Effects of the Resin Content and Particle Size on the Properties of Particleboard Made of *Neolamarckia* and *Leucaena* Particles

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A shortage in the rubberwood supply is becoming a reality in Malaysia. To find alternative raw materials for Malaysian wood-based industries, fast-growing species have been identified and need to be analyzed in particleboard manufacturing. This study evaluated the properties of particleboard made with a 50:50 ratio of *Neolamarckia cadamba* and *Leucaena leucocephala* with melamine urea formaldehyde as the resin at different contents (10%, 12%, and 14%) and particle sizes (1.0 mm, 2.0 mm, and unscreened particles). The particleboards were tested according to EN 312 (2003). The results showed that the particleboard mechanical properties were significantly improved with increase of the resin content and particle size. The thickness swelling value dropped as resin content was increased, showing better stability of the board.

Keywords: Leucaena leucocephala; Neolamarckia cadamba; Particleboard; Particle size; Resin content

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INTRODUCTION

Rachtanapun *et al*. (2012), highlighted the invention of particleboard in the 1930s. The production of particleboard has helped to address two critical issues: a deficit in the supply of lumber and a need to dispose of biomass waste, namely sawdust and agricultural waste material. Currently, many species are being used to manufacture particleboard, with lower density wood species as the normal selection. Trianoski *et al*. (2011) reported a broad flexibility of particleboard in application and the great growth of the furniture industry being closely related to this wood panel.

Approximately 1.8% of the Malaysian wood-based product export is particleboard. The value has increased from RM159.23 million in 2012 to RM254.83 million in 2017 (Malaysian Timber Industry Board 2017), which reflects the recovery at the end of recession cycle in 2014. In Malaysia, particleboard, especially when laminated, is frequently utilized in furniture making, which is a sector that makes up more than 30% of the Malaysian wood-based export value. The most common raw material used in Malaysian particleboard and furniture is rubberwood (*Hevea brasiliensis*) because of its features, which include a bright color, unique wood grain, ease of furnishing with other materials, and durability. This has created a higher demand for rubberwood. Paridah *et al.* (2014) reported that, the higher demand has led to a shortage of supply and increased price of rubberwood. Inevitably an alternative raw material for particleboard manufacturing needs to be explored and commercialized.

The species *Neolamarckia cadamba* and *Leucaena leucocephala* have been found to have fast growth rates. Zayed *et al.* (2014) reported that the short rotation period of *N. cadamba* can give early commercial returns within 8 years to 10 years. Additionally, *L. leucocephala* grows rapidly on favorable sites with high rainfalls and conditions that are hot, humid, and lacking in frost. Both species are capable of providing fast solutions to the raw material needs in particleboard production. Work on fast growing species usage has been cited by Loh *et al.* (2010) on Mahang and *Hevea brasiliensis* mixture with lowering of mechanical properties with increase of Mahang ratio. Trianoski *et al.* (2011) showed that fast growing species *Acrocarpus fraxinifolius*, *Melia azedarach*, *Schizolobium parahyba* dan *Toona ciliate* gave acceptable results in particleboard properties. Study on acoustic properties by Karlinasari *et al.* (2012) showed suitability of *Paraserianthes falcataria*, *Maesopsis eminii* and *Acacia mangium* in particleboard manufacture. Stronger modulus of rupture was seen for higher density board.

As addition, the goal of this study was to determine the mechanical and physical properties of particleboards made from a mixture of *N. cadamba* and *L. leucocephala* wood with different resin contents and particle sizes.

