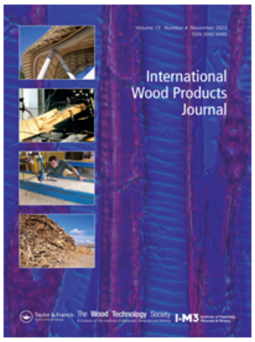


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# Strength index-based timber classification of Sri Lankan timbers and potential for finger-joint production from wood off-cuts

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**ABSTRACT**

Shorter sections of sawn timber material resulted from timber industry are considered to be wastes; thus regularly dumped by sawmills. Finger-joint, a method which connects two small pieces of timber together is recognized as a sound technique to minimize the wastage. In this process, sections of different timber species are bonded together for making finger-joint boards. In this connection, selection of the best possible combination of timber species is vital as the success largely depends on the mechanical properties of the pieces. In this study, commonly used 32 timber species were employed to develop a timber classification system based on strength properties of timber species. Cluster analysis was used in grouping the species with similar strength properties. Accordingly, timber species were grouped into five strength classes as very low, low, medium, high and very high. A significant correlation ($P = 0.000$) between the strength index and timber density was also observed.

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**KEYWORDS**
Timber classification; universal testing machine; strength index; workability; finger-joint

## Introduction

Timber is considered to be a scare resource; thus any wastage of timber is a matter of great concern (Muthumala et al. 2020). Shorter sections of sawn timber material and wood off-cuts are common problems associated with timber industry in Sri Lanka where a considerable amount of timber waste is regularly dumped by sawmills. However, a certain fraction of waste is used effectively in fuel kiln-dried boilers (Muthumala et al. 2018). The preparation of finger-joint boards combining shorter sections of timber is another alternative use of timber wastes (Figure 1).

Finger-joints are described as interlocking end joints which are formed by machining a number of similar tapered symmetrical fingers using a finger-joint cutter and then bonded together (Institution 2014). Finger-joint is therefore recognized to be an eco-friendly and economically valuable technique in the furniture industry. It ensures the sustainable utilization of small wood cut pieces which are usually considered as waste (Sandika et al. 2017). The finger- joint timber manufacturing is a newly introduced technology to Sri Lankan furniture industry (Abeysinghe et al. 2016).

The properties of timber vary with the species; thus special attention is needed to pay when different timber species are used in finger-joint productions. Each timber species possesses a unique density range at maturity. Strength also varies with the species and certain growth characteristics (Yeomans 2003). Therefore, some failures can always be expected when mixing different species for finger-joint productions. Quantitative characteristics of a wood and its behaviour in response to external forces depend on mechanical properties. Therefore it is apparent that the performance and strength of wood used in structural applications could vary with the mechanical properties of wood (Winandy 1994).

Timber classification is basically done based on the wood properties and the use of such classifications in timber industry is a common practice in many countries (Ali et al. 2008; Dávalos and Bárcenas 1999). However, a strength-based timber classification system is yet to be developed in Sri Lanka. The existing timber classification system in Sri Lanka has been developed considering the factors such as timber availability, demand and supply. However, with the expansion of finger-joint productions, the need for a reliable timber classification system based on the strength and workability characteristics is highlighted. This is particularly important when different timber species are used in preparing finger-joint boards. The key objective of the present study was to develop a strength-based timber classification system. Commonly used 32 timber species were employed in the study and the relationship between the strength index and density of selected timber species was also evaluated.

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**Figure 1.** Finger-joint door prepared with shorter sections of different timber species (98 cm × 190 cm).

## Methodology

### *Timber sample selection*

Locally available 32 timber species representing all the timber classes; Super luxury, Luxury, Special upper, Special, Class I, Class II, Class III and below Class III according to the timber classification chart of the State Timber Corporation of Sri Lanka were selected for the study (Table 1). The selected species are commonly used for structural and non-structural purposes in Sri Lanka. In this study, 32 solid timber samples were employed to develop a timber classification system based on the strength properties of 32 timber species.

**Table 2.** Standard sizes for samples.

| Mechanical test | Standard Size (mm) |
|---|---|
| Flexural test | 20 × 20 × 300 |
| Compression Parallel to grain test | 20 × 20 × 60 |
| Compression Perpendicular to grain test | 50 × 50 × 50 |

Universal testing machine (model: OZ-UTM-100PC, capacity: 100 KN, Power: 230 Hz) was used for testing.

### *Sample preparation*

The samples were taken from the heart wood portion of the timbers at the breast height. Ten small clear specimens were prepared representing each timber species and each test was replicated ten times. The specimens were free from timber defects and they were seasoned to reduce the moisture content down to 12%. BS:373-1957 standards were followed in preparing specimens (Table 2).

### *Determination of wood density*

Dry weight of the timber samples was taken after placing them in an oven for 48 h at 100–105°C (British Standard Institution 1999).

