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Research paper

Mechanical and Physical Properties of Kelempayan (Neolamarckia Cadamba) Particleboard

Nazri W. M[1], Nur Sakinah M. T[2*] & Jamaludin K.[3]

[1 2 3] Faculty of Applied Sciences, University Technology MARA, 40450 Shah Alam
**Corresponding author E-mail: sakinah292@yahoo.com*

Abstract

The aim of this study was to investigate the role of the particle size, board density, resin content and hot press temperature on the properties of particleboard composite. Single-layered Kelempayan (*Neolamarckia cadamba*) particleboards bonded with phenol formaldehyde (PF) resins were manufactured. The boards were fabricated with three different particle sizes (0.5, 1.0 and 2.0 mm), two different board densities (600 and 700 kgm^{-3}), two different resin contents (9 and 11%) and two different hot press temperatures (155 and 165˚C). The boards produced were evaluated for their modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and thickness swelling (TS) in accordance with the Malaysia Standards. The study revealed that boards from smaller particles, higher resin contents and higher hot press temperatures gave higher MOE, MOR, IB and improved the TS. However, boards with higher densities gave higher MOE, MOR, IB and TS. Overall, the boards with the particle size of 0.5 mm, board density of 700 kgm^{-3}, resin content of 11% and 165˚C of hot press temperature exhibited the greatest performance and were able to fulfill the Malaysia Standard specifications for furniture grade used in dry (PF1) and humid (PF2) and also for load-bearing applications in dry (PS1).

Keywords: *Kelempayan, Modulus of elasticity, Particleboard*

1. Introduction

With the constant increase in population and rapid development of the global economy, the overall demand for wood composites is rising, while the available wood supply will decrease due to deforestation of natural forests [1]. Consequently, the search for alternative raw material had come into focus. Fast growing species, annual crops and wood waste have recently become valuable raw materials for particleboard fabrication [2]. The raw materials for particleboard should be available in sufficient quantities to support sustained production over many years. A suitable raw material should have comparable physical and mechanical properties to the wood and compatible to the existing processing technologies [3].
Nowadays, there has been a shift in the supplies of wood from natural forests to plantation forests that are dominated by fast growing species [4]. The use of fast growing species in wood composite industry had increased due to the market needs and most welcomed of the introduction of new raw materials to the market [5]. According to [6], fast growing species can satisfy the increasing need for wood and wood products. Fast growing species means the trees are growing very quickly than other trees. The establishment of fast growing tree plantations in many countries is due to their advantages of short production time and low cost [7].
Kelempayan (*Neolamarckia cadamba*) is a fast-growing tropical tree species and belongs to the family of Rubiaceae. The self-pruning and straight bole characteristics of the tree have attracted attention to the tree as a potentially useful species for tree plantation. This species is known as Kadam in India, Jabon in Indonesia, Kaatoan Bangkal in the Philippines, Taku in Thailand, Entipong in Sarawak, Limpoh in Sabah and Kelempayan in Peninsular Malaysia [8]. The tree is described as 'miracle tree' in the Philippines because of the multiples uses and rapid growth [9]. The future of this tree as a source of raw material is great due to its multiple uses. Research has shown that the timber can be used for making a wide range of products such as plywood, packing case, wooden sandals, toys, disposable chopsticks and possibly as a short-fibred pulp [10].
Hence, this study was conducted to enhance the utilization of Kelempayan by helping in promoting the material as an input for the production of particleboard. This study also conducted to investigate the influence of particle size, board density, resin content and hot press temperature to the mechanical and physical properties of Kelempayan particleboard.

2. Main Body

2.1. Materials and Methods

2.1.1. Preparation of Kelempayan Particles

Kelempayan trees used in this study were harvested from UiTM Pahang Forest Reserve. The tree diameter of breast height (DBH) is of 35–45 cm. The felled trees were sawn into 1 in × 1 in × log length of small billets, 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 0.5, 1.0 and 2.0 mm particle sizes using a vibrating screener. The screened particles were further oven-dried at 80 °C for 2 to 3 days to reduce the moisture content to less than 5%.

