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Research paper

Properties of plywood from planted *Paraserianthes falcataria* and *Neolamarckia cadamba*

Wan Mohd Nazri Wan Abd Rahman[1*], Muhammad Fitri Sa'ad[1], Nor Yuziah Yunus[1]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA Shah Alam, 40450 Shah Alam, Selangor, Malaysia*
**Corresponding author E-mail:wmdnazri@pahang.uitm.edu.my*

Abstract

This study is focused on a new wood material for plywood production in Malaysia. Depleting supply of big diameter log from virgin forest had contributed to discovering use of fast-growing species from a systematic forest plantation scheme. Batai (*Paraserianthes falcataria*) and Kelampayan (*Neolamarckia cadamba*) were used as raw materials to manufacture the new plywood product. This study also investigated the chemical properties for both species to further justify the plywood properties. The chemical analysis is carried out according to TAPPI Standard. The tree samples were harvested from the trial plot in UiTM Jengka Pahang and sent to plywood mills nearby for plywood production. Logs are peeled into different size of veneer (1.5 meter and 2.7 meter) and thickness. The plywood was composed in five layers and seven layers with 12 mm thickness and used melamine urea formaldehyde (MUF) as a binder based on commercial industry production. Boards were cut and tested according to Japanese Agriculture Standard (2014) at Forest Research Institute Malaysia (FRIM). Based on minimum standard requirement, results showed that both species are suitable to be made into plywood for general use and structural (decorative) purpose. In addition, increased veneer layers improved the board strength.

Keywords: *Plywood, Chemical Properties, Mechanical Properties,*

1. Introduction

Plywood is one of wood composite that has been highly commercialized other than wood furniture and solid wood. According to the Malaysian Timber Industry Board [1], value price export of major timber products from Malaysia is as high as RM 20 billion per years to which plywood contributes RM 5.2 billion after wooden furniture (RM 6.3 billion). However, value unit of export for plywood from 2008 (4.62 million m3) to 2014 (3.10 million m3) shows a decrease of more than 30% of export value. This is due to a shortage of supply of raw material from natural tropical forest which cycle rotation for tree to growth takes many years.

Alternative ways to combat this situation is using raw material from fast growing species. There are 8 selected species that had been gazette in Malaysia under National Forest Plantation Programme (NFPPP) for forest plantation species which is Rubberwood (Hevea brasiliensis), Acacia (Acacia spp.), Kelampayan (Neolamarckia cadamba), Sentang (Azadirachta excelsa), Binuang (Octomeles sumatrana), Khaya (Khaya ivorensis), Batai (Paraserianthes falcataria) and Jati (Tectona grandis) [2]. The combination of light hardwood and medium hardwood can produce many types of plywood which is used as general plywood, decorative structures and furniture.

2. Materials and Methods

In this study, there are two species that had been selected for plywood making which is Batai (Paraserianthes falcataria) with density of 220 - 340 kg/m3 and Kelampayan (Neolamarckia cadamba) with density of 370 – 465 kg/m3 and diameter of 28-45 cm. These trees were obtained from the trial plot plantation in UiTM Jengka. All logs were cut into required length of 1.5 meter (5 feet's) and 2.7 meter (9 feet's) for peeling process and disk sample from tree portion was also taken from each tree and species for chemical analysis. Then the logs were sent to a plywood mill for peeling process into veneer and plywood manufacture.

2.1 Wood chemistry

All wood samples of Batai and Kelampayan from the top, middle and bottom portion are processed by cutting into match sticks and ground into fine particles. Then it was screened for 40 mesh size. The chemical analysis was carried out according to TAPPI Standard: Cold Water (T 207 os-75), Hot Water (T 202 os-75), Alcohol Toluene Soluble (T 222 os-75) Ash Content (T 15 os-58) and Lignin Content (T 222 os-75).

2.2 Plywood manufacturing

Fig. 1 shows the flow process for plywood making in production. Boards from the finished product were cut into 610 mm x 610 mm panels, before it was cut into specific measurement for bending (parallel and perpendicular), bonding shear and panel shear tests according to the Japanese Agricultural Standard for Plywood (JAS 2014) and tested at the Forest Research Institute Malaysia (FRIM) laboratory. All specimen tests were carried out using a 50 kN Shimadzu universal testing machine. The specimen for bending strength is cut into 338 mm in parallel x 50 mm in perpendicular of surface board for parallel bending and 338 mm in perpendicular x 50 mm in parallel of surface board for perpendicular bending. Samples for panel shear are cut into 255 mm in parallel direction x 85 mm in perpendicular direction to the surface board. Then the length side of samples was holed to place bolt for tightened steel plate with sample to allow samples break in middle part. For bonding shear strength, samples were cut into slits with any two bonding layers (except parallel bonding) of samples test. The samples are immersed in boiling water for 4 hours, then placed in an oven with a temperature of 60 °C for 20 hours and further immersed in boiling water, and then lastly immersed in water for cooling down. Samples are gripped on both ends, pulling toward the direction of both ends. The load continued for all test until each specimen break occurred.