Density values were determined using the following equation:

$$\text{Density} = \frac{\text{Weight of oven dry wood (kg)}}{\text{Volume of wood (m}^3)} \quad (1)$$

### *Flexural strength test*

Seasoned specimens placed at room temperature (27°C) exhibited better structural performances compared to those placed at hot (35°C) and cool (15°C) conditions (Vievek et al. 2016). Clear timber specimens were tested by three-point bending for determining the bending strength. The span was

**Table 1.** Selected timber species.

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

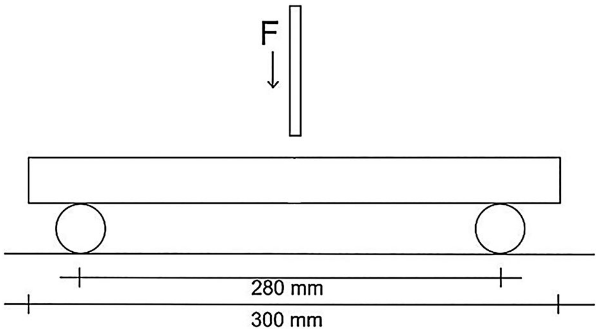


**Figure 2.** Loading setup for bending test.

280 mm for the test and load was applied on the mid span of the specimen at a loading speed of 6 mm min$^{-1}$ (Figure 2).

Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) values were calculated using Equations (2) and (3) corresponding to test data.

$$\mathrm{MOR} = \frac{3F_2L_1}{2bd^2} \quad (2)$$

where $F_2$ is the maximum force (N), $L_1$ is the length of the span (mm), $b$ is the width of the specimen (mm) and $d$ is the depth/thickness of the specimen (mm).

$$\mathrm{MOE} = \frac{F_3L_1^3}{4\delta bd^3} \quad (3)$$

where $F_3$ is the maximum load at proportionate state (N), $L_1$ is the length of the beam between supports (mm), $b$ is the width of the specimen (mm), $d$ is the depth/thickness of the specimen (mm) and $\delta$ is the deflection of timber specimen (mm).

### Compressive strength parallel to grain

Compressive strength parallel to grain test was carried out at a loading plate moving speed of 0.5 mm min$^{-1}$ (Figure 3) where load vs. displacement variation was obtained. The maximum load of the elastic limit was used to determine the serviceability state of compressive strength. Compressive strength parallel to grain values was calculated using the following equation:

$$\text{Compressive strength parallel to grain} = \frac{\text{Max. Load act on specimen}}{\text{Load acting area}}\,\mathrm{N\,mm^{-2}} \quad (4)$$

### Compressive strength perpendicular to grain

Failure of the specimens was obtained by perpendicular to grain at a loading plate moving speed of 0.5 mm min$^{-1}$ (Figure 4). A displacement curve was plotted with the load applied. Compressive strength perpendicular to grain values was calculated using the

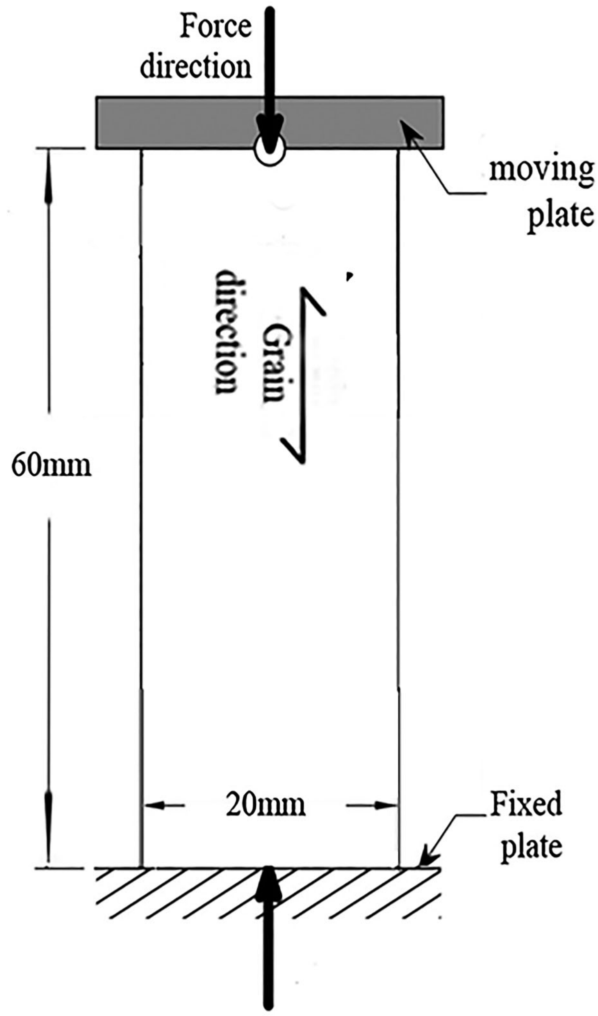


**Figure 3.** Loading setup for compressive strength parallel to grain test.

following equations:

$$\text{Compressive perpendicular to grain strength} = \frac{\text{Max. Load act on specimen}}{\text{Load acting area}}\,\mathrm{N\,mm^{-2}} \quad (5)$$

### Assessment of workability

Ten specimens representing each species were evaluated by a team of trained carpenters for the easiness of hand sawing, nailing and sanding and the specimens were categorized as easy, normal and hard. Three categories (very good, good and normal) were also used to determine the quality of the polished specimens.

