# VARIATION IN MECHANICAL PROPERTIES OF TWO RUBBERWOOD CLONES IN RELATION TO PLANTING DENSITY

**HR Naji[1, 2, *], ES Bakar[1], MH Sahri[3], M Soltani[4], H Abdul Hamid[1] & SE Ebadi[1, 4]**

[1]*Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia*
[2]*Department of Forestry, Ilam University, Pajouhesh Blvd, Ilam, Iran*
[3]*Faculty of Science and Natural Resources (Forestry Complexes), Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[4]*Department of Wood and Paper Science and Technology, Islamic Azad University, Chalous Branch, Iran*

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**NAJI HR, BAKAR ES, SAHRI MH, SOLTANI M, ABDUL HAMID H & EBADI SE. 2014. Variation in mechanical properties of two rubberwood clones in relation to planting density.** *Hevea brasiliensis* as a fast-growing species with rotation age of about 25 years is usually managed under intensive silviculture techniques. Normally, it has a high amount of lower quality juvenile wood that needs to be characterised for proper usage. Samples from four planting densities (500, 1000, 1500 and 2000 trees ha$^{-1}$) of two new rubberwood clones [RRIM 2020 (A) and RRIM 2025 (B)] were subjected to selected mechanical tests. Significant differences in modulus of rupture (MOR) and modulus of elasticity (MOE) between planting densities were found except for MOE from clone B. The significant difference in clone B for compression parallel to grain was between the lowest planting density and the rest. In clone A, the significant difference for hardness was between densities of 1000 and 2000 trees ha$^{-1}$ and in clone B between 500 and 1000 trees ha$^{-1}$. Planting density was responsible for significant differences in shear parallel to grain between the lowest and highest planting densities in clone A and between 500 and 1500 trees ha$^{-1}$ in clone B. Wood density moderately correlated with mechanical properties, so the regression equations were established directly with the planting densities. Properties including compression and hardness from clone A and MOE and compression from clone B were not successfully quantified in relation to planting density using a regression approach. Consequently, the mechanical properties in young trees were not highly affected by planting density. There were more visible differences between low and extreme planting densities than with moderate densities. Low planting density emerged as the optimum density.

Keywords: Wood strength properties, plantation density, rubberwood, clonal effects

## INTRODUCTION

Overexploitation of natural forest populations has resulted in greater interest towards genetically improved trees. Growth in these trees is fast and the plantation is usually managed under intensive silviculture techniques to achieve high wood yield in a short-term rotation. Consequently, the competition between trees to obtain sufficient sunlight is increased. Under such conditions, higher proportion of juvenile wood will be formed; hence juvenile wood forms the major portion of the tree stem (Harris 2007). This kind of timber often represents significantly different properties compared with that from natural mature stands. Thus, properties of juvenile wood need to be identified for effective utilisation of this resource (Zobel & van Buijtenen 1989, Tsoumis 1991, Josue 2002, Neimsuwan & Laemsak 2010).

A key property for evaluation of any newly introduced plantation-grown tree is the strength property, i.e. strength and resistance of the material to deformation (Desch & Dinwoodie 1996, Haygreen & Bowyer 1996). Zhou and Smith (1991) noted that mechanical properties of wood were dependent on the growth conditions of trees and the age at which they are harvested. The main tests of mechanical properties are static bending, compression parallel to grain, hardness and shear parallel to grain. These mechanical tests are useful and should be taken into account for efficient use of a timber species when designing load-bearing timber elements (Lathsamy 1998).

Studies to distinguish wood properties of any new rubberwood (*Hevea brasiliensis*) clones are still needed. There is an apparent lack of some

*hrnaji2000@gmail.com

basic information, particularly on the wood mechanical strength of plantation-grown trees. Therefore, this study attempts to quantify the impact of four different planting densities on the mechanical properties of two new clones of rubberwood (RRIM 2020 and RRIM 2025) and determine the optimal planting density. Five different mechanical properties were evaluated, viz bending strength or modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain, hardness and shear parallel to grain.