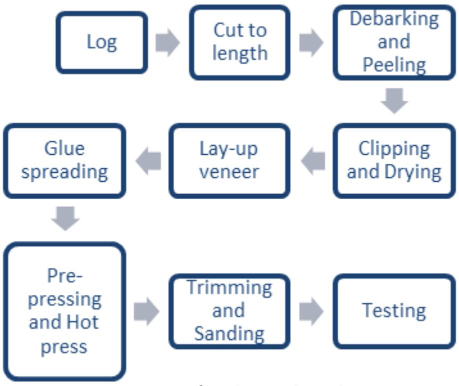

Fig. 1: Process for plywood production

3. Results and Discussion

This section will look into the wood chemical properties and plywood properties. The inter-correlation of the two sets of property will be analysed for impact significance between the plywood performance and the wood chemical content.

3.1. Chemical properties

Chemical analysis of wood is important as the chemical composition in wood used as a raw material in wood composite such as extractive in wood might impart wood characteristic and provide natural durability of wood [3]. Table 1 shows the average percentage of chemical component of Batai (*Paraserianthes falcataria*) and Kelampayan (*Neolamarckia cadamba*) to species and tree portion while Table 2 show analysis of variance (ANOVA) of the effect of species and tree portion and their interaction on the chemical component.

Table 1: Average of Chemical Properties According to Species and Tree Portion

Species	Tree Portion	Cold Water (%)	Hot Water (%)	Alcohol Toluene (%)	Ash (%)	Lignin (%)
Batai (*Paraserianthes falcataria*)	Top	4.08	4.59	2.35	0.92	26.92
	Middle	4.77	4.68	2.44	0.89	28.23
	Bottom	4.61	4.92	3.05	0.94	27.72
	Average	**4.49**	**4.73**	**2.61**	**0.92**	**27.62**
Kelampayan (*Neolamarckia cadamba*)	Top	6.66	7.95	3.60	0.52	32.77
	Middle	7.74	7.53	3.97	0.60	37.82
	Bottom	7.44	8.76	4.23	0.68	30.86
	Average	**7.28**	**8.08**	**3.93**	**0.60**	**33.81**

Table 2 shows analysis of variance (ANOVA) on the effect of species and tree portion. Species and tree portion were found to effect chemical properties significantly. The interaction of species and tree portion show significant difference for alcohol-toluene and ash content and not significant for the others.

Table 2: Analysis of Variance (ANOVA) on Chemical Properties

SOV	Df	Cold Water	Hot Water	Alcohol Toluene	Ash	Lignin
Species	1	436.29**	437.43**	2144.44**	327.24**	25.24**
Tree Portion	2	14.90**	7.63**	189.38**	8.48**	3.57*
Species *Portion	2	0.70ns	3.14ns	14.05**	3.42*	2.27ns

Note: ns= not significant at $p<0.05$, *= significant at $p<0.05$, **= highly significant at $p<0.01$

Cold and hot water soluble are evaluation of water solubles extract such as starch, sugar, tannin and phenolic compound within any lignocellulosic material [4]. Table 3 shows Kelampayan is significantly different for cold and hot water when compared to Batai. For alcohol-toluene solubles, Kelampayan extractives level is significantly higher compared to Batai. Higher percentage of extractive in wood gave more resistant and reinforce of wood structure [5].

