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The Suitability of Fast Growing Tree Species for Particleboard Production

Wan Mohd Nazri Wan Abdul Rahman, Nur Sakinah Mohamed Tamat, Jamaludin Kasim

Abstract*: This study evaluates the suitability of using Kelempayan (Neolamarckia cadamba), a fast growing tropical species for the production of particleboard. Boards were pressed at various board density levels using different phenol formaldehyde (PF) resin contents, under various hot press temperatures. Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and thickness swelling (TS) of the boards were determined based on Malaysian Standards (MS) for particleboard. The results showed that boards made from the density of 700 kg/m^3 and 11% resin at 165˚C of hot press temperature showed superior values of MOE, MOR and IB. The boards passed the minimum requirements for furniture and structural in dry condition. The lowest percentage of TS showed by the boards made from density of 500 kg/m^3 and 11% resin at 155 and 165˚C hot press temperature. The boards met the requirements for furniture in dry and humid, and structural in dry. This study demonstrated that Kelempayan species were potentially useful for the production of particleboard.

Index Terms*: Kelempayan, board density, hot pressing temperature, resin content, particleboard.

I. INTRODUCTION

Wood-based industry in Malaysia is facing raw material shortage due to insufficient supply of rubberwood [1]. Rubberwood estate owners willing shifted to oil palm plantation because of less profit in the rubber industry due to low latex price in world market [2]. In addition, the issues of declining of labor due to low rate of wages become constraint in rubber plantation [3]. Therefore, it is imperative to establish an alternative source of rubberwood.

Kelempayan (*Neolamarckia cadamba*) is a fast growing species with a short rotation plantation cycle of within 15 years [4]. Kelempayan is selected as plantation species in National Timber Industry Policy (NATIP) plantation programme [5]. The tree can be used for face and core veneer in plywood, particleboard, cement board, packing cases, source of short fibre pulp and less expensive furniture [6]. This species can be focused to offset the decline in rubberwood supply and the lack of viable alternative wood sources to support the ongoing development of the wood-based industry mainly particleboard manufacturing. Particleboard consists of varying shapes and sizes of lignocellulosic material bonded together with an adhesive hence consolidating a loose mat with heat and pressure into a board [7]. Particleboard has gained popularity over the last decade and attracted researchers especially with its properties and advantages. Although the strength properties of particleboard are generally lower than natural lumber, it is more consistent. Another added benefit of particleboard arises from the fact that its properties can be engineered, meaning that the uniformity and range of properties can be controlled during manufacturing process. Particleboard can utilize low grade logs like twisted, bowed and thinning logs. This will minimize solid waste content and conserve the natural resources [8].

This study explores the potential suitability of Kelempayan as a raw material for manufacturing particleboard and to investigate the effects of board density, resin content and hot press temperature on the mechanical and physical properties of the boards produced.

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* Correspondence Author
Wan Mohd Nazri Wan Abdul Rahman*, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia.
Nur Sakinah Mohamed Tamat, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia.
Jamaludin Kasim, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia.

II. MATERIALS AND METHODS

A. Preparation of Kelampayan Particles

Kelempayan trees were felled from UiTM Forest Reserve in Jengka, Pahang. The trees were sawn into 1 in by 1 in by log length of small billets. Chips produced by chipper were flaked by a knife ring flaker. After flaking, the particles were air-dried for 1 week and then screened into 2.0 mm particle size. Screened particles were dried in the oven set at 80 °C until the moisture content reach 3 to 5%.

B. Board making

Measured quantities of particles for the production of 12 mm thick single layer boards were sprayed in a glue mixing tank at 7, 9 and 11% resin mix containing PF and water. Target board density was set at 500, 600 and 700 kgm^{-3}. The sprayed particles were laid in a wooden mould and pre-pressed at 1000 psi. The consolidated mat was finally pressed at 145, 155 and 165 °C for 6 minutes.

