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PHYSICAL AND MECHANICAL PROPERTIES OF JUVENILE WOOD FROM *Neolamarckia cadamba* PLANTED IN WEST MALAYSIA

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ABSTRACT

Juvenile *Neolamarckia cadamba* or kelempayan tree has been harvested from forest plantation and converted into sawn timber. Some basic properties of timber such as physical and mechanical were determined from different parts of the tree namely lower, center and upper. The physical properties were evaluated. The mechanical properties were conducted using small test clear specimens. The results indicated that the physical and mechanical properties of the lower portion of the trunk were significantly superior compared to the upper portion of the trunk. The investigation revealed that the wood be able to use as a substitute material of the furniture components after some modification undertaken on its properties.

Keywords: Density, kelempayan, modulus of elasticity, modulus of rupture, moisture content, shrinkage, swelling.

INTRODUCTION

Kelempayan is one of the fast-growing timber species which has been proposed as a forest plantation crop by the Malaysian government (Ismail *et al*. 1995). It has great potential as a sustainable material for wood based industries. It grows abound in the surrounding countries of Asian. Kelempayan is a lesser-known commercial timber (LKCT) with a broad crown and a straight cylindrical bole (Ismail *et al*. 1995, Lim *et al*. 2005). This tree usually grows in moist areas and near water sources at about 1000 m altitude by streams, rivers and in open sites on deep moist alluvial soil (Choo *et al*. 1999, Lim *et al*. 2005). The properties of 20 yr-old planted kelempayan at five different height levels have been investigated on specific gravity, green moisture content, shrinkage properties, bending properties and anatomical variations (Ismail 1993). These mature wood properties were suggested suitable as general utility timber (Ismail 1993). On the other hand, kelempayan wood is categorized as light hardwood (LHW) with the density of 290 to 465 kg/m^3 (Lim *et al*. 2005) and it is included in the strength group D (Choo *et al*. 1999). In some cases, juvenile wood of 10-15 yr-old softwood that were harvested for commercial uses can be easily differentiated but these were not obviously seen in hardwood (Chauhan *et al*. 2006). The nondestructive techniques can be used to predict modulus of rupture (MOR) and

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modulus of elasticity (MOE) of tropical hardwood such as longitudinal resonance method, flexural resonance method and ultrasound method instead of using the static bending test (Baar *et al.* 2015). However, the MOE in static bending test was related to wood sample orientation on each of its four faces because the choice of face is significant to modulus strength (Icimoto *et al.* 2015). Therefore, basic information on properties of planted juvenile *N. cadamba* wood is necessary in order to study their potential as a substitute material for wood based industry.

Malaysia was the world's exporter of furniture with exports to over 180 countries and major destinations are Japan, United States, India and Taiwan (Malaysian Timber Industrial Board, 2014). In 2013, the investment of furniture sub-sector showed the highest performance with 44% from other sub-sector with the value of RM 259,4 million or equivalent to 41 projects (Malaysian Investment Development Authority 2013). The statistics from export of the major products show that the total export of wooden furniture for January-August 2014 was the highest about RM 4,13 billion or 31% as compared to other forest products (Malaysian Timber Industrial Board 2014). The supply of prime tropical timber for furniture such as merbau, tembusu, chengal, mata ulat, kempas, keruing, nyatoh and others today is very limited compared to past 20 years (Malaysian Timber Industrial Board 2013). This is because many forests have been cleared for development, settlement, agriculture, and farming (Butler 2013). This effort could be done on the kelempayan wood because it was found suitable to be used as furniture components because machining properties is easy for re-saw, cross-cut, planning and also the planed surface produced is smooth (Choo *et al*. 1999). By a modification the properties of juvenile *N. cadamba* wood, it hopes that the strength and durability of the wood could be improved. A study showed that thermal modified of 5, 9 yr-old *Eucalyptus grandis* wood had improved dimensional stability and elasticity properties (Calonego *et al*. 2012). Heat treatment at two different temperatures (160 and 200 °C) of Obeche (*Triplochiton scleroxylon*) wood gave the lower the number of hydroxyl groups and the higher the relative crystallinity index, which would result in improving the dimensional stability and stiffness (Fabiyi and Ogunleye 2015, Korkut and Aytin 2015). Modification treatment by ammonia and steam of beech densified the wood and enhance its modulus of elasticity and hardness properties as compared to the native beech (Pařil *et al*. 2014). Meanwhile, the resin based modification of maritime pine wood (*Pinus pinaster*) was enhanced the behaviour on wet conditions improved up to 60% (Lopes *et al.* 2015). Indeed, wood modification can improve some mechanical properties and turn the wood into engineered structural and non-structural products.