## MATERIALS AND METHODS

### Clones RRIM 2020 and RRIM 2025

The rubber tree clones RRIM 2020 and RRIM 2025 are Latex Timber Clones (LTC) from RRIM 2000 series. These clones produce high latex yield and have vigorous growth, suitable for timber production. Both clones have one parentage of the same genetic source breed: IAN 873. The next parentage for clone RRIM 2020 is PB 5/51 and for clone RRIM 2025 is RRIM 803 (MRB 2003).

### Study site and sample preparation

The tree samples were obtained from a 9-year-old rubber plantation plot (latitude 5° 45' N and longitude 102° 30' E) in Terengganu, Peninsular Malaysia. The trial area comprising approximately 3 ha of nearly flat topography and less than 1% slope was established in the year 2000. The annual precipitation reported for the previous three years (available records) averaged 3752 mm (Anonymous 2009).

The two new clones, RRIM 2020 (A) and RRIM 2025 (B), each at four planting densities (PDs) of 500 (I), 1000 (II), 1500 (III) and 2000 (IV) trees per hectare (trees $ha^{-1}$) were sampled to simulate growth suppression (Table 1). The sample trees were chosen from the dominant storey, with fairly straight bole, free of any defects and growing on fairly uniform land. Trees growing nearby the roadside, big gaps or leaning trees were avoided. Due to the small size of the experimental plantation, we were not allowed to sample more than two trees in each PD, and hence a total of 16 trees were sampled. However, based on previous research, this sample size was considered adequate (Leal et al. 2003, Githiomi & Kariuki 2010, Uetimane & Ali 2011). After felling the sample trees, their stumps were uprooted to prevent outbreak of any root pest infection in the plantation.

Wood sampling and general requirements for wood density (WD, g $cm^{-3}$) tests were carried out in accordance with ISO standard 3129-1975 (E). The ISO 3131-1975 (E) procedure was used to measure WD. The average values of WD for the two clones at the respective PDs are presented in Table 1.

### Preparation of specimens for strength tests

As depicted in Figure 1, a 1-m bolt from the lower part of each sample tree was cut out. This bolt was considered as the first bolt of a tree with

**Table 1** Basic plantation parameters and number of specimens in each test and in each planting density of *Hevea brasiliensis*

| Clone | Pd (m) | PD (trees $ha^{-1}$) | dbh (cm) | N | WD (g $cm^{-3}$) | FL (μm) | FWT (μm) | VA (%) | RA (%) |
|---|---|---|---|---|---|---|---|---|---|
| A | 4.0 × 5.0 | 500 | 20.22 b | 48 | 0.59 c | 1249 a,b | 4.88 a | 17.76 a | 14.87 a |
| | 4.0 × 2.5 | 1000 | 19.19 a, b | 48 | 0.57 b | 1300 a | 4.78 a | 11.12 c | 15.24 a |
| | 3.0 × 2.2 | 1500 | 17.43 a | 48 | 0.54 a | 1218 b, c | 4.43 b | 12.21 c | 15.13 a |
| | 2.0 × 2.5 | 2000 | 17.54 a | 48 | 0.54 a | 1187 c | 4.41 b | 15.13 b | 13.62 a |
| B | 4.0 × 5.0 | 500 | 19.96 b | 48 | 0.64 b | 1340 a | 4.71 a | 10.40 a | 13.32 a |
| | 4.0 × 2.5 | 1000 | 16.29 a | 48 | 0.54 a | 1279 b | 4.06 b | 10.19 a | 13.42 a |
| | 3.0 × 2.2 | 1500 | 15.27 a | 48 | 0.52 a | 1272 b | 3.99 b | 11.80 a | 13.52 a |
| | 2.0 × 2.5 | 2000 | 15.07 a | 48 | 0.54 a | 1276 b | 3.98 b | 9.70 a | 13.12 a |