### Statistical analysis

The data generated from the study were subjected to analysis of variance (ANOVA) with SPSS 16.0 and Minitab computer software. Factor and cluster analysis were also performed as appropriate.

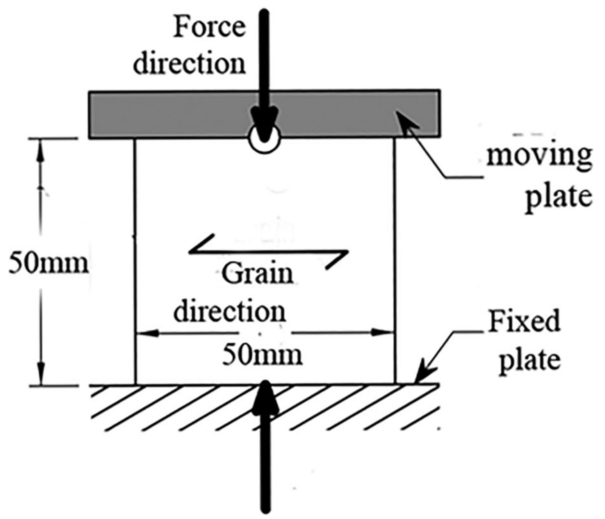


**Figure 4.** Loading setup for compressive strength perpendicular to grain test.

## Results and discussion

### *Calculated strength values*

The density values, strength and stiffness values of 32 timber species are shown in Table 3.

Variations in the values of wood density and mechanical properties were reported by several researchers (Zhang 1995; Zobel and van Buijtenen 1989). In the present study, the timber species were grouped into five categories based on their strength values using a dendrogram. Density is considered to be the most important indicator of the strength of a wood which could therefore be used in predicting some other characteristics such as hardness, ease of machining and nailing resistance as well (Hoadley 2000). In contrast to other material used in constructions, wood displays to have a stronger relationship between strength and density. Therefore, strength properties of a wood could be used in selecting a suitable type of wood for a particular use (Reinprecht 2016).

Cluster analysis was employed in grouping the species which possess similar strength properties such as modulus of rupture, modulus of elasticity, compression parallel to grain and compression perpendicular to grain (Barry n.d). Ward's hierarchical clustering method was employed here as it uses the minimum variations. According to Ward's method, the nearest neighbour species can be used to find the same cluster. Figure 5 shows the dendrograms used in grouping 32 timber species.

Dendrograms show the height at which mechanical properties and 32 timber species are joined together. The most similar species shows as the coloured boxes in each dendrogram.

### *Compressive parallel to grain test results*

Higher strength values in compressive parallel to grain were showed in Micro, Na, Palu, Ebony and Milla

