniemi, 2001).

***Lignin*:** The lignin content of sapwood and heartwood in the *A.* hybrid increases with temperature and heat treatment duration.

Table 2. Average values of colour variation in L*, a* and b* of oil heat-treated *A.* hybrid wood.

Wood types	Temp. (ºC)	Treatment duration (min.)	L*			a*			b*		
			B	M	T	B	M	T	B	M	T
	Control	Control	73.6	73.0	71.4	6.9	6.6	7.3	21.2	22.3	21.4
		30	66.7	70.0	65.5	7.4	8.7	8.5	21.9	23.3	23.4
	180	60	65.4	62.7	63.0	8.8	9.9	9.8	25.7	26.3	24.1
		90	65.6	61.9	62.9	9.3	10.9	10.2	27.3	27.5	26.3
		30	63.5	63.5	58.2	9.5	10.0	9.9	26.4	26.1	26.2
Sapwood	200	60	56.9	57.2	56.9	11.4	11.9	10.7	27.5	27.1	26.5
		90	50.7	54.6	51.6	12.2	12.4	12.2	27.9	28.9	28.0
		30	56.5	53.0	53.4	11.7	10.6	10.3	27.6	26.9	26.7
	220	60	48.7	47.9	43.2	12.3	12.7	11.2	27.8	27.6	27.8
		90	41.5	40.6	39.2	13.9	13.5	12.6	28.1	29.3	28.9
	Control	Control	54.1	54.8	53.5	14.2	15.1	13.9	26.8	26.3	25.2
		30	53.6	52.7	52.9	13.4	12.9	12.0	25.0	24.8	24.1
	180	60	51.7	51.6	50.7	11.9	11.1	11.5	23.6	23.2	23.5
		90	50.4	50.2	48.2	11.2	10.8	10.7	23.0	21.5	22.3
		30	51.4	52.1	48.6	11.5	10.3	11.3	23.7	24.1	23.9
Heartwood	200	60	49.1	50.5	46.9	11.0	9.7	10.7	23.4	21.5	21.9
		90	45.9	46.7	43.5	9.9	8.9	10.2	23.1	21.2	20.9
		30	50.7	50.8	46.3	10.0	9.0	10.2	22.6	22.9	21.0
	220	60	46.6	47.4	38.8	8.3	8.3	8.4	21.1	19.8	17.2
		90	40.0	40.9	33.1	6.7	7.1	7.3	20.5	19.0	15.1

Note: Temp. = temperature, L*= lightness, a* = red, b* = yellow, B = Bottom, M = Middle, T = Top

There was an increment of lignin content in the sapwood from 20.8% (untreated wood) to 24.7% (hot oil treated wood), while the lignin content of the heartwood from 22.4% (untreated heartwood) to 25.0% (hot oil treated wood). Similar observations were also made by Brito *et al.* (2008), Mburu *et al.* (2008), Inari *et al*. (2007), Yildiz *et al*. (2006) and Sarni *et al*. (1990) in their respective heat treatment studies. Changes in the lignin constituents indicated some changes occurred in the lignin structure of wood. Sandermann and Augustin (1964) stated that the loss of polysaccharides material during the heating process leads to an increase in the lignin content of wood.

Analysis of Variance on Chemical Composition

Significant different were observed between the temperatures and treatment duration relating to content of lignin (see Table 5). Almost all of the chemical components were significantly affected by temperature, treatment duration and wood types. Significant different were also noted between the treatment temperature, duration and wood type of the treatment in the constituents of holocellulose, cellulose and lignin. It can be concluded that the effects of treatment temperature, duration and wood types were the primary caused in the change in chemical constituents of these chemical

Table 3. Bending strength (MOR, MOE) of sap- and heartwood *A.* hybrid through hot oil-heat treatment process.

