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Effect of Post Heat Treatment on Dimensional Stability of UF Bonded Particleboard

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ABSTRACT
The objective of this present study was to propose a post heat treatment as a method to improve particleboard dimensional stability by decreasing wood hygroscopicity and releasing hotpressing stress. Rubberwood panels from rubberwood were treated in a laboratory press at three different temperatures (100, 150 and 180°C) for about 90, 180 and 270 sec. The wood-water relation variables, Thickness Swelling (TS) and Water Absorption (WA) were determined and compared with untreated panels. The results showed that the proposed thermal treatment was effective to reduce TS but didn't affect WA. WA and density were not directly influenced by the treatment but it had been reduced with the increase of the duration of the treatment. Some of the panels were found meet the Japanese Industrial Standard which determines maximum values of 12%.

Key words: Post heat treatment, thickness swelling, dimensional stability, Japanese Industrial Standard, water absorption, urea formaldehyde

INTRODUCTION
The popularity of particleboard was increasing continually in Malaysia due to the reduction of solid wood supply (Ratnasingam and Wagner, 2009). The wood supply in Peninsular Malaysia has been decreasing rapidly especially of rubberwood. Due to this reason, lesser known and fast species such as Mahang were used experimentally as a substitution for rubberwood (Loh *et al*., 2010). In recent studies, pepper stalks (Guntekin *et al*., 2008), dhaincha (Islam *et al*., 2006) and kenaf core (Izran *et al*., 2009) have been investigated and found technically suitable in particleboard manufacturing. Despite its feasibility, this action showed a great dependency toward the particleboard, particularly in the furniture manufacturing.

Particleboard industries in Malaysia rely solely on Urea Formaldehyde (UF) resins due to its economically cheap cost and desired particleboard properties (Nemli and Ozturk, 2006), although Melamine Urea-Formaldehyde (MUF) has been successfully proved its potential as an alternative binding agent for UF (H'ng *et al*., 2011). Over the past decade, a lot of potential efforts have been made to reduce formaldehyde emission from particleboard. The most effective and economical method of reducing formaldehyde emission from particleboard still focus to reduce its formaldehyde content of UF resin. Particleboard made with lower mole ratio of formaldehyde to urea (F/U) resins emitted less formaldehyde but, unfortunately the other physical and mechanical properties were influenced negatively. Basically, reduced formaldehyde to urea mole ratio primarily affects internal bond and thickness swelling of particleboard (Mayer, 1979). Que *et al*. (2007) found that the

Modulus of Rupture (MOR), Internal Bond (IB) and Thickness Swelling (TS) of particleboard experienced the deterioration because of the decrease of the mole ratio of urea formaldehyde resin from 1.27 to 0.97.

Specifically for wood-based panels, there are several methods of treatment to improve dimensional stability which can be divided into three different means of application; pre-treatment, post-treatment and production technology. The production technology methods involve those that are related to improving resin content (Hashim *et al.*, 2001) and application of water repellents (Winistorfer *et al.*, 1992). While the post-treatment are applied to the consolidated panel and the thermal treatment is the most usual (Suchsland and Xu, 1991).

The thermal modification of wood has long been recognized as the potentially useful method to improve the dimensional stabilization of wood and increase its decay resistance. Tiemann (1915) was one of the first workers that found a reduction of 10-25% for moisture sorption, with relatively low reduction in strength when he heated air-dry wood in superheated steam at 150°C for 4 h. A lot of work about the ability of heat treatment to impart dimensional stability has been studied in the past 20 years. Hsu *et al.* (1989) verified an enhancement in TS after heat treated phenol-formaldehyde bonded waferboard at 240°C for a period of time.

A research on the effect of different level of resin content and wax on the mechanical properties of UF bonded particleboard has been studied in my last paper. Thickness swelling of the particleboards is greatly affected by the resin and wax content that was applied but the TS still did not meet the minimum requirement of the JIS A5908:2003. Hence, the present work aims to propose a thermal treatment to improve the dimensional stability of UF bonded particleboard.