**Table 3.** Density, compression strength and flexural strengths of 32 timber species.

| Timber Species (Spp. No) | Density (kg m$^{-3}$) | SD | Compression Parallel To grain (MPa) | SD | Compression perpendicular to grain (MPa) | SD | MOE (GPa) | SD | MOR (MPa) | SD |
|---|---|---|---|---|---|---|---|---|---|---|
| Albizia (28) | 425 | (20) | 10.43 | (0.53) | 3.5 | (0.34) | 1.939 | (1.428) | 17.36 | (2.70) |
| Caribbean Pine (20) | 465 | (22) | 48.5 | (10.15) | 4.1 | (1.57) | 6.910 | (1.683) | 69.86 | (14.73) |
| Cypress(26) | 502 | (22) | 24.91 | (2.61) | 3.4 | (0.43) | 4.491 | (1.792) | 53.13 | (5.95) |
| Ebony (30) | 1120 | (30) | 52.9 | (11.64) | 20.97 | (1.39) | 8.676 | (2.301) | 136.05 | (2.81) |
| Ehela (1) | 960 | (23) | 37.63 | (4.02) | 12.65 | (2.16) | 9.928 | (0.353) | 107.96 | (9.11) |
| Ginisapu (3) | 570 | (18) | 28.3 | (2.15) | 9.1 | (0.48) | 5.336 | (0.593) | 65.72 | (10.67) |
| Grandis-red (4) | 570 | (17) | 47.22 | (5.32) | 4.92 | (0.26) | 8.026 | (0.800) | 68.48 | (10.67) |
| Halmilla (5) | 796 | (24) | 43.84 | (4.74) | 8.77 | (0.26) | 8.141 | (1.865) | 91.14 | (21.57) |
| Havari nuga (6) | 651 | (30) | 40.05 | (13.1) | 8.528 | (1.11) | 9.836 | (2.031) | 84.56 | (10.91) |
| Hora (7) | 806 | (21) | 44.36 | (3.69) | 15.46 | (1.79) | 13.603 | (0.984) | 83.03 | (30.93) |
| Jack (8) | 645 | (16) | 42.75 | (6.44) | 14.48 | (0.95) | 5.872 | (0.674) | 63.92 | (3.71) |
| Kaya (29) | 600 | (14) | 37.09 | (2.50) | 11.77 | (1.16) | 8.879 | (1.269) | 81.5 | (11.54) |
| Kolon (9) | 708 | (16) | 34.12 | (3.79) | 6.16 | (0.72) | 6.196 | (1.094) | 66.45 | (12.96) |
| Kumbuk (10) | 756 | (22) | 34.56 | (5.60) | 8.74 | (0.81) | 5.719 | (0.839) | 60.58 | (9.41) |
| Lunumidella (11) | 400 | (16) | 16.7 | (6.97) | 3.79 | (0.28) | 4.206 | (0.999) | 25.6 | (4.88) |
| Madan (12) | 720 | (14) | 23.71 | (4.68) | 9.62 | (0.29) | 5.211 | (2.152) | 48.87 | (11.34) |
| Mahogany (13) | 570 | (13) | 29.87 | (0.27) | 8.56 | (0.92) | 6.140 | (1.067) | 66.22 | (7.06) |
| Margosa (14) | 733 | (14) | 48 | (3.20) | 12.25 | (1.71) | 7.438 | (0.402) | 76.75 | (8.06) |
| Mango (27) | 600 | (20) | 28.96 | (2.22) | 10.1 | (1.48) | 5.033 | (1.092) | 55.92 | (8.15) |
| Mee (15) | 973 | (23) | 37.06 | (3.52) | 10.24 | (2.51) | 5.810 | (0.621) | 64.16 | (9.75) |
| Milla (16) | 892 | (24) | 51.24 | (7.14) | 16.97 | (0.50) | 6.736 | (1.234) | 74.76 | (38.77) |
| Na (17) | 1087 | (30) | 56.36 | (5.41) | 10.68 | (0.85) | 12.175 | (2.757) | 140.65 | (19.86) |
| Nedun (32) | 795 | (25) | 34.21 | (3.98) | 12.75 | (0.67) | 8.715 | (1.135) | 111.88 | (23.49) |
| Palu (18) | 1100 | (26) | 53.09 | (12.2) | 17.21 | (1.98) | 11.349 | (1.703) | 82.71 | (14.54) |
| Paramara (19) | 650 | (23) | 29.93 | (3.96) | 4.99 | (0.30) | 3.974 | (1.585) | 38.41 | (15.79) |
| Robusta (31) | 775 | (27) | 38.22 | (6.49) | 7.36 | (0.96) | 9.723 | (0.507) | 98.84 | (13.25) |
| Rubber (21) | 680 | (22) | 29.59 | (10.03) | 5.71 | (1.19) | 7.911 | (1.647) | 75.78 | (15.51) |
| Satin (22) | 980 | (18) | 45.18 | (4.46) | 16.0 | (0.56) | 11.489 | (3.948) | 142.66 | (22.88) |
| Suriyamara (23) | 840 | (16) | 43.74 | (2.57) | 11.95 | (1.49) | 5.454 | (4.102) | 102.79 | (20.35) |
| Teak (24) | 720 | (19) | 49.31 | (6.51) | 10.08 | (1.17) | 8.478 | (0.957) | 90.76 | (13.46) |
| Tallowwood (2) | 910 | (20) | 62.47 | (7.08) | 11.46 | (1.91) | 14.919 | (1.006) | 127.34 | (10.95) |
| Welan (25) | 640 | (22) | 26.49 | (7.87) | 7.31 | (0.72) | 5.760 | (0.643) | 59.88 | (3.01) |