Wood Type	Temp. (ºC)	Treatment duration (min)	MOR (N/mm²)			MOE (N/mm²)		
			B	M	T	B	M	T
Sapwood	Control	Control	69.78	67.22	65.08	3864.54	3803.57	3776.72
	180	30	64.05 (8.21)	61.98 (7.80)	63.37 (2.63)	3535.7 (8.51)	3455.43 (9.15)	3492.52 (7.53)
		60	63.43 (9.10)	59.66 (11.25)	52.23 (19.74)	3475.95 (10.06)	3416.45 (10.18)	3265.79 (13.53)
		90	62.31 (10.71)	55.82 (16.96)	47.99 (26.26)	3470.29 (10.20)	3412.22 (10.29)	3207.16 (15.08)
	200	30	55.06 (11.64)	54.85 (18.40)	45.31 (30.28)	3407.97 (11.81)	3328.01 (12.50)	3094.19 (18.07)
		60	60.11 (13.86)	54.70 (18.63)	44.86 (31.07)	3333.09 (13.75)	3228.98 (15.11)	3035.35 (19.63)
		90	55.38 (20.64)	50.41 (25.01)	42.85 (34.16)	3244.75 (16.04)	3172.19 (16.60)	2972.25 (21.30)
	220	30	53.9 (22.76)	49.72 (26.03)	40.57 (37.66)	3216.75 (16.76)	3101.06 (18.47)	2938.18 (22.20)
		60	51.42 (26.31)	46.89 (30.14)	38.15 (41.38)	3133.38 (18.92)	3046.50 (19.90)	2716.33 (28.08)
		90	41.21 (40.94)	40.33 (40.00)	37.03 (43.10)	3001.51 (22.33)	2787.39 (26.72)	2599.31 (31.18)
Heartwood	Control	Control	68.51	70.76	90.43	3975.49	4004.07	4067.94
	180	30	67.42 (1.59)	65.24 (7.80)	66.70 (26.24)	3676.91 (7.51)	3637.29 (9.16)	3721.56 (8.51)
		60	66.77 (2.54)	63.47 (10.30)	54.98 (39.20)	3658.9 (7.96)	3634.52 (9.23)	3437.94 (15.49)
		90	65.59 (4.26)	58.81 (16.89)	51.06 (43.54)	3587.34 (9.76)	3599.88 (10.09)	3376.74 (16.08)
	200	30	63.27 (7.65)	58.75 (16.97)	47.74 (47.21)	3577.19 (10.02)	3547.83 (11.39)	3291.87 (19.08)
		60	58.8 (14.17)	57.74 (18.40)	47.7 (47.25)	3545.84 (10.81)	3503.17 (12.51)	3229.33 (20.62)
		90	58.57 (14.51)	53.63 (24.21)	45.67 (49.50)	3488.98 (12.24)	3435.31 (14.20)	3162.30 (22.26)
	220	30	57.96 (15.40)	52.89 (25.25)	43.62 (51.76)	3422.08 (13.92)	3299.28 (17.60)	3159.49 (22.33)
		60	55.30 (19.28)	50.42 (28.75)	41.02 (54.6()	3369.22 (15.25)	3275.80 (18.19)	2920.83 (28.20)
		90	44.31 (35.32)	44.7 (36.83)	39.81 (55.98)	2997.64 (24.60)	3227.43 (19.40)	2794.95 (31.29)

Note: ( ) = % change from control samples, B = Bottom, M = Middle, T = Top

component. There was no significant difference in the wood type in the treatment relating to the content of hemicelluloses. The wood types did not affect the changed in hemicellulose content in oil thermally modified process. The effect of the temperature and treatment duration causes the decrement in hemicellulose constituents. The changes in the chemical contents of the wood increased with the increased in temperature. The chemical constituents in *A.* hybrid wood were highly affected by the hot oil treatment temperature, duration and wood types in oil thermally modified process.

