Effects of Mechanical Properties and Water Resistance of Particleboard from Kelempayan (*Neolamarckia cadamba*) Wood with Variation of Hot Pressing Temperatures and Board Densities

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Abstract: Kelempayan is a lesser-known, fast growing species and can be cultivated in Malaysia. This species has the potential as an alternative resources for the coming years due to shortage of rubberwood which is the most popular raw material for Malaysian furniture and panel board industries. This study was conducted to explore the potential of kelempayan for particleboard manufacturing and to characterize mechanical properties and water resistance of kelempayan particleboard as affected by various levels of hot pressing temperatures (HPT) and board densities. Single layer particleboard was fabricated from 2.0 mm particle size and bonded with 7% phenol formaldehyde (PF) adhesive. Variation of HPT (145°C and 165°C) and board densities (500, 600, 700 kg/m^3) were used as variable factors. The experimental panels were tested for modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding strength (IB) and thickness swelling (TS) according to the procedures defined by Malaysian Standard (MS). Overall results showed that samples made from density 700 kg/m^3 had the highest MOE, MOR, IB and TS values whereas the physical and mechanical properties of boards with different HPT were insignificantly different. However, boards with 165°C HPT are slightly higher in mechanical properties but lower water resistance. It appears that thickness swelling values in this study exhibited insufficient results for furniture in accordance to MS. We concluded that kelempayan possesses potential for particleboard manufacturing with promising qualities.

Keywords: Kelempayan, Particleboard, Phenol formaldehyde

1. Introduction

The demand for tropical timbers as raw material in wood-based industries has increased dramatically. However, wood based industries nowadays are facing difficulty in obtaining raw material because of the prime natural forests species becoming scarce. In order to meet the increasing demand of wood resources, there is a need to rely on lesser known and plantation grown species. Continued research efforts also should be made to look for alternative species to reduce pressure on the most popular species, rubberwood. Shorter forest management periods and short rotational plantations have been practiced all over the world to overcome such problem (Guler et al., 2007). These can help to protect natural resources like soil, water and wildlife and also reduce the demand on natural forest (Nourbakhsh, 2010).

Neolamarckia cadamba is locally known as Kelempayan and belongs to the family of *Rubiaceae*. It is a fast-growing species with a tall and straight bole. The timber is light creamy yellowish colour. This species is categorized under Light Hardwood with a density 290 to 465 kg/m^3 air dry (Lim et al, 2005). Ismail et al. (1995) mentioned that this species grows well in exploited and denuded areas. According to Lim et al. (2005), kelempayan is distributed from lowlands to mountain forest with an upper limit of 1000 m. This species is mostly found by streams and in open sites in the forest. Kelempayan has the potential to be commercialized for sawn timber, veneer, chips pulp and composites (Lim et al., 2005). As it is a fast-growing species, it can replace traditional wood in wood-based industries such as in particleboard manufacturing.

Particleboard (PB) is a homogeneous material in the form of discrete wood particles of various sizes which are bonded together with synthetic glue under heat and pressure (Colak et al., 2011). The demand for particleboard has increased especially for both construction and industrial production (Sari et al., 2012a). Nemli et al. (2008) mentioned that the strength properties of particleboard are more consistent compared to natural lumber. Particleboard is widely used in furniture, wall and ceiling panels, office dividers, flooring, cabinets, bulletin boards, counter tops and desk tops (Wang et al., 2007).

It is important to create good bonding strength in composite panel production. Hence, processing parameters such as pressing temperature, pressing duration and pressure should be adjusted to achieve good adhesion between components. Choosing a proper board density also has great impact on board performance. In order to determine the best pressing temperature and board density, this research was conducted on the particleboard manufacturing process. The aim of the present work is to assess the potential of kelempayan for manufacturing particleboard and to study the effects of hot pressing temperature and board density on the physical and mechanical properties of the board produced.

2. Materials and Methods

2.1 Sample Preparation and Particleboard Manufacturing

Kelempayan trees with the diameter of breast height (DBH) of 35 to 45cm were used in this study. The trees were harvested from UiTM Pahang Forest Reserve. The felled trees were cross-cut into eight-foot bolts before they were sawn into 1in x 1in x log length of planks. Later the logs were fed into wood chipper to produce chips and then flaked into small particles using knife ring flaker. The particles were air dried for a week in a shaded area. Kelempayan particles were then screened into 1.0 mm particle size using a vibrating screener. The screened particles were dried in an oven with a temperature of 60°C for 24 hours to reduce the moisture content to less than 5%.