Table 3: Summary DMRT on the Effect of Species for Chemical Properties

Species	Cold Water	Hot Water	Alcohol Toluene	Ash	Lignin
Batai (*Paraserianthes falcataria*)	4.48b	4.73b	2.61b	0.91a	27.64b
Kelampayan (*Neolamarckia cadamba*)	7.32a	8.08a	3.93a	0.59b	33.81a

Note: Means with the same letter down the column are not significantly different at $p < 0.05$

Table 4: Correlation Coefficients of Chemical Properties and Species

	Cold Water	Hot Water	Alcohol Toluene	Ash	Lignin
Species	0.92**	0.92**	0.91**	-0.90**	0.53**
Tree Portion	0.18ns	0.13ns	0.38**	0.20ns	-0.05ns

Note: ns= not significant at $p<0.05$, *= significant at $p<0.05$, **= highly significant at $p<0.01$

Ash content for Batai is significantly different compared to Kelampayan. Batai wood might contain more nonflammable inorganic materials such as silica as stated by [6], which attributed presence of high silica content heartwood as ash contributor. Lignin is amorphous phenolic polymer that provides stiffness to the cells walls and bond individual cells in middle lamella region [7]. For lignin content, Kelampayan is highly significantly different compared to Batai. The correlation analysis (Table 4) further revealed that the chemical properties shows a positively correlation with increase of density from Batai to Kelampayan, except for ash content which is shows a negative correlation (r= -0.90**). Meanwhile for effect of tree portion (Table 5) only alcohol toluene content had a significant difference between all tree portion which is further emphasized by Table 4, the positive correlation (r= 0.38**) with highly significant difference to tree portion.

Table 5: Summary DMRT on the Effects of Tree Portion for Chemical Properties

Tree Portion	Cold Water	Hot Water	Alcohol Toluene	Ash	Lignin
Top	5.39b	6.27b	2.97c	0.71b	29.96b
Middle	6.25a	6.10b	3.21b	0.75b	33.01a
Bottom	6.06a	6.84a	3.64a	0.80a	29.22b

Note: Means with the same letter down the column are not significantly different at $p < 0.05$

3.2. Plywood properties

Table 6 shows an average result for plywood tested. The result showed that board with five and seven layers of Batai and Kelampayan passed minimum requirement for general plywood. General plywood used includes house flooring, counter table and other type of furniture. Board with seven layers of Kelampayan passed for decorative structural and structural plywood which is used in sliding door; wall paneling and other structural part include tongue and groove processing.

Table 6: Mechanical Properties of Batai and Kelampayan Plywood

Layer	Spp.	Parallel Grain (0^0)		Perpendicular Grain (90^0)		Density	Shear		Panel Shear
		MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	Kg/cm^3	Bonding MPa	Adhesive Level Type	MPa
5	B	20.38	2453	29.76	2878	339	1.18	1,2	5.45
5	K	40.04	4272	49.46	5362	575	1.40	2	7.07
7	B	25.35	2733	34.18	3867	360	1.43	1,2	5.68
7	K	48.43	5720	60.14	5408	587	2.38	1,2	6.73
JAS For Plywood									
General Plywood		n.a	n.a	n.a	n.a	n.a	0.70	Type 1/2	n.a
Decorative Structural Plywood		n.a	4000	n.a	4000	n.a	0.70	Type 1	n.a
Structural Plywood		22.00	5500	20.00	3500	n.a	0.70	Type 1	3.20

Note: Spp.= Species, B = Batai (*Paraserianthes falcataria*), K = Kelampayan (*Neolamarckia cadamba*), MOR = Modulus of Rupture, MOE = Modulus of Elasticity, n.a = not available

The analysis of variance (ANOVA) on the effect of layer and species are shown in Table 7 and Table 8. Layer were found to significant affect most board properties except for density and panel shear while species shows a significant difference to all mechanical properties. The interaction of layer and species shows significant difference in board properties.

Table 7: Summary of ANOVA on Mechanical Properties for Parallel and Perpendicular Grain

SOV	Df	Parallel Grain (0^0)		Perpendicular Grain (90^0)	
		MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)
Layer	1	83.06**	295.22**	34.53**	118.57**
Species	1	816.26**	2285.63**	315.64**	1792.91**
Layer *Species	1	6.48*	134.84**	5.95*	98.38**

Notes: ns= not significant at p>0.05, * significant at p<0.05, ** highly significant at p<0.01

Table 8: Summary of ANOVA on Mechanical Properties for Density, Bending and Panel Shear

		Density	Bonding Shear	Panel Shear
SOV	Df		MPa	MPa
Layer	1	3.72ns	85.70**	3.55ns
Species	1	17.80**	76.90**	31.32**
Layer *Species	1	37.89**	29.25**	36.52**

Notes: ns= not significant at p>0.05, * significant at p<0.05, ** highly significant at p<0.01

3.3. Effects of layer

Fig. 2 shows effect of five and seven layers of plywood. Results show highly significance difference (Table 7 and Table 8) with increasing of veneer layers from five layers to seven layers. According to [8], the number of layers in plywood is an important factor that gives value in strength properties of plywood. However, result at panel shear show no significant difference between layers. This might be due to five and seven layers having similarity of thickness in which is the main strength for panel shear testing is dependent on the thickness of plywood and density of wood.