Means in each clone followed by the same letter are not significantly different at the $p < 0.05$ as determined by Duncan's mulfiple range test; Pd = planting distance, PD = planting density (trees $ha^{-1}$), dbh = diameter at breast height, N = number of testing specimens in each planting density, WD = wood density, FL = fibre length, FWT = fibre-wall thickness, VA = vessel area, RA = ray area; the anatomical data were taken from Naji et al. (2013, 2014)

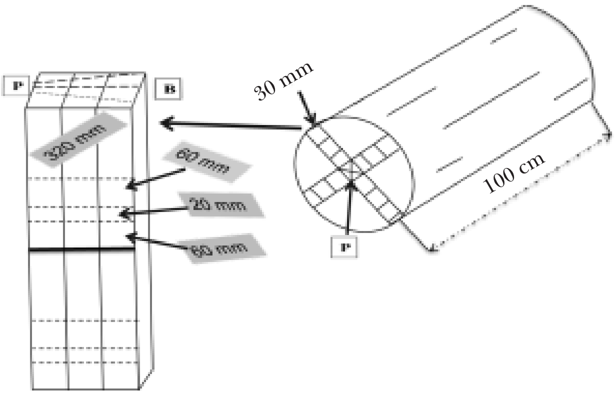


**Figure 1** Schematic diagram of the samples prepared for mechanical property determination; P = pith, B = bark

the highest wood quality compared with other bolts of trees. Wood sampling method and the general requirements for mechanical tests were in accordance with the International Standards Organisation (ISO) provision 3129-1975 (E). The boards were then kiln-dried based on tests using 25-mm thick specimens (Grewal 1988). After drying, intact specimens were cut from the boards in accordance with ISO standards. Then MOR (ISO 3133 1975), MOE (ISO 3349 1975), compression strength parallel to grain (ISO 3787 1976), shear strength parallel to grain (ISO 3347 1976) and hardness perpendicular to grain (ISO 3350 1975) were determined. All selected samples were clear of defects such as cross grains and knots. The specimens were finally room-conditioned at 22 ± 3 °C and 65% relative humidity (RH) in accordance with ISO 554 (1976) to reach the equilibrium moisture content prior to testing. After acclimatisation, mechanical properties of the rubberwood samples were determined. The tests were conducted using a computer-controlled Universal testing machine in a standard testing room (22 ± 3 °C and 65% RH).

## Analysis of data

The variations in wood mechanical properties were analysed using PASW (SPSS®; Statistics Processor, version 18) for Windows. The data were subjected to one-way analysis of variance followed by Duncan's post-hoc test to examine the differences in mechanical properties between PDs of each clone (Duncan's multiple range test, DMRT). The level of confidence for statistical analysis was set at 95% ($p < 0.05$). Independent sample t-test was carried out to detect differences between two identical PDs of clone A and clone B. The normality of collective data was tested by Skewness, followed by Shapiro–Wilk test (Ho 2006). Pearson's correlations were calculated to explore the relationships between the wood properties and PD. Simple linear regression equations were established to predict wood mechanical properties using PD as the predictor variable. The established models were evaluated based on the coefficient of determination ($r^2$) and significance. Guilford's Rule of Thumb (1956) was used to describe the magnitude of correlation ($r < 0.2$: negligible relationship; $r = 0.2–0.4$: low relationship; $r = 0.4–0.7$: moderate relationship; $r = 0.7–0.9$: high relationship; and $r > 0.9$: very high relationship).

# RESULTS

## Intra-clonal variations in mechanical properties

### *Static bending*

The MOR and MOE values for the individual PD of the two clones are presented in Figures 2a and b. When tested for MOR, the specimens exhibited a descending trend from PD I to PD IV with no significant differences between PDs III and IV in clone A. The MOR for clones A and B ranged from 83.10 to 87.18 MPa and from 85.43 to 98.22 MPa respectively. The differences in mean MOR between the high and low PDs corresponding to the two clones were 4.68 and 13.02% respectively. In clone A, significant differences were observed between PDs I and IV, while in clone B, differences were observed between PD I and the others, and between PDs III and IV.

