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BRIEF ORIGINAL

Physico-mechanical properties of particleboard made from heat-treated rubberwood particles

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Abstract Physico-mechanical properties of particleboard fabricated from heat-treated rubberwood particles were investigated. Reduction in water absorption and mass loss were observed in heat-treated rubberwood particles, and it was associated with the properties of particleboard. The density and moisture content of the particleboard decreased with increasing treatment temperature and time. Heat treatment of particles improved the dimensional stability of the particleboard, but the mechanical properties were adversely affected.

1 Introduction

Dimensional instability of particleboard in use is highly undesirable as it will functionally and visually affect the performance of particleboard. Therefore, several attempts have been made to improve the dimensional stability of the particleboard using pre- and post-heat treatment (Lee et al. 2015; Kwon and Ayrilmis 2016). Heat treatment of wood has long been recognized as an effective method to enhance the dimensional stability and decay resistance of wood and wood-based panel (Lee et al. 2015; Umar et al. 2016). In addition, interest in heat treatment of wood is growing due to the stringent regulations in the application of toxic wood preservatives, making heat treatment the most investigated treatment method in the past few years (Salman et al. 2016). Boonstra et al. (2006) treated Norway spruce and Scots pine chips using two-stage heat pre-treatment and observed a significant reduction in thickness swelling and internal bond of the produced particleboard. Kwon and Ayrilmis (2016) heat-treated radiata pine flakes and concluded that the optimum condition for the flakes was 150 °C for 2 h in order to produce flakeboard with improved dimensional stability and only slight decrement in mechanical strength. To the author's knowledge, there is little or no information on the pre-heat treatment of rubberwood particles and its relation to the performance of particleboard. Therefore, the objective of this study was to evaluate the properties of the particleboard made from heat-treated particles.

2 Materials and method

Rubberwood (*Hevea brasiliensis*) particles were used to produce particleboard in this study. 1.5 kg of rubberwood particles were heat-treated in a laboratory oven at temperatures of 50, 100, 150 and 200 °C for 1, 2 and 3 h under moist and dry condition. The rubberwood particles treated in moist condition were pre-soaked in water before put in the oven. 1 kg of treated particles was weighed out prior to the blending process, and the remaining particles were used to determine weight loss and water absorption of the particles. Homogeneous single layer particleboards (340 mm × 340 mm × 12 mm) with a target density of 680 kg/m^3 were produced. 8% of urea formaldehyde resin based on dry particles weight incorporated with 0.5% wax and 1% hardener (ammonium chloride) were sprayed onto the particles. To achieve the targeted density, 944 g of resinated particles from each treatment were weighed after the blending process and manually spread into a wooden mould to form a mat. The formed mat was hot-pressed at 180 °C with 4 MPa pressure for 270 s. A set

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of particleboard made from untreated particles served as control. A total of 25 particleboard panels [(4 temperature levels × 3 treating durations × 2 treatment conditions) + 1 control] was made and evaluated in this study. After pressing, the particleboards were conditioned in a conditioning room at 20 ± 2 °C and relative humidity of 65 ± 5% prior to properties evaluation. Properties of the particleboards such as density, moisture content (MC), water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) were evaluated according to Japanese Industrial Standard (JIS) A 5908:2003. Analysis of variance (ANOVA) was conducted using IBM Statistical Package for the Social Sciences (SPSS) Statistics V21.0 procedure to analysis the data. Tukey's honest significant difference (HSD) tests were then applied to further determine the significant level of average values for each treatment. Regression analysis was performed to determine the relation between density and mechanical properties.