EXPERIMENTAL

Materials and Methods

Neolamarckia cadamba and *L. leucocephala* wood were logged from Universiti Teknologi MARA Educational Forest in Jengka, Malaysia. The diameters of the *Neolamarckia cadamba* and *Leucaena leucocephala* logs were 45 cm and 5.5 cm, respectively. Meanwhile, the height of trees averaged at 14.6 m (*Neolamarckia cadamba*) and 6.7 m (*Leucaena leucocephala*). The wood was cut and immediately transported to the workshop, chipped, air dried for a week, screened, and oven dried to a moisture content below 10%. The dried chips were classified into the particle size ranges 0.5 mm to 1.0 mm, 1.1 mm to 2.0 mm, and unscreened particles, which were designated as 1 mm, 2 mm, and US, respectively. Unscreened particles are defined as particles in which only the fines (< 0.5 mm) have been removed. Size range selection was based on the particle size distribution pattern and reflects commercial requirement. Particleboards with the dimensions 340 mm × 340 mm × 12 mm were prepared for each size range using a 50:50 ratio of *N. cadamba* and *L. leucocephala*. The boards were prepared in triplicate. Melamine urea formaldehyde was used at three resin contents 10%, 12%, and 14% against the dry biomass amount. The resin was blended with the particles, formed, cold-pressed, and finally hot-pressed at a temperature of 165 °C with a pressure cycle of 1800 psi to 1200 psi to 600 psi. The particleboards were conditioned for 24 h at a 65% relative humidity and 20 °C prior to the preparation of the test specimens. The mechanical and physical properties of the particleboard specimens were tested in accordance with EN 312 (2003). Additionally, cyclic exposure tests were performed according to EN 321 (2002). The cyclic test consisted of a three-cycle accelerated aging treatment, followed by strength testing. The sample size dimensions were 50 mm × 50 mm × 12 mm. In each cycle, the conditioned test samples were immersed in water at 20 °C for 3 d (72 h), frozen at -12 °C for 1 d (24 h), and oven-baked at 70 °C for 3 d (72 h). The tensile strength of the particleboards was measured to determine the internal bond (IB) and internal bond for cyclic exposure (IB-CT). All of the results were analyzed with analysis of variance (ANOVA) using IBM SPSS statistical 20 software (Armonk, NY, USA).

RESULTS AND DISCUSSION

Particleboard Properties

Table 1 shows the physical and mechanical properties of the particleboards made from a 50:50 mixture of *N. cadamba* and *L. leucocephala* with three resin contents and three particle size ranges. A generally increasing trend was observed for the mechanical properties as the resin content increased. Meanwhile, the physical properties of the board improved as the resin content increased. Larger particle sizes produced particleboards with improved physical and mechanical properties. All of the mechanical properties of the boards met the requirements listed in EN 312 (2003); however, the thickness swelling (TS) needed to be improved.

Table 1. Physical and Mechanical Properties of the Particleboards made of *N. cadamba* and *L. leucocephala* (50:50) with Different Particle Sizes and Resin Contents

No.	PS (mm)	RC (%)	MOE (MPa)	MOR (MPa)	IB (MPa)	IB-CT (MPa)	TS (%)	WA (%)
1	1.0	10	2681	20.87	0.63	0.15	24.75	88.12
2	1.0	12	2764	23.70	0.70	0.21	23.12	76.83
3	1.0	14	3171	25.70	0.98	0.32	19.88	72.44
4	2.0	10	2809	23.21	0.77	0.22	23.12	75.31
5	2.0	12	3429	25.92	0.78	0.33	21.37	70.58
6	2.0	14	3850	25.28	0.86	0.49	18.67	68.31
7	US	10	3060	23.28	0.70	0.15	24.63	84.32
8	US	12	3147	23.57	0.79	0.23	22.90	75.85
9	US	14	3522	26.56	0.82	0.41	19.38	72.29
Minimum requirement			2050	15	0.45	0.15	14	-
EN 312 (2003)			EN 310 (2003)	EN 310 (2003)	EN 319 (2003)	EN 321 (2002)	EN 317 (2003)	-

PS = particle size; RC = resin content; MOE = modulus of elasticity; MOR = modulus of rupture; IB = internal bond; IB-CT = internal bond for cyclic test; WA = water absorption; and TS = thickness swelling

Effects of the Resin Content

According to many researchers, the type (Anisuzzaman *et al.* 2014) and quantity of the resin (Ratkhe *et al.* 2012; Salari *et al.* 2013) determine the bonding quality and performance of panels. Increasing the resin content was the first choice to respond to the board strength needs. The modulus of elasticity (MOE) and modulus of rupture (MOR) are shown in Fig. 1, which significantly increased as the resin content increased. The particleboard with a 14% resin content had the highest MOE and MOR at 3520 MPa and 28.6 MPa, respectively. According to Boquillon *et al*. (2004), when the resin content increases, the MOR and MOE will increase, which is caused by an increase in the surface contact between the resin and particles and leads to improved bonding properties. For the 10% and 12% resin content comparison, the MOE and MOR showed no significant difference.