The mean values of MOE for clone A ranged from 8589 to 9239 MPa and tended to decrease with higher PD. Significant differences were observed between PD I and PDs III and IV ($p < 0.05$). However, in clone B, the MOE values were all in a very close range (with an average of 9015 MPa) with no statistically significant difference ($p \geq 0.05$).

### *Compression parallel to grain*

The compression test parallel to grain for the different PDs of the two clones were in close range (Figure 2c). In clone A, the differences were not significant and ranged from 17.39 to 17.69 MPa. In contrast, this was not so in the case of clone B, where highest values were observed in PD I (18.15 MPa) and PD IV (18.48 MPa), and were significantly different from PDs II and III with low values (16.76 MPa).

### *Hardness*

The specimens' performance for hardness from the different PDs in clone A did not differ strongly from low to high PDs. In clone B, significant differences in performance were observed. The average values of hardness decreased from 5.10 to 4.84 KN in clone A and from 5.81 to 4.65 KN in clone B (Figure 2d). Further, the mean levels of hardness in the low PDs of both clones showed magnitudes of 9.19 and 18.59% compared with

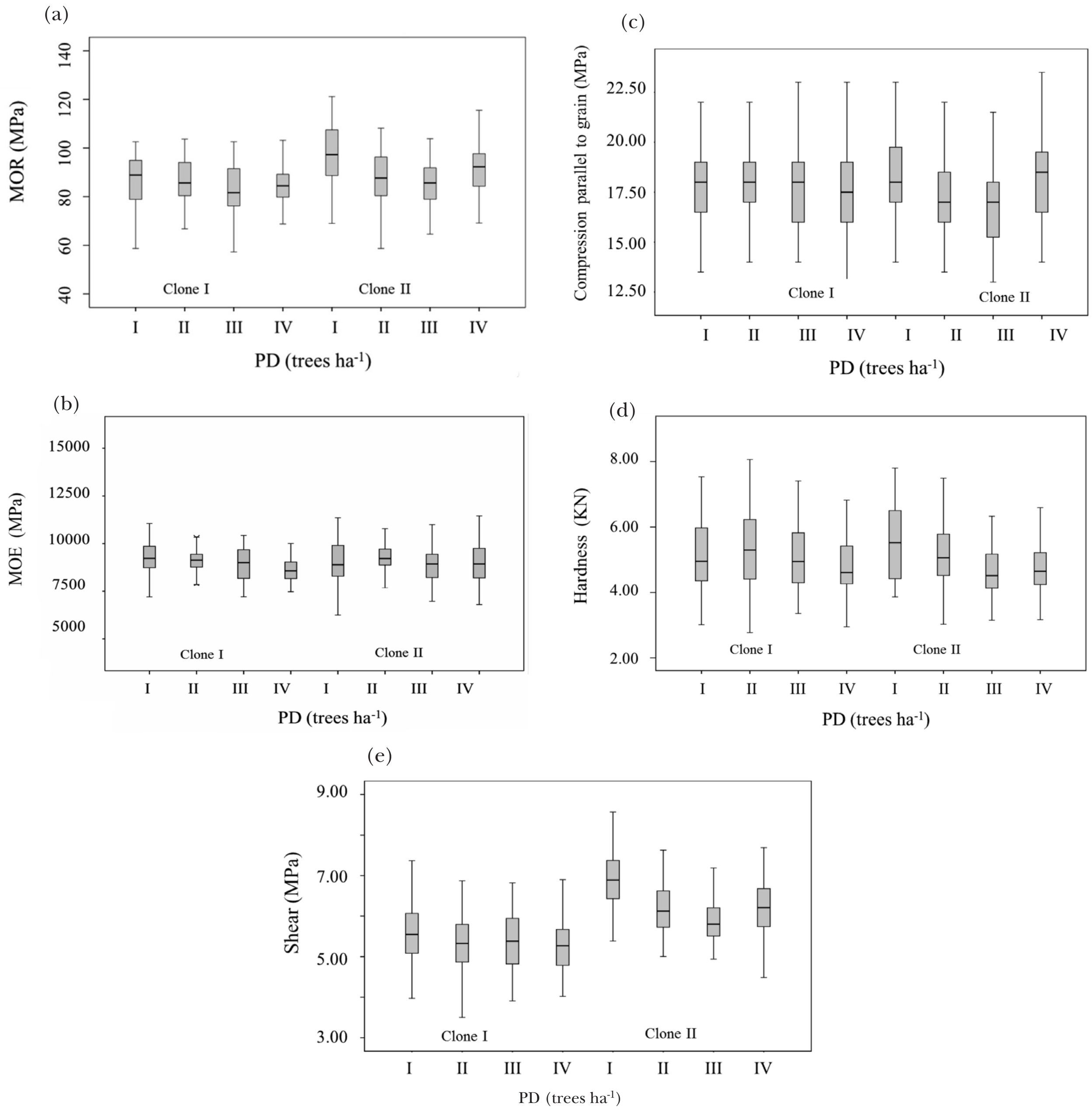


**Figure 2** Box-plots of (a) MOR, (b) MOE, (c) compression, (d) hardness and (e) shear parallel to grain measured at different planting densities of the two clones; a box represents the interquartile range; a line across the box indicates the mean; bars extend from the box to the highest and lowest values; MOR = modulus of rupture; MOE = modulus of elasticity; PD = planting density

the high PDs. In clone A, a significant difference was observed between PDs II and IV, while in clone B, significant differences were observed between PD I and the others as well as between PD II and PDs III and IV.

