INTRODUCTION

Timber, one of the oldest and natural building materials is extensively used worldwide in the furniture and construction industries. When it is employed in construction and furniture manufacturing industries, off-cut and shorter sections are unavoidable wastes that are often dumped. Since timber is a limited resource, any sort of dumping is a matter of great concern. A certain portion of these wastes is used as fuel in kiln-dried boilers (Muthumala et al. 2018). Joining pieces of off-cuts and shorter sections together to make finger joint panels is identified as another alternative use of timber wastes.

Finger joints are described as interlocking end joints formed by machining several similar tapered symmetrical fingers in the ends of timber members using a finger joint cutter and then bonded together (British Standard Institution Eropian Norm 2014). The finger joint is recognized to be a sustainable, eco-friendly and economically viable technique which minimizes waste generation in furniture manufacturing and construction activities (Sandika et al. 2017). Though the technique is relatively new to Sri Lanka, the State Timber Corporation (STC) has produced finger joints worth Rs.5.2 million for the year 2018. (STC 2018).

SYSTEMATIC CLASSIFICATION OF COMMONLY USED TIMBER SPECIES FOR FINGER-JOINT MIXED PANELS IN SRI LANKA

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ABSTRACT

Off-cut wood pieces are often dumped or used as fuel wood. A certain portion of timber has to be removed also due to inadequate length of sawn timber material. Finger joint, a method which connects two small pieces of timber is identified as a sound technique to minimize timber wastage. At the finger joint production process, different timber species are bonded together for making finger-jointed mixed panels. In this connection, the selection of the best possible combination of timber species is vital as the success largely depends on the mechanical and physical properties of the pieces. Workability, on the other hand, is another key factor which minimizes manufacturing defects. However, expansion of the finger joint industry is restricted due to the unavailability of a reliable timber classification system based on wood properties. Therefore, the present study focused on developing a classification system for selected 32 clear timber species based on physical, mechanical and anatomical properties of wood. Factor analysis was used in preparing the Total Wood Index (TWI) and timbers were grouped into four categories as low, medium, high and very high based on TWI. It is recommended for selecting suitable timber species from the TWI-based groups to ensure the best matching thereby the attractive aesthetic appearance in finger-joint manufacturing can be achieved.

Keywords: Timber classification, finger-joints, wood properties

INTRODUCTION

Timber, one of the oldest and natural building materials is extensively used worldwide in the furniture and construction industries. When it is employed in construction and furniture manufacturing industries, off-cut and shorter sections are unavoidable wastes that are often dumped. Since timber is a limited resource, any sort of dumping is a matter of great concern. A certain portion of these wastes is used as fuel in kiln-dried boilers (Muthumala et al. 2018). Joining pieces of off-cuts and shorter sections together to make finger joint panels is identified as another alternative use of timber wastes.

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Variations of wood density and mechanical properties have also been reported by several researchers (Zhang 1995; Zobel and Van 1989). 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 (Hoadley 2000). Wood has a relatively high strength to its density when compared with other materials used in construction. The strength properties of wood depend upon its density and structure, which assists in selecting a suitable type of wood for a particular use (Reinprecht 2016).

Moreover, unlike many other materials, wood cannot be cut in any direction. It is sensitive to ambient temperatures and unpredictable internal stresses and possesses (Ratnasingam, and Tanaka 2002). For this reason, an understanding of wood anatomy is very important in the use of wood as a material. The relationship between anatomical and physical properties has been exploited up to a certain extent by wood scientists (Toong et al. 2014).

The existing Sri Lankan timber classification system has been prepared by taking the availability, demand, user experience and visual grading into account. No attention has been paid to the strength properties, anatomical features, and physical properties of timber species. However, classification based on wood properties is widely used in many countries and considered to be a crucial necessity for effective use of timber (Da’valos and Ba´rcenas 1999: Ali et al. 2008). The mechanical properties of wood are important because they can significantly influence the performance and strength of the timber used in structural applications (Winandy 1994). The main objective of this study is to develop a timber classification system based on wood properties to be used in the production of finger joints in Sri Lanka.

