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Rhizophora apiculata: Comparative Properties Between Solid and Engineered Laminated Boards

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Abstract: The study investigated the elucidation properties between the solid wood and engineered laminated boards of matured *Rhizophora apiculata*. Harvested logs segregated into the bottom, middle and top portions and subsequently sawn into wooden planks. The samples for laminated boards were cut into specific thicknesses and bonded with adhesive using pressed clamped. Preparation for testing samples for the solid and laminated boards made following the International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM) standards. Properties such as the moisture content, density, basic density, static bending (MOR and MOE), and compression were determined. The results showed an improvement in properties from the solid to laminated board. The values in density, MOR, and MOE increases in the range of 2-6%, 29-42%, and 13-36%, respectively. However, values in the moisture content, basic density, and compression indicated vice versa trend ranging from 1-2%, 2-6%, and 8-24%, respectively. The bottom portion was more durable and robust compared than other portions.

Keywords: *Rhizophora apiculata*, solid wood, laminated wood, physical and mechanical properties.

INTRODUCTION

Mangrove forests inhabited the coastal and riverine shores of the tropics and sub-tropics [1];[2];[3] and constituted a dominant coastal vegetation community in tropical Asia where Malaysia-Indonesia is the centre of distribution [4]. Seventy species of mangrove plants distributed worldwide and divided into 20 genera [5]. According to [6], *Rhizophora apiculata* is a species of plant in the *Rhizophoraceae* family. The main agroforestry uses from this species are soil stabilization, coastal protection, wildlife/marine habitat for marine fauna and also as timber products which are fuelwood, charcoal, dyes, and traditional medicines [7];[8]. Nowadays, mangrove species can be further enhanced in constructions of dwellings, making furniture, rafts, boats, fences and even as a dying agent from the extracted tannin [9].

Economically the mangroves forests consist of both monetary and non-monetary such as forest industry, fisheries industry, wildlife conservation, tourism and environment protection [3];[10]. The most typical representatives' species in the mangrove forest are the *Rhizophora apiculata*, *Rhizophora mucronata* and *Rhizophora mangle* [11]. The mangrove trees is a complex combination of roots, trunk, branches and leaves [1], the trees can grow up to 30 metres in height with trunk diameters up to 0.5 metres in width, elliptic-shaped leaves stained dark green with simple green in the middle and reddish-brown at the base of the leaves, bisexual flowers, round-shaped fruit up to pearl-shaped and brown, 18-38 cm long and 1-2 cm wide [12]. On properties perception, wood density is a critical characteristic defining the mechanical properties of the wood and its performance with high wood density has been found to decrease vessel implosion by reducing the mechanical stresses associated with the negative pressure in the water column during drought [13]. Greenwood of the mangrove *R. apiculata* trunk possesses higher density than water, but dry mangrove wood with a lower density floats in seawater and resistance to the marine deterioration [1].

Wood and modified wood-based materials have long been used in many applications due to their excellent features in aesthetic appearance, reasonable cost, ease of use, low density, high mechanical strength, etc. [14]. Excellent mechanical properties enable them to be utilized in a broad range of products especially after undergoing modification in the production of layered (laminated) wood with better strength or bending properties [15]. Wood laminating materials are obtained by bonding two or more layers with adhesive and joining the fibre directions of the layers parallel or perpendicular to each other [16]. Laminating is a

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technique that improves the value of the wood material while enabling changes in the wood's properties and can be altered via in various ways which comprise multiple layers of wood, most frequently in the form of veneers (thin slices), glued and pressed together [15]. The established laminated products which are oriented strand board (OSB), laminated veneer board (LVL), Strand-based composites include parallel strand board (PSL), laminated strand board (LSL) and oriented strand board (OSL), and also Glue-laminated timber (GLULAM) [17];[18];[19]. The study was focusing on the strength of physical and mechanical properties via solid wood and laminated wood. The differences properties between portions (bottom, middle, and top) investigated.

MATERIALS AND METHODS

Sample Preparation

The *Rhizophora apiculata* used in this study harvested from a mangrove forest in Inanam, Sabah. The mangrove trees chosen have an average height of 15 m and a diameter of 20 cm at dbh level. The trees cut from the bottom to the first branch (harvesting measurement on 30 cm from ground level). The logs then cross-cut into three (3) portions namely, the bottom, middle and top portions. The bottom portions were cut 50% of the total length of the logs, middle portions 30% and top portions 20%. Subsequently, the samples will be cut to the size required for physical and mechanical testing and provided inappropriate conditions. This study, the samples divided into two groups consisting of solid-wood and laminated wood.

