Investigation of the Relationship Between Densities Versus Mechanical Properties of Sri Lankan Timber Species

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Abstract The aim of this study was to investigate the relationships among wood density, modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain (CNP) and compression perpendicular to grain (CPG) in 32 timber species grown in Sri Lanka. Defects free stem section from each timber was taken at the breast height and samples were prepared according to BS 373: 1957 standard. The tests for mechanical properties were performed through the Universal Testing Machine (UTM 100 PC). Linear Regression Analysis was done for interpreting the effectiveness of the relationship in wood density with other mechanical properties (MOR, MOE, CPG, CNG). The relationship between wood density and mechanical strength properties were analyzed by regression models. Wood density showed strong positive relationship with CPG and MOR. Results in the regression test revealed a significant relationship ($P = 0.001$) among wood density and other mechanical properties such as MOR, MOE, CNP and CPG. These results can be used for developing effective timber classification system in Sri Lanka.

Keywords Density · Mechanical properties · Timber classification

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1 Introduction

Wood is considered to be an excellent material for furniture, interior decorations and construction purposes. Density is very important physical character for consideration in selecting wood for numerous uses, such as furniture manufacturing, construction of frame, bridge, building structures, sporting goods, measuring instruments, musical instruments and decorative surfaces etc. The density of a material is the mass per unit volume at some specified condition. For a hydroscopic material such as wood, density depends on two factors: the weight of the wood structure and moisture retained in the wood.

Density is the single most important indicator of strength in wood and may therefore predict such characteristics as hardness, ease of machining and nailing resistance [1].

Wood has a relatively high strength in relation to its density when compared with other materials used in construction. The strength properties of wood depend upon its density and structure, which assist us in selecting a suitable type of wood for a particular use [2].

Mechanical properties of wood indicate the ability of wood to resist various types of external forces, static or dynamic, which may act on it. Mechanical properties are particularly considered when timber is used for constructional and structural purposes. These properties not only vary with species, with reference to the nature of their fibre structure but also with the moisture content, temperature and defects of wood. Quantitative characteristics of wood and its behaviour to external influences other than applied forces depend on mechanical properties. These properties are important because they can significantly influence the performance and strength of wood used in structural applications [3].

Mechanical property values are given in terms of stress (force per unit area) and strain (deformation resulting from the applied stress) [4].

The strength of a timber depends on its species and the effects of certain growth characteristics [5]. Different wood species have different strength characteristics, and also within a species these characteristics may also vary. Therefore, in practice, a classification system of strength classes is used. There is no proper timber classification system applicable for timber industry in Sri Lanka, the present study focused on developing a classification system for selected 32 timber species based on their strength properties. In this study, the relationships among wood densities and mechanical properties of 32 timber species grown in Sri Lanka have been evaluated.

Table 1 Selected timber species

Common name	Scientific name	Common name	Scientific name
1. Albizia	*Albizia molucana*	17. Mango‘	*Mangifera indica*
2. Cypress	*Cypressus macrocarpa*	18. Margosa	*Azadirachta indica*
3. Ebony	*Diospyros ebenum*	19. Mi	*Modhuca longifolia*
4. Ehela	*Cassia fistula*	20. Micro	*Eucalyptus microcorys*
5. Ginisapu	*Michelia champaca*	21. Milla	*Vitex pinnata*
6. Grandis	*Eucalyptus grandis*	22. Na	*Mesua ferrea*
7. Halmilla	*Berrya cordifolia*	23. Nedun	*Pericopsis mooniana*
8. Havarinuga	*Alstonia macrophylla*	24. Palu	*Manilkara hexandra*
9. Hora	*Dipterocarpus zeylanicus*	25. Paramara	*Samanea saman*
10. Jack	*Artocarpus heterophyllus*	26. Pine	*Pinus caribaea*
11. Khaya	*Khaya senegalensis*	27. Robusta	*Eucaliptus robusta*
12. Kolon	*Adina cordifolia*	28. Rubber	*Hevea brasiliensis*
13. Kumbuk	*Terminalia arjuna*	29. Satin	*Chloroxylon swietenia*
14. Lunumidella	*Melia dubia*	30. Suriyamara	*Albizia odoratissima*
15. Madan	*Syzygium cumini*	31. Teak	*Tectona grandis*
16. Mahogany	*Swietenia macrophylla*	32. Welang	*Pterospermum suberifolium*

2 Materials and Methods

2.1 Wood Samples

The study was conducted with 32 timber species available in Sri Lanka. Trees of 30–40 years-old with straight trunks, normal branching and no disease or pest symptoms were selected and felled. Stem section from each tree was taken at the breast height (Table 1).