3 Results and discussion

The results revealed that mass loss of particles is already visible at heat treatment of 50 °C and the mass loss increased along with increased treatment temperature and time. A reduction of 1–21% in mass and 2–30% in WA was observed in the heat-treated particles compared to that of control particles. It is interesting to note that, although statistically insignificant, the numeric results suggested that reduction in mass and WA is more severe in particles treated under moist condition. The properties of particleboards were found to be directly related to the properties of heat-treated particles. Table 1 displays the physical properties of the particleboard produced in this study. The density and MC of the particleboards decreased along with increasing treatment temperature and time. Oddly, despite the attempt to control the final density, the density ranges of the particleboard varied widely from 604 to 713 kg/m^3. One of the probable reason is higher amount of particles

Table 1 Physical properties of the particleboards made with treated and untreated particles

Treatment temperature (°C)	Treatment duration (h)	Density (kg/m^3)	MC (%)	WA (%)	TS (%)
Control	Control	694.9 ± 5.4^{ab}	11.4 ± 0.4^{k}	89.8 ± 0.4^{k}	46.6 ± 3.2^{m}
Moist condition					
50	1	691.4 ± 6.3^{abc}	11.6 ± 0.1^{k}	82.4 ± 1.1^{ghi}	33.7 ± 1.0^{jk}
50	2	668.8 ± 8.4^{defgh}	9.5 ± 0.6^{ghi}	79.9 ± 1.0^{fghi}	31.5 ± 0.8^{ghijk}
50	3	660.4 ± 16.9^{efgh}	9.2 ± 0.3^{fghi}	79.1 ± 2.2^{jk}	24.0 ± 1.0^{abc}
100	1	674.0 ± 5.4^{bcdef}	10.0 ± 0.4^{hij}	89.2 ± 2.0^{ijk}	25.9 ± 0.7^{bcde}
100	2	665.0 ± 6.2^{efgh}	8.3 ± 0.5^{def}	85.7 ± 4.0^{defg}	25.9 ± 0.2^{abcd}
100	3	623.8 ± 5.2^{jk}	8.2 ± 0.3^{cdef}	75.4 ± 2.6^{bcde}	23.9 ± 1.1^{abc}
150	1	671.2 ± 11.7^{cdefg}	8.6 ± 0.9^{efg}	72.1 ± 0.7^{bcd}	29.0 ± 0.9^{defgh}
150	2	664.2 ± 2.7^{efgh}	7.1 ± 0.1^{abc}	70.6 ± 1.9^{abc}	24.1 ± 0.8^{abc}
150	3	615.7 ± 14.9^{jk}	7.1 ± 0.3^{abc}	68.4 ± 2.5^{abc}	23.1 ± 0.7^{ab}
200	1	668.8 ± 5.0^{defgh}	7.3 ± 0.3^{abcd}	70.4 ± 0.8^{bcd}	25.8 ± 0.8^{abcd}
200	2	647.8 ± 3.8^{hi}	6.8 ± 0.3^{ab}	67.9 ± 1.1^{abc}	22.9 ± 0.2^{ab}
200	3	604.3 ± 4.7^{k}	6.7 ± 0.1^{a}	63.2 ± 0.9^{a}	21.8 ± 1.0^{a}
Dry condition					
50	1	713.1 ± 6.7^{a}	10.1 ± 0.2^{ij}	88.0 ± 3.5^{jk}	40.7 ± 2.9^{l}
50	2	689.5 ± 0.8^{bcd}	10.0 ± 0.2^{hij}	84.7 ± 2.0^{ijk}	33.6 ± 1.7^{ijk}
50	3	672.1 ± 7.3^{cdefg}	9.9 ± 0.1^{hij}	77.5 ± 2.2^{efgh}	27.6 ± 0.5^{cdefg}
100	1	681.1 ± 7.6^{bcde}	10.9 ± 0.1^{jk}	73.1 ± 4.5^{cdef}	32.4 ± 1.5^{hijk}
100	2	673.2 ± 3.5^{bcdef}	9.9 ± 0.6^{hij}	73.1 ± 1.7^{cdef}	30.2 ± 0.2^{fghijk}
100	3	662.6 ± 2.0^{efgh}	8.9 ± 0.4^{fgh}	70.9 ± 3.4^{bcde}	30.1 ± 1.0^{fghijk}
150	1	671.7 ± 4.7^{cdefg}	8.3 ± 0.2^{def}	73.8 ± 2.5^{cdefg}	34.1 ± 1.6^{k}
150	2	665.1 ± 4.9^{efgh}	8.3 ± 0.2^{def}	71.0 ± 0.5^{bcde}	30.0 ± 1.6^{efghij}
150	3	651.9 ± 6.8^{fghi}	8.3 ± 0.1^{def}	67.8 ± 1.3^{abc}	29.5 ± 1.0^{defghi}
200	1	664.3 ± 0.4^{efgh}	7.8 ± 0.1^{bcde}	71.9 ± 0.6^{bcde}	30.7 ± 0.9^{fghijk}
200	2	650.5 ± 3.5^{ghi}	7.7 ± 0.2^{abcde}	65.9 ± 2.0^{ab}	28.2 ± 1.0^{ijk}
200	3	630.4 ± 3.7^{ij}	7.3 ± 0.23^{abcd}	62.1 ± 0.6^{a}	27.3 ± 0.4^{jk}