2.1.2. Board Making

Single-layered particleboards at the density of 600 and 700 kgm^{-3} were fabricated. Commercial phenol formaldehyde (PF) resin was used. A weighted amount of particles was blended separately with 9 and 11% of PF resins. The resulting mat was manually formed to a size 350 × 350 × 12 mm. 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 155 and 165 °C hot press temperature. Three replicate boards were fabricated for each treatment with a total of 72 boards produced. All boards were kept at 20 °C and 65% relative humidity in a conditioning room for 1 week before they were cut into various sizes for property evaluation.

2.1.3. Evaluation of Mechanical and Physical Properties

Finished particleboards were cut into required sizes for testing MOE, MOR, IB and TS according to [11, 12, 13]. Three samples with the dimensions of 30 × 5 × 1.2 cm from each board were used for bending strength test (MOE and MOR) according to [14]. Seven samples with the dimensions of 5 × 5 × 1.2 cm from each panel were used for IB test based on [15]. Both tests were conducted using an Instron Universal Testing Machine with movable crosshead speed 10 mm/min for bending strength test and 1.5 mm/min for IB test. TS test was carried out on 7 samples cut from each board with the dimensions of 5 × 5 × 1.2 cm. Determination of TS was done in accordance to [16]. Thickness of the samples was measured before and immediately after soaking 24 hours in water.

2.2. Results and Discussion

In general comparison, the mechanical properties of the boards fabricated using 0.5 mm of particle size were relatively higher in comparison with 1.0 mm and 2.0 mm of particle size (Table 1).

Table 1: Properties of particleboards

T	PS (mm)	BD (kgm^{-3})	RC (%)	HPT (˚C)	MOE (MPa)	MOR (MPa)	IB (MPa)	TS (%)
1	0.5	600	9	155	2596	19	0.64	11
2	0.5	600	9	165	2603	21	0.62	14
3	0.5	600	11	155	2346	19	0.67	13
4	0.5	600	11	165	2351	20	0.69	15
5	0.5	700	9	155	3492	30	0.88	20
6	0.5	700	9	165	3499	32	0.86	22
7	0.5	700	11	155	3820	36	0.96	12
8	0.5	700	11	165	3833	38	0.97	13
9	1.0	600	9	155	2527	21	0.61	15
10	1.0	600	9	165	2593	22	0.74	18
11	1.0	600	11	155	2685	23	0.74	14
12	1.0	600	11	165	2684	24	0.86	16
13	1.0	700	9	155	3241	33	0.67	16
14	1.0	700	9	165	3248	32	0.70	18
15	1.0	700	11	155	3575	35	0.92	15
16	1.0	700	11	165	3584	34	0.91	17
17	2.0	600	9	155	2163	19	0.50	23
18	2.0	600	9	165	2347	17	0.59	22
19	2.0	600	11	155	2818	22	0.57	17
20	2.0	600	11	165	2790	21	0.58	16
21	2.0	700	9	155	3233	26	0.69	27
22	2.0	700	9	165	3427	32	0.78	23
23	2.0	700	11	155	3461	30	0.77	19
24	2.0	700	11	165	3447	34	0.82	16
		PF1			1800	13	0.40	n.a
		PF2			2000	14	0.45	15
		PF3			2000	16	0.45	12
		PS1			2100	15	0.40	16
		PS2			2500	18	0.45	11
		PS3			2500	18	0.45	9

Note: T = treatment, PS = particle size, BD = board density, RC = resin content, HPT = hot press temperature, MOE = modulus of elasticity, MOR = modulus of rupture, IB = internal bond strength, TS = Thickness swelling, PF1 = furniture in dry, PF2 = furniture in humid, PF3 = furniture in high humid, PS1 = structural in dry, PS2 = structural in humid, PS3 = structural in high humid.