MATERIALS AND METHODS

Raw material preparation: This study was initiated from March 2011. Rubberwood (*Hevea brasiliensis*) particles were obtained from a commercial particleboard plant located in Negeri Sembilan, Malaysia. The particles were dried to 3% moisture content prior to the particleboard fabrication. The dried rubberwood particles were screened to obtain required size for surface and core materials. All the particles were prepared in commercial particleboard manufacturers. The classification of the particles is shown in Table 1.

Low Formaldehyde to Urea ratio (F/U) Urea Formaldehyde, RD 100 from Norse Chem Resins Sdn. Berhad was used in the study. The solid content of this resin was ranged from 60-65%. The wax applied was wax emulsion with 60% solid content obtained from a commercial particleboard plant. Ammonium chloride (NH_4Cl) with 25% solid content was used as hardener in the study.

Particleboard manufacturing: Three layers boards were fabricated from rubberwood particles in dimensions of 340 mm long x 340 mm wide x 12 mm thick. Three levels of resin usage (7% in core layer and 10% in surface layer, 8% in core layer and 11% in surface layer and 9% in core and 12% in surface layer) and three levels of wax content (0, 0.5 and 1.0%) was applied in two density levels (680 and 750 kg m^{-3}).

Table 1: The classification of rubberwood particle for surface and core layer

Range of particle dimensions	Surface (mm)	Core (mm)
Length	2-5	10-30
Width	1-2	2-4
Thickness	0.3-0.5	0.2-0.4

One percent hardener (ammonium chloride) was applied in the core layer while 3.8% was applied in the surface layer for each panel. The panels were hot-pressed under 180°C with 100 bar press pressure for 270 sec. After pressing, the boards were conditioned 7 days with 20±2°C and relative humidity of 65±5%. After this, 5 samples for each treatment were obtained according to JIS (Japanese Industrial Standard) A5908:2003 for thickness swelling and water absorption tests. The experimental design for this study was shown in Table 2.

Time/temperature and treatment application: The thermal consisted treatment of heating the samples in a laboratory press in three temperature level (100, 150 and 180°C) for three different time periods (90, 180 and 270 sec). Each temperature-time combination was considered as a different treatment. The applied pressure was only to provide the contact between the sample's surface and the press plate. Summery of all the treatments is provided in Table 3.

Table 2: Experimental design for the study

Type	Density (kg m^{-3})	Wax content (%)	Resin usage (Core:Surface %)
1	680	0	7:10
2			8:11
3			9:12
4		0.5	7:10
5			8:11
6			9:12
7		1	7:10
8			8:11
9			9:12
10	750	0	7:10
11			8:11
12			9:12
13		0.5	7:10
14			8:11
15			9:12
16		1	7:10
17			8:11
18			9:12

Table 3: Summary of the treatments

Treatment	Heating temperature (°C)	Heating time (sec)
A	100	90
B	100	180
C	100	270
D	150	90
E	150	180
F	150	270
G	180	90
H	180	180
I	180	270

Evaluation of the effects of the treatment: After the treatment, the samples were reconditioned (20±2°C, 65±5% humidity). Then, they were measured and weighed to determine the Loss of Weight (LW), the dimensional changes (width, thickness and volume) and the density (D). After that, the samples were tested for Thickness Swelling (TS) and Water Absorption (WA). The evaluation for TS and WA were made in 24 h according to JIS A5908:2003.

Statistical analysis: The test results were submitted to Analysis of Variance (ANOVA) and the comparison among treatments' means was tested using Tukey HSD test at 5% significance level.

RESULTS AND DISCUSSION

Effect of the treatment on the physical characteristics of the panel: The thermal treatment imposed loss of weight and reduction of the dimensions of the panels. Heating of wood results in a reduction in mass and a decrease in volume, the extent of reduction is dependent upon the treatment method, temperature and time of exposure (Rusche, 1973; Fung *et al.*, 1974). The decrease values for mass of the treated panels are presented in Table 4.

With the reduction of the thickness and the width of the panels, an increase of density was observed on the panels treated with 100°C. However, with the increase of the duration and temperature (150 and 180°C) of the treatment, the panel lost more mass and consequently, its density was reduced as presented in Table 5. Heat treatment at lower temperatures results in low mass loss mainly associated with loss of volatiles and bound water. Loss of macromolecular components can occur at temperature above 100°C and this assumes greater significance as time and heating temperature are increased (Millett and Gerhards, 1972).