2.2 Sample Preparation

The wood species were machined and trimmed to standard size of 20 mm × 20 mm × 60 mm for determination of density, 20 mm × 20 mm × 300 mm for bending tests, 20 mm × 20 mm × 60 mm for compression parallel to grain tests and 50 mm × 50mm × 50 mm for compression perpendicular to grain tests. The samples were replicated five times [6].

2.3 Determination of Density

To avoid the effect of the weight of water in the wood, use oven-dry weight for standard measurements of density. The samples were dried in an oven at 100 ± 2 °C for 24 h. The samples were then removed and transferred to a desiccators and allowed to reach equilibrium temperature in the laboratory before the oven-dry weight was obtained. This procedure was repeated until a substantially constant weight was obtained. Equation 1 was used to determine the density based on the oven-dry weight and water displacement method was used in determining the density.

$$\text{Density} = \frac{\text{Weight of oven dried wood (kg)}}{\text{Volume of wood}\left(\text{m}^3\right)} \tag{1}$$

2.4 Mechanical Tests

Mechanical tests conducted on the wood species included modulus of rupture and modulus of elasticity (MOR and MOE). The tests were performed on a Universal Testing Machine (UTM) at the wood laboratory of State Timber Corporation, Battaramulla, Sri Lanka.

MOR and MOE were calculated using the Eq. 2 and 3 as stated below.

The load was applied at a constant speed of 2 mm/s at UTM.

$$MOR = \frac{3\text{PL}}{2\text{bd}^2} \tag{2}$$

where:

MOR = Modulus of rupture
P = Maximum Load (N)
L = Length of sample (mm)
b = width of the sample (mm)
h = thickness of the sample (mm)

$$MOE = \frac{\text{PL}^3}{4\text{bd}^3\Delta} \tag{3}$$

where:

P = Maximum load at proportionate stage (N)
L = Length of sample (mm)
b = Width of the sample (mm)

d = Thickness of the sample (mm)
$\triangle$ = Slope of the graph

Compression parallel to grain and Compression perpendicular to grain values were calculated using the following Eq. (4).

The load was applied at a constant speed of 0.5 mm/s at UTM.

$$\begin{array}{l}\text{Serviceability compressive}\\ \text{strengthof the specimen}\end{array} = \frac{\text{Maximum Load at Serviceability state}}{\text{Load acting area}} \quad (4)$$

3 Results and Discussions

Variations in wood densities and mechanical properties are given in Table 2.

Variations in wood density and mechanical properties have also been reported by several researchers [7, 8, 9]. As the data were normally distributed, the Pearson correlation test was done and positive correlations among densities with other variables were evident at the results. To find out the relationship between density with other mechanical properties, Linear regression test was done.

Following scatter plots show the relationship between density (kg/m^3) and mechanical strength (N/mm^2) properties of 32 timber species grown in Sri Lankan conditions (Figs. 1, 2, 3 and 4).

Among other predictors, CPG showed the highest value of R^2value (0.576), indicating the best goodness of fit for the density. The effectiveness order of other predictors for the dependent variable of density is CPG > MOR > CNG > MOE as indicated in the scatter plots (See Figs. 1–4).

As shown by Table 3, results show a significant relationship ($p = 0.000$) between dependant variable of density with the independent variables of other mechanical properties.

Table 4 represents the correlation between density with other mechanical properties and the strength relationship among mechanical properties. Strong correlations (0.745 and 0.759 respectively for density with MOR and density with CPG were observed. While other two variables (MOE and CNG) showed moderate correlations (0.609 and 0.646 respectively) with wood density.

Multicolliniarity relationships among the independent variables were not evident as indicated with low VIF values (less than 5)and high Tolerance values (higher than 0.25) of the regression test.

Table 2 Density values (kg/m^3) and mechanical strengths (N/mm^2)of timber species

Timber species	Density	Com. Para. to grain	Com. Per. to grain	MOE	MOR
Albizia	525	10.433	3.504	1939.81	17.360
Cypress	502	24.918	3.408	4491.91	53.133
Ebony	1120	52.902	20.970	8676.39	136.050
Ehela	960	37.639	12.657	9928.79	107.960
Ginisapu	570	28.305	9.003	5336.39	65.723
Grandis	570	47.225	4.920	8026.14	68.482
Halmilla	796	43.841	8.775	8141.7	91.140
Havarinuga	651	40.058	8.528	9836.82	84.564
Hora	806	44.361	15.463	13603.9	83.033
Jack	645	42.750	14.480	5872.66	63.927
Kaya	600	37.092	11.775	8879.29	81.501
Kolon	708	34.125	6.167	6196.25	66.455
Kumbuk	756	34.562	8.743	5719.41	60.585
Lunumidella	400	16.708	3.797	4206.02	25.608
Madan	720	23.718	9.620	5211.13	48.870
Mahogany	570	29.875	8.560	6140.01	66.221
Mango	600	28.964	10.101	5033.35	55.923
Margosa	733	48.000	12.255	7438.61	76.755
Mi	973	37.063	10.247	5810.99	64.165
Micro	910	62.478	11.469	14919.8	127.34
Milla	892	51.241	16.973	6736.23	74.760
Na	1087	56.368	10.685	12175.2	140.654
Nedun	795	34.216	12.753	8715.65	111.880
Palu	1100	53.095	17.213	11349.9	82.719
Paramara	650	29.936	4.992	3974.98	38.419
Pinus	465	48.500	4.108	6910.6	69.864
Robusta	775	38.221	7.363	9723.76	98.847
Rubber	680	29.596	5.711	7911.07	75.785
Satin	980	45.187	16.000	11489.6	142.660
Suriyamara	840	43.742	11.950	5454.79	102.795
Teak	720	49.312	10.080	8478.26	90.766
Welan	640	26.490	7.313	5760.22	59.880