Overall, board density of 700 kgm^{-3} performed better than 600 kgm^{-3} and 11% resin content also contributed to better performance. The MOE, MOR and IB increased with increasing the board density and resin content. Boards pressed using higher hot press temperature had good performance than lower hot press temperature. Particle size of 0.5 mm at the density of 700 kgm^{-3} presence of 11% resin content and pressed under 165˚C of hot press temperature (Treatment 8) contributed to the highest board performance in mechanical properties. The values of MOE, MOR and IB are 3833 MPa, 38 MPa and 0.97 MPa, respectively. The boards can be used for PF1, PF2 and PS1. However, boards fabricated using 0.5 mm of particle size at the density of 600 kgm^{-3} with 9% resin content and pressed under 155˚C of hot press temperature (Treatment 1) possessed the lowest TS value of 11%. The boards achieved the requirements for PF1, PF2, PF3, PS1and PS2. Most of the boards met the minimum requirement of the MS standard for their mechanical properties. Particleboards from 2.0 mm of particle size at the density of 600 kgm^{-3} presence of 9% resin content pressed under 155˚C and 165˚C of hot press temperatures (Treatment 17 and Treatment 18) failed to comply with the minimum requirement of MOE for PS2 and PS3. Boards fabricated from 2.0 mm of particle size with the density of 700 kgm^{-3} at 9% of resin content and pressed using 155˚C of hot press temperature (Treatment 21) had the highest TS values and failed to achieve the requirement of the Malaysian Standard (MS1036).

2.2.1. Statistical Significance

Table 2 shows the analysis of variance (ANOVA) on the effects of

Table 2: Summary of the ANOVA on Boards Properties

SOV	Df	MOE	MOR	IB	TS
PS	2	10.76*	42.47*	208.60*	623.67*
BD	1	2529.02*	2392.79*	1117.70*	185.49*
RC	1	115.21*	145.88*	355.65*	717.72*
HPT	1	3.96*	18.61*	62.70*	25.89*
PS × BD	2	42.02*	21.17*	127.81*	44.63*
PS × RC	2	21.17*	1.96ns	57.68*	142.57*
BD × RC	1	10.55*	25.04*	29.49*	169.55*
PS × BD × RC	2	60.92*	19.62*	4.20*	122.59*
PS × HPT	2	1.57ns	4.2*	19.41*	116.26*
BD × HPT	1	0.01ns	8.6*	9.86*	15.14*
PS × BD × HPT	2	0.08ns	22.38*	16.01*	5.38*
RC × HPT	1	4.52*	0.01ns	2.31ns	0.09ns
PS × RC × HPT	2	3.08*	0.11ns	8.21**	4.14*
BD × RC × HPT	1	0.13ns	0.90ns	0.14ns	1.43ns
PS × BD × RC × HPT	2	0.08ns	1.03ns	0.96ns	0.24ns

Note: SOV = source of variance, Df = degree of freedom, PS = particle size, BD = board density, RC = resin content, HPT = hot press temperature, MOE = modulus of elasticity, MOR = modulus of rupture, IB = internal bond strength, TS = thickness swelling, ns = not significant at p > 0.05, *significant at p < 0.05

particle size, board density, resin content, hot press temperature and their interactions with the board properties. All the main factors were found to affect all the board properties significantly. The interaction effects of particle size, board density and resin content showed significant effect on mechanical properties and TS of the boards. A significant interaction effect of particle size, board density and hot press temperature was recorded on mechanical properties and thickness swelling except for MOE. However, there was insignificant interaction effect between the particle size, board density, resin content and hot press temperature on MOE, MOR, IB and TS.

2.2.2. Effects of Particle Size

Figure 1 shows the effect of particle size on the mechanical properties of Kelempayan particleboards. The MOE of particleboards were observed to decrease significantly with increase in particle size. Boards made from particle size of 1.0 mm have significantly higher MOR compare to 0.5 and 2.0 mm of particle sizes. The correlation analysis further revealed that the MOE and MOR showed insignificant negative correlation with increasing particle size (r = -0.08ns and r = -0.10ns) (Table 3). Particle size was found to affect the bending properties of particleboards. Decrease in particle size produces a stiffer and stronger board in bending. Smaller particles tend to absorb much of the resin in particleboard than bigger particles because of larger surface area. This is in agreement with a previous study by [17] which stated that reduction of particle size improves stiffness, toughness and tensile strength of board by improving the load transfer between particle and increased surface area of particle.