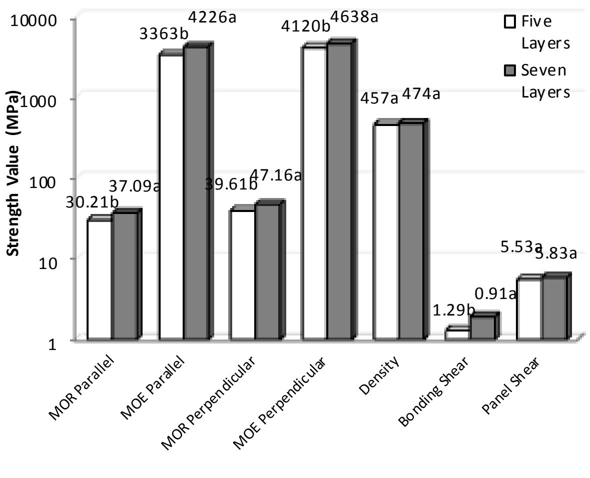

Fig. 2: Effects of layer on board properties

3.4. Effects of species

Fig. 3 shows the effect of species on plywood. Results show significant difference between species on strength of plywood where Kelampayan was higher than Batai as Kelampayan has higher density. Bending strength and panel shear is related to wood density while bonding shear strength depends on veneer surface. The properties of plywood depend on different veneer species, layer replacement and adhesive for bonding veneer [9].

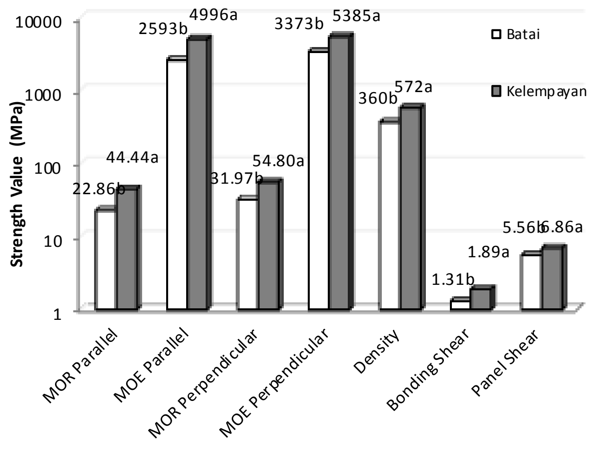

Fig. 3: Effect of Species on board properties

3.5. Inter-correlation of wood chemical and plywood properties

Chemical properties of wood might give a significant effect toward plywood properties. Table 9 further revealed correlation analysis of cold water which show positive correlation with parallel bending (MOR) (r= 0.35*), perpendicular bending (MOE) (r= 0.41*) and panel shear (r= 0.51**). Meanwhile correlation analysis of hot water (r= 0.45**) and alcohol toluene (r= 0.45*) shows a positively correlation with panel shear strength. For ash content, correlation analysis show a negative correlation with perpendicular bending (MOE) (r= -0.50**) and panel shear strength (r= -0.57**).

Table 9: Inter-correlation of Wood Chemical with Plywood Properties

	Parallel (0^0)		Perpendicular (90^0)		Bonding Shear	Panel Shear
	MOR	MOE	MOR	MOE		
Chemical Properties						
Cold Water	0.35*	0.25ns	0.26ns	0.41*	0.14ns	0.51**
Hot Water	0.11ns	0.01ns	0.04ns	0.26ns	-0.11ns	0.45**
Alcohol Tolu-ene	0.28ns	0.17ns	0.21ns	0.40ns	0.04ns	0.45*
Ash	-0.32ns	-.19ns	-0.26ns	-0.50**	0.01ns	-0.57**
Lignin	0.06ns	0.02ns	0.04ns	0.08ns	0.14ns	0.12ns

Note: ns= not significant at p<0.05, *= significant at p<0.05, **= highly significant at p<0.01

4. Conclusion

In conclusion, Batai (*Paraserianthes falcataria*) and Kelampayan (*Neolamarckia cadamba*) are suitable for plywood manufacturing as it passed the JAS standard. This shows that forest plantation species within five years old is suitable to be harvested for raw material purpose. Based on the above plywood properties further study should be done on the other forest plantation species with focus on higher density wood such as Eucalyptus (*Eucalyptus pellita*) and Sentang (*Azadirachta excelsa*).

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