Colour Changes

Table 2 presents the colour changed values of treated sapwood and heartwood. Based on the colour measurement of both the sapwood and heartwood, the effect on colour through oil heat treatment can be readily observed at different treatment temperature and treatment time, compared to the original color of the specimen.

Lightness (L*) of Wood Colour

The factor that effect the colour changes for both the sapwood and heartwood is the lightness (L*). The variation in L* has as more responsive sign in the colour change to the human eye which accompany the change in chromic characters a* and b* (Keey, 2004). Thulasidas *et al*. (2006) reported that the variability in darkness or lightness is the main cause of wood colour variability.

The changed in lightness (L*) values for both the sapwood and heartwood showed decreases in lightness in the first 30 minutes of every treatment. The changes continued progressively with the increase of treatment temperature and duration. The L* values of heartwood did not changed considerably when compared to L* values of sapwood. This might be due to the brightness in the wood colour itself as the sapwood of acacia has a brighter colour than heartwood. The sapwood becomes slightly darker, while heartwood becomes considerably darker when exposed to vary treatment conditions.

The bottom, middle and top sections of the sapwood treated at 220°C in 30 minutes showed L* values almost similar with L* values of untreated heartwood. This also can be observed obviously from the below figure shown.

Table 4. Correlations between mechanical, colour and chemical properties of 15 year-old cultivated *A.* hybrid.

Wood Properties	MOR	MOE	L*	a*	b*	Holo	Hemi	Cell	Lignin
MOR	1.00	0.60**	0.40**	-0.06 ns	0.02 ns	0.42**	-0.19*	0.42**	-0.36**
MOE		1.00	0.34**	0.05 ns	-0.01 ns	0.35**	-0.24**	0.37**	-0.31**
L*			1.00	-0.37**	0.11 ns	0.51**	-0.33**	0.53**	-0.75**
a*				1.00	0.47**	0.11 ns	-0.02 ns	0.10 ns	0.15*
b*					1.00	-0.07 ns	-0.07 ns	-0.04 ns	-0.01 ns
Holo						1.00	-0.34**	0.96**	-0.69**
Hemi							1.00	-0.59**	0.61**
Cell								1.00	-0.77**
Lignin									1.00

Table 5. ANOVA on chemical compositions of oil heat treated 15 year-old *Acacia* hybrid.

Source of Variance	Dependent Variable	Sum of Squares	Df	Mean Square	F-Ratio
Temperature	Holocellulose	1618.96	3	539.65	564.15**
	Hemicellulose	139.12	3	46.37	85.82**
	Cellulose	2460.23	3	820.08	1018.75**
	Lignin	368.90	3	122.97	461.45**
Duration	Holocellulose	250.82	2	125.41	131.10**
	Hemicellulose	7.43	2	3.72	6.88**
	Cellulose	210.26	2	105.13	130.60**
	Lignin	12.69	2	6.35	23.81**
Wood types (Sap and Heartwood)	Holocellulose	96.80	1	96.80	101.20**
	Hemicellulose	0.01	1	0.01	0.01ns
	Cellulose	95.20	1	95.20	118.27**
	Lignin	52.22	1	52.22	195.94**

The decreased in L* values from 200°C-220°C was larger than at 180°C in sapwood when compared to heartwood. The L* values in heartwood changed slightly when temperature exceed 200°C. The major changed of treatment duration of both wood types occurred between treatments of 60 - 90 minutes. This indicates the changed in L* values gradually decreased with the increased in the treatment temperature and treatment time.

The summary of correlation coefficient of colour variation with other wood properties of treated acacia is given in table 4. There was a correlation between L* and chemical component of acacia wood. The holocellulose and cellulose constituents shows positive correlations with L*. The hemicellulose and lignin on the other hand were negatively correlated with the colour. The conclusion is that the changed in wood colour were influenced by the chemical components of the wood. The differences in the chemical constituents of the sapwood and heartwood extractive and lignin might probably be the main reason for the dissimilar in colour appearances (Sundqvist, 2004). Burti *et al*. (1998) stated that during heat treatment at elevated temperatures, polyphenols compounds found in hybrid walnut heartwood which conferred dark color to heartwood, may migrate in the sapwood region and changed the sapwood colour from light to dark colour.