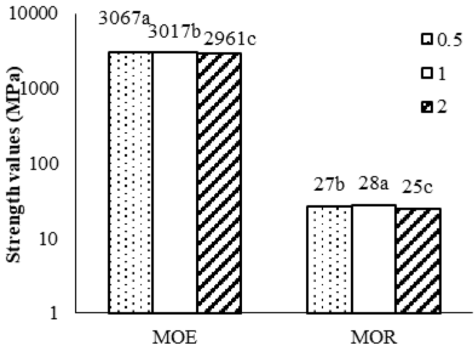

Fig. 1: Effects of particle size on modulus of elasticity (MOE) and modulus of rupture (MOR)

By comparing between particle sizes on IB, it was seen that particleboards manufactured from 0.5 mm of particle size was superior in IB, exceeding that of 1.0 and 2.0 mm particle sizes (Figure 2). The correlation analysis further revealed that the IB showed a significant negative correlation with increasing particle size (r = -0.37*) (Table 3). The higher IB found from the particleboards manufactured from the smaller particles was expected due to less gaps between the smaller particles compared to the boards manufactured using bigger particles. Smaller particles can fill up the gap which encourage to high bond contact between the particles [18]. The use of bigger particles can reduce the bonding ability because of more gaps between the particles. Moreover, many chances of voids being left unfilled when used bigger particles during board making.
Figure 2 shows the effects of particle size on TS behaviour of Kelempayan particleboard. Particle size plays a role in controlling the board response to water. TS values of the board increases as the particle size is increased. The correlation analysis indicated that a significant positive correlation between the particle size and TS (r = 0.58*) (Table 3). The results revealed that the ability of the boards to resist the uptake of water were better when the smaller particles used in board fabrication. Study conducted by [19] reported that smaller particles led to better dimensional stability of the boards than bigger particles. Smaller particles were more compressed with fewer overlapping areas. This leads to more uniform homogenous cells which had lower voids. In addition, smaller particles give smooth appearances for particleboard than bigger particles [19]. Boards with smooth surfaces and appearances are energy saving because no sanding is required during the fabrication process. Boards manufactured using bigger particles tend to have more void space during consolidation, resulting in higher porosity and easier water diffusion into the boards when soaked [20].

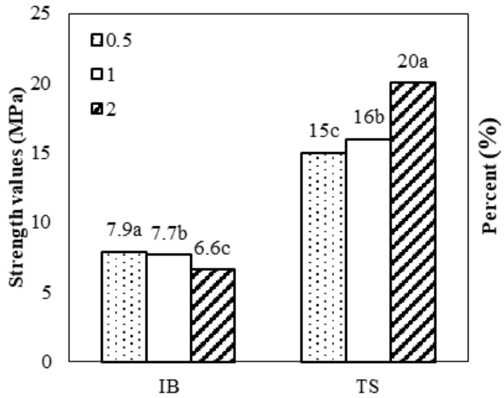

Fig. 2: Effects of particle size on internal bond strength (IB) and thickness swelling (TS)

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

Variable	MOE	MOR	IB	TS
PS	-0.08ns	-0.10ns	-0.37*	0.58*
BD	0.90*	0.90*	0.65*	0.23*
RC	0.19*	0.22*	0.37*	-0.46*
HPT	0.04ns	0.08ns	0.15*	-0.09ns

Note: PS = particle size, BD = board density, RC = resin content, HPT = hot press temperature, MOE = modulus of elasticity, MOR = modulus of rupture, IB = internal bond strength, TS = thickness swelling, ns = no significant correlation, *correlation is significant at the 0.05 level

2.2.3. Effects of Board Density

Figure 3 shows the MOE and MOR of particleboards with different densities. The MOE values increased as the board density increased. Higher MOE values were obtained for particleboards from the density of 700 kgm^{-3}. This was mainly attributed to the greater volume of wood particles that are compacted and higher contact between particles. Studies have indicated that there is a positive correlation between bending properties and board density [21, 22]. MOR results also follow a similar trend as the MOE.

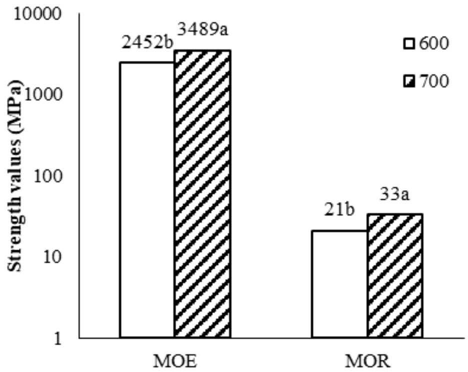

Fig. 3: Effects of board density on modulus of elasticity (MOE) and modulus of rupture (MOR)

Board density of 700 kgm^{-3} had significantly higher MOR as compared to the density of 600 kg^{-3}. High compression rate and high surface contact between the particles of higher density board therefore resulted in MOR improvement of the board. The increase in MOR with an increase in board density according to [23] is a common phenomenon. The correlation analysis further revealed that the MOE and MOR showed a significant positive correlation with board density (r = 0.90*) (Table 3).