A single layered particleboard was fabricated at 500, 600 and 700kg/m^3 density. Phenol Formaldehyde (PF) was used as adhesive. The adhesive was supplied by Malayan Adhesives and Chemicals Sdn. Bhd., Shah Alam, Selangor. The properties of the PF adhesive are given in Table 1:

Table 1. Properties of the PF adhesive

Property	Phenol Formaldehyde
pH at 30°C	12.62/m
Viscosity at 30°C	0.43p
Specific Gravity at 30°C	1.182
Solid Content (%)	40.3

A measured amount of kelempayan particles were blended with 7% of PF adhesive. The resulting mat was formed manually to a specific size (35 x 35 x 1.2 cm). The mat was pre-pressed with a cold press at 1000 psi for 1 min before being hot pressed to the required thickness for 6 min at 145°C and 165°C. The hot press used a removable steel stopper to achieve a constant thickness of particleboard. Three boards were prepared for each treatment. All boards were kept at 20°C and 65% relative humidity in a conditioning room for one week before they were cut into various sizes for property evaluation.

2.2 Mechanical and dimensional stability testing

Finished particleboards were cut into required sizes for modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB) and dimensional stability testing. The samples were evaluated based on Malaysian Standards (MS). Three samples (30 x 5 x 1.2 cm dimensions) from each board were used for bending strength test according to MS1787: part 10: 2005 and MS1787: part 11: 2005. Bending strength included MOE and MOR. Seven samples (5 x 5 x 1.2 cm dimensions) from each type of panel were used for IB test. Both tests were conducted using an Instron Universal Testing Machine Model UiTM-5569 with movable crosshead speed 10mm/min for bending strength test and 1.5 mm/min for IB test. The thickness swelling (TS) tests were carried out on seven samples cut from each particleboard (5 x 5 x 1.2 cm dimensions). Determination of dimensional stability was done in accordance to MS1787: part 6: 2005. Samples were soaked in water for 24 hours. The thickness of the samples was measured before and immediately after soaking.

3. Results and Discussion

Properties of particleboard from variations of board density and hot pressing temperatures are presented in Table 2. Table 2 also shows the comparison properties of particleboard from variations of board density and hot pressing temperatures with classification of particleboard for furniture grade set by MS 1036:2006. According to these classifications, furniture grade particleboard is to be used as furniture components used in dry (PF1), humid (PF2) and high humid (PF3). Boards produced from target density of 700 kg/m^3 and pressed under 165°C of hot pressing temperature gave the highest bending strength (MOE; 3189 MPa and MOR; 26 MPa). At a density of 500 kg/m^3, the board had very low IB strength. The IB strength increased as the density increased, and the highest value (0.64 MPa) was recorded at a density of 700 kg/m^3 under 165°C of hot pressing temperature. The mechanical properties of the boards manufactured at 600 kg/m^3 and more for both levels of hot pressing temperatures met the standard requirement. TS values varied between 25% and 41% after soaking for 24 hours. The boards produced with the density of 500 kg/m^3 under a hot pressing temperature of 145°C gave the lowest percentage of TS. Poor dimensional stability (41%) was indicated by the boards with target density of 700 kg/m^3 and pressed under 165°C hot pressing temperature. None of the boards fulfilled the minimum requirement of TS for furniture grade particleboard. This standard requires a TS value less than 12% and 15%. Overall, boards with target density of 700 kg/m^3 performed better than 500 kg/m^3 and 600 kg/m^3 and higher hot pressing temperature also contributed to the better performance. Table 3 illustrates the analysis of variance (ANOVA) of the effects of hot pressing temperature, board density and their interactions with the board properties. All the main factors of board density and hot pressing temperature were found to affect the board properties significantly except for hot pressing temperature on modulus of elasticity (MOE). Interaction effects between board density and hot pressing temperature showed significant difference and thus affected board properties.