MATERIALS AND METHODS

Sample preparation

Kelempayan [*Neolamarckia cadamba* (Roxb.) Bosser, syn. *Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp., Rubiaceae] trees were obtained from in Research Station of Forest Research Institute Malaysia (FRIM) at Maran, Pahang (Figure 1). The trees were planted in June 2006 in a trial plot plantation with valley area near the streams. Fifteen (15) trees were randomly chosen based on straightness of bole and absence of excessive defects and harvested in April 2013. The estimated trees age was about 7 yr-old therefore it was called juvenile. The characteristics of these trees are summarized in Table 1. In this study only five out of fifteen trees were chosen to determine the basic properties and the remainder are meant for further study. The logs were cut into three billets lower, center and upper parts with length approximately of 180 cm each (Figure 2). Each end billet was cut into small diameter wood disc with thickness was approximately 10 cm for physical experiment purpose. The rest of the billets were ripped into flitches then cut into sticks with cross-sectional dimensions of 30 mm by 30 mm for mechanical testing.

Figure 1. Plantation area of *N. cadamba* at Research Station of Forest Research Institute Malaysia (FRIM) Maran, Pahang.

Figure 2. The logs of 7 yr-old *N. cadamba* cut into the billets.

Table 1. Inventory characteristics on selection of 7 yr-old *N. cadamba* tree in plot area.

Tree No.	Height at first branch (m)	Tree height (m)	Diameter at breast height (dbh, cm)	Circumferece at breast height (cbh, cm)	Description of defects occurring
1	6,80	14,0	22,5	7,5	-
2	7,35	14,3	22,2	7,6	-
3	6,50	10,4	20,5	6,8	-
4	5,60	9,2	19,3	5,5	-
5	5,58	8,0	20,8	6,5	-
6	4,80	10,0	21,7	5,5	Dead knot
7	5,60	9,9	26,5	6,1	-
8	4,33	8,0	19,0	4,7	-
9	6,50	10,1	23,0	6,7	Rot pith
10	9,30	11,2	23,0	8,9	-
11	5,84	13,8	19,1	6,3	-
12	7,61	10,3	21,8	8,4	Heart shake
13	7,94	15,0	27,1	10,5	Rot pith
14	5,44	11,6	26,5	7,6	-
15	7,39	9,7	15,8	6,3	-
Average	6,44	11,03	21,92	6,99	

Physical properties

The wood sequences were evaluated for their physical properties including moisture content, density and changes in dimensional and volumetric. The moisture content was conducted in accordance to MS 837 (2006) and BS EN 13183-1 (2002). The moisture content of juvenile *N.cadamba* wood determined at three difference conditions was green, air dried and oven dried according to lower, center and upper portions of the trunk height. For moisture content test specimens of 25 mm by 25 mm were used and weighed immediately after cutting. The test specimens were dried in an oven at a temperature of 103±2 ºC for 24 h or until constant weight and re-weighed the dried specimens. The moisture content was conducted as in Eq. 1:

$$Moisture\ content : \frac{m_i - m_o}{m_o}\ x\ 100 \qquad (1)$$

where m_i is the initial weight of test specimen (g) and m_o is the oven-dry weight of test specimen (g).