The effects of the resin content on the tensile strength of the particleboard specimens are shown in Fig. 2. The particleboard made with a 14% resin content had the highest IB (0.86 MPa) and IB-CT values (0.44 MPa), while a 10% resin content resulted in the lowest IB and IB-CT values.

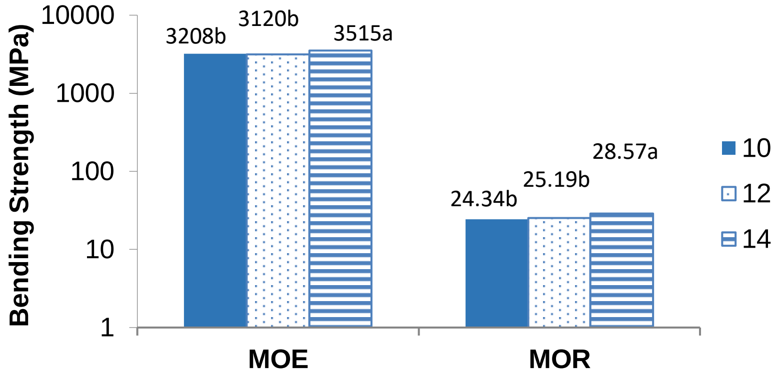

Fig. 1. MOE and MOR of the particleboards with different resin contents: Legend entries 10, 12, and 14 denote resin percentages; and letters a and b indicate values in cluster to be significantly different at $p \leq 0.05$.

Saad and Kamal (2011) reported that higher amounts of resin encourage stronger interfacial bonding between particles in the boards, thus improving the ability of the boards to withstand the pulling force in the test. The increase in the resin content led to an improvement in the IB of the particleboards (Eslah *et al.* 2012). The IB and IB-CT values had a significant proportional relationship to the resin content. The IB-CT identifies the board behavior when subjected to a high moisture content and indicates the resistance of the board to swelling and contraction. The board with a 14% resin content retained 51% of its strength. In comparison, the boards with a 12% and 10% resin content only retained 41% and 24% of the dry IB strength, respectively.

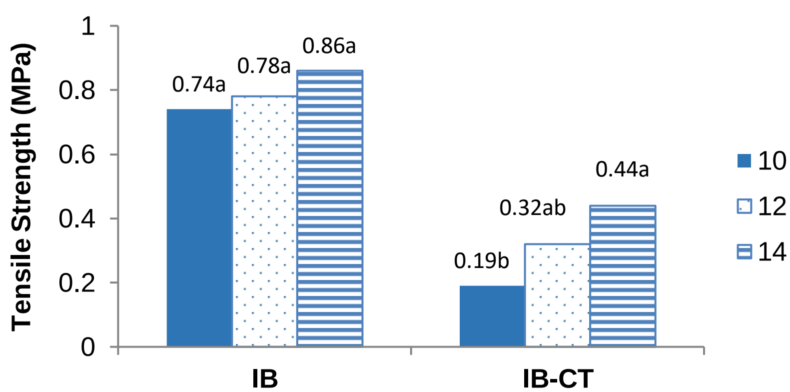

Fig. 2. IB and IB-CT of the particleboards with different resin contents: Entries 10, 12, and 14 denote resin percentages; and letters a, b indicate values in cluster to be significantly different at $p \leq 0.05$.

The TS and water absorption (WA) of the particleboards showed significant decreasing trends as the resin content increased (Fig. 3). As was expected, the particleboard with 14% resin content exhibited the highest dimensional stability. It had the lowest TS value of 14.05%. According to Medved *et al*. (2011), the TS decreases with an increasing resin content because the adhesive forms a barrier that helps to minimize the impact of water or moisture on particles. Stronger covalent bonds between particles, as seen for the IB, leads to more resistance against the TS.