C. Board evaluation

All the boards were cut into test pieces in accordance with previous study [9, 10, 11]. Strength and dimensional stability tests were carried out according to Malaysian Standard (MS 1787) [12, 13, 14].

III. RESULTS AND DISCUSSION

The properties of particleboard from variation of board density, resin content and hot press temperature are presented in Table 1. Boards with the density of 700 kgm^{-3}, 11% of resin and pressed at 165˚C (Treatment 27) gave the highest mechanical properties MOE (3447 MPa), MOR (34 MPa) and IB (0.82 MPa). The boards met the requirements for furniture and structural purposes in dry. Boards manufactured from the density of 600 kgm^{-3} with 11% of resin and pressed under 165˚C of hot press temperature (Treatment 18) also surpassed the minimum requirements for furniture and structural purposes in dry condition. TS data ranged from 15% to 39% after soaking for 24 hours. The boards made from the density of 500 kgm^{-3} with 11% of resin and pressed using 155 and 165˚C hot press temperature (Treatment 6 and Treatment 9) gave the lowest percentage of TS (15%).

Table 1: Properties of particleboards

T	BD (kgm^{-3})	RC (%)	HPT (˚C)	MOE (MPa)	MOR (MPa)	IB (MPa)	TS (%)
1	500	7	145	1516	11	0.36	25
2	500	9	145	1608	12	0.35	17
3	500	11	145	2078	17	0.45	17
4	500	7	155	1445	12	0.33	33
5	500	9	155	1560	11	0.37	19
6	500	11	155	2026	15	0.45	15
7	500	7	165	1422	10	0.32	30
8	500	9	165	1645	12	0.43	21
9	500	11	165	2047	17	0.48	15
10	600	7	145	2291	18	0.49	35
11	600	9	145	2440	17	0.48	22
12	600	11	145	2897	22	0.55	17
13	600	7	155	1890	17	0.46	27
14	600	9	155	2163	19	0.50	23
15	600	11	155	2818	22	0.57	17
16	600	7	165	2169	19	0.65	28
17	600	9	165	2347	17	0.59	22
18	600	11	165	2790	21	0.58	16
19	700	7	145	2837	23	0.54	37
20	700	9	145	3040	26	0.60	31
21	700	11	145	3305	29	0.65	21
22	700	7	155	3007	23	0.52	37
23	700	9	155	3233	26	0.69	27
24	700	11	155	3461	30	0.77	19
25	700	7	165	3189	26	0.64	39
26	700	9	165	3427	32	0.78	23
27	700	11	165	3447	34	0.82	16
Furniture in dry				1800	13	0.40	n.a
Furniture in humid				2000	14	0.45	15
Furniture in high humid				2000	16	0.45	12
Structural in dry				2100	15	0.40	16
Structural in humid				2500	18	0.45	11
Structural in high humid				2500	18	0.45	9

Note: T = treatment, BD = board density, RC = resin content, HPT = hot press temperature

The boards surpassed the minimum requirement for mechanical properties and maximum requirement for TS for furniture in dry and humid and for structural in dry condition. Poor dimensional stability (39%) was indicated by the boards manufactured from the density of 700 kgm^{-3} at 7% resin content and pressed using 165˚C of hot press temperature (Treatment 25). None of the boards surpassed the requirements of physical properties for furniture in high humid, structural in humid and high humid condition. Most of the boards from the density of 500 kgm^{-3} failed to meet standard requirement for physical and mechanical properties for all classification. Overall, boards with the density of 700 kgm^{-3} performed better than 500 kgm^{-3} and 600 kgm^{-3}, and higher resin content also contributed to the better performance.

A. Statistical significance

ANOVA results of board density, resin content, hot press tempera-ture and their interactions on the particleboard properties are shown in Table 2. All the main factors were found to affect the mechanical properties and thickness swelling significantly. The interaction between board density and resin content had affected the board properties significantly. Meanwhile, the interaction between resin content and hot press temperature had significantly affected the board properties except for MOE and MOR. Statistical analysis indicated that there is significant interaction effect of all main factors (board density, resin content and hot press temperature) on board properties except for MOE.