The values after ± are standard deviations. Means followed by the same superscript letter in the same column are not significantly different at $P \leq 0.05$

Table 2 Mechanical properties of the particleboards made with treated and untreated particles

Treatment temperature (°C)	Treatment duration (h)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
Control	Control	15.1 ± 1.4^{a}	1681 ± 119^{a}	0.70 ± 0.02^{a}
Moist condition				
50	1	14.5 ± 0.5^{ab}	1585 ± 16^{ab}	0.64 ± 0.02^{abc}
50	2	14.3 ± 0.5^{abc}	1557 ± 19^{abc}	0.41 ± 0.03^{gh}
50	3	14.2 ± 0.4^{abc}	1543 ± 39^{abc}	0.31 ± 0.01^{jkl}
100	1	13.9 ± 1.0^{abcd}	1503 ± 65^{abcd}	0.55 ± 0.01^{de}
100	2	13.3 ± 1.0^{abcde}	1472 ± 19^{bcde}	0.36 ± 0.03^{hij}
100	3	12.1 ± 0.8^{bcdefg}	1443 ± 49^{bcdefg}	0.21 ± 0.02^{mno}
150	1	11.8 ± 0.9^{defghi}	1387 ± 86^{cdefghi}	0.42 ± 0.01^{gh}
150	2	10.7 ± 1.4^{ghijk}	1355 ± 141^{defghij}	0.32 ± 0.02^{ijk}
150	3	8.9 ± 0.81^{jk}	1155 ± 1264^{k}	0.20 ± 0.01^{no}
200	1	10.8 ± 0.7^{fghij}	1283 ± 18^{fghijk}	0.40 ± 0.01^{gh}
200	2	10.4 ± 0.2^{ghijk}	1252 ± 10^{hijk}	0.25 ± 0.01^{lmn}
200	3	8.4 ± 0.4^{jk}	1135 ± 24^{k}	0.18 ± 0.02^{o}
Dry condition				
50	1	13.0 ± 0.6^{abcdef}	1469 ± 18^{bcdef}	0.67 ± 0.06^{ab}
50	2	12.0 ± 0.8^{cdefgh}	1430 ± 75^{bcdefgh}	0.61 ± 0.01^{bcd}
50	3	11.2 ± 0.9^{efghij}	1377 ± 34^{cdefghij}	0.60 ± 0.01^{cd}
100	1	10.8 ± 0.5^{fghij}	1297 ± 47^{efghijk}	0.58 ± 0.05^{cde}
100	2	10.4 ± 1.0^{ghijk}	$1265 \pm 48_{ghijk}$	0.51 ± 0.01^{ef}
100	3	10.1 ± 0.8^{ghijk}	1264 ± 54^{ghijk}	0.31 ± 0.01^{ijkl}
150	1	10.0 ± 0.6^{ghijk}	1228 ± 50^{ijk}	0.47 ± 0.04^{fg}
150	2	9.7 ± 0.6^{hijk}	1148 ± 30^{k}	0.38 ± 0.01^{hi}
150	3	9.6 ± 0.5^{hijk}	942 ± 19^{l}	0.27 ± 0.01^{klm}
200	1	10.5 ± 0.2^{ghijk}	1203 ± 17^{ijk}	0.36 ± 0.02^{hij}
200	2	9.5 ± 0.1^{ijk}	1194 ± 27^{jk}	0.27 ± 0.02^{klm}
200	3	9.0 ± 0.2^{jk}	933 ± 22^{l}	0.25 ± 0.01^{lmno}