*Shear parallel to grain*

The mean values of shear strength were in the ranges of 5.55–5.24 and 6.92–5.93 MPa in clone A and clone B respectively (Figure 2e). The decreases in the value from low to high PDs were estimated on the basis of direct comparison of the highest and lowest values of both clones and amounted to 5.78 and 14.31% of mean levels. The shear parallel to grain in clone A had a pronounced significant difference between PDs I and IV, while in clone B significant differences were detected only between PDs I and III.

## Relationships between wood mechanical properties vs wood density and planting density

The correlation between average wood density and planting density in *H. brasi*liensis was examined. Specifically, WD was moderately related to PD. Therefore, based on the magnitudes of WD–PD correlations (r = -0.58 and -0.66), WD in this study was not a reliable parameter to judge variations in wood mechanical properties (Figure 3). Hence,

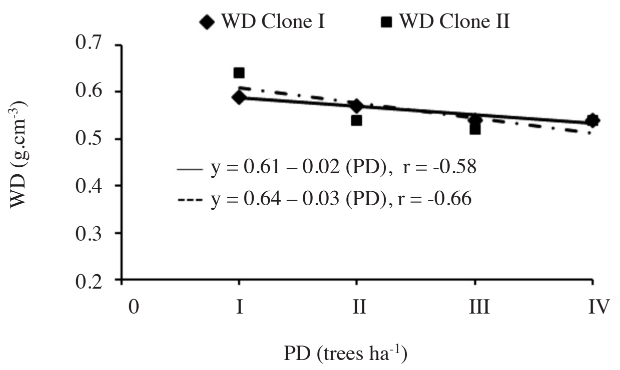


**Figure 3** Correlation between planting density (PD) and wood density (WD) in the two clones

the correlations of the different mechanical properties were determined directly with PD.

Generally, the wood mechanical properties exhibited various degrees of correlation with PD. The average MOR and shear parallel to grain with PD showed a significant and negative correlation in both clones. However, relatively weak correlations between these two variables and PD were observed. The correlation between MOE and PD in clone A was significant with a negative and low strength relationship (r = -0.299). In clone B, MOE was independent of the PD. The compression parallel to grain in both clones was also independent of the PD. Only in clone B, hardness was found significantly and negatively correlated with PD (r = -0.409) with a moderate strength in relationship (Table 2).