Table 2. Properties of Particleboard from Variation of Board Density and Hot Pressing Temperature

BOARD DENSITY (kg/m^3)	HOT PRESSING TEMPERATURE (°C)	MOE (MPa)	MOR (MPa)	IB (MPa)	TS (%)
500	145	1516	11	0.36	25
500	165	1422	10	0.32	30
600	145	2291	18	0.48	34

600	165	2169	19	0.52	28
700	145	2837	23	0.54	37
700	165	3189	26	0.64	41
Furniture grade (MS 1036:2006)					
PF1		1800	13	0.40	n.a
PF2		2000	14	0.45	15
PF3		2000	16	0.45	12

Note: MOE- modulus of elasticity, MOR- modulus of rupture, IB- internal bonding, TS- thickness swelling

Table 3. Summary of the ANOVA on the Properties of Particleboard

SOV	Df	MOE	MOR	IB	TS
BD	2	678.98**	383.70**	381.56**	340.02**
HPT	1	1.74ns	13.22*	23.60**	4.28*
BD × HPT	2	20.12**	7.38*	27.12**	93.83**

Note: BD: Board density, HPT: hot pressing temperature, SOV: source of variance, ns = not significant at p>0.05, *significant at p<0.05, **highly significant at p<0.01

4. Effects of Board Density

Fig. 1 and **2** indicated the Duncan Multiple Range Test (DMRT) on the effect of board density on mechanical and physical properties of particleboard. It is a well-known fact that mechanical properties of particleboard improves with increasing panel density. It is evident that MOE, MOR and IB values increased significantly with increasing board density as it can be seen in Figure 1 and Figure 2. The correlation analysis (Table 4) further revealed that the MOE, MOR and IB showed positive correlation with increase in board density (r = 0.97**, r = 0.95** and r = 0.92**) respectively. This may have been due to the tighter structure, more compact and low porosity of the particleboard at high-density compared to the lower density boards (Nemli et al., 2005). High density board consists of high amount of wood material. Moreover, the resin is used based on the weight of the particles. For this reason, specimens at 700 kg/m^3 density had higher amount of resin compared to panels at 500 kg/m^3 and 600 kg/m^3 which resulted in tighter and more compact structure of the panels. Previous work also found that high density particleboards had lower porosity so that particles and adhesive can interact with each other more easily to form stronger crosslink compared to low density particleboards (Zheng et al., 2007). Youngquist (1999) mentioned that choosing a proper board density is an essential step in particleboard industry so that proper density can be determined based on the intended application requirements.

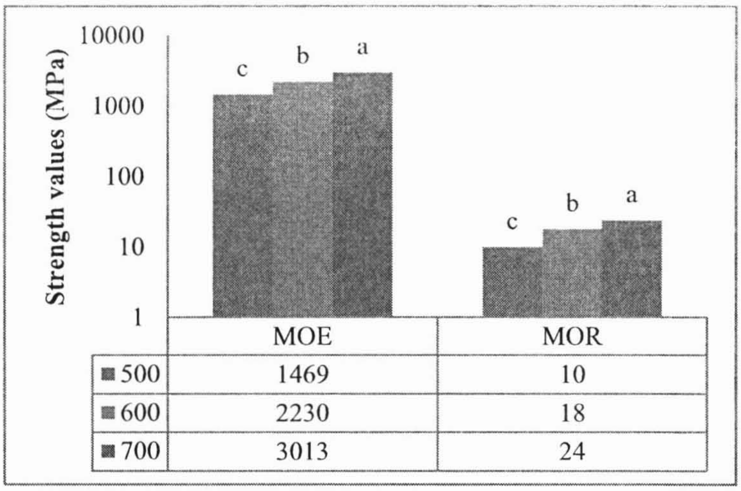

Fig. 1 Effects of Board Density on Bending Properties

Fig. 2 shows the effect of varying board density on TS properties. Results revealed that the increase in board density leads to the increase in TS. TS of the samples showed significant difference from each other. The correlation analysis (Table 4) further revealed that a positive correlation between board density and TS (r = 0.84**). Based on the findings of this work, particleboard with the density 700 kg/m^3 showed the greatest board swelling. The negative influence of the board density on the TS values of particleboard might be due to larger amount of wood particles required to produce 700 kg/m^3 particleboard compare to those 500 kg/m^3 and 600 kg/m^3 boards. This trend agrees with previous studies by Sari et al. (2012b), and Mohd Hazim et al. (2013). Bowyer et al. (2007) also stated that dimensional stability may be adversely affected by increased board density. Ordinarily, it is known that TS tends to increase with increasing board density due to the swelling of wood itself (Kenji et al., 2015). Colak et al. (2010) in their study found that high density wood absorbs more water than wood of low density because of more cell membrane presence in the high density wood. Moreover, in this study no hydrophobic substance or wax has been added during panel manufacturing. Taramian et al., (2007) mentioned that the addition of wax (0.5-1%) to the mixture of adhesive and particles during manufacturing process may improve water resistance. Heat treatment and chemical treatments also could be considered to enhance TS and water absorption (Mohd Hazim et al., 2013).