The values after ± are standard deviations. Means followed by the same superscript letter in the same column are not significantly different at $P \leq 0.05$

is needed to achieve the target board density due to the heat-induced weight loss of particles. Higher amount of particles might have inhibited the board from obtaining an adequate compression ratio. Higher thickness was observed in the board fabricated using particles treated at higher temperature. Higher thickness increased the volume of the board and subsequently led to lower board density. Another explanation is wood particles are more pliable at higher levels of MC, therefore, treated particles with lower MC failed to produce a more compressible mat. Moreover, low MC slows the heat transfer from the surfaces to the core and results in a non-uniform panel density.

Particleboards with improved dimensional stability were observed when fabricated from the heat-treated particles with less hygroscopicity. A reduction of 53% in TS was observed in the particleboard made from particles heat-treated at 200 °C for 3 h under moist condition. WA, another dimensional stability attribute, also decreased from 90% (control) to 62% (200 °C for 3 h under dry condition). The improvement in dimensional stability is mainly due to the hydrophobic nature of treated particles led by degradation of hemicelluloses and amorphous cellulose (Pandey et al. 2016). On the contrary, reduction in mechanical strength was observed based on the data summarized in Table 2. The decrement of bending properties (MOR and MOE) along with increasing treatment temperature and time was in agreement with Kwon and Ayrilmis (2016). MOR decreased as much as 44 and 40% in the board made with particles treated at 200 °C for 3 h under moist and dry condition, respectively. Lower MOE ranging from 933 to 1585 N/mm^2 was observed in the board made with treated particles in comparison with control board (1681 N/mm^2). Apart from bending strength, reduction in IB is also obvious and the decrement trend mirrored that of MOR and MOE. Boonstra et al. (2006) suggested that the reduction in IB could be imputed to the reduction of shear strength of wood particles caused by heat-induced acid catalyzed cleavage of the carbohydrates. In addition, lower particle

MC after heat treatment might also contribute to the reduction in bending strength as its poor surface wetting characteristics inhibited the transfer and flow of the resin (over absorption) to achieve sufficient particle bonding. Nevertheless, heat treatment processes are not the sole factor that caused the reduction in mechanical properties of particleboard in this study as the mechanical properties are also dependent on the density of the particleboard. The reduction in density was found to exert a certain extent of influence on the strength of particleboard. Linear regression analysis suggested that IB ($r^2 = 0.7405$) is the most affected property by density compared to that of MOR and MOE ($r^2 = 0.3227$ and 0.2815, respectively).

4 Conclusion

The results showed that the dimensional stability of the particleboards was improved by heat treatment of the particles. The properties of particleboards were closely related to the properties of heat-treated particles. Unfortunately, the mechanical strength of the particleboards was adversely affected by both heat-induced degradation and density reduction of the board. Therefore, density control of the produced particleboard is vital to exclude the influence of density for an unbiased evaluation of solitary effect of heat treatment on the particleboard. Longer pressing time with lower pressing temperature might be needed to obtain an adequate compression to ensure the density consistency among samples.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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