Evaluation on mechanical properties of plywood from two fast growing species: *Neolamarckia cadamba* and *Paraserianthes falcataria*

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Abstract. *Neolamarckia cadamba* (Laran@Kelampayan) and *Paraserianthes falcataria* (Batai) are both fast growing species known to be planted in Malaysia for their high growth rate, therefore made as reforestation species. This study had been done in evaluating the mechanical properties of these species as a new wood material for plywood production as an alternative and discovering used for the depleting supply of big diameter log from virgin forest. The tree samples were harvested from trial plot in UiTM Pahang, Bandar Tun Razak Jengka, Pahang, Malaysia and sent to plywood mills nearby for plywood production. Plywood was composed in five layers and seven layers with 12 mm thickness and used melamine urea formaldehyde (MUF) as their binder based on commercial industry production. Panels were cut and tested according to Japanese Agriculture Standard for plywood (JAS 2014) at Forest Research Institute Malaysia (FRIM), Kepong, Selangor, Malaysia. Based on minimum standard requirement, results show that both species were suitable to be used in plywood production for general use and structural (decorative) purpose. In addition, increased veneer layers were improved the panel strength. This study shows those species had potential to be an alternative wood material for plywood industry in Malaysia thus can reduce independency of wood species from virgin forest.

1. Introduction
In wood-based industry, plywood is one of the wood composite were highly produced for the downstream based commercialization, same goes like solid wood and wood furniture [1, 2]. In 2014, plywood contribute about RM5.2 billion of value price export from total wood-based products value price export from Malaysia, which is as high as RM20 billion per years [3]. But, there are show a highly deacreasing value unit of export for plywood from 2008 (4.62 million m³) to 2014 (3.10 million m³), which is more than 30% of export value was decreased. This happen because of the shortage supply of logs from upstream based due to cycle rotation for tree growth in compartment area.
However, an alternative choices to deal with this by manipulate logs from fast growing species which is suggested to be planted as forest plantation. Therefore, there are eight selected timber species that had been gazette in Malaysia under National Forest Plantation Programme for forest plantation species which is Acacia (Acacia spp.), Rubberwood (Hevea brasiliensis), Binuang (Octomeles sumatrana), Laran@Kelampayan (Neolamarckia cadamba), Batai (Paraserianthes falcataaria), Sentang (Azadirachta excelsa), Jati (Tectona grandis) and Khaya (Khaya ivorensis) [4]. Hopefully, these fast growing timber species which is consists of light and medium hardwood can produce many type of plywood which is used as general plywood, decorative structural, furniture and other else.

2. Materials and Methods
In this study, two species which is Neolamarckia cadamba (370-465kg/m$^3$) and Paraserianthes falcataaria (220-340kg/m$^3$) with diameter around 28-45cm at breast height (DBH) (around 5-10 years old) were selected for plywood making. Tree samples were obtained from trial plot plantation in UiTM Pahang, Bandar Tun Razak Jengka, Pahang, Malaysia. All logs were cut into required length of 1.5 and 2.7m before undergoing for peeling process into veneer and plywood manufacture at mill.

Plywood that produced were cut into 610 x 610mm panels, before it was cut into specific measurement for bending (parallel and perpendicular), panel and bonding shear tests which is according to Japanese Agricultural Standard (JAS) for Plywood [5] which tested at Forest Research Institute Malaysia (FRIM) laboratory, Kepong, Selangor, Malaysia. All specimen tests were carried out using 50kN Shimadzu universal testing machine. The specimen for parallel bending strength was cut into 338mm in parallel and 50mm in perpendicular, meanwhile the cutting size for perpendicular bending strength was vice versa than parallel.

Meanwhile, samples with size of 255mm in parallel and 85mm in perpendicular to the surface panel were cut for panel shear strength test with the length side of samples was holed to place bolt for tightened steel plate with sample to allow samples break in the middle part. While, for bonding shear strength, samples were cut slits with any two bonding layers (except parallel bonding) of samples test. Next, samples were immersed in boiled water for 4 hours, before going to placed in oven with temperature of 60°C for 20 hours and further immersed in boiled water, lastly immersed in distilled water for cooling down. Samples are gripped on both ends of the samples, pulling toward the direction of both ends and continuing loading till the samples reach the break limit.

3. Results and Discussion
Table 1 shows an average result for plywood tested, whereas panel with five and seven layers of Neolamarckia cadamba and Paraserianthes falcataaria passed minimum requirement for general plywood which is 0.70MPa for bonding shear strength Type 2. General plywood was used for counter table, house flooringe and other type of furniture that not include for structural plywood.

Panel with seven layers of Neolamarckia cadamba passed for decorative structural and structural plywood which is required minimum strength for bending strength in parallel and perpendicular and bonding shear with adhesive level Type 1. This type of plywood commonly be part as wall paneling besides as sliding door and other structural part including tongue and groove processing.