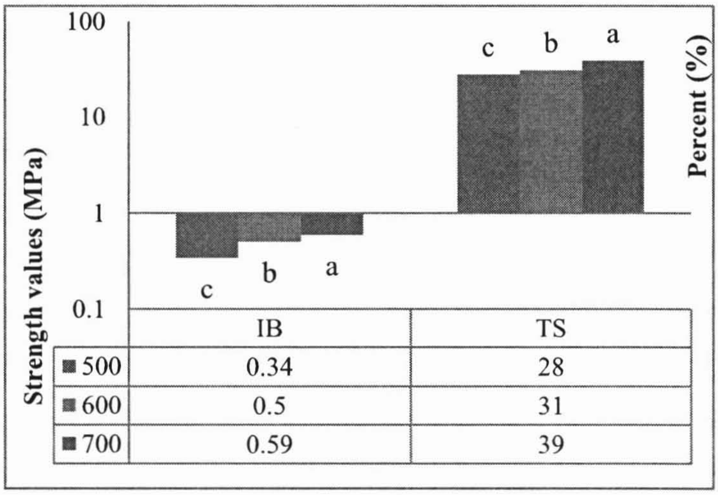

Fig. 2 Effects of Board Density on Internal Bond Strength and Thickness Swelling

Table 4. Correlation Coefficients of the Effects of Board Density and Hot Pressing Temperature on Board Properties

Variable	MOE	MOR	IB	TS
BD	0.97**	0.95**	0.92**	0.84**
HPT	0.35ns	0.13ns	0.16ns	0.07ns

Note: ns = no significant correlation, **Correlation is significant at the 0.01 level

5. Effects of Hot Pressing Temperature

Fig. 3 shows the bending properties of particleboard manufactured at different hot pressing temperatures. The bending properties of the boards manufactured at 145°C and 165°C increased insignificantly. The correlation analysis (Table 4) further revealed that the hot pressing temperature of the board had a positive correlation with MOE and MOR (r = 0.35ns and r = 0.13ns) respectively. However, the values of MOE and MOR of the boards manufactured at 165°C were slightly higher than those at 145°C. According to Korai et al. (2012), this is likely because higher hot pressing temperature was considered to accelerate the curing of the resin and thus improve board performance. Research conducted by Malanit et al. (2009) discovered that increased pressing temperature will increase the resin bonding rate thus enhanced strength, whereas the use of lower hot pressing temperature in board manufacturing resulted in the low strength because the resin did not fully cure. But, when very high hot pressing temperature was used, the resin would be over-cured hence reduce the bonding strength in adhesive bond. The trend of the IB strength was similar with the bending properties (**Fig. 4**). Duncan's multiple range test analysis discovered that the IB strength of various hot pressing temperatures was not significantly different from each other. The correlation analysis (Table 4) further revealed that IB showed a positive correlation (r = 16ns) with increase in hot pressing temperature. However, the IB values of boards manufactured under 165°C hot pressing temperature were 1.1 times higher than those at 145°C. Heinemann et al. (2002) mentioned that pressing temperature may influence the adhesion ability of resin to wood materials. Pressing temperature will influence water flow in wood hence cause the diffusion of resin molecules into the voids of the wood. The high pressing temperature will encourage more resin diffusion into the wood and will increase the mechanical bonding strength. The authors also stated that pressing temperature may affect the chemical exchange of the substrate surface. For example, the degradation of hydrogen bonds or the melting of lignin which have an essential role in bond strength. The low pressing temperatures will reduce the mobility of the reactive (OH-) group of polymeric molecules. Moreover, unstable methyl ether bridges do not convert into stable methylene bridges hence resulted in low bond strength.