The density was conducted following ISO 3131 (E) (1975). The test specimens for density of 25 mm by 25 mm also obtained from the same wood disc for moisture content determination. The test specimens for density also obtained from same wood disc and cube dimension. Then they were weighed to the accuracy of 0,01 g and measured the sides of cross-section and length along the axes of symmetry to nearest 0,1 mm. Oven dried at 103±2 ºC to constant mass then re-weighed. The dimensions of the test specimens measured again to obtain their oven-dry volumes. The formula to determine the density according to Eq. 2, Eq. 3 and Eq. 4.

$$\rho_w = \frac{W_w}{L_{wB_{w}\ H_w}} = \frac{W_w}{V_w} \qquad (2)$$

where $_w$ is the test pieces at the moisture content, ρ_w is the conventional density, W_w is weight of the test piece at moisture content (g), L_w is length of the test piece at moisture content (mm), B_w is breadth of the test piece at moisture content (mm), H_w is height of the test piece at moisture content (mm) and V_w is volume of the test piece at moisture content (mm³).

$$\rho_o = \frac{W_o}{L_{o B_o H_o}} = \frac{W_o}{V_o} \qquad (3)$$

where $_o$ is the test pieces in the absolutely dry (oven-dry) condition, ρ_o is the oven dry density, W_o is weight of the test piece in the absolutely dry condition (g), L_o is length of the test piece in the absolutely dry condition (mm), B_o is breadth of the test piece in the absolutely dry condition (mm), H_o is height of the test piece in the absolutely dry condition (mm) and V_o is volume of the test piece in the absolutely dry condition (mm³).

$$\rho_b = \frac{W_o}{L_{\max B_{\max} H_{\max}}} = \frac{W_o}{V_o} \qquad (4)$$

where, $_b$ is the test pieces at a moisture content greater than or equal to the fibre saturation point (green volume), ρ_b is the basic density, W_o is weight of the test piece in the absolutely dry condition (g), L_{max} is length of the test piece in the green condition (mm), B_{max} is breadth of the test piece in the green condition (mm), H_{max} is height of the test piece in the green condition (mm) and V_{max} is volume of the test piece in the green condition (mm³).

Dimensional and volumetric changes of the juvenile kelempayan is measured based on air dry condition. The specimens were cut into dimension of 20 mm by 20 mm by 20 mm and marked wood directions according to tangential, radial and longitudinal. This method just to know slight changes occurs when the piece of woods is put in a conditioning desiccator. The shrinking process of the specimen was dried in a desiccator with saturated solution of salts. Meanwhile, for swelling process of the specimen was conditioned inside a desiccator with distilled water. The wood directions of the specimens were recorded at each equilibrium condition using a digital calliper. The formula to determine shrinking and swelling of the specimens are expressed in Eq. 5 and Eq. 6 (Haygreen and Bowyer 1996).

$$Percent\ shrinking = \frac{\text{(decrease in dimension or volume)}}{\text{original dimension or volume}} x\ 100 \qquad (5)$$

$$Percent\ swelling = \frac{\text{(decrease in dimension or volume)}}{\text{original dimension or volume}} x\ 100 \qquad (6)$$

Mechanical properties testing

The mechanical properties evaluated by using small diameter of plantation logs as stipulated in BS 373 (1957). The strength properties evaluated were static bending, compression parallel to grain, compression perpendicular to grain and compression shear parallel to grain. The tests were measured using Instron machine model 5568 with a capacity of 100 kN. The static bending test is carried out by three-point bending method. The dimension of the test specimen was 20 mm by 20 mm by 300 mm. The distance between the points of support of the test specimen was 280 mm and a constant loading speed of 6 mm/mim has been applied throughout the test. Modulus of rupture (MOR) and modulus of elasticity (MOE) are calculated following Eq. 7 and Eq. 8 respectively.

$$MOR = \frac{3}{2}\frac{F}{WT^2} \qquad (7)$$

$$MOE = \frac{L^3}{4WT^3}\frac{\Delta F}{\Delta l} \qquad (8)$$

where F is maximum load (N), L is span length of the test specimen (mm), W is width of the test specimen (mm), T is depth of test specimen (mm) and $\frac{\Delta F}{\Delta l}$ is slope linear portion of the load-deflection graph (N/mm).