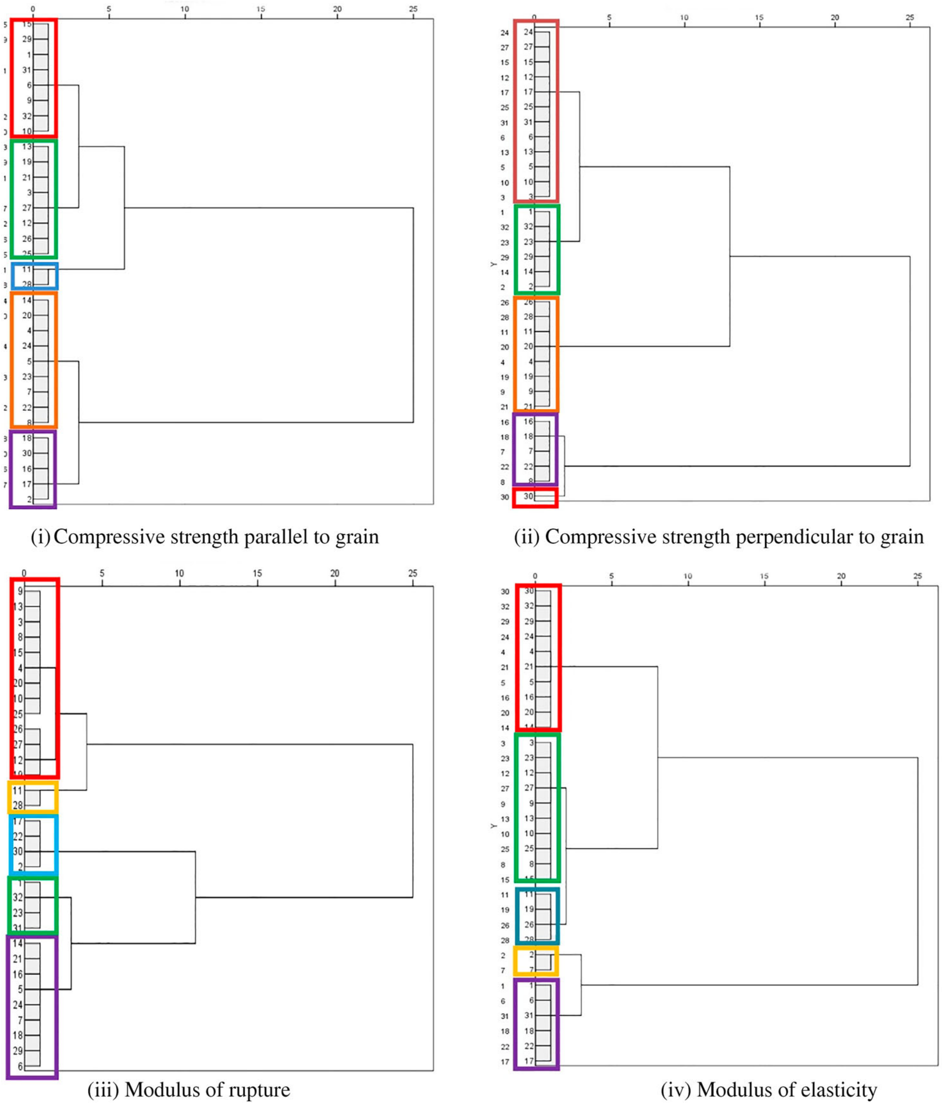


**Figure 5.** Dendrograms of four mechanical tests.

timber species (Table 4). The highest value was recorded in Micro (62.47 MPa) and the lowest from Albizia (10.43 MPa).

## Compressive perpendicular to grain test results

As shown in Table 5, the highest value for compressive perpendicular to grain was observed in Ebony (20.97 MPa) with lowest from Cypress (3.40 MPa) timber species.

**Table 4.** Grouping the timber species based on the results of ccompressive parallel to grain test.

| Group | Compression parallel to grain (MPa) | Timber species |
|---|---|---|
| Group1 | <20 | Albizia, Lunumidella |
| Group2 | 20–29 | Madan, Cypress, Welan, Ginisapu, Mango, Rubber, Mahogany, Paramara |
| Group3 | 30–39 | Kolon, Nedun, Kumbuk, Mi, Khaya, Ehela, Robusta, Hawarinuga |
| Group4 | 40–49 | Jak, Suriyamara, Halmilla, Hora, Satin, Red Grandis, Margosa, Pine, Teak |
| Group5 | >50 | Milla, Ebony, Palu, Na, Micro |

## Modulus of rupture

The modulus of rupture of the tested samples ranged from 17.36 MPa to 142.65 MPa. As revealed by Table 6, higher modulus of rupture values were recorded in Satin, Na, Ebony and Micro timber species. The highest value was recorded in Satin (142.65 MPa) and the lowest from Albizia (17.36 MPa).

**Table 5.** Grouping the timber species based on the results of compressive perpendicular to grain test.

| Group | Compressive perpendicular to grain (MPa) | Timber species |
|---|---|---|
| Group 1 | Very low <6.5 | Cypress, Albizia, Lunumidella, Pine, Red Grandis, Paramara, Rubber, Kolon |
| Group 2 | Low 6.5–11 | Welan, Robusta, Hawari nuga, Mahogany, Kumbuk, Halmilla, Ginisapu, Madan, Teak, Mango, Mee, Na |
| Group 3 | Medium 11–15.5 | Tallowwood, Khaya, Suriyamara, Margosa, Ehela, Nedun, Jack, Hora |
| Group 4 | High 15.6–19.5 | Satin, Milla, Palu |
| Group 5 | Very high >19.5 | Ebony |

**Table 6.** Grouping of the timber species based on the results of modulus of rupture test.

| Group | MOR (MPa) | Timber species in study sample |
|---|---|---|
| Group 1 | Very low <49 | Albizia, Lunumidella |
| Group 2 | Low 49–70 | Paramara, Madan, Cypress, Mango, Welan, Kumbuk, Jack, Mee, Ginisapu, Mahogany, Kolon, Red Grandis, Pine |
| Group 3 | Medium 71–90 | Milla, Rubber, Margosa, Khaya, Palu, Hora, Hawari nuga,Teak, Halmilla |
| Group 4 | High 91–112 | Robusta, Suriyamara, Ehela,Nedun |
| Group 5 | Very high >112 | Ebony Tallowwood, Satin, Na |