The effect of board density on IB were observed to be significant (Figure 4). Increasing board density from 600 to 700 kgm^{-3} improved the IB of the boards. The correlation analysis indicated that the IB had significant positive correlation with increased of board density (r = 0.65*) (Table 3). Larger amount of wood particles used to fabricate a high-density board can contribute to the higher compaction ratio existing in the board. Boards with higher compaction ratio result in greater inter-particle contact because of more effective bonding forming between the particles [24]. This seemed to happen because of the spread over of resin to a greater particle surface area instead of filling the voids existence in-between the particles. According to [25], board with higher compaction ratio tends to have a more closed structure.

As shown in Figure 4, TS of particleboards increased significantly with increasing board density. The correlation analysis also revealed that the TS showed significantly positive correlation with increasing the board density (r = 0.23*) (Table 3). Generally, the particleboards experienced an increase in the weight and thickness after being soaked in water. Swelling occurs due to the release of compressive stresses and hygroscopic particles. Irreversible thickness swells or 'springback' of high-density board occurred due to release of compressive stress imparted to the board when the particles were pressed in the hot press. This finding is similar to those reported by [20]. If the forces are great enough, the resin can debond from the particle which may result in a weak spot within the composite matrix during springback [26]. Since the high-density board composed of more wood material, the hygroscopic swelling of wood itself could be attributed to the higher TS or springback of the board. Springback is the common behaviour of any wood composites when they are soaked in water which the board manifests itself in the form of higher TS [23].

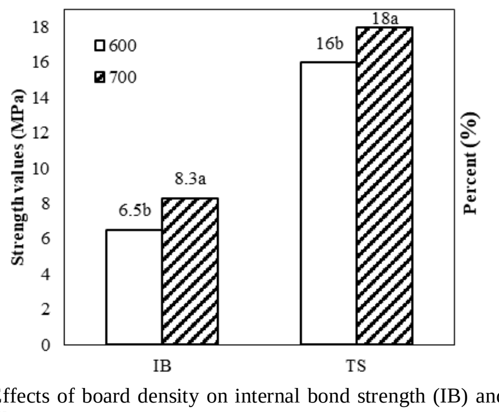

Fig. 4: Effects of board density on internal bond strength (IB) and thickness swelling (TS)

2.2.4. Effects of Resin Content

Figure 5 depicts the results of the effects of resin content on bending properties of Kelempayan particleboards. Addition of more resin into the board significantly improved the MOE and MOR values of the board. The same trend has also been observed by [27]. The correlation analysis showed a significant positive correlation of MOE and MOR with increasing resin content (r = 0.19* and r = 0.22*) (Table 3). Increases in mechanical properties are expected with increases of resin content, which may be attributed to the higher resin amount per particle. Higher amount of resin available/particle may result in better bonding, which may increase the mechanical properties of particleboards. Previous work on particleboard produced from athel (*Tamarix aphylla*) wood reported a similar trend when resin content was increased [28].

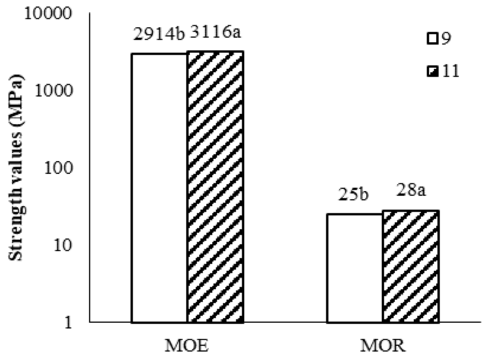

Fig. 5: Effects of resin content on modulus of elasticity (MOE) and modulus of rupture (MOR)

From Figure 6, an increase in resin content led to a rise in IB. Particleboards with higher resin content shows significantly higher IB. The correlation analysis further revealed that the IB showed a significant positive correlation with resin content (r = 0.37*) (Table 3). Higher values were obtained for particleboards with 11% PF. The higher resin content contributed to increase in IB of particleboards because of the greater amount of resin available per particle. This leads to better bonding and increased IB. Higher percentage of resin improves the distribution of resin to particle, which increases the bonding strength of particleboard [21, 29].