Table 2: Summary of the ANOVA on Boards Properties

SOV	Df	MOE	MOR	IB	TS
BD	2	1896.86*	1389.43*	2243.37*	445.31*
RC	2	265.81*	210.65*	383.57*	2425.81*
HPT	2	6.01*	19.71*	172.23*	25.92*
BD × RC	4	10.43*	11.10*	18.36*	36.98*
BD × HPT	4	15.75*	15.58*	47.59*	37.75*
RC × HPT	4	2.06ns	0.39ns	23.31*	6.61*
BD × RC × HPT	8	0.99ns	4.00*	2.75*	43.35*

Note: SOV = source of variance, Df = degree of freedom, BD = board density, RC = resin content, HPT = hot press temperature, ns = not significant at $p > 0.05$, *significant at $p < 0.05$

B. Effects of board density

Average MOE and MOR of the samples are shown in Fig. 1 and Fig. 2. The density of the board is an important index of strength. In general, boards of higher density feature higher strength. Density of the board must be as uniform as possible along board thickness to ensure uniformity properties. In this study, it was evident that the MOE and MOR values increased significantly with increasing board density. A significant positive correlation was found between the MOE and MOR with increasing board density (r = 0.90* and r = 0.88*) (Table 3). High density board had more compact structure [15], thus it shows higher MOE and MOR due to the stronger bonding among the tightly packed particles.

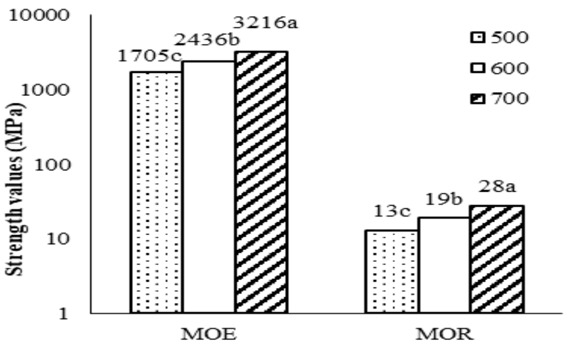

Fig. 1: Modulus of elasticity (MOE) and modulus of rupture (MOR) of particleboard from three densities

Table 3: Correlation coefficients of the effects of board density, resin content and hot press temperature on board properties

Variable	MOE	MOR	IB	TS
BD	0.90*	0.88*	0.85*	0.34*
RC	0.33*	0.33*	0.35*	-0.85*
HPT	0.03ns	0.10ns	0.23*	-0.09ns

Note: BD = board density, RC = resin content, HPT = hot press temperature, ns = no significant correlation, *correlation is significant at the 0.05 level

Fig. 2 shows the IB of the particleboards. The IB was obviously enhanced as the board density increased. The correlation analysis revealed that board density showed significant positive correlation with IB (r = 0.85*) (Table 3). According to [16], IB of particleboard is directly influenced by board density. This is particularly true since the values of IB increase with a linear increase in board density. Increase in board density causes an increase in compression ratio and therefore increase surface contact between wood particles which results in higher IB.

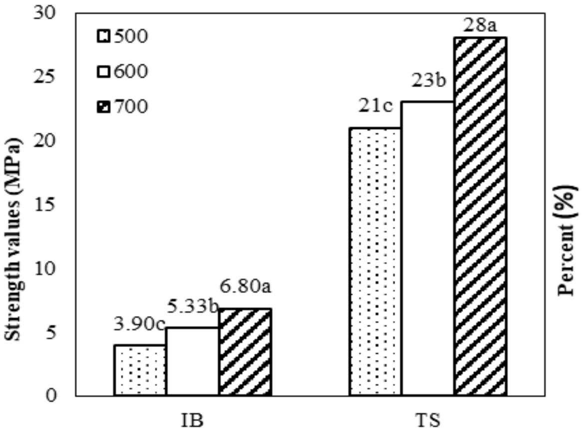

Fig. 2: Internal bond strength (IB) and thickness swelling (TS) of particleboard from three densities