Table 4: Loss of weight of the treated panels in percent (%)

Type	A	B	C	D	E	F	G	H	I
1	-0.81	-1.05	-1.17	-1.95	-4.28	-2.97	-3.29	-2.47	-3.74
2	-0.79	-1.11	-1.21	-2.26	-3.77	-2.84	-2.84	-2.09	-3.93
3	-0.83	-1.29	-1.46	-2.71	-4.29	-3.11	-3.96	-2.77	-3.96
4	-0.86	-1.28	-1.29	-2.02	-3.79	-3.51	-3.58	-2.48	-3.91
5	-0.74	-1.32	-1.53	-2.54	-3.52	-2.50	-3.39	-2.54	-4.15
6	-0.64	-1.11	-1.18	-2.60	-3.46	-2.18	-3.43	-2.87	-3.61
7	-0.54	-1.24	-1.41	-1.66	-3.14	-2.11	-3.60	-3.78	-5.44
8	-0.77	-0.95	-1.50	-1.84	-3.24	-2.27	-3.56	-3.77	-5.13
9	-0.64	-1.31	-1.69	-1.91	-3.59	-2.39	-3.91	-4.35	-5.45
10	-0.54	1.09	-1.28	-1.63	-3.12	-2.43	-3.30	-3.50	-4.80
11	-0.68	-1.10	-1.36	-1.89	-3.80	-2.84	-3.66	-3.26	-4.61
12	-0.63	-1.11	-1.27	-1.70	-3.47	-2.84	-3.52	-3.06	-4.11
13	-0.43	-1.07	-1.31	-2.82	-4.14	-3.22	-3.85	-3.02	-4.22
14	-0.43	-0.87	-1.10	-2.41	-3.99	-3.65	-3.70	-2.97	-4.05
15	-0.34	-0.97	-1.46	-2.43	-4.40	-3.64	-3.68	-3.05	-4.04
16	-0.35	-0.79	-1.20	-2.28	-4.21	-3.32	-3.53	-2.54	-4.54
17	-0.35	-0.82	-1.44	-2.76	-4.48	-3.18	-3.74	-2.77	-4.31
18	-0.31	-0.69	-0.86	-2.32	-4.10	-3.52	-3.54	-2.52	-3.95

Table 5: Loss of density of the treated panels in percent (%)

Type	A	B	C	D	E	F	G	H	I
1	0.94	0.95	0.93	0.03	-2.31	-1.03	-1.36	-0.48	-1.84
2	0.86	0.87	0.79	-0.29	-1.78	-0.90	-0.90	-0.09	-2.04
3	0.94	0.64	0.64	-0.76	-2.32	-1.17	-2.04	-0.79	-2.06
4	0.84	0.66	0.80	-0.08	-1.81	-1.58	-1.66	-0.49	-2.00
5	0.99	0.93	0.50	-0.55	-1.54	-0.55	-1.46	-0.55	-2.26
6	1.13	0.73	0.81	-0.61	-1.47	-0.22	-1.50	-0.89	-1.71
7	1.23	0.62	0.50	0.31	-1.14	-0.16	-1.67	-1.82	-3.57
8	0.99	0.98	0.45	0.22	-1.25	-0.32	-1.63	-1.81	-3.25
9	1.08	0.61	0.32	0.05	-1.61	-0.44	-1.99	-2.41	-3.58
10	1.21	0.78	0.74	0.34	-1.13	-0.48	-1.36	-1.54	-2.91
11	1.04	0.78	0.60	0.07	-1.82	-0.90	-1.74	-1.29	-2.72
12	1.15	0.77	0.79	0.29	-1.48	-0.90	-1.59	-1.08	-2.22
13	1.32	0.77	0.64	-0.82	-2.17	-1.29	-1.93	-1.05	-2.32
14	1.31	1.01	0.78	-0.50	-2.01	-1.72	-1.78	-0.99	-2.15
15	1.38	0.94	0.39	0.46	-2.43	-1.71	-1.76	-1.07	-2.14
16	1.98	1.08	0.74	-0.36	-2.23	-1.40	-1.60	-0.55	-2.66
17	1.41	1.07	0.45	-0.78	-2.51	-1.25	-1.81	-0.79	-2.43
18	1.39	1.25	1.11	-0.37	-2.13	-1.59	-1.61	-0.54	-2.05