Figure 6 shows an increase in resin content result in a significant decrease in TS. The correlation analysis revealed that the TS values had significant negative correlation with increased of resin content (r = -0.46*) (Table 3). Increases in resin content normally result in decreases in TS. This result may be attributed to the higher resin amount per particle which improve bonding and reduced TS. High resin content results into high bond quality between the particles and attributed to a physical barrier to the water intake into the boards. A study by [30] observed that higher resin content has been consistently shown to improve thickness swell behaviour of particleboards.

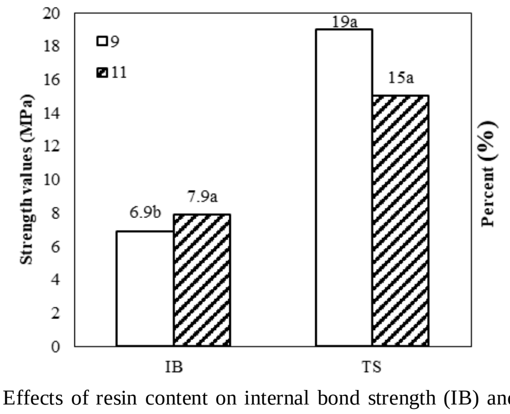

Fig. 6: Effects of resin content on internal bond strength (IB) and thickness swelling (TS)

2.2.5. Effects of Hot Press Temperature

The MOE and MOR of particleboards increased insignificantly with increasing hot press temperature (Figure 7). The values showed insignificant positive correlation with hot press temperature (r = 0.04ns and r = 0.08ns) (Table 3). Press temperature is one factor that influences adhesion ability of resin to particle. Higher press temperature generates better mechanical interlocking between resin and particle in the boards, resulting in improved mechanical strength. Water flow in wood is influenced by the press temperature. High press temperature caused to increase the diffusion of resin molecules into the voids of particles and leads to increase the mechanical strength [31]. The decreases in MOE and MOR of particleboards manufactured from low pressing temperature caused by low diffusion of resin into the particle.

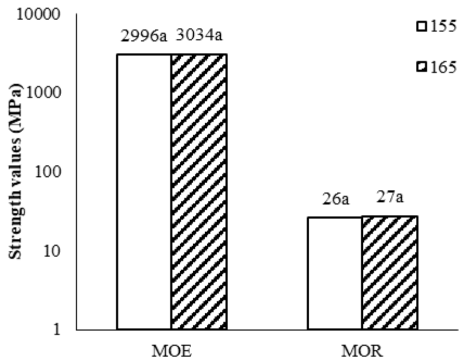

Fig. 7: Effects of hot press temperature on modulus of elasticity (MOE) and modulus of rupture (MOR)

The effects of hot press temperature on IB are shown in Figure 8. The IB increased significantly as the hot press temperature increased from 155 to 165˚C. The correlation analysis showed a significant positive correlation of IB with hot press temperature (r = 0.15*) (Table 3). This probably occurred due to the promotion of adhesiveness at 165˚C of hot press temperature. It is generally agreed that high press temperature can increase the curing of resin in particleboard. Increase the curing of resin, in general, provided more effective bonding and in turn led to better IB of the board. A study by [32] found that the IB of particleboard was obviously enhanced as the hot press temperature increased.

Figure 8 also illustrates the TS values of Kelempayan particleboards manufactured from variation of hot press temperature. The TS values for both types of boards were insignificantly different to each other. The correlation analysis further revealed that TS had insignificant negative correlation with hot press temperature (r = -0.09ns) (Table 3). Boards compressed at 165˚C had lower TS in comparison to the boards compressed at 155˚C. This indicates that more resin within the boards at 165˚C had been cured than those of boards at 155˚C. At higher hot press temperature, wood particles are compressed easily because of their thermoplastic behaviour. Decreasing in internal stresses would result in better dimensional stability of the boards. According to [33], the quantity of hydroxyl (-OH) groups within wood decreases as the press temperature increased due to the degradation of certain chemical components such as hemicellulose and thus resist the entry of water molecules into the boards.