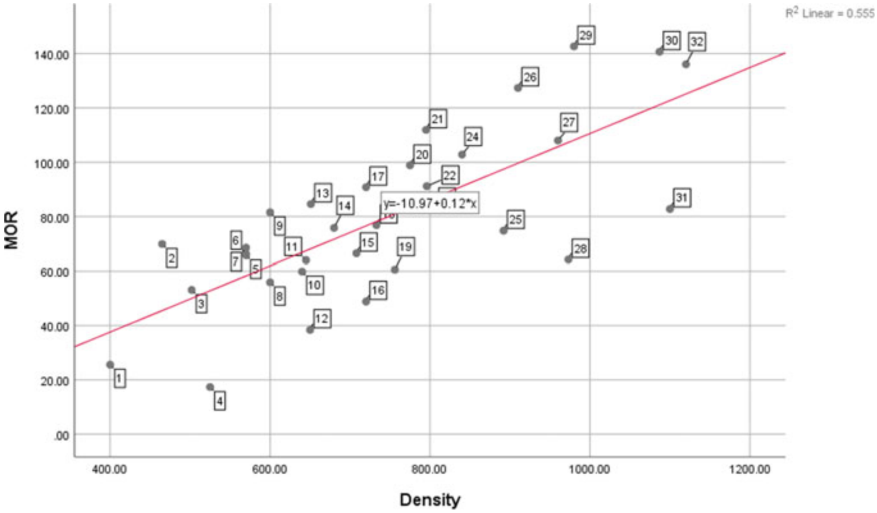

Fig. 1 The relationship between wood density (kg/m^3) versus modulus of rupture (MOR) (N/mm^2)

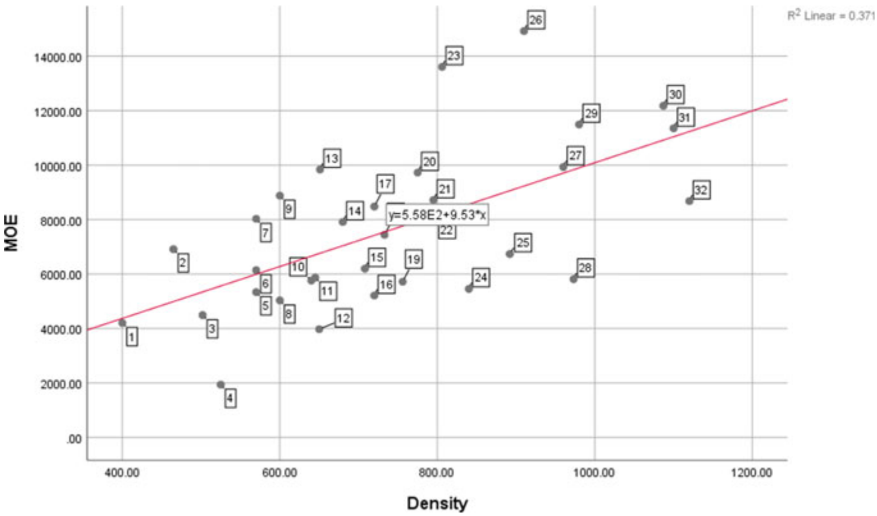

Fig. 2 The relationship between wood and density (kg/m^3) and modulus of elasticity (MOE) (N/mm^2)

4 Conclusion

Inadequate length of sawn timber material is also reported to be a limiting factor for fully utilization of timbers. Finger joint, a method which connects two small pieces of timber together is identified as a sound technique to minimize the wastage. As