**Table 2** Fitted regression equations for wood mechanical properties as a function of planting density

| Clone | Equation label | DV | Slope | Intercept | r | $r^2$ | p |
|---|---|---|---|---|---|---|---|
| A | 1 | MOR | -1.252 (PD) | 88.312 | -0.148 | 0.022 | < 0.05 |
| | 2 | MOE | -223.369 (PD) | 9514 | -0.299 | 0.089 | < 0.05 |
| | 3 | Comp. | NA | – | NS | NS | **0.31** |
| | 4 | Hard. | NA | – | NS | NS | **0.91** |
| | 5 | Shear | -0.091 (PD) | 5.602 | -0.133 | 0.018 | < 0.05 |
| B | 6 | MOR | -2.527 (PD) | 96.727 | -0.227 | 0.051 | < 0.05 |
| | 7 | MOE | NA | – | NS | NS | **0.19** |
| | 8 | Comp. | NA | – | NS | NS | **0.75** |
| | 9 | Hard. | -0.583 (PD) | 6.348 | -0.409 | 0.167 | < 0.05 |
| | 10 | Shear | -0.244 (PD) | 6.923 | -0.351 | 0.123 | < 0.05 |

Only significant relationships are shown ($p < 0.05$); bold type indicates no significant differences at the 0.05 probability level; DV = dependent variables, Comp. = compression parallel to grain, hard. = hardness, shear = shear parallel to grain, NA = not applicable, NS = not significant, PD = planting density

### Empirical modelling of wood mechanical properties in relation to planting density

The relationship between the mechanical properties with the PDs of both clones can be illustrated by simple linear regression analysis. The regression equations for the prediction of mechanical properties as a function of PD are illustrated in Table 2. Unfortunately, a model for compression parallel to grain in both clones, hardness in clone A, and MOE in clone B could not be established ($p \geq 0.05$). Moreover, only a small amount of wood variations were ascribed to PD in the models.

According to the $r^2$ values, only little variation in MOR and shear parallel to the grain from PD I of both clones was accounted for by the effect of PD. Likewise, 8.9% of MOE variation in clone A and 16.7% of hardness variation in clone B were described by PD. Hence, MOE in clone A followed by hardness and shear parallel to grain attributes in clone B were the best explanatory variables for the prediction of mechanical property variations (Table 2).

### Inter-clonal variations in mechanical properties

Independent sample t-test was established to compare the same properties from the two identical PDs of the two clones. The mean MOR values of PDs II and III in clone A were not significantly different from identical PDs in clone B. By comparing the means of the properties, the best performance of MOR in both clones was revealed at PD I of clone B (with a 12.66% increase) compared with PD I of clone A. With respect to MOE, only PD IV was significantly different ($p < 0.05$) and the remainder were found not to have significant differences. In the case of compression parallel to grain, no significant differences were found between the respective PDs I and II. No significant differences were observed for hardness among the identical PDs II and IV. The mean values of shear parallel to grain in all PDs of clone B were significantly higher than the identical PDs from clone B.

## DISCUSSION

No definite study conducted on the effect of PD on rubberwood mechanical properties has been earlier reported. It has been emphasised that wood density is the most effective indicator to predict suitability of wood for many end-product uses and wood strength (Panshin & de Zeeuw 1980, Lim & Fujiwara 1997, Alteyrac et al. 2006, Korkut 2011).

The mean value of MOR from this study was almost the same as that reported for rubberwood while that of MOE was lower (Table 3). Based on the deduction linked to the age of the plantation (MTIB 1982, Gnanaharan & Dhamodaran 1992), this may be related to the more rapid growth; thus with a higher proportion of juvenile wood, the young trees will hardly attain the average wood density and strength of older trees. The results of this study suggest that high PD wood was easier to bend than low PD wood. This phenomenon may