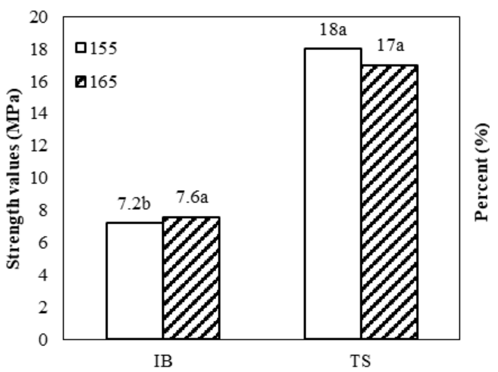

Fig. 8: Effects of hot press temperature on internal bond strength (IB) and thickness swelling (TS)

3. Conclusions

It can be concluded that particle size, board density, resin content and hot press temperature were influential to the increment of mechanical and physical properties of Kelempayan particleboard. Particleboard made from 0.5 mm of particle size, 700 kgm^{-3} of board density, 11% of resin content and 165˚C of hot press temperature showed the highest mechanical properties and lowest thickness swelling. The board were complied with the standard requirement values MOE, MOR, IB and TS in accordance with Malaysia Standards MS 1036 (2006).

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References

[1] Kusumah SS, Umemura K, Yoshioka K & Miyafuji H (2016), Utilization of sweet sorghum bagasse and citric acid for manufacturing of particleboard I : Effects of pre-drying treatment and citric acid content on the board properties. *Industrial Crops & Products* 84, 34–42.

[2] Khanjanzadeh H, Bahmani AA, Rafighi A & Tabarsa T (2012), Utilization of bio-waste cotton (*Gossypium hirsutum* L.) stalks and underutilized Paulownia (*Paulownia fortunie*) in wood-based composite particleboard. *African Journal of Biotechnology* 11, 8045–8050.

[3] Chaowana P (2013), Bamboo: An alternative raw material for wood and wood-based composites. *Journal of Materials Science Research* 2, 89-102.

[4] Karlinasari L, Hermawan D, Maddu A & Martiandi B (2012), Development of particleboard from tropical fast-growing species for acoustic panel. *Journal of Tropical Forest Science* 24, 64–69.

[5] Boruszewski P, Borysiuk P, Mamiński M & Czechowska J (2016), Mat compression measurements during low-density particleboard manufacturing. *BioResources* 11, 6909–6919.

[6] Taghiyari HR, Bari E, Schmidt O, Ghanbary MAT, Karimi A & Paridah MT (2014), Effects of nanowollastonite on biological resistance of particleboard made from wood chips and chicken feather against *Antrodia vaillantii*. *International Biodeterioration & Biodegradation* 90, 93-98.

[7] Bal BC (2016), Some technological properties of laminated veneer lumber produced with fast growing Poplar. *Maderas Ciencia y tecnologia* 18, 413–424.

[8] Anonymous (2010). *Laran*, available online: http://woodwizard.mtc.com.my:8888/report.asp?AttrID=79&ItemID=5, last visit: 11.09.2010

[9] Ismail J, Jusoh MZ & Sahri MH (1995), Anatomical variation in planted Kelempayan (*Neolamarckia cadamba*, Rubiaceae). *IAWA Journal* 16, 277–287.

[10] Choo KT, Gan KS & Lim SC (1999), Timber notes-light hardwoods VI (Dedali, Kedondong, Kelempayan, Kelumpang, Kembang Semangkok). Timber Technology Bulletin No. 16. Forest Research Institute Malaysia, Kepong.

[11] Malaysian Standard (MS) 1036 (2006). Wood-based panels - Particleboards - Specification (first revision): Department of Malaysian Standard.

[12] Malaysian Standard (MS) 1787 Part 2 (2005). Wood-based panels – Sampling and cutting of test pieces. Putrajaya: Department of Malaysian Standard.

[13] Malaysian Standard (MS) 1787 Part 3 (2005). Wood-based panels – Determination of dimensions of test pieces. Putrajaya: Department of Malaysian Standard.