The decreased in lightness resulted from the high temperature of heat treatment was due to decrement in certain chemical constituents in wood such as hemicelluloses and lignin (Mitsui *et al*., 2001; Bourgios *et al*., 1991). The wood colour changes can be an indicator of chemical modification that took place in wood (Burti *et al*., 1998; Bekhta and Niemz, 2003; Sundqvist *et al*., 2004).

Chroma Colour, a* (Reddish Colour)

The a* and b* are a combination of red (a*) and yellow (b*) in the chroma coordinates, Both of the sapwood and heartwood showed some differences due to changes in a* and b* values. The a* values of the sapwood increased while a* values of heartwood decreased through this treatment. This might be due of the original colour of the wood itself. The original colour of the sapwood is light yellowish red while the colour of heartwood is brownish red. Increased in treatment temperature tends to increase the a* values of sapwood. The a* values reaches a maximum values after treated at 220°C temperature.

Table 6. ANOVA of colour appearances of treated *A.* hybrid

Source of Variance	Dependent Variable	Sum of Squares	Df	Mean Square	F-Ratio
	L*	9538.60	3	3179.53	110.70**
Temperature	a*	9.33	3	3.11	0.42ns
	b*	35.41	3	11.80	1.10ns
	L*	1257.57	2	628.79	21.89**
Duration	a*	1.43	2	0.72	0.10ns
	b*	2.67	2	1.33	0.12ns
	L*	6537.30	1	6537.30	227.60**
Wood Types	a*	94.80	1	94.80	12.82**
(Sap and	b*	294.70	1	294.70	27.55**
Heartwood)	L*	222.61	2	111.31	3.88*
Sampling Height	a*	0.78	2	0.39	0.05ns
	b*	23.77	2	11.89	1.11ns

Table 7. ANOVA on the strength properties of oil heat treated *A.* hybrid

Source of Variance	Dependent Variable	Sum of Squares	Df	Mean Square	F-Ratio
Temperature	MOR	12076.80	3	4025.59	15.99**
	MOE	1.81	3	6.02	12.66**
Duration	MOR	3425.40	2	1712.70	6.80**
	MOE	2.72	2	1.36	2.86ns
Wood Types	MOR	565.80	1	565.80	2.25ns
(Sap and Heartwood)	MOE	2.16	1	2.16	4.55*
Sampling Height	MOR	3098.58	2	1549.29	6.15**
	MOE	2.06	2	1.03	2.17ns

** = significant at $p \leq 0.01$, * = significant at $p \leq 0.05$, ns = not significant, MC= Moisture Content, BD= Basic Density, MOR= Modulus of Rupture, MOE = Modulus of Elasticity, L*= Lightness, a*= Reddish, b*= Yellowish, Holo= Holocellulose, Hemi= Hemicellulose, Cell= Cellulose

The colour of sapwood becomes more reddish than before while the red colour in heartwood becomes lessen. The reddish colour and the increased in saturation substantiated as a decrease in hue and increase in chroma might be the results of the formation in secondary condensation or degradation products of the quinine and quinonemethide types (Hon *et al*., 1991).

There was a correlation between a* and chemical component of acacia wood (see Table 4). Positive correlations were observed between a* and b*, holocellulose, cellulose and lignin. However, the hemicellulose were negatively correlated with a*. However a* did not significant correlated with all chemical component except for lignin.

The heat treated wood colours changed from yellow to brown as the results of the photo-oxidation of lignin and wood extractives, with produced coloured quinines component (Charrier *et al*., 2002; Grelier *et al*., 1997).