The test specimen dimension for compression parallel to grain was 20 mm by 20 mm by 60 mm. The rectangular test specimen was smooth and normal to the axis of force. The top compression platen kept parallel to bottom platen. The test made by loading the specimen between parallel compression platen in the radial direction. The compression shear test was performed by loading the specimen parallel to the grain direction. The load compression curve was plotted to the point when the compression of the test specimen reached 10 mm. The test specimen dimension was 20 mm by 20 mm by 20 mm. A constant loading speed of 0,6 mm/min was applied during the experiment. The compression and shear strength were calculated according to Eq. 9.

$$\text{Compressive stress at maximum load} = \frac{F}{A} \qquad (9)$$

where F is the maximum load (N) and A is cross-sectional area (mm^2).

RESULTS AND DISCUSSION

Physical properties analysis

The physical properties that were determined including moisture content, density, shrinkage and swelling of juvenile *N. cadamba* wood were indicated in Table 2. The mean green moisture content was 80,92% air dried moisture content was 15,31% and oven dried moisture content was 11,43%. The statistical analysis shows that the moisture content at lower portion was significantly higher than the upper portion (Figure 3, left) meanwhile the moisture content at different conditions were significance (Figure 3, right). In comparison, the mature planted kelempayan tree containing higher green moisture content was about 175% as compared to juvenile tree. It also was revealed that the green moisture content of mature planted kelempayan at five different height levels were comparable trend with juvenile tree (Mohd Hamami and Ismail 1992). On the other hand, young planted *Azadirachta excelsa* shows lower initial moisture content that was 49,2% (Trockenbrodt *et al*. 1999). Determination of green moisture content of wood is important as initial information to know directly the weight of the logs and green lumber for the purpose of harvesting design and transportation equipment where it helps a manager in making cost estimation (Shmulsky and Jones 2011).

Table 2. Analysis of variance and mean for physical properties of juvenile *N. cadamba* wood.

Physical Properties	N	Portion			Mean
		Lower	Center	Upper	
Moisture content (%)					HS*
Green	15	87,59 (9,64)	80,01 (5,75)	75,16 (8,70)	80,92 (9,25)
Air dried		15,48 (0,61)	15,39 (0,23)	15,05 (0,43)	15,31 (0,46)
Oven dried		12,22 (1,15)	11,27 (0,25)	10,80 (0,45)	11,43 (0,91)
Density (g/cm³)					HS*
Green	15	0,65 (0,07)	0,63 (0,07)	0,59 (0,07)	0,62 (0,07)
Dry		0,39 (0,04)	0,36 (0,04)	0,34 (0,04)	0,36 (0,04)
Basic		0,36 (0,04)	0,33 (0,03)	0,32 (0,03)	0,34 (0,04)
Shrinkage (%)					HS**
Volumetric	15	0,95 (0,23)	0,67 (0,12)	0,58 (0,31)	0,73 (0,27)
Tangential		0,50 (0,10)	0,41 (0,09)	0,41 (0,23)	0,44 (0,15)
Radial		0,36 (0,11)	0,23 (0,11)	0,22 (0,17)	0,27 (0,14)
Longitudinal		0,09 (0,09)	0,03 (0,04)	0,03 (0,04)	0,05 (0,07)
Swelling (%)					HS*
Volumetric	15	4,50 (0,95)	4,25 (1,02)	3,47 (0,64)	4,07 (0,94)
Tangential		3,27 (0,52)	3,18 (0,74)	2,62 (0,42)	3,02 (0,61)
Radial		1,06 (0,29)	0,97 (0,27)	0,77 (0,27)	0,94 (0,29)
Longitudinal		0,12 (0,16)	0,07 (0,07)	0,06 (0,07)	0,08 (0,10)