**Table 3** Mechanical properties of some common timber species in comparison with the present study on rubberwood †

| Species | MOR (MPa) | MOE (MPa) | Comp. (MPa) | Hardness (KN) | Shear (MPa) |
|---|---|---|---|---|---|
| *Hevea brasiliensis** | 83.10–98.22 (87.80) | 8589–9239 (8985) | 17.35–18.48 (17.68) | 4.65–5.81 (5.09) | 5.24–6.92 (5.84) |
| *Hevea brasiliensis* (17 years) | 84.27 | 9933 | 38.13 | 7.01 | 17.00 |
| *Azadirachta excelsa* | 83.85 | 6862 | 41.95 | 3.03 | 13.34 |
| *Anthocephalus chinensis* (11 years) | 58.23 | 5518 | 37.00 | 2.60 | 14.72 |
| *Shorea acuminata* | 61.82 | 7622 | 33.50 | NA | 7.49 |
| *Eucalyptus camaldulensis* | 132.00 | 14,800 | 69.90 | 8.51 | 20.00 |
| *Tectona grandis* | 100.00 | 10,190 | 49.50 | 4.86 | 15.00 |

† Adapted from Neimsuwan and Laemsak (2010); * present study on 9-year-old trees (values in parentheses are means); the ages of the trees were as indicated in parentheses; the ages of some species were not available; NA = not available, MOR = modulus of rupture, MOE = modulus of elasticity, Comp. = compression

be clarified by the relationship of MOR and MOE with WD that this parameter is highly influenced by fibre-wall thickness (Zobel & van Buijtenen 1989, Sass & Eckstein 1995) .

The variability of compression parallel to grain did not fully follow the WD pattern. The low compression parallel to grain in this study as compared with the values of MTIB (1982), Gnanaharan and Dhamodaran (1992), and Neimsuwan and Laemsak (2010) was likely related to the age and consequently the WD of the specimens. This conflict may be related to the anatomical property variations, especially in terms of vessel and wood ray characteristics, and the microfibril angle (MFA) (Tsoumis 1991, Neimsuwan & Laemsak 2010). Variation in MFA is one of the most demerit growth features influencing wood mechanical properties. MFA decreases with increasing tree diameter and age (Groom et al. 2002).

Dominant patterns of variation in hardness of *H. brasiliensis* highlights that specimens taken from low PD were harder than those from high PD. This is related to the role of WD to increase hardness as indicated by Uetimane and Ali (2011) with a significant and positive relationship in ntholo, acacia and *Proposis*. This phenomenon may be related to the anatomical properties, especially fibre length as tabulated in Table 1.

Like other mechanical properties, the shear strength parallel to grain kept track of WD changes in PDs. The findings of this study are in agreement with those of Rokeya et al. (2010) on teak and acacia. These findings may be severely affected by anatomical characteristics especially large ray cells (Table 1) or earlywood–latewood variations which are more visible in temperate species.

With reference to Gnanaharan and Dhamodaran (1992) and Teoh et al. (2011), it is generally believed that rubberwood has suitable strength quality for machining and furniture making. This study also provides more evidence to support this fact (Table 3).

In general, the mechanical properties were weakly influenced by PD. The present study clearly demonstrates that PD plays a weak role in causing significant variation in wood mechanical properties. Variations in wood properties within species often arise due to factors such as genetics, growth conditions and ecological factors. In addition, tree age, cell size and orientation, sample size, and the test procedure also affect test results (Haygreen & Bowyer 1996). Since the trees were exposed to similar ecological factors, the variations are largely attributed to inheritance within each PD of the clones rather than the PD.

## Relationships between wood mechanical properties vs wood density and planting density

WD–mechanical properties relationship has been long considered as an important factor in wood science studies (Zhang 1997). Usually, in studies that focus on the effect of PD on wood quality, wood mechanical properties are judged as a function of WD if WD is highly correlated with the PD (Fang et al. 2003, Zhu et al. 2007). Specifically in this work, the correlation analysis exhibited no high degrees of correlation between PD and selected mechanical properties (Table 2). It might be related to the low variation in WD between trees from various PDs (Jiang et al. 2007). Faster growing trees with higher radial growth increment were heavier, and mechanical properties were negatively correlated with high PD which was in agreement with Jiang et al. (2007) in poplar (*Populus xiaohei*). This showed that fast growth rate resulted in higher mechanical properties. Lasserre et al. (2005) has illustrated that declined mechanical properties in trees may be related to the effect of a complex of features. These features can be resulted from the effect of low WD as well as the low values of anatomical properties such as wood fibre architecture, ray cell features and MFA.