**Table 7.** Grouping of the timber species based on the results of modulus of elasticity test.

| Group | MOE (GPa) | Timber species in study sample |
|---|---|---|
| Group 1 | Very low | Albizia, Paramara, Lunumidella, Cypress |
| Group 2 | Low | Mango,Madan, Ginisapu, Suriyamara, Kumbuk, Welan, Mee, Jack, Mahogany, Kolon, |
| Group 3 | Medium | Milla, Pine, Margosa, Rubber, Red Grandis, Halmilla, Teak, Ebony, Nedun, Khaya |
| Group 4 | High | Robusta, Hawari nuga, Ehela, Palu, Satin, Na |
| Group5 | Very high | Hora, Tallowwood |

## Modulus of elasticity

As shown in Table 7, higher modulus of elasticity values were recorded in Hora and Micro timber species. The highest value was recorded in Micro (14.919 GPa) timber species. The lowest modulus of rupture value was in Albizia (1.939 GPa).

## Factor analysis

Factor analysis was performed using the compressive strength- parallel to grain, compressive strength-perpendicular to gain, modulus of elasticity, modulus of rupture, to develop total wood linkage index where the highest common variance from all variables was put into a common score. Principal component analysis was used to decide the number of factors and Eigen values were selected.

Figure 6 shows the scree plots for the 4 Eigen values for each of the groups. Factor 1 and factor 2 were used to calculate the strength index (Table 8).

## Calculation of strength index

The factor score was calculated using factor loading coefficients. Then the variance contribution rate of each factor was divided by the cumulative variance rate of all the selected factors and the weights of each factor were determined. The factor weight of each factor was multiplied by their factor scores and then added together to develop the strength index.

$$\text{Strength Index (S)} = \alpha 1 \text{ Factor 1} + \alpha 2 \text{ Factor 2} \qquad (6)$$

where

$$\alpha 1 \text{ Factor} = \left( \frac{\text{cum. value of average strength values of 4 tests} \times \text{factor coefficient}}{\text{Number of variables (4)}} \right) \times \text{variance}(1.0865)$$

$$\alpha 2 \text{ Factor} = \left( \frac{\text{cum. value ofaverage strength values of 4 tests} \times \text{factor coefficient}}{\text{Number of variables (4)}} \right) \times \text{variance}(1.0283)$$

Strength index values were calculated using Equation (6) (Figure 7).

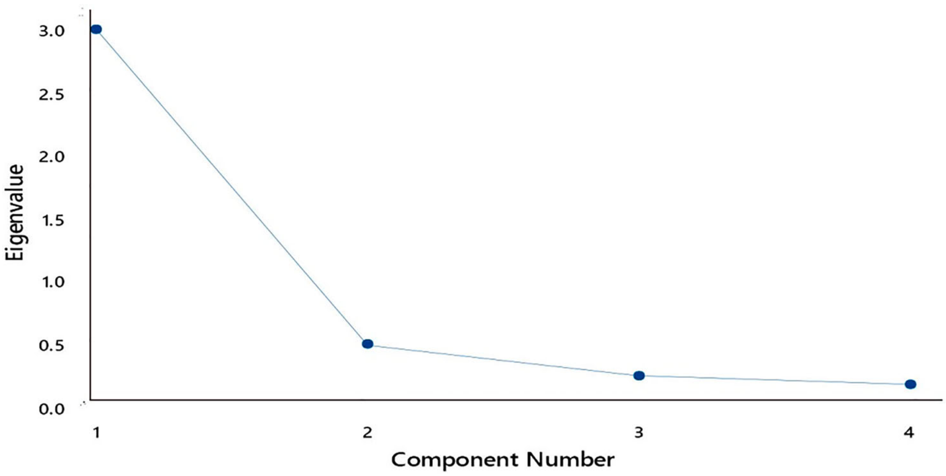


**Figure 6.** Scree plots for the 4 Eigenvalues obtained from the Factor Analyses.

**Table 8.** Rotated factor loadings and communalities (varimax rotation).

| Variable | Factor1 | Factor2 | Factor3 | Factor4 | Communality |
|---|---|---|---|---|---|
| Com. Parallel to grain | 0.289 | 0.347 | −0.84 | −0.301 | 1 |
| Com. Perpendicular to grain | 0.926 | 0.191 | −0.234 | −0.228 | 1 |
| MOE | 0.222 | 0.847 | −0.34 | −0.342 | 1 |
| MOR | 0.311 | 0.392 | −0.332 | −0.8 | 1 |
| Variance | 1.0865 | 1.0283 | 0.9857 | 0.8995 | 4 |
| % Variance | 0.272 | 0.257 | 0.246 | 0.225 | 1 |

Factor 1, factor 2 and variance values were used to calculate the strength index.