Fig. 2 also shows the effect of varying board density on TS properties. TS of the samples showed significant difference from each other. The correlation analysis revealed that a significant positive correlation between board density and TS (r = 0.34*) (Table 3). It can be seen that higher density board had higher TS value. Higher density board would have large amount of particles per unit volume. This would decrease resin efficiency in gluing, thus more water can penetrate into the board. Mohd Hazim et. al. [17] and Bowyer et. al. [18] also reported similar relationships. Taramian et. al. [19] suggested that wax (0.5-1%) can be added to the resin mixture during blending.

C. Effects of resin content

Fig. 3 and Fig. 4 show the effects of resin content on board properties. The MOE and MOR improved significantly with increase in resin content. This was further revealed by the correlation analysis which indicated that the properties of MOE and MOR increased with increasing resin content (r = 0.33* and r = 0.33*) (Table 3). Jamaludin [20] pointed out that the addition of resin content can give rise to more bonding sites which lead to increase in the mechanical properties because more particles surface is covered by the resin. Research conducted by Ashori & Nourbaksh [21] and Jamaludin et. al. [22] also found a similar resin content relationship.

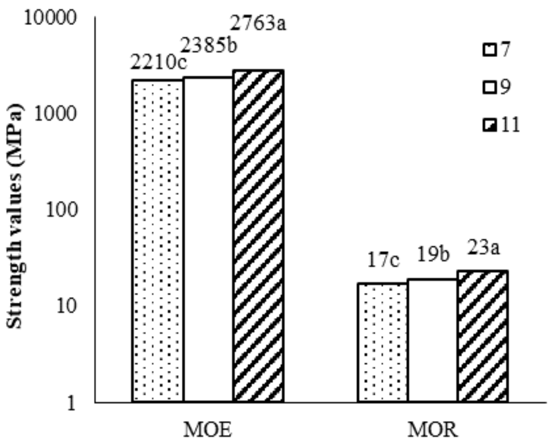

Fig. 3: Modulus of elasticity (MOE) and modulus of rupture (MOR) of particleboard from three resin contents

The IB exhibits almost a similar trend to bending properties with a significant increment of the IB (Fig. 4). The correlation analysis further revealed that a significant positive correlation between resin content and IB existed (r = 0.35*) (Table 3). The IB increase with the increasing of resin content [23]. The proper resin level should be determined for specific uses with considerations of reasonable cost during manufacturing particleboard.

Fig. 4 shows the effects of resin content on TS of particleboard. It can be seen that the TS of the boards was significantly improved by increasing resin content. The correlation analysis revealed that a significant negative correlation between resin content and TS existed (r = -0.85*) (Table 3). Low TS values of higher resin board is related to more crosslinking resulting in retarded water penetration. This result is in agreement with the finding of Rachtanapun [24].

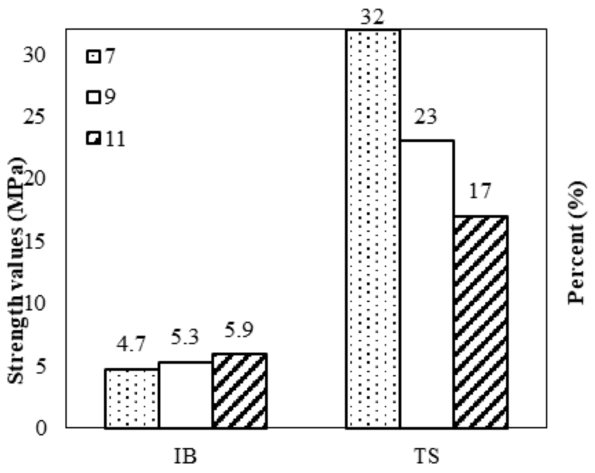

Fig. 4: Internal bond strength (IB) and thickness swelling (TS) of particleboard from three resin contents