Chroma Colour, b* (Yellowish Colour)

The b* values of heartwood shows the negative change from the start of the treatment. The yellowish colour in the heartwood started to decrease once the temperature reached 180°C and it decreases drastically when exposed to 220°C at longer treatment duration.

There was a correlation between b* and a* of *A.* hybrid wood (Table 4). Positive correlations were noted between the a* and b*. Besides a*, b* does not significantly correlated with other wood properties in this study.

Strength Properties (MOR and MOE in Bending Tests)

The result of strength properties of treated *A.* hybrid wood is presented in table 3. It is clearly observed the values of both wood types (sapwood and heartwood) for modulus of rupture (MOR) and modulus of elasticity (MOE) decreased through oil thermally modified. The untreated wood still obtained the highest strength values compared to treated wood. The strength properties of wood usually decrease with increasing temperature and increase with decreasing temperature (Smith *et al*., 2003). For the thermally modified wood, the highest values of MOR and MOE of every portion were starting to decreased when the treatment temperature reaching 180°C. This strength values respectively decreased when treated at 200°C and 220°C. From the results obtained the values of MOR and MOE of untreated and treated wood showed a decrement with increasing sampling height. The variations in MOR and MOE along the tree height can be explained by the decrease in maturity of wood and fibre length from the base to the top of the tree (Rulliarty and America, 1995).

Wood treated at 180 to 200°C in the presence of moisture was noted to result in a large reduction of their resistance to MOR, MOE and compression strength (Giebeler, 1983). The wood strength can be reduced by up to 50% if the treatment temperature reached over 200°C (Bekhta and Niemz, 2003; Sailer *et al*., 2000; Kamden *et al*., 1999). The increased treatment duration which is 30 to 90 minutes also prolong the decreasing effect on strength. This testifies a value of MOR for treated wood is influenced by treatment temperature and duration. The higher the temperature the longer the treatment duration the lower is the strength value. However, MOE did not show significantly difference with treatment duration and this is reinforced by the ANOVA in tables 4 and 7.

The strength properties of the oil heat treated wood are reduced by the oil treatment process. The strength reduction is mainly due to the hemicelluloses degradation (Kocaefe *et al*., 2007). The effects, however varies according to the wood species, anatomical features and the treatment methods (Mburu *et al*., 2008; Kocaefe *et al*., 2007). Studied on the effect of high temperature on spruce wood found that MOE of spruce wood started to decrease once the temperature rose over 100°C (Bekhta and Niemz, 2003). The mechanical properties of the wood started to weaken and become brittle when the treatment temperatures reached over 200°C (Sundqvist, 2004).

Compression failure typically occurs in wood having low density (Nordahlia, 2008; Bodig and Jayne, 1982). The reduction of density in the treated material can caused reduction in some of the strength properties (Rafidah *et al*., 2008; Janssen, 1981). The strength loss increases with the increased in treatment temperature and time. This is why the oil heat treated wood is no recommended for use in the load bearing constructions application (Korkut *et al.*, 2007; Jamsa and Viitaniemi, 2001). However, their dimensional stability and durability increases (Yildiz *et al*., 2006).

Analysis of Variance on the Strength Properties

The analysis of variance for the strength properties are shown in table 7. The analysis was conducted to determine whether there was significance difference between physical properties with treatment temperatures, duration, wood types and sampling height. There were significant difference between moisture content with treatment temperatures, duration and wood types. No significant difference was observed between the moisture content and the wood height (bottom to the top). For basic density, there were significant difference was observed with treatment temperatures, duration, wood types and sampling height.

The analysis of variance indicated that for MOR there are significant differences in treatment temperature, duration of treatment and sampling height. However, there is no significant difference in the wood type. For MOE, only two significant differences were observed, which are

treatment temperature and wood types. There is no significant difference in duration of treatment and sampling height.