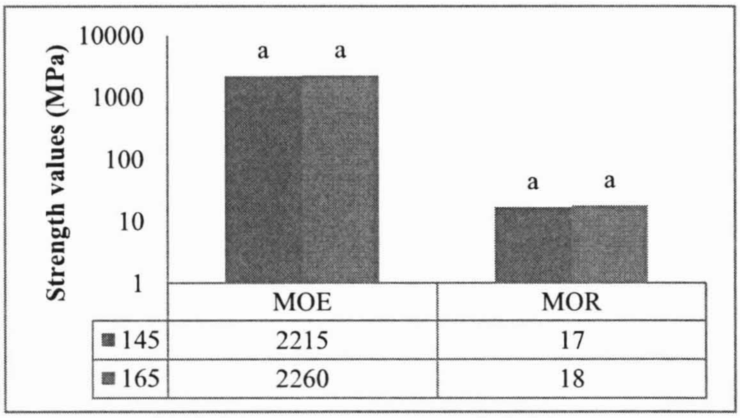

Fig. 3 Effects of Hot Pressing Temperature on Bending Properties

Fig. 4 shows the effects of hot pressing temperature on TS of the boards. Hot pressing temperature was found not to affect TS significantly. This was further revealed by the correlation analysis (Table 3) that TS insignificantly correlated with hot pressing temperature (r = 0.07ns). The TS at 165°C hot pressing temperature should be lower than 145°C hot pressing temperature. This is because wood particles are plasticized under high temperature which improved the contact between wood particles. The improved contact therefore prevented water from infiltrating into the board (Korai et al., 2012). However, the results were the contrary, and the thickness swelling was slightly lower when board manufactured at 145°C hot pressing temperature. In this study, perhaps at 145°C hot pressing temperature the, resin was completely cure and the adhesive bonds were developed. Maybe an excess pressing temperature can reduce bonding strength in the glue line thus allowing more water molecules to penetrate into the boards (Malanit et al., 2009).

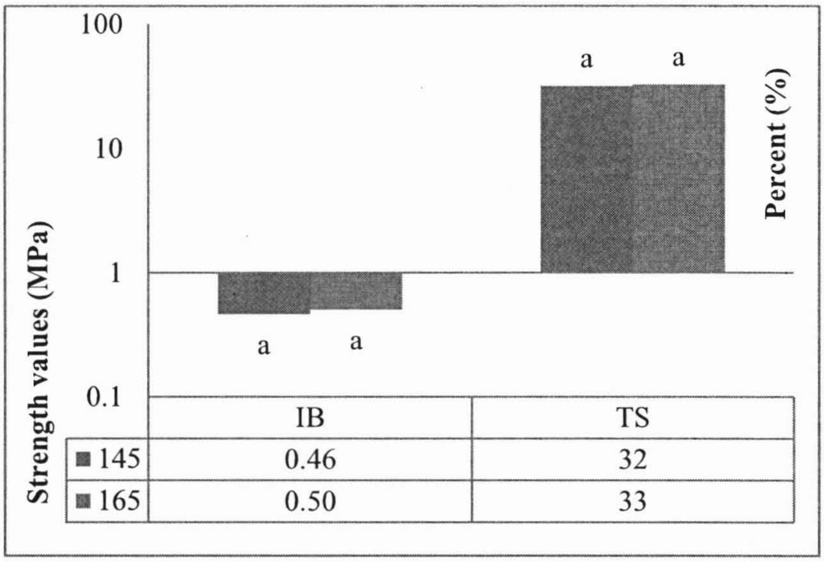

Fig. 4 Effects of Hot Pressing Temperature on Internal Bonding Strength and Thickness Swelling

6. Conclusion

The effects of board density and hot pressing temperature on the physical and mechanical properties were investigated. The mechanical properties improved with increasing board density but the physical properties are vice versa. The best mechanical properties was obtained by board manufactured at density 700 kg/m^3, whereas better dimensional stability indicated by the board with lower density. No significant effect of hot pressing temperature on physical and mechanical properties of the board observed. However, the board manufactured at 165°C was slightly higher in mechanical properties. But, the physical properties improved insignificantly when board was manufactured at 145°C. The results of thickness swelling in this work failed to meet the requirements of the furniture grade as stated in MS. In future, further work will be conducted to improve the dimensional stability and performance of particleboard.

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