[14] Malaysian Standard (MS) 1787 Part 10 (2005). Wood-based panels – Determination of modulus elasticity in bending and bending strength. Putrajaya: Department of Malaysian Standard.

[15] Malaysian Standard (MS) 1787 Part 11 (2005). Wood-based panels – Determination of tensile strength perpendicular to the plane of the panel. Putrajaya: Department of Malaysian Standard.

[16] Malaysian Standard (MS) 1787 Part 6 (2005). Wood-based panels – Determination of swelling in thickness after immersion in water: Department of Malaysian Standard.
[17] Lauke B, Feng X-Q, Mai Y-W & Fu S-Y (2008), Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate-polymer composites. *Composites Part B Engineering* 39, 933-961.
[18] Ahmad Fauzi O, Nurrohana A, Jamaludin K et al. (2008), Effects of particle size, resin content and board density on properties of Sesendok particleboard. *Jurnal Gading* 12, 1-10.
[19] Maisarah T, Zuraida A & Hanafi I (2016), A review of natural fibers and processing operations for the production of binderless boards. *BioResources* 11, 5600-5617.
[20] Atta-Obeng E, Via BK & Fasina O (2012), Effect of microcrystalline cellulose, species and particle size on mechanical and physical properties of particleboard. *Wood and Fiber Science* 44, 1-9.
[21] Bufalino L, Albino VCS, Va de Sa, Correa AAR, Mendes LM & Almeida NA (2012), Particleboards made from Australian red cedar: Processing variables and evaluation of mixed species. *Journal of Tropical Forest Science* 24, 162-172.
[22] Enayati AA, Eslah F & Farhid E (2013), Evaluation of particleboard properties using multivariate regression equations based on structural factors. *Journal of Agricultural Science and Technology*15, 1405-1413.
[23] Enayati AA & Eslah F (2014), Modelling beech (*Fagus orientalis*) particleboard properties based on resin content and board density. *Journal Indian Academic Wood Science* 11, 45-49.
[24] Wong ED, Zhang M, Wang Q & Kawai S (1999), Formation of the density profile and its effects on the properties of particleboard. *Wood Science and Technology* 33, 327-340.
[25] Iwakiri S, Trianoski R, Da Cunha AB et al. (2014), Evaluation of the quality of particleboard panels manufactured with wood from *Sequoia sempervirens* and *Pinus taeda*. *Cerne*, *Lavras* 20, 209-216.
[26] Nemli G & Demirel S (2007), Relationship between the density profile and the technological properties of the particleboard composite. *Journal of Composite Material* 41, 1793-1802.
[27] Sekaluvu L, Tumutegyereize P & Kiggundu N (2014), Investigations of factors affecting the production and properties of maize cob-particleboards. *Waste Biomass Valor* 5, 27-32.
[28] Zheng Y, Pan Z, Zhang R, Jenkins BM & Blunks S (2006), Properties of medium density particleboards from saline athel wood. *Industrial Crops and Products* 23, 318-326.
[29] Zhang J, Li J & Zhang S (2011), Properties of particleboard manufactured with modified urea-formaldehyde resin. *Advanced Materials Research* 150-151, 1135-1138.
[30] Rachtanapun P, Sattayarak P & Ketsamak N (2012), Correlation of density and properties of particleboard from coffee waste with urea-formaldehyde and polymeric methylene diphenyl diisocyanates. *Journal of Composite Materials* 46, 1839-1850.
[31] Iswanto AH, Febrianto F, Hadi YS, Ruhendi S & Hermawan D (2013), The effect of pressing temperature and time on the quality of particleboard made from jatropha fruit hulls treated in acidic condition. *Makara Seri Teknologi* 17, 145-151.
[32] Zhao Z & Umemura K (2015), Investigation of a new natural particleboard adhesive composed of tannin and sucrose. 2. Effect of pressing temperature and time on board properties, and characterization of adhesive. *BioResources* 10, 2444-2460.
[33] Yang F, Fei B, Wu Z, Peng L & Yu Y (2014), Selected properties of corrugated particleboards made from bamboo waste (*Phyllostachys edulis*) laminated with medium-density fiberboards panels. *BioResources* 9, 1085-1096.