The samples were cut by using a band saw into specific sizes and thickness (as followed standard requirement; for solid wood). For laminated wood, the samples with specific thickness were bonded together to perform as laminated wood. PVC glue branded, Pye Bond used for the process. Samples were conditioning for 48 hours using clamping jig to maintain the position and apply the pressure. The samples were conducted as followed by the International Organization for Standardization, ISO 3131-1975 [20];[21] and the American Standard Testing Method, ASTM D 143 for mechanical testing [22].

The test is conducted according to the standard specification, International Organization for Standardization, Wood-determination of Density of Physical Test, ISO 3131-1975 [20];[21]. The physical tests carried out are moisture content, density and basic density.

Moisture Content

The test is carried out according to the International Organization for Standardization which is ISO/TR 22157 [23];[24], the method that was used to determine the moisture content based on oven-dry weight. In this study, the samples were cut following the indicator of 25 mm x 25 mm x 25 mm with weight approximately 1–8g.

Determination of Density and Basic Density

Density defined as the mass per unit volume, which is moisture content of sample, at 12%. Basic density is defined as the mass per unit volume in oven-dry condition [20];[23]. Samples of size 10 mm x 30mm x 30 mm were taken and oven-dried for 48 hours at 105±2 °C to attain a constant weight. The samples were then weighed to give the oven-dried weight. The green volume, the samples were placed in water under a vacuum of about 700 mm Hg for 24 hours until thoroughly saturated. The volume of the fully saturated samples was then obtained using the water displacement method.

Mechanical Test

The mechanical tests carried out are according to standard specifications, American Standard Testing Method, Standard Test Methods for Mechanical Properties of Wood-based Structural Material, ASTM D 143-2 [25];[26];[27] with modification. Two tests carried out were static bending tests and compression tests in parallel with the grain. The machine used to test the sample is the Universal Testing Machine (UTM). Before the mechanical testing, labelled timber samples will be kept at a standard temperature of 20 ± 2ºC and 65 ± 5% Relative Humidity (RH) or at least in a cold room and uniform temperature.

Statistical Analysis

Results presented as a mean ± standard error. The statistical analyses of experimental findings based on the one-way Analysis of Variance (ANOVA). A significant difference was statistically considered at the level of $P<0.05$. All experiment were triplicated (n=3).

RESULTS AND DISCUSSION

Investigate of Moisture Content

Three (3) types of physical tests conducted on mangrove samples prepared in two groups, which is group 1 (sample in solid-state) and group 2 (sample in double-layer laminate). Physical properties were the moisture content (% MC), density (g/cm^3) and basic density (g/cm^3).

Overall the result for moisture content highlighted bottom sample has an average of 46.83% moisture content and is the highest percentage. The average of moisture content at the middle portion indicated to 44.08%. The lowest percentage of moisture content shown at the top portion with 42.76%. The graph of moisture content in sample group 2 (double-layer laminate conditions) indicated a similar trend. The highest percentages of moisture content highlighted at bottom with 46.22%, followed by the middle and top portion with 43.35% and 42.47%, respectively. The statistical analysis (Table 1) highlighted there are no significant differences between the portions (bottom, middle, and top) to both groups (solid and laminated).

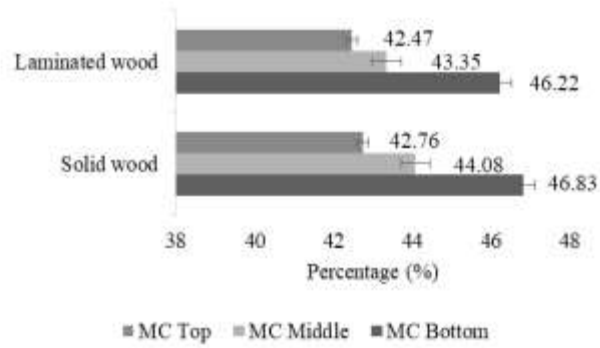

Figure 1: Moisture content for solid wood and laminated wood due to the different portion.

That result influence by different between trees and species or in the same tree. On a single tree, wood core moisture content or parts of each tree may be different. This may be due to the moisture content of the tree is influenced by the age of the tree, species, external factors such as the condition or area of growth of the tree and internal factors such as the structure of the wooden anatomy. Mangrove tree *Rhizophora apiculata* is a kind of tree where the base of the tree is soaked in a state of stagnant water all year round. The base part of the root, including the root is the closest part to the soil and serves to facilitate the absorption of water to other parts of the tree. Based on the results obtained, the bottom of mangrove trees has the highest percentage of moisture content compared to other parts, due to the presence of water around the habitat. Moisture content significantly affects the mass of the wood, its dimensions, volume, physical, and mechanical properties (strength), and its resistance to attacks by fungi, molds, and insects [28].