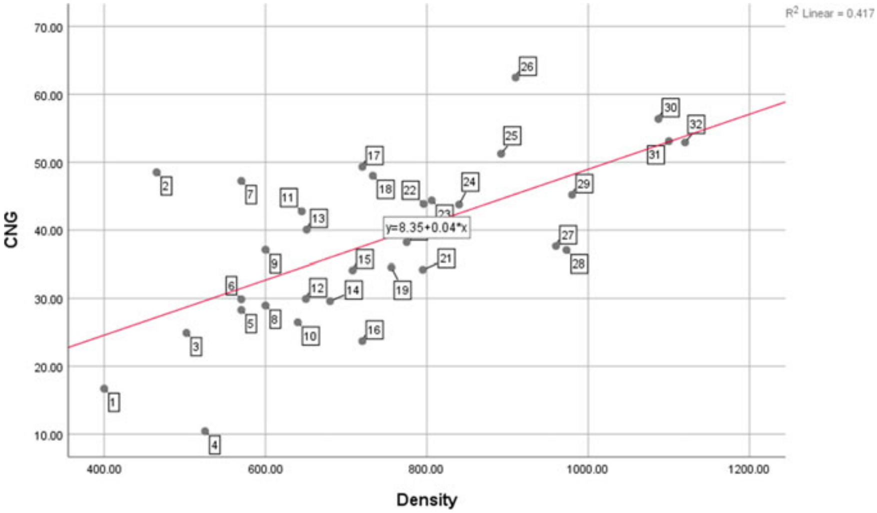

Fig. 3 The relationship between wood density (kg/m^3) versus compression parallel to grain (CNG) (N/mm^2)

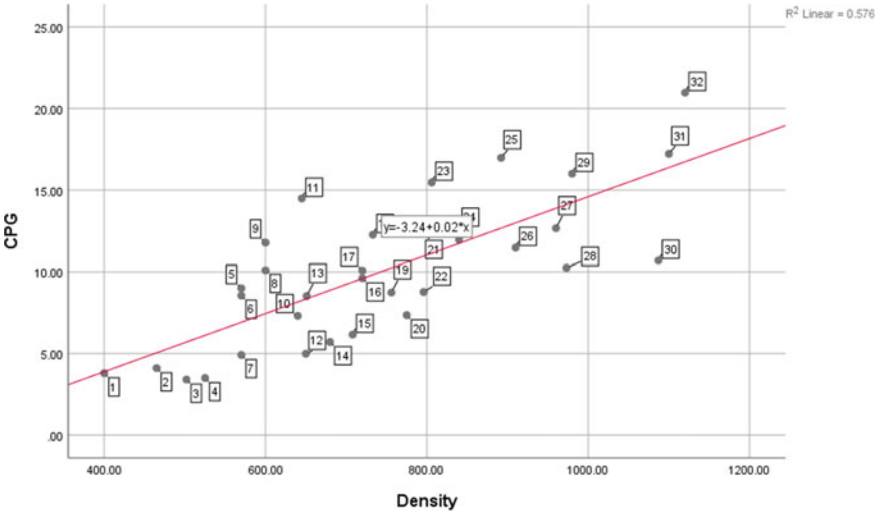

Fig. 4 The relationship between wood density (kg/m^3) versus compression perpendicular to grain (CPG) (N/mm^2)

there is no timber classification system applicable for finger joint technique in Sri Lanka. In the present research study is focused to evaluation the relationship between wood density and mechanical properties of 32 wood species. These results can be used for developing effective timber classification system in Sri Lanka.

The following conclusions were drawn from the study:

Table 3 ANOVA test results in linear regression

Model		Sum of squares	df	Mean square	F	Sig
1	Regression	761305.973	4	190326.493	15.677	0.000[b]
	Residual	327798.246	27	12140.676		
	Total	1089104.219	31			

b indicates significant

Table 4 Relationship between density versus mechanical properties

Model		95.0% Confidence interval for B		Correlations			Collinearity statistics
		Lower bound	Upper bound	zero-order	Partial	Part	Tolerance
1	(Constant)	167.868	447.025				
	MOR	0.049	4.975	0.745	0.374	0.221	0.291
	MOE	−0.024	0.024	0.609	−0.002	−0.001	0.322
	CNG	−4.823	6.760	0.646	0.066	0.036	0.354
	CPG	7.713	32.127	0.759	0.542	0.354	0.570

- The mechanical properties (MOR, MOE & CPG, CNG)showed positive relationship with the wood density.
- CPG showed the highest value for R^2 (coefficient determination) of 0.576 expressing the best goodness of fit for the density.
- The order of independent variables of CPG > MOR > CNG > MOE showed the goodness of fit to the model which could predict the effectiveness of the dependent variable of density.
- MOR and CPG showed strong correlation with density with the value of 0.746 and 0.759 respectively while other two variables showed moderate correlation as 0.609 and 0.646 for MOE and CNG respectively.
- Significant relationship ($P = 0.001$) between wood densities, and mechanical properties of CPG, MOR, CNP and MOE was recorded.
- Independent variables didn't show the multicollinearity relationship. Therefore, the relationship between mechanical properties and density can be used for the developing of an effective timber classification system in Sri Lanka.

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