## Empirical modelling of wood mechanical properties in relation to planting density

The regression analysis showed that the PD could not describe the variations in compression parallel to grain and hardness in clone A and MOE and compression parallel to grain in clone B. For other variables, very small variations were explained by PD (in total less than 20%). This shows that these models were not satisfactory in describing the relationships of wood mechanical properties with PD. Hardness and shear parallel to grain in clone B were the best explanatory variable (16.7 and 12.3% respectively). Generally, these models did not very well explain the relationship of wood mechanical properties with

PD, specifying that more effective explanatory variables may be combined into these models. As indicated by Nobuchi and Sahri (2008), the effect of tension wood as the usual phenomenon in rubberwood on wood strength is great which may partly lead to the relatively low $r^2$ value of mechanical properties. In general, these models provide an alternative method for prediction of wood strength from PD, since these mechanical properties can be achieved by various non-destructive testing methods.

The analyses largely indicated that PD at the initial age of the trees could not be an important factor in determining wood mechanical properties. Accordingly, some wood mechanical properties may be improved by altering tree growth parameters such as diameter at breast height and tree height. Even though wood characteristics, in general, can be changed by genetic manipulation, environmental conditions also have an important role in defining wood quality (Yang 1994). Therefore, PD can be operated in forest management to change the crown improvement and tree growth parameters by altering the growing conditions of trees that finally lead to enhancing the wood quality produced.

### Inter-clonal variations in mechanical properties

In inter-clonal variations among the two clones, WD can play a significant role among the identical PDs. It was earlier stated that wood with high density is hard to bend (Bowyer et al. 2007, Neimsuwan & Laemsak 2010). Low or no significant differences of MOR among most identical PDs could be related to the absence of visible diversity associated with the WDs (Knowles et al. 2006). None of the two identical PD I in both clones showed better performance with regard to MOE. The narrow range of the flexural properties (MOR and MOE) in the present study may be explained by the lower WD of the specimens and low variations among them. The low variation could be raised from the same age of trees, their same origin, and same growing conditions (FPL 1999). Low and insignificant differences in compressive strength parallel to grain among identical PDs of both clones could be related to the narrow range of wood ray area (13.12–15.24%) as shown in Table 1. For hardness, dominant variation was indicated between the identical PD I of both clones. This highlights the effect of WD as in clone B WD was higher than that in clone A. Therefore, the variation of hardness among the different PDs of *H. brasiliensis* of the different clones was mostly seen between the PD I of both clones. This shows that specimens taken from clone B were harder than those in clone A. This is more obvious by the significant difference in WD between the PD I of both clones.

In shear parallel to grain, although it has been documented that wood density is a good indicator of mechanical properties, the effects of some anatomical properties may make remarkable differences. More specifically, strength is usually determined by the abundance and length of cells (with focus on fibres and parenchyma cells) and the arrangement of the cells (vessels) (Tsoumis 1991, Neimsuwan & Laemsak 2010). Therefore, different PDs, while producing wood with the same or a very narrow range of WD, can appear as differences in some anatomical properties (Table 1).

On the whole, most of the anatomical and physical properties discussed earlier are fundamental to the performance of a piece of wood and are implied, in the main, by differences at the cellular level. To sum up, silvicultural interventions that can alter some of these cellular properties may change the structural features of the timber.

## CONCLUSIONS

From the results of the present study on the two rubberwood clones, it can be concluded that the selected mechanical properties showed different levels of significance between the PDs in each clone. The variations of mechanical properties mostly follow the WD. Therefore, juvenile wood in low PD can be said to be relatively strong and stiff. Average WD was not strongly correlated with PD. Hence WD could not be considered as a reliable predictor of mechanical properties. These results combined with the anatomical properties suggest that there is a possibility to increase tree growth, WD and at the same time, some mechanical characteristics of juvenile wood in rubber tree. Based on the strength values of the rubberwood in this study, PD 500 trees ha$^{-1}$ of clone B clearly resulted in the best performance.

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