Differentiation of Density and Basic Density

Figure 2, the result in group 1 (solid) indicated the highest density at a bottom portion with 0.91 g/cm^3 and followed by the middle and top portion with 0.88 g/cm^3 and 0.86 g/cm^3, respectively. While in group 2 (laminated) highlighted that the density which are 0.93 g/cm^3, 0.91 g/cm^3, and 0.83 g/cm^3 for the bottom, middle, and top, respectively. According to Table 1, statistical analysis shows there are not significantly different between the portions at group 1 (solid). There are significant differences between portions at group 2 (laminated) with value $p \leq 0.05$.

Nevertheless, the graph indicated that the trend of basic density in group 1 (solid) decreasing from bottom to the top with 0.80 g/cm^3, 0.76 g/cm^3, and 0.71 g/cm^3. While in group 2 (laminated), highlighted that the highest basic density at the bottom of 0.75 g/cm^3 followed by the middle and top portions with 0.74 g/cm^3 and of 0.68 g/cm^3, respectively. The statistical analysis (Table 1) shows there are significant differences between portion for both groups (solid group and laminated group) with value $p \leq 0.05$.

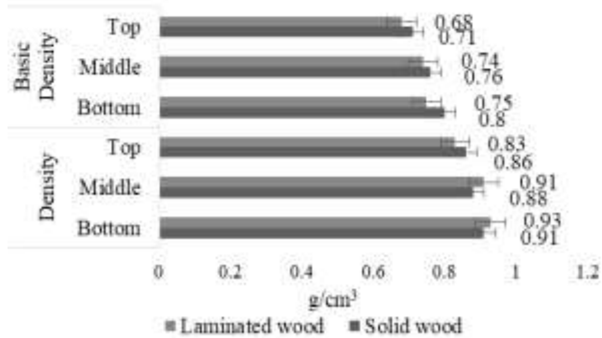

Figure 2: Density and basic density for solid wood and laminated wood due to the different portion

The difference in density of wood in parts is influenced by the structure of the wood anatomy, size and arrangement of cells, length and density of fiber, cell wall thickness and chemical content in the wood [29]. In addition, the moisture content in wood cells can affect the value of wood density, the specific gravity of wood, wood dimensions and other wood strengths. High moisture content increases the density value [30]. Based on the results obtained from the physical properties test, it can be explained that the laminated wood has slightly higher in density compared to the solid wood. The results supported by [14], highlighted that density of the laminated wood materials has more superior values than the solid wood materials which were representing their kinds. The increase is assumed to be due to glue usage and layered structure.

Table 1: Data analysis for physical tests in group 1 (solid) and group 2 (laminated)

Group	Tests Type	Sum of square	Mean square	P-Value	Sig. level
Solid	MC	34.5386	17.2693	0.1448	ns
	Density	0.0057	0.00288	0.1465	ns
	Basic Density	0.0170	0.0085	0.0261	*
Laminated	MC	30.7368	15.3684	0.2981	ns
	Density	0.0229	0.0114	0.0188	*
	Basic Density	0.0110	0.0055	0.0124	*

*** : significant at P < 0.01; * : significant at P < 0.05; ns ; not significant*

Determination of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) on Static Bending Test

The result (Figure 3) in group 1 (solid) indicated that bottom portion has the highest MOR value with 168.20 N/mm^2 and followed by the top and middle portion which is 167.88 N/mm^2 and 165.28 N/mm^2, respectively. Whereas in group 2 (laminated), highlighted the trend of MOR value decreasing from bottom to the top, which are 284.83 N/mm^2, 256.85 N/mm^2 and 237.35 N/mm^2, respectively. There is no significant difference between portions in group 1 (solid) (see Table 2). While highlighted significant difference between portions in group 2 (laminated) with value $p \leq 0.05$.

Figure 3 indicated the MOE in group 1 (solid) has a higher value on the bottom portion with 20330.81 N/mm^2 and followed by the top and middle portion which is 19744.86 N/mm^2 and 18208.88 N/mm^2, respectively. While in group 2 (laminated) highlighted the MOE value in decreasing order from bottom to the top, which is 27553.66 N/mm^2, 24424.42 N/mm^2, and 22664.09 N/mm^2, respectively. Nevertheless, (Table 2) the statistical analysis in group 1 (solid) and group 2 (laminated) highlighted there is no significant difference between a portion ($p \geq 0.05$).