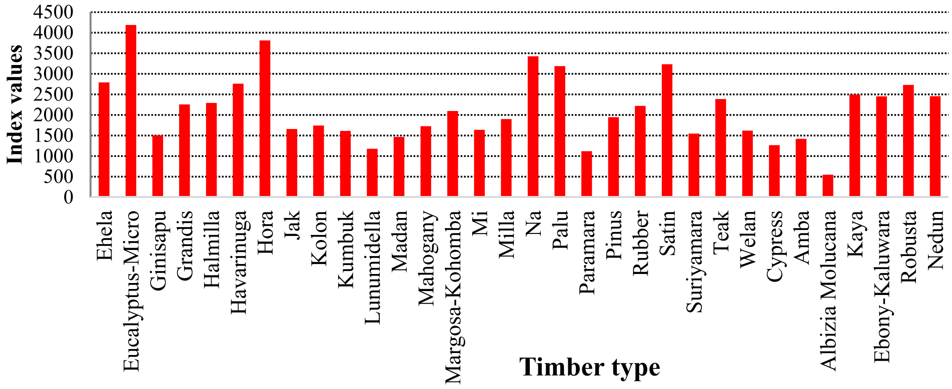


**Figure 7.** Strength indexes values of 32 timber species where stiffness and failure values were considered together.

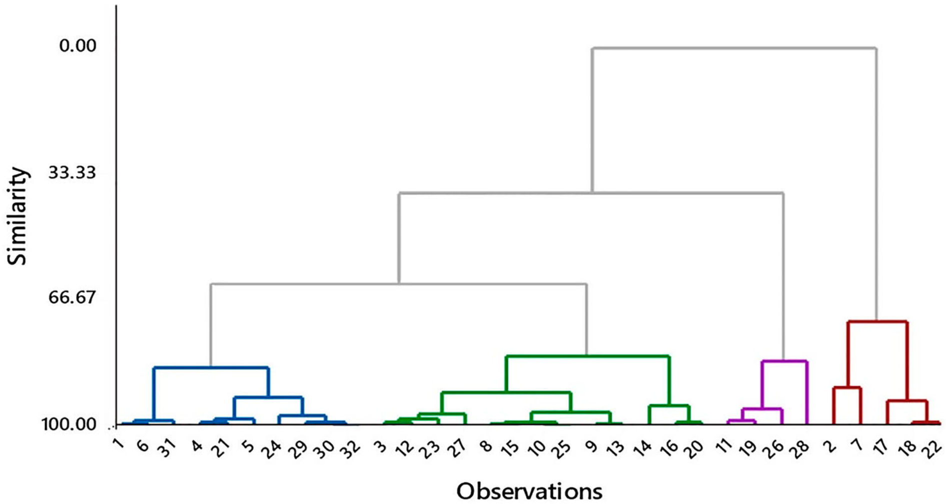


**Figure 8.** Dendrogram of strength index.

Figure 5 represents the dendrogram which was created using strength index values of 32 timber species (Figure 8, Table 9).

## *Classification of timber species according to workability*

Hand sawing, nailing, sanding and polishing properties of 32 timber species were evaluated and five workability groups were identified in ascending order as shown in Table 10. The dendrogram of workability is shown in Figure 9 with the complete linkages.

**Table 9.** Timber classification based on strength index.

| | Index value | Timber species |
|---|---|---|
| Group 1 | Very low (<1400) | Albizia, Paramara, Lunumidella, Cypress |
| Group 2 | Low(1401–2200) | Mango, Madan, Ginisapu, Suriyamara, Kumbuk, Welan, Mee, Jack, Mahogany, Kolon, Milla, Pine, Margosa |
| Group 3 | Medium (2201–3000) | Rubber, Red Grandis, Halmilla, Teak, Ebony, Nedun, Khaya, Robusta, Hawari nuga, Ehela |
| Group 4 | High (3001–3800) | Palu, Satin, Na |
| Group 5 | Very High (>3801) | Hora, Talllowwood |

According to the dendrogram shown in Figure 8, five timber groups were prepared based on the index values.

**Table 10.** Classification of 32 timber species according to workability.

| Group number | Timber species |
|---|---|
| Group 1 | Ehela, Kumbuk, Mee, Milla, Na, Palu, Kaluwara, Madan, Satin |
| Group 2 | Jack, Margosa, Teak, Nedun, Suriyamara, Hora |
| Group 3 | Hawari nuga, Robusta, Khaya, Paramara, Tallow wood |
| Group 4 | Halmilla, Kolon, Mahogany, Welan |
| Group 5 | Ginisapu, Lunumidella, Pinus, Cypress, Red Grandis, Rubber, Mango, Albizia |

**Table 11.** *P* values and R-squared values.

| | *P* value | R-square (%) |
|---|---|---|
| Compression parallel to grain (CPG) | 0.000 | 38.0 |
| Compression perpendicular to grain (CPG) | 0.001 | 32.6 |
| MOE | 0.000 | 33.68 |
| MOR | 0.000 | 33.87 |
| Strength index | 0.000 | 33.88 |

R-squared values calculated from mean values for the species.