D. Effects of hot press temperature

Fig. 5 shows the effects of hot press temperature on bending properties of particleboard. Hot press temperature was found to affect MOE and MOR significantly. It is seen that the MOR values of 145˚C and 155˚C hot press temperature was insignificantly different from each other at $p < 0.05$. However, the values of MOE and MOR of the boards pressed under 165˚C of hot press temperature were significantly higher than those of 145˚C and 155˚C. This is because higher hot press temperature was considered to accelerate the curing of the resin and thus improve board performance. Table 3 shows correlation analysis of hot press temperature and mechanical properties of particleboard produced. It is clear from this Table that the MOE and MOR had insignificant positive correlation with increased of hot press temperature (r = 0.03ns and r = 0.10ns). A similar trend in the bending properties of particleboards at high hot press temperature also reported by Korai et. al. [25] and Malanit et. al. [26].

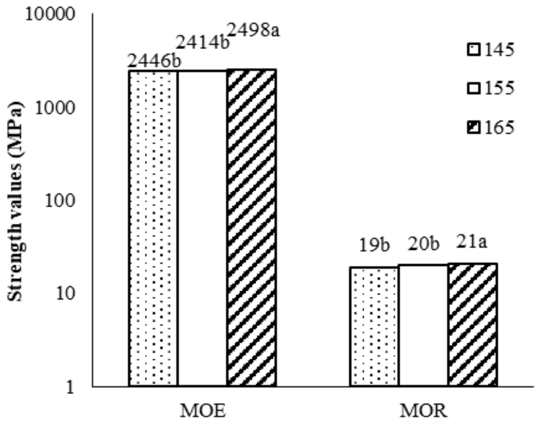

Fig. 5: Modulus of elasticity (MOE) and modulus of rupture (MOR) of particleboard from three hot press temperatures

Fig. 6 showed that there is a significant improvement in IB with increasing of hot press temperature. The correlation analysis further revealed that IB showed a significant positive correlation with increase in hot press temperature (r = 0.25*) (Table 3). The IB values of board manufactured under 165˚C of hot press temperature was significantly higher than those of 145˚C and 155˚C. The IB indicated significantly higher value at 165˚C hot press temperature would be sufficient heating in the inner layer at 165˚C compare with the boards pressed under 145˚C of hot press temperature. Heinemann et. al. [27] found that press temperature influences the adhesion ability of resin to wood materials. It influences flow of water in wood hence causes the molecules of resin to diffuse into the voids.

Fig. 6 also shows the effects of hot press temperature on the TS of the board. The lowest TS value was obtained from the board pressed under 165˚C of hot press temperature. The difference in TS values was significantly affected by hot press temperature. Table 3 shows insignificant negative correlation between TS and hot press temperature (r = -0.09ns). During hot pressing, heat functions to cure the resins in synthetic resins bonded particleboard and the resin would assist in spreading the heat widely and rapidly [28]. Wood particles are plasticized under high temperature and the contact between wood particles was improved [25]. The results in this study showed that the TS was significantly higher when the board was pressed under 145˚C compared to 155˚C and 165˚C. The resin would be incompletely cured at lower hot press temperature which results in less crosslinking between the particles. As a result, the bonding would be weaker allowing water to easily enter and bulking.

Thus, the particleboard experienced increase in TS. Previous study found that the bond quality between wood particles affected the TS [29]. The particleboard pressed under 165˚C had the lowest TS values, which was consistent with the results of IB. This might be at that temperature the particles were bonded well by the resins and had better bonding property, which gives the resultant board decreasing in swelling. Wong et. al. [30] mentioned that producing a good contact between particles can reduce water penetration into the boards.