Table 6: Effect of press temperature and duration on thickness swelling (TS) of particleboard

Type	A	B	C	D	E	F	G	H	I	J
1	20.09 ± 0.16^{a}	22.04 ± 0.28^{a}	20.12 ± 0.53^{a}	23.61 ± 0.42^{a}	21.45 ± 0.94^{a}	23.49 ± 0.56^{a}	20.28 ± 0.31^{a}	21.13 ± 0.43^{a}	20.84 ± 0.19^{a}	22.39 ± 1.10^{a}
2	20.81 ± 0.39^{ab}	21.20 ± 0.27^{abc}	23.03 ± 0.61^{bcde}	25.25 ± 0.67^{e}	21.41 ± 0.80^{abcd}	18.32 ± 0.90^{a}	24.96 ± 1.39^{cde}	25.02 ± 0.96^{de}	21.51 ± 1.18^{abcde}	24.91 ± 0.43^{cde}
3	18.51 ± 0.49^{cd}	16.47 ± 0.20^{abc}	17.70 ± 0.59^{bcd}	18.09 ± 0.82^{bcd}	19.99 ± 0.34^{d}	17.67 ± 0.39^{bcd}	14.49 ± 0.40^{a}	15.79 ± 0.79^{ab}	16.28 ± 0.31^{abc}	19.23 ± 0.52^{d}
4	17.26 ± 0.15^{ab}	18.55 ± 0.13^{abc}	17.00 ± 0.78^{a}	19.54 ± 0.35^{abcd}	21.01 ± 0.60^{cd}	20.02 ± 0.54^{bcd}	17.12 ± 0.21^{a}	18.62 ± 0.53^{abc}	19.89 ± 0.38^{cd}	22.39 ± 0.74^{d}
5	16.47 ± 0.28^{ab}	17.39 ± 0.34^{ab}	15.29 ± 0.35^{a}	17.27 ± 0.70^{ab}	15.15 ± 0.84^{a}	16.10 ± 0.22^{ab}	17.07 ± 0.39^{ab}	20.17 ± 1.02^{c}	18.52 ± 0.20^{bc}	18.49 ± 0.41^{bc}
6	21.30 ± 0.30^{ab}	19.95 ± 0.22^{a}	18.31 ± 0.37^{a}	19.75 ± 0.14^{a}	19.33 ± 0.80^{a}	21.04 ± 1.76^{a}	17.69 ± 0.35^{a}	24.72 ± 1.02^{b}	19.01 ± 1.01^{a}	20.93 ± 0.45^{a}
7	13.17 ± 0.13^{a}	16.10 ± 0.25^{ab}	14.69 ± 0.26^{ab}	14.29 ± 0.54^{ab}	14.99 ± 0.32^{ab}	15.22 ± 0.37^{ab}	20.48 ± 1.19^{b}	18.74 ± 1.52^{ab}	20.20 ± 1.15^{b}	17.98 ± 1.91^{b}
8	12.95 ± 0.33^{a}	14.24 ± 0.17^{ab}	17.57 ± 1.10^{bcd}	17.33 ± 0.72^{bcd}	17.18 ± 0.49^{bcd}	16.18 ± 1.53^{abc}	21.17 ± 1.08^{de}	20.14 ± 0.89^{cde}	23.15 ± 0.85^{e}	20.10 ± 0.72^{cde}
9	12.04 ± 0.30^{a}	13.94 ± 0.26^{abc}	11.41 ± 0.24^{a}	12.78 ± 0.69^{ab}	11.14 ± 0.20^{a}	13.78 ± 0.83^{abc}	17.23 ± 0.55^{cd}	17.92 ± 0.48^{d}	15.74 ± 0.60^{bcd}	17.07 ± 0.95^{cd}