### Table 1. Mechanical properties of Neolamarckia cadamba and Paraserianthes falcataaria plywood.

| No. of layer | Species                  | Parallel grain (0°) MOR (MPa) | MOE (MPa) | Perpendicular grain (90°) MOR (MPa) | MOE (MPa) | Density kg/m$^3$ | Shear Bonding Type | Adhesive level | Panel shear MPa |
|--------------|--------------------------|-------------------------------|-----------|-------------------------------------|-----------|------------------|-------------------|-----------------|-----------------|
| 5            | Neolamarckia cadamba     | 40.04                         | 4272      | 49.46                               | 5362      | 575              | 1.40              | 2               | 13.62           |
| 5            | Paraserianthes falcataaria | 20.38                        | 2453      | 29.76                               | 2878      | 339              | 1.18              | 1.2             | 7.89            |
| 7            | Neolamarckia cadamba     | 25.35                         | 2733      | 34.18                               | 3867      | 360              | 1.43              | 1.2             | 11.80           |
| 7            | Paraserianthes falcataaria | 25.35                        | 2733      | 34.18                               | 3867      | 360              | 1.43              | 1.2             | 11.80           |
Table 2 below shows the analysis of variance (ANOVA) on the effect of layer and species for the plywood manufacturing. It shown that layer was found to have significant affect most on panel properties except for density and panel shear, meanwhile species shows a significant difference to all mechanical properties. Combination of the interaction between layer and species shows significant difference for panel properties.

Table 2. ANOVA on Mechanical properties for *Neolamarckia cadamba* and *Paraserianthes falcataria* plywood.

| Variable                  | df | Parallel grain (0°) | Perpendicular grain (90°) | Density (kg/m³) | Bonding shear (MPa) | Panel shear (MPa) |
|---------------------------|----|---------------------|---------------------------|-----------------|---------------------|------------------|
|                           |    | 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

3.1 Layering Factor on Mechanical Properties

Figure 1 shows factor by layering of five and seven layers on plywood production. Results show that highly significance difference (Table 1) existing between both layering for all mechanical properties except for the panel shear test with increasing of veneer layers from five to seven layers shows that higher result for them (Figure 1). Even though, panel shear test shows that seven layers had higher than five layers, but there are no significance difference existing between of them according to ANOVA on Table 1 above.

![Figure 1. Mechanical properties of *Neolamarckia cadamba* and *Paraserianthes falcataria* plywood between layers.](image)

Seven layers’ panel shows a higher result for bending in parallel and perpendicular for MOR and MOE than to five layers’ panel. According to Özen [6], number of layers in plywood production is an important factor that give value in strength properties of plywood. Meanwhile, for bonding shear, seven layers shows higher than five layers with significantly difference. According to Bekhta et al. [7], veneer bonding is an important process that would affect plywood’s physical and mechanical characteristic. But, there are no significant difference existing between layers for panel shear properties and it could happen due to similarity panel thickness by five and seven layers, wheres thickness is the main strength for panel shear testing besides the density of wood. Figure 1 also shows there are no significant different in density for both layer.
3.2 Comparison Plywood Production between Species

Figure 2 shows comparison of mechanical properties between species on plywood production. Results show significant difference between species on strength of plywood, where *Neolamarckia cadamba* plywood has higher strength than *Paraserianthes falcataria*. This might be due to *Neolamarckia cadamba* has higher density than *Paraserianthes falcataria*.

Nordahlia et al. [8] reported that the density of *Neolamarckia cadamba* is 370-465 kg/m³, meanwhile *Paraserianthes falcataria* is 220-430 kg/m³ which classified both species as light hardwood in Malaysia. *Neolamarckia cadamba* panel shows a significant different than *Paraserianthes falcataria* panel on density of plywood. According to Youngquist et al. [9] and Razak et al. [10], wood and panel density have an effect on panel shear and bending strength, while the veneer surface affecting the bonding shear strength. As overall, plywood properties is related on different layer replacement, veneer species and resin application for bonding veneer.

4. Conclusion

As conclusion, *Neolamarckia cadamba* and *Paraserianthes falcataria* species are reasonable in plywood making as it passed the JAS standard, which is *Neolamarckia cadamba* shows better result for mechanical properties compare to *Paraserianthes falcataria*. From that, these fast growing species that suggested by National Forest Plantation Programme for forest plantation are suitable to be harvested within 5-10 years old to be used as raw logs for plywood manufacturing. As suggested, next study can be done on the other forest plantation species with focus on higher density wood such as *Azadirachta excelsa* (Sentang) and *Eucalyptus pellita* (Eucalyptus) regarding on the plywood properties.

Acknowledgement

The authors would like thank to the Universiti Teknologi MARA Pahang, Jengka Campus and Forest Research Institute Malaysia for the facilities in supporting this study.

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