Note: Values in parenthesis indicate standard deviation
HS* indicates has significant at alpha ≤ 0,05
HS** indicates has significant at alpha ≤ 0,01
NS indicates not significant

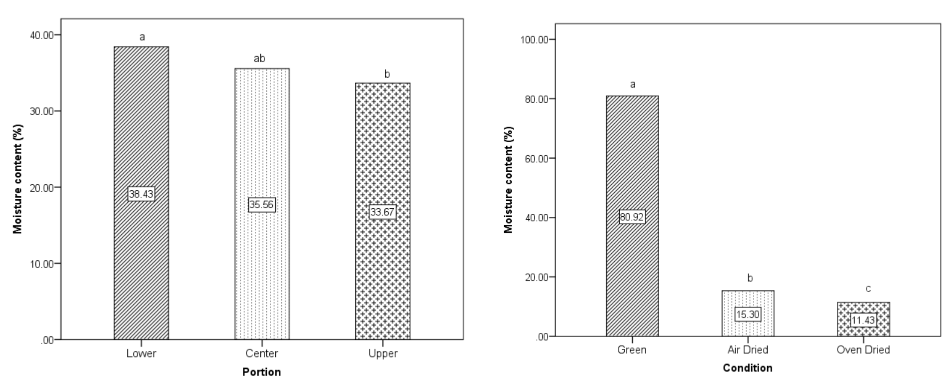

Figure 3. Moisture content of juvenile *N.cadamba* wood at different portions (left) and conditions (right).

The density of juvenile *N. cadamba* wood was significantly decreasing from lower portion to upper portion and the comparison at different conditions showing the wood samples at green density was (0,62 g/cm³) higher than the dry density (0,36 g/cm³) and the basic density (0,34 g/cm³) as indicated in Figure 4. Density of juvenile *N. cadamba* is considered lower (315-360 kg/m³) in comparison to other forest plantation species (Mohd Hamami *et al*. 2008) such as *A. excelsa* was 480-540 kg/m³, *Acacia mangium* was 500-600 kg/m³, *Hevea brasiliensis* was 560-650 kg/m³ and (Trockenbrodt *et al*. 1999) young *A. excelsa was* 480 kg/m³. The increasing of moisture content increases the density of wood (Tsoumis 1991). Based on the results, the moisture content has a direct relationship with the density at which the moisture content of green wood and the density of green wood were higher than they were in dried condition. Meanwhile, the density of wood in a vertical direction is a tendency for reduction from base to top of a tree (Tsoumis 1991). A greater density at the base of a tree is contributed by the formation of heartwood where the proportion of heartwood is higher than the proportion of sapwood. The density at the upper of the tree is lower because influenced by the presence of juvenile wood around the pith in vertical variation.

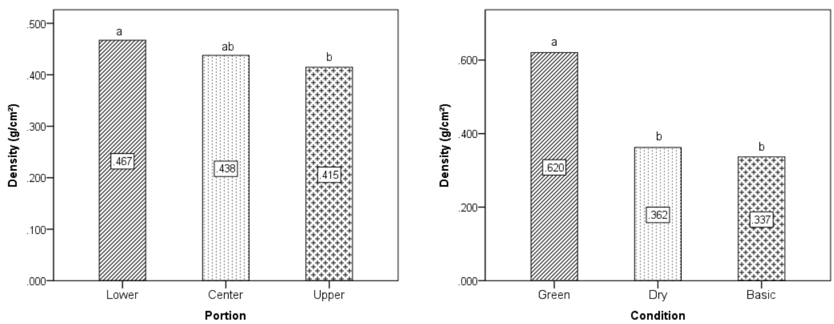

Figure 4. Density of juvenile *N.cadamba* wood at different portions (left) and conditions (right).