10	13.05 ± 0.21^{a}	12.88 ± 0.13^{a}	13.93 ± 0.39^{ab}	14.49 ± 0.58^{ab}	13.12 ± 0.10^{ab}	15.19 ± 0.45^{ab}	17.62 ± 0.30^{cd}	15.46 ± 0.84^{bc}	14.39 ± 0.14^{ab}	18.07 ± 0.57^{d}
11	13.33 ± 0.19^{abc}	11.95 ± 0.29^{a}	13.22 ± 0.28^{ab}	13.83 ± 0.41^{abc}	12.36 ± 0.55^{a}	14.86 ± 0.19^{bcd}	15.90 ± 0.35^{d}	15.27 ± 0.79^{cd}	14.86 ± 0.51^{bcd}	16.25 ± 0.24^{d}
12	14.02 ± 0.14^{a}	14.01 ± 0.30^{a}	17.79 ± 0.58^{b}	16.98 ± 0.65^{b}	17.12 ± 0.69^{b}	17.97 ± 0.54^{b}	19.17 ± 0.58^{b}	18.48 ± 0.35^{b}	18.17 ± 0.51^{b}	19.18 ± 0.31^{b}
13	11.69 ± 0.17^{a}	11.68 ± 0.35^{a}	11.59 ± 0.32^{a}	13.31 ± 0.32^{ab}	13.59 ± 0.72^{ab}	13.72 ± 0.55^{ab}	12.63 ± 1.36^{ab}	14.09 ± 0.79^{ab}	14.61 ± 0.40^{ab}	15.37 ± 0.82^{b}
14	14.39 ± 0.28^{ab}	16.68 ± 0.15^{bc}	15.47 ± 0.54^{abc}	12.89 ± 0.84^{a}	13.21 ± 0.64^{a}	14.03 ± 0.24^{ab}	13.71 ± 0.68^{ab}	15.10 ± 0.55^{abc}	14.17 ± 0.38^{ab}	17.86 ± 0.87^{c}
15	15.64 ± 0.09^{d}	14.42 ± 0.10^{bcd}	14.53 ± 0.51^{cd}	10.74 ± 0.50^{a}	14.71 ± 0.28^{cd}	11.56 ± 0.49^{ab}	12.16 ± 0.69^{abc}	15.36 ± 0.39^{d}	15.81 ± 0.42^{d}	16.35 ± 0.78^{d}
16	12.76 ± 0.14^{ab}	14.87 ± 0.25^{bc}	13.47 ± 0.52^{abc}	12.54 ± 0.32^{ab}	11.69 ± 0.41^{a}	13.49 ± 0.41^{abc}	13.74 ± 0.48^{abc}	14.79 ± 0.39^{bc}	15.32 ± 0.29^{c}	15.26 ± 0.64^{c}
17	13.55 ± 0.26^{bcd}	15.06 ± 0.13^{d}	14.35 ± 0.48^{cd}	12.18 ± 0.56^{ab}	10.50 ± 0.39^{a}	11.91 ± 0.39^{ab}	12.88 ± 0.25^{bc}	13.58 ± 0.36^{bcd}	13.69 ± 0.90^{d}	15.19 ± 0.30^{bcd}
18	15.53 ± 0.23^{d}	13.83 ± 0.20^{abc}	15.45 ± 0.15^{cd}	12.60 ± 0.44^{a}	13.06 ± 0.28^{ab}	12.62 ± 0.35^{a}	14.41 ± 0.25^{bcd}	15.14 ± 0.38^{cd}	14.65 ± 0.57^{bcd}	15.95 ± 0.33^{d}