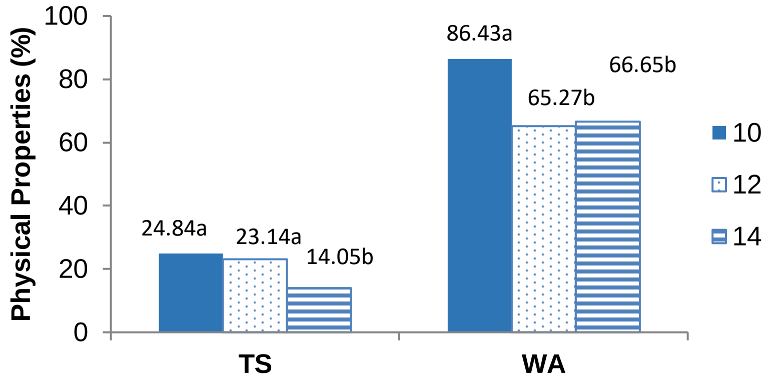

Fig. 3. TS and WA of the particleboards with different resin contents: Entries 10, 12, and 14 denote resin percentages; and letters a, and b indicate values in cluster to be significantly different at $p \leq 0.05$.

Effects of the Particle Size

High quality particleboards with a high strength, smooth surface, and equal swelling are normally obtained by using a homogeneous material with a high degree of slenderness (long and thin particles), but without oversized particles, splinters, or dust (Pan *et al.* 2007). Figure 4 shows that the particleboards made with a particle size of 2.0 mm had the highest MOE (3760 MPa) and MOR values (28.4 MPa). For the MOE and MOR, there was a significant difference as the particle size increased. Thinner and longer particles yield a higher aspect ratio, larger surface area, and increased contact area in the glue line, which contributes to a better interaction and thus better strength (Juliana *et al.* 2012; Kasim *et al.* 2018). Gozdecki *et al.* (2011) also reported that the tensile and flexural properties increase gradually with an increasing particle size. Differences in the wood type, shape, and size have been reported to have a remarkable effect on the properties of the produced particleboard (Maloney 1993; Frybort *et al.* 2008).

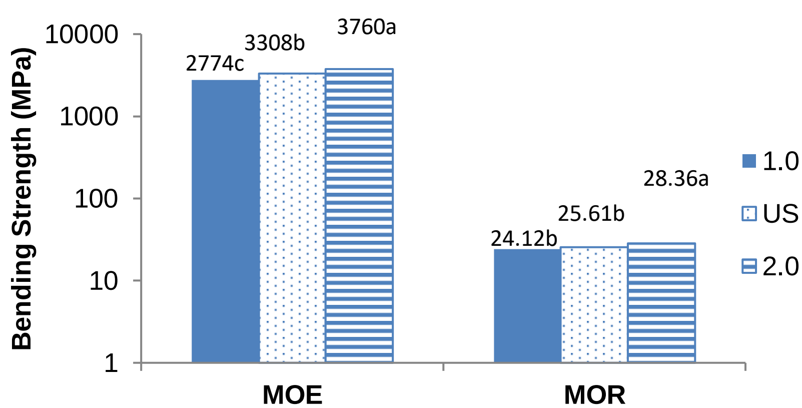

Fig. 4. MOE and MOR of the particleboards made with different particle sizes: Entries 1.0, US, and 2.0 represent particle size; and letters a, b, and c indicate values in cluster to be significantly different at $p \leq 0.05$.

Figure 5 shows the effect of the particle size on the IB and IB-CT of the particleboards. For the IB, there was no significant difference between the results for the different particle sizes. There were mixed results for the IB behavior. Dai *et al*. (2008) showed that the IB increased with increases in the particle thickness. Meanwhile, Astari *et al*. (2018) worked on waste wood usage and showed that finer particles resulted in higher IB values for the panels. The difference could have been related to variation in the gluing properties for different species. Wood species have different percentages of cellulose, lignin, and extractives, which could impact the curing performance and wettability properties of glue.

For the IB-CT, there was a significant difference between the 1-mm and 2-mm particle sizes. The 1-mm size retained 30% of its original IB strength, while the 2-mm size retained 50%. Exposure to wet and dry cycles caused an increase in the thickness of the boards, which damaged the bonding strength (Suffian *et al*. 2010). The impact was stronger on the smaller particle size because it has a higher surface area to volume ratio.