### *Relationship between density with MOE, MOR, compression parallel to grain, compression perpendicular to grain and strength index*

There is a positive relationship between the strength index of timber and density values ($P < 0.05$). Though the timber density is significantly predicted by the strength index, it was not good to fit into the model of the independent variable indicating the possibility of other independent variables which could affect the strength index (Table 11).

As revealed by previous research, positive relationships were found among mechanical properties (modulus of rupture, modulus of elasticity, compression parallel to grain and compression perpendicular to grain) and the wood density (Muthumala et al. 2020). Figure 10 shows the relationships between density vs. strength index.

Finger-jointed furniture manufacturing would be benefited from strength index classification as it could assist in matching different timber species for the production of finger-joint panels, doors or other boards minimizing possible wood defects and dimensional effects. Further TWI groups could be used effectively in enhancing the quality of finger-joint manufacturing industry and used in planning and implementing reforestation and afforestation programmes effectively.

## Conclusions

The selection of timber species for different uses is basically done based on the strength properties of the species concerned. Density, modulus of rupture, modulus of elasticity, compression parallel to grain and compression perpendicular to grain are generally used for the strength classification.

In the present study, timber species were grouped into five strength classes namely; very low, low, medium, high and very high based on the results of strength index. These classes could be effectively used in selecting timber species for finger-joint furniture manufacturing. When different timber species are employed in producing finger-joint boards, the matching of species could be based on the strength index. Accordingly, selecting the species coming under different strength classes is discouraged in order to minimize the possible defects of finger-joint products. Further studies are however needed as some other compatibility issues associated with bonding dissimilar wood species together would affect the quality of the final products. Mechanical properties

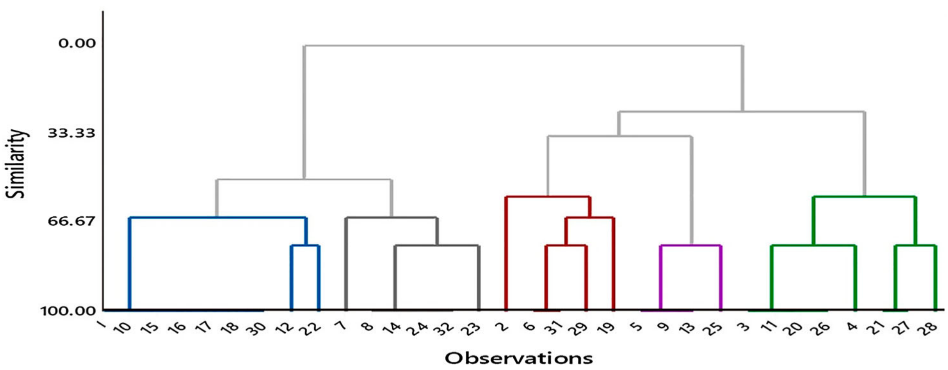


**Figure 9.** Dendrogram of workability.

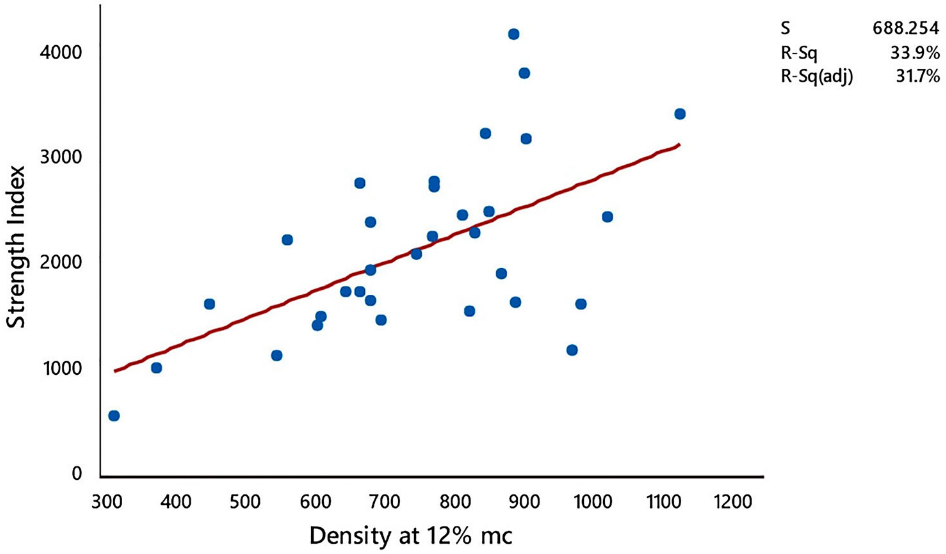


**Figure 10.** Regression between density and strength index.

may also depend on the location and climate in the forests where the tress are grown, thus further investigations using the specimens drawn from trees grown in diverse environments are recommended.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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