Within the same column, mean values followed by different capital letters are significantly different at $p<0.05$ using Tukey's test

Effect of the treatment on the dimensional stability: The TS results of the treated particleboard are presented in Table 6. It can be observed that the TS of the particleboard were reduced after treated by heat. The largest reduction recorded when the panels were heated at 150°C. Some of the panels which heated under this temperature recorded a 50% decrease in TS compare to the untreated panel (J). The WA results of the treated particleboard are presented in Table 7 which shows no clear relationship between WA and the treatment conditions applied. All the untreated panels fail to meet the Japanese Industrial Standard (JIS A5908:2003).

Table 7: Effect of press temperature and duration on water absorption (WA) of particleboard

Type	A	B	C	D	E	F	G	H	I	J
1	71.77±2.14^{ab}	80.19±1.57^{ab}	90.53±5.02^{b}	63.62±1.83^{a}	79.60±8.59^{ab}	60.46±0.40^{a}	83.12±0.85^{ab}	69.13±0.97^{ab}	83.71±7.16^{ab}	71.20±5.11^{ab}
2	70.05±2.15^{abc}	60.13±3.72^{a}	78.42±1.02^{c}	59.57±1.00^{a}	73.10±2.53^{bc}	62.27±3.06^{ab}	60.60±2.92^{ab}	59.20±0.46^{a}	71.49±2.08^{abc}	63.30±4.92^{ab}
3	77.75±2.00^{abcd}	72.63±1.55^{ab}	81.62±0.84^{cd}	74.10±1.35^{abc}	77.82±0.82^{abcd}	76.77±1.17^{abc}	85.00±1.57^{d}	79.66±2.68^{bcd}	78.47±1.60^{abcd}	70.75±2.12^{a}
4	69.35±1.73^{ab}	64.10±1.18^{a}	65.64±0.95^{a}	66.77±1.94^{ab}	68.79±1.34^{ab}	70.90±1.00^{ab}	73.53±0.81^{bc}	80.71±1.48^{c}	70.54±0.76^{ab}	69.00±3.13^{ab}
5	69.12±2.96^{a}	72.51±2.07^{ab}	70.13±0.51^{a}	72.06±1.26^{ab}	77.18±2.11^{ab}	74.52±1.27^{ab}	81.62±0.52^{b}	74.36±3.57^{ab}	77.55±0.81^{ab}	73.69±2.58^{ab}
6	66.72±1.11^{ab}	65.99±1.38^{ab}	66.11±1.05^{ab}	71.71±2.40^{bc}	73.41±1.07^{c}	66.33±0.73^{ab}	66.20±0.57^{ab}	71.08±0.53^{bc}	69.50±1.60^{abc}	63.74±2.07^{a}
7	58.98±1.35^{bcd}	53.70±2.62^{abc}	51.43±1.19^{ab}	48.70±0.54^{ab}	54.50±1.03^{abc}	47.25±3.71^{a}	67.10±1.61^{d}	68.14±2.20^{d}	50.12±3.66^{ab}	64.84±3.56^{cd}
8	54.17±1.85^{ab}	43.18±1.78^{a}	52.36±4.51^{ab}	64.75±3.33^{b}	55.14±4.98^{ab}	68.80±4.36^{b}	60.26±5.29^{ab}	67.01±5.72^{b}	68.40±1.30^{b}	50.17±7.08^{ab}
9	46.03±1.90^{a}	49.84±0.83^{ab}	51.66±0.28^{b}	54.07±0.74^{bc}	52.22±1.37^{bc}	54.53±1.69^{bc}	64.02±0.71^{e}	64.07±0.60^{e}	62.23±0.62^{de}	57.13±1.52^{cd}
10	42.88±1.24^{a}	44.37±1.54^{ab}	44.50±0.93^{ab}	53.61±0.90^{bc}	49.79±1.12^{abc}	51.67±0.98^{abc}	56.56±1.21^{cd}	64.71±4.48^{d}	65.52±1.57^{d}	51.58±3.06^{abc}
11	48.34±1.39^{a}	51.30±1.44^{ab}	52.74±1.73^{ab}	56.27±0.64^{bc}	53.62±0.91^{abc}	53.10±0.63^{abc}	63.13±0.88^{de}	66.92±1.23^{e}	58.52±1.23^{cd}	58.52±1.00^{cd}
12	43.62±0.89^{a}	47.79±2.04^{ab}	48.97±1.29^{abc}	52.86±0.51^{bc}	50.55±1.05^{bc}	49.77±1.15^{bc}	53.65±0.64^{c}	61.76±0.65^{d}	62.38±1.82^{d}	51.10±0.95^{bc}
13	54.43±2.17^{de}	59.97±1.80^{e}	52.58±1.73^{cd}	37.59±0.75^{a}	34.05±1.10^{a}	40.76±0.53^{ab}	55.29±1.99^{de}	49.20±1.04^{cd}	46.34±1.51^{bc}	49.30±1.88^{cd}
14	50.12±3.91^{bcd}	45.96±1.32^{abcd}	44.81±1.60^{abc}	37.85±1.22^{a}	42.33±1.47^{ab}	53.49±3.12^{cd}	53.58±1.08^{cd}	55.67±1.23^{d}	50.31±0.31^{bcd}	38.70±2.68^{a}
15	47.97±1.45^{cd}	48.74±1.76^{cd}	44.68±0.83^{bcd}	34.47±0.68^{a}	39.96±1.57^{ab}	40.79±0.74^{ab}	43.64±0.77^{bc}	49.82±2.54^{cd}	50.74±1.08^{d}	45.40±1.52^{bcd}
16	39.31±1.79^{bc}	39.58±0.65^{bc}	39.52±0.79^{bc}	32.57±0.90^{a}	34.38±0.59^{a}	37.15±0.76^{ab}	42.45±0.71^{c}	43.69±0.95^{c}	40.88±0.65^{bc}	39.68±1.58^{bc}
17	51.52±0.93^{bcd}	56.40±0.81^{d}	55.96±4.46^{cd}	39.93±1.53^{a}	39.25±0.87^{a}	46.94±0.99^{ab}	50.12±1.25^{bcd}	49.95±0.52^{bcd}	48.19±0.67^{bc}	45.71±0.41^{ab}
18	42.47±0.93^{b}	41.05±1.02^{b}	45.51±2.29^{b}	32.60±0.34^{a}	34.61±1.30^{a}	40.23±0.66^{b}	43.61±1.04^{b}	43.70±1.17^{b}	42.93±0.70^{b}	42.34±1.12^{b}