The analysis of variance shows that the shrinkage (Figure 5) and swelling (Figure 6) properties were significance at different portions and condition (volumetric and dimensional) changes. The mean changes in shrinkage were volumetric of 0,73% tangential of 0,44% radial of 0,27% and longitudinal of 0,05%. The mean changes in swelling were volumetric of 4,07% tangential of 3,02% radial of 0,94% and longitudinal of 0,08%. In this case the air dried sample was used to evaluate volumetric and dimensional changes in equilibrium humidity therefore the changes are slight. If humidity changes are small, the volumetric and dimensional changes not be noticed and no impact on satisfactory use however the problems can arise when a wood product under humidity and temperature conditions that cycle along periods (Shmulsky and Jones 2011). The shrinkage and swelling properties have been determined according to percentage of volumetric and dimensional directions (tangential, radial and longitudinal) due to moisture content changes. The changes swelling properties are greater than shrinkage properties. This means that if the wood exposed to the high humidity it was easily to absorb the moisture because wood is a hygroscopic material. The moisture entering into the mass of wood is the attraction of water molecules by the hydroxyls of its chemical constituents, mainly cellulose, so that the wood starts to swell (Tsoumis 1991).

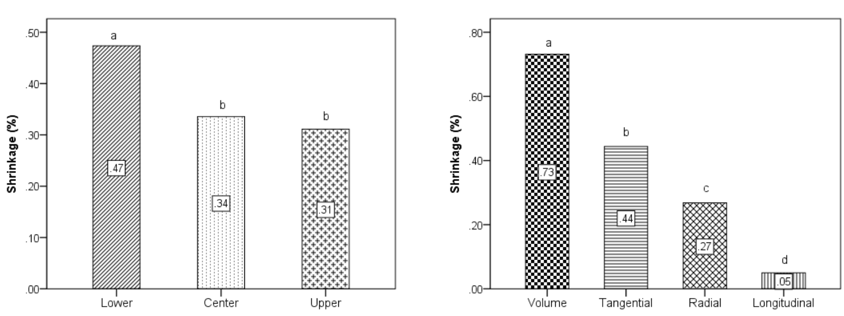

Figure 5. Shrinkage properties of juvenile *N. cadamba* wood at different portions (left) and wood changes according to volumetric and dimensional (right).

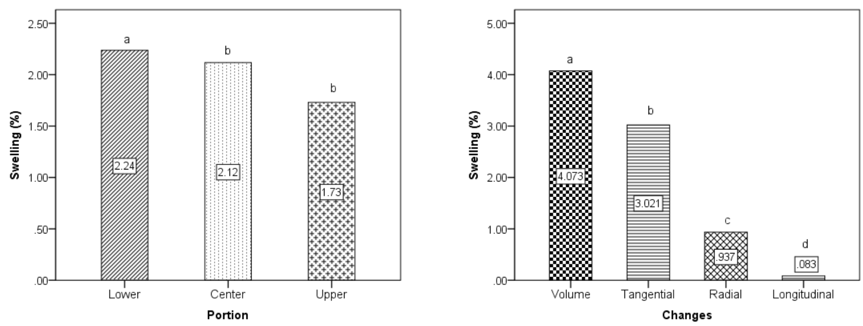

Figure 6. Swelling properties of juvenile *N. cadamba* wood at different portions (left) and wood changes according to volumetric and dimensional (right).