Correlation Coefficient between the Chemical, Colour and Strength Properties

The correlation among wood properties of *A.* hybrid wood is presented in table 4. There exist strong correlation between the moisture content and the chemical composition in the cultivated acacia wood. Moisture contents has positive correlation to the holocellulose (r = 0.81) and cellulose (r = 0.82). While hemicellulose (r = -0.40) and lignin (r = -0.76) were negatively correlated with moisture content. According to Smith *et al*. (2003), due to the existence of hydrogen bonding sites in hydroxyl groups present in cellulose, hemicellulose and lignin, wood is a hygroscopic material. From this treatment, dimensional stability is increased due to decrement in moisture. There was positive correlation between moisture content and basic density of acacia wood in this treatment, but the correlation was not significant. A similar result was observed by Nordahlia (2008) in *Azadirachta excelsa* where moisture content and basic density was not correlated.

There was also a correlation between moisture content and strength properties in this study. Positive correlations were observed between moisture content and modulus of rupture (r = 0.50) and modulus of elastic (r = 0.40). Smith *et al.* (2003) noted that wood contains five or six layers of attached water molecules when in the saturated condition. While only one layer of water molecules at moisture of about 6% which is directly attached to cells walls by hydrogen bonding in dried wood. Mechanical properties of wood may degrade when there is a change happen in this layer due to many new hydrogen bonds are generated in the microfibrils with removal water molecules from cell walls, resulting in an increase of crystalline regions. The correlation between the basic density and other wood properties are presented in table 4. There was a correlation between basic density and strength properties (MOR and MOE) and chemical composition of acacia wood. Positive correlations were observed between basic density and modulus of rupture (r = 0.37), modulus of elasticity (r = 0.42), holocellulose (r = 0.24) and cellulose (r = 0.24).

The correlation between the strength properties and other wood properties are presented in table 4. There were a correlation between MOR and MOE, physical properties, colour and chemical composition of treated wood. Positive correlation were obtained between MOR and MOE (r = 0.60), moisture content (r = 0.50), basic density (r =0.37), lightness (L*) (r = 0.40), holocellulose (r = 0.42) and cellulose (r = 0.42). While hemicellulose (r = -0.19) and lignin (r = -0.36) were negatively correlated with MOR. For MOE there were also a correlation between physical properties, colour and chemical composition of treated wood. Positive correlation were obtained between MOE and moisture content (r = 0.40), basic density (r = 0.42), lightness(r = 0.34), holocellulose (r = 0.35) and cellulose (r = 0.37). While hemicellulose (r = -0.24) and lignin (r = -0.31) were negatively correlated with MOE.

CONCLUSIONS

The hot oil thermal modification process caused some features changed in the chemical composition of *A.* hybrid wood. The degradation in holocellulose, cellulose, and hemicellulose contents was recognized when acacia woods were exposed to oil thermally modified process. Holocellulose and celulose degraded with the increasing of treatment temperature and time of heating exposure, while lignin showed the increment in content through this treatment. The sapwood and heartwood of *A.* hybrid colour becomes darker once they are exposed to the high temperature and longer treatment time in the hot oil thermal modification process. The degree of the changes varies between both wood types. The sapwood tends to darken more than the heartwood. The increment in colour of both woods increases with temperature and treatment time. Treatment temperature at 200°C and treatment time of 90 min. and 220°C at 30 min. of the sapwood becomes uniform with the colour of the original untreated heartwood. The hot oil thermal modification process induced extensive darkening and reddening of *A.* hybrid wood. For the strength properties of the oil heat treated *A.* hybrid wood, the values of both MOR and MOE decreased throughout the treatment process. The decreases in values were influenced by treatment temperature and duration. The value of MOR and MOE of the treated wood were influenced by the treatment temperature. The increase in the holocellulose and cellulose contents causes an increase in the strength (MOR and MOE) of the *A.* hybrid wood. On the other hand, the reduction of the hemicellulose and lignin contents causes the drop in strength of the hot oil treated *A.* hybrid.

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