Within the same column, mean values followed by different capital letters are significantly different at $p<0.05$ using Tukey's test

However, after treated by heat, some of the panels were found meet to the Japanese Industrial Standard which determines maximum values of 12%.

It is believed that TS reduction was due to the compression stress release and because the treatment changed the panel's hygroscopicity. Stamm (1964) proposed that the initial process occurring in the thermal degradation of wood was a breakdown of hemicelluloses to form furfural polymers that are less hygroscopic than the hemicelluloses.

For TS, Table 6 shows the result of the Tukey's test for the mean comparison between treated (A-I) and untreated panels (J). There was no significant difference detected among panels type 1 to type 6 (0% of wax). The thermal treatment improved dimensional stability to a higher extent at the higher wax level (1%). This behaviour could be related to the redistribution of the wax in the panels. Jansson (1982) suggested that oleoresinous materials (which act as sizing agents) are redistributed during heat treatment. According to Spalt (1977), collection of vapors from hardboard undergoing heat treatment showed that sizing wax was being volatilized. Spalt suggested that this process redistributed the wax as a monomolecular layer on all fiber surfaces, with a resulting increase in water repellency.

Based on Table 7, the behaviour of WA was very different from that observed for TS. Most of the panels didn't show significant improvement of WA compare to the untreated panels. These result suggested that WA wasn't influenced by thermal treatment, the same way as it was observed for TS. The WA was mainly affected by the density of the panels. In this study, the WA of panels which treated at 180°C was found greater than the untreated panels. This is because those panels were experienced the greatest mass loss. The thermal treatment provided a reduction of panel density and consequently caused the treated panel became more porous for easiest water penetration and increasing WA. Kelly (1997) stated that the absorption of water is larger with smaller specific mass since there are more empty spaces.

CONCLUSIONS

The temperature applied in this study was milder than the commercial thermal modification. However, it reduced the thickness swelling of the particleboard. Water absorption and density were not directly influenced by the treatment but it had been reduced with the increase of the duration of the treatment. Some of the panels were found meet the Japanese Industrial Standard which determines maximum values of 12%. Thus, the required thickness swelling value can be achieved by the combination of the application of water repellent and heat treatment.

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