Mechanical properties analysis

The mechanical properties of juvenile *N. cadamba* wood as indicated in Table 3. The oven dried samples show greater mechanical properties compared to air dried samples at lower, center and upper portions. Static bending properties of juvenile *N. cadamba* wood have significance different between portions and conditions. Figure 7 (left) shows the MOR and MOE at lower portion were significantly resistance compared to the upper portion but comparable to center portion. Figure 7 (right) reveals the respective MOR of air dried and oven dried were 44,58 N/mm² and 50,90 N/mm² while the respective MOE of air dried and oven dried were 5,291 N/mm² and 15,292 N/mm². The compression parallel-to-grain (Figure 8) and shear parallel-to grain (Figure 9) also show the similar trend as static bending. The mean compression parallel-to-grain of air dried and oven dried were 26,52 N/mm² and 33,76 N/mm², respectively however, the shear parallel-to-grain indicates lower values respectively for air dried and oven dried were 9,31 N/mm² and 10,65 N/mm². In comparison to the *H. brasiliensis* of 9 yr-old at 15% moisture content (Mohd Hamami *et al*. 2008), it shows that the static bending (MOR was 66 N/mm² and MOE was 9240 N/mm²), compression parallel-to-grain (32 N/mm²) and shear strength (11 N/mm²) are higher than the juvenile *N. cadamba* wood. Moisture content affects the mechanical properties when it changes below the fiber saturation point. When the moisture is reduced, strength is increases in wood and vice versa. The strength of air dried wood is lower in comparison to oven dried wood due to different moisture content were 15% and 11%, respectively. The moisture-strength relationship is important during in service by given equilibrium moisture content of the wood. According to Tsoumis (1991), a 1% change of moisture content changes the strength in parallel compression by 6%, MOR of static bending by 5% and MOE of static bending by 2%. It is assumed that maximum crushing strength in compression parallel-to-grain is approximately tripled in drying from green to oven-dry meanwhile the static bending MOR is more doubled in the process, however the stiffness is increased by only about half (Hoadley 2000). Thus, drying activities varies considerably among wood species and need to be noted that overdrying wood below peak moisture of strength properties can cause detrimental effects (Shmulsky and Jones 2011) and make wood appear brittle.

Table 3. Analysis of variance and mean for mechanical properties of juvenile *N. cadamba* wood at different portions.

Mechanical Properties	N	Portion						Mean	
		Lower		Center		Upper			
		AD	OD	AD	OD	AD	OD	AD	OD
Static bending (N/mm²) MOR (HS**) MOE (HS*)	16	50,23 5978	55,98 16576	43,41 5290	53,36 15641	40,10 4604	43,37 13660	44,5855291	50,90 15292
Compression (N/mm²) Parallel-to-grain (HS**)	16	29,77	37,36	27,40	35,00	22,38	28,94	26,52	33,76
Shear (N/mm²) Parallel-to-grain (HS**)	16	11,26	12,24	8,55	10,45	8,11	9,24	9,31	10,65

Note: AD indicates air dried
OD indicates oven dried
MOR indicates modulus of rupture
MOE indicates modulus of elasticity
HS* indicates has significant at alpha ≤ 0,05
HS** indicates has significant at alpha ≤ 0,01