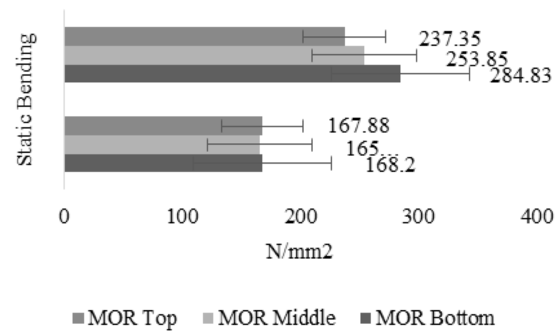

Figure 3: Modulus of rupture for static bending test on solid wood and laminated wood due to the different portion

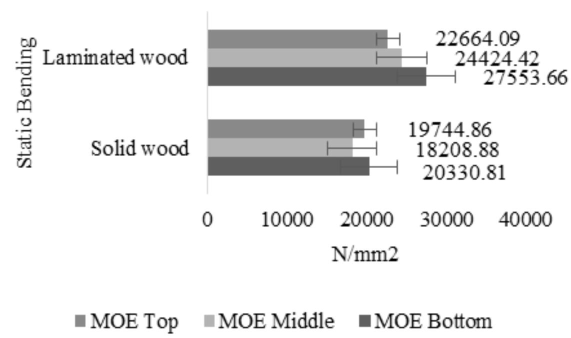

Figure 4: Modulus of elasticity for static bending of solid and laminated wood at a different portion

The factors that influence the evaluation of wood strength is density. The mechanical characteristics or wood strength, such as static wood bending are closely related to the density of the wood [31];[32]. The static flexural strength of the wood will increase by increasing the density from the base to the top. It can be explained that the base portion of mangrove trees *Rhizophora apiculata* has the highest static bending test value also has the highest density value. The strength of wood is also influenced by other factors such as genetics, tree parts, presence of timber knots, wooden anatomy structures, length and density of cells, tree age or species [29];[33].

Table 2: Table 1: Data analysis for static bending tests in group 1 (solid) and group 2 (laminated).

Group	Test	Sum of square	Mean square	P-Value	Sig. level
Solid	MOR	20.5617	10.2808	0.945	ns
	MOE	4.9065	2.45325	0.616	ns
	Compression	65.838	32.919	0.2301	ns
Laminated	MOR	4647.43	2323.72	0.0289	*
	MOE	9.60688	4.80344	0.155	ns
	Compression	472.178	236.089	0.0007	**

*** : significant at P < 0.01; * : significant at P < 0.05; ns ; not significant*

Determination of Compression Test

Figure 5 shows the highest value of compression on group 1 (solid) at a bottom portion with 71.59 N/mm^2 and followed by the top and middle portion with respectively around 68.72 N/mm^2 and 65.86 N/mm^2. While group 2 (laminated) indicated that the compression value decreasing from bottom to the top portion with 65.96 N/mm^2, 64.65 N/mm^2, and 52.05 N/mm^2. The statistical analysis result (Table 2) highlighted that there are no significant differences between portions in group 1 (solid). While group 2 (laminated) indicated that there are significant differences between portions with value p≤0.01.

The higher density as an important factor that influences the results. Mechanical characteristics or wood strength such as wood compression strength are closely related to the density of wood in which the density of wood is an important feature in determining the strength of a tree [32];[34]. The compressive strength of the wood will increase with increasing density from the base to the top. Thus, it can be explained that the *R. apiculata* mangrove root base has the highest compression test value also has the highest density value. However, the strength of wood is also influenced by internal factors such as genetics, tree parts, presence of timber book, wood anatomy structure, length and density of cells, tree age or species and external factors such as growth areas [29].

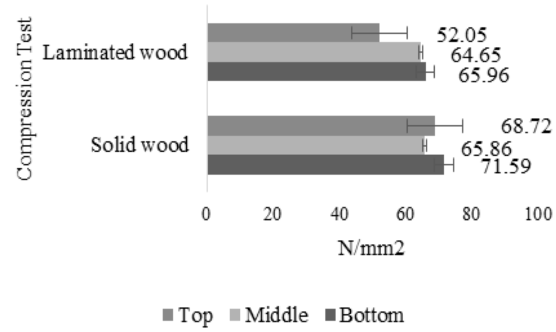

Figure 5: Compression test on solid wood and laminated wood due to the different portion.

CONCLUSION

Results of the study on different properties from matured *Rhizophora apiculata* indicated an improvement in the physical and mechanical properties from solid to the engineered laminated wood.

In the physical properties, the moisture content highlighted that the decreasing order from bottom to the top and from solid wood to the laminated wood in the range 1-2%. Density indicated an increase in values from solid to the laminated wood with a variety of around 2-5% while the basic density shows the vice versa results in a variation of 2-6%.

In the mechanical properties, the static bending highlighted the MOR and MOE value improved the strength from solid to the laminated by the range 29-42% and 13-26%, respectively. The compression strength, however, shows the solid wood are stronger compared than laminated wood with a range of around 8-24%.

The study also found that the bottom portion indicated the highest value in physical and mechanical testing.

The factor that influence of results may be due to the natural morphological in *R. apiculata* with content, high fibre strength and also complex microstructure at the bottom portion.

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