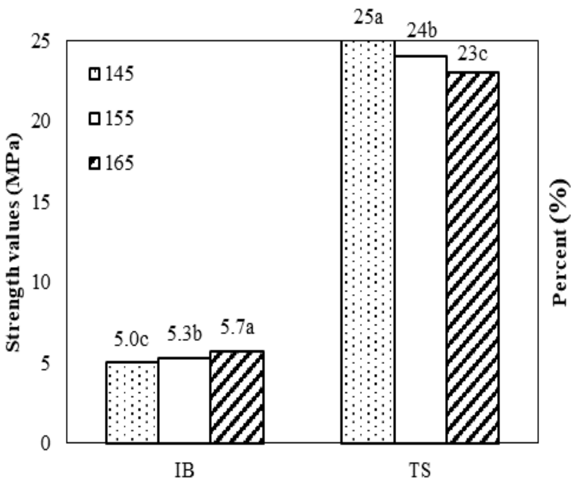

Fig. 6: Effects of hot press temperature on internal bond strength (IB) and thickness swelling (TS)

IV. CONCLUSIONS

The study of particleboards made from fast growing species (Kelempayan) demonstrated good mechanical and physical properties.

Boards made from density of 700 kgm^{-3}, 11% of resin content and 165˚C of hot press temperature showed the highest mechanical properties whereas the lowest percentage of thickness swelling showed by the boards made from density of 500 kgm^{-3}, 11% of resin content and pressed using 155 and 165˚C of hot press temperature. The boards were complied with the standard requirement values of MOE, MOR, IB and TS in accordance to Malaysian Standards.

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AUTHORS PROFILE

Wan Mohd Nazri Wan Abdul Rahman is associate professor at the Department of Wood Industry, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Jengka Campus, Pahang. He started teaching at UiTM since 2000. He obtained his Bachelor of Science (Forestry) degree in 1998 and a Master degree of Science (Wood Utilization) in 2000 at Universiti Putra Malaysia. He also holds a Philosophy degree in 2009 from Universiti Teknologi MARA. His research fields in forest plantation, biomass and wood composite.

Nur Sakinah Binti Mohamed Tamat was born on February 29th 1988 in Kota Bharu, Kelantan, Malaysia and started her primary education at Sekolah Kebangsaan Kor, Kota Bharu.Her secondary level education was taken in Sekolah Menengah Sains Tengku Muhammad Faris Petra, Pengkalan Chepa, Kelantan, Malaysia. From 2006 to 2007 Nur Sakinah studied in Kedah Matriculation College in Life Science and obtained her Degree in Science (Furniture Technology) with honours in 2010 from the MARA University of Technology (UiTM) Shah Alam, Selangor, Malaysia.

Her PhD in Wood Science and Technology was done in Universiti Teknologi MARA, Selangor, Malaysia. Her PhD thesis involved evaluation on the effects of particle size, board density, resin content, hot press temperature and alkaline concentration on properties of Kelempayan (*Neolamarckia cadamba*) particleboard. She managed to present papers in an international conferences and received best poster award in International Conference on Biomechanics and Medical Engineering 2018 (ICBME 2018) at Seri Pacific Hotel, Kuala Lumpur, Malaysia. She published her work in Scopus-Index Journals, Open-Access Journals, Book Chapter and International Conference Proceedings.

Jamaludin Kasim is a former Professor of Wood Industry, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Jengka Campus, Pahang. He started teaching at UiTM since 1984. He obtained his diploma (Wood Technology) in 1979 at the Institut Teknologi MARA, Malaysia and a Master of Science (Forestry) degree in 1984 from the University of Los Banos, Philippines. He also holds a Philosophy degree in 2000 from Universiti Putra Malaysia and earned a Professor in 2009. He completed his teaching and research career in 2018.