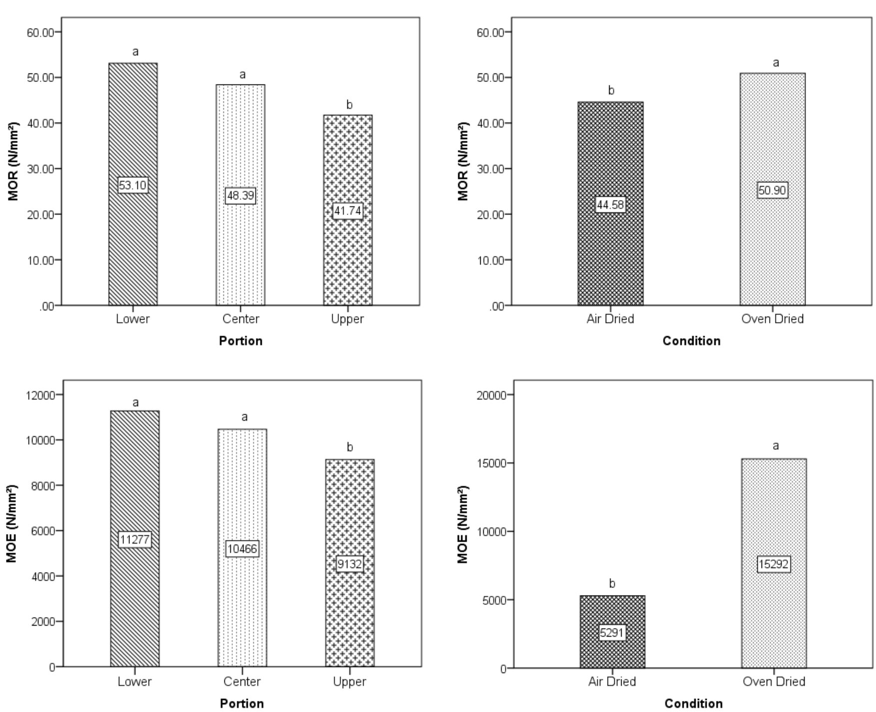

Figure 7. Static bending of juvenile *N. cadamba* wood at different portions (left) and conditions (right).

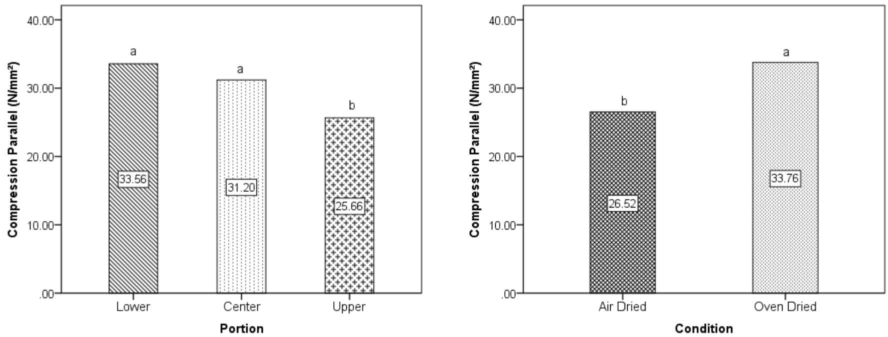

Figure 8. Compression parallel-to-grain of juvenile *N. cadamba* wood at different portions (left) and conditions (right).

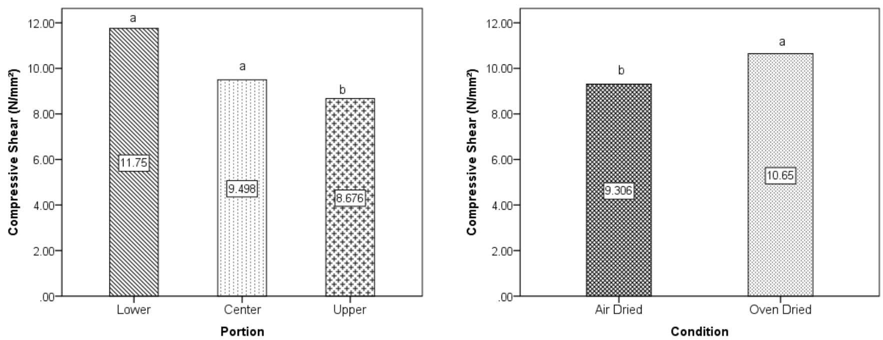

Figure 9. Shear parallel-to-grain of juvenile *N. cadamba* wood at different portions (left) and conditions (right).

CONCLUSIONS

Physical and mechanical properties of juvenile *N. cadamba* wood have been determined for the purposes of timber modification in order to increase the value of a product, especially in terms of strength and durability of the wood. The physical properties of the wood identified were moisture content, density, shrinkage and swelling. The green moisture content of juvenile *N. cadamba* wood is lower as compared to mature kelempayan however the moisture content in dry condition is comparable with others timber species. The density of juvenile *N. cadamba* wood is considered lower to others plantation species due to basic density value was 0,34 g/cm^3. When the wood is low in density it means that the wood contains less water in their cell walls. Moisture content and density affect the shrinkage or swelling because wood is naturally anisotropic. The percentage of dimensional change for shrinkage and swelling is double in tangential direction against radial direction. The relationship between physical properties and trunk portions were significantly difference which the lower portion is greater than upper portion. The mechanical properties of oven dried wood were significantly resistance than air dried wood from the lower portion to the upper portion.

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