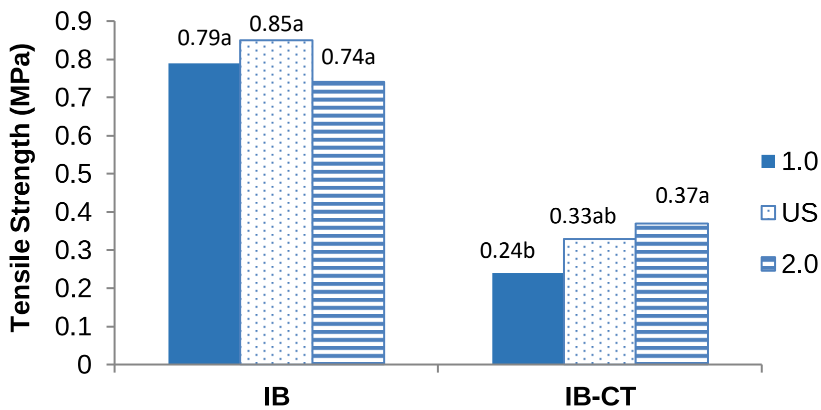

Fig. 5. IB and IB-CT of the particleboards made with different particle sizes: Entries 1.0, US, and 2.0 represent particle sizes; and letters a, b, and c indicate values in cluster to be significantly different at $p \leq 0.05$.

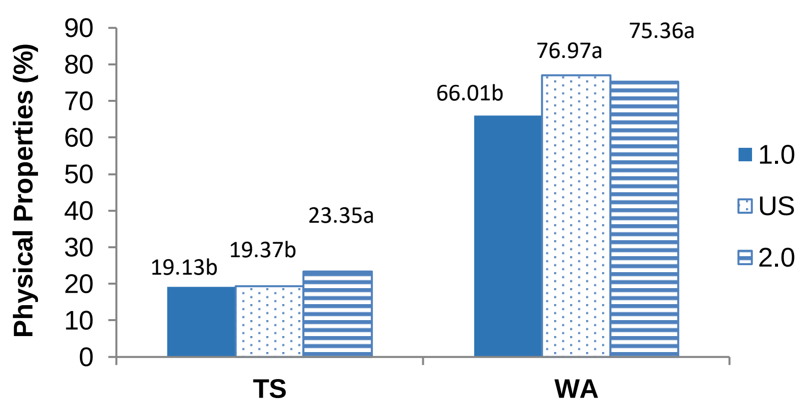

Fig. 6. TS and WA of the particleboards made with different particle sizes: Entries 1.0, US, and 2.0 represent particle sizes; and letters a, and b indicate values in cluster to be significantly different at $p \leq 0.05$.

Paridah *et al.* (2014) stated that when the TS is lower, the dimensional stability of particleboards is better. The effects of the particle size on the physical properties of the particleboard are shown in Fig. 6. The particleboards made with a 1.0-mm particle size had the lowest TS value (19.13%). Meanwhile, the particleboards made with the US particles had the highest WA percentage. Both the TS and WA trends showed a significant decrease as the particle size decreased. This finding was in line with the results of Lias *et al.* (2014) for 100% *N. cadamba* particleboard. Smaller particle size has higher surface area volume ratio, which allow it to be more exposed to moisture. This can lead to higher water absorption. Theoretically, the presence of water near the hydroxyl component of cellulose and hemicellulose encourage H-bond interaction. The alignment between hydrogen and hydroxyl group causes an expansion which will contribute to the swelling of particleboard.

CONCLUSIONS

The potential of the *N. cadamba* and *L. leucocephala* mixture in particleboard manufacturing was demonstrated via the performance of in the mechanical properties of the board. The 50:50 mixture achieved the highest performance for the MOE and IB-CT (3850 MPa and 0.49 MPa, respectively) with a 14% resin content. The combination of small and large particles affected the IB test, but the highest value was 0.98 MPa with the particleboard made with the 1.0-mm particles and a 14% resin content. Board stability was enhanced by large particles and high resin content. However, more work is needed, especially for improvement of the TS values. The *N. cadamba* and *L. leucocephala* mixture gave a good indication on the possibility of mixing two hardwood species despite the difference in density of the two species.

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