**MATERIALS AND METHODS**

In this study, physical properties, anatomical

Timber properties vary with the species. Every matured timber species possess a unique density, strength and stiffness range. Shrinkage is also shown to vary with different timber species. Therefore, a certain degree of failures could be expected if timber species are not matched for the production of finger joints (Fig.1). Quantitative characteristics of wood and its response to external forces depend largely on mechanical properties. The mechanical properties thus have a significant influence on the performance and strength of the wood used in structural applications (Winandy 1994). Apart from the species, the strength of timber could vary with the growth stages of the plant as well (Yeoman 2003).

The dimensional changes that accompany the shrinking and swelling of wood are major sources of both visual and structural problems in furniture. Shrinking and swelling occur as the variations in the moisture content of the wood in response to daily as well as seasonal changes in the relative humidity of the atmosphere. The shrinkage of wood upon drying depends on several variables including specific gravity, rate of drying and size of the piece. As wood is an anisotropic material, its dimensional changes occur differently in three directions: tangentially, radially, and longitudinally. Tangential shrinkage is about twice that of radial shrinkage and longitudinal (Rowell 2013). Wood shrinkage is affected by tangential vessel diameter, vessel frequency and vessel diameter (Moya et al. 2012; Sympson 1991).

Figure 1. The appearance of finger-joint board, prepared by using different timber species

![Figure 1. The appearance of finger-joint board, prepared by using different timber species](image)
Table 1: Selected 32 timber species

| No. | Common Name | Botanical Name | Family   | Origin | STC class | Floristic region |
|-----|-------------|----------------|----------|--------|-----------|------------------|
| 1   | Albizia     | Albizia falcata | Fabaceae | Exotic | C-III LG  | UC/LCWZ          |
| 2   | Caribbean Pine | Pinus caribaea | Pinaceae | Exotic | C-III     | LCWZ/UC          |
| 3   | Cypress     | Cupressaceae    | Exotic   | C-II   | UC        |                  |
| 4   | Ebony       | Diospyros ebenum | Ebenaceae | Indigenous | SL   | DZ/IN |
| 5   | Ehela       | Cassia fistula | Leguminosae | Indigenous | C-II | DZ     |
| 6   | Ginisapu    | Magnoliaceae   | Exotic   | C-II   | WL        |                  |
| 7   | Grandis(red) | Eucalyptus grandis | Myrtaceae | Exotic | C-II     | UC    |
| 8   | Halmilla    | Malvaceae      | Indigenous | L | LCDZ     |                  |
| 9   | Havarinuga  | Alstonia macrophylla | Apocynaceae | Exotic | C-II     | LCWZ |
| 10  | Hora        | Dipterocarpus | Indigenous | C-I   | LCWZ     |                  |
| 11  | Jack        | Artocarpus heterophyllus | Moraceae | Exotic | L | LCWZ |
| 12  | Khaya       | Khaya senegalensis | Meliaceae | Exotic | C-II     | DZ/IN |
| 13  | Kolon       | Adina cordifolia | Rubiaceae | Indigenous | SPU | LCDZ  |
| 14  | Kumbuk      | Terminalia arjuna | Combretaceae | Indigenous | SP | LCDZ  |
| 15  | Lunimidella | Melia dubia | Meliaceae | Exotic | C-II | LCIN  |
| 16  | Madan       | Syzygium cumini | Myrtaceae | Indigenous | C-I | DZ    |
| 17  | Mahogany    | Swietenia macrophylla | Meliaceae | Exotic | L | IN    |
| 18  | Margosa     | Azadirachta indica | Meliaceae | Exotic | SPU | LCWZ  |
| 19  | Mango       | Mangifera indica | Anacardiaceae | Exotic | C-III | WZ/DZ |
| 20  | Mee         | Madhuca longifolia | Sapotaceae | Indigenous | C-I | DZ/WZ |
| 21  | Milla       | Vitex pinnata | Lamiaceae | Indigenous | L | IN    |
| 22  | Na          | Mesua ferrea | Calophyllaceae | Indigenous | Na | LCWZ |
| 23  | Nedun       | Pericopsis mooniana | Leguminosae | Indigenous | SL | LCWZ |
| 24  | Palu        | Manilkara hexandra | Sapotaceae | Indigenous | SPU | DZ    |
| 25  | Paramara    | Albizia saman | Leguminosae | Exotic | C-I | DZ/WZ |
| 26  | Robusta     | Eucalyptus robusta | Myrtaceae | Exotic | C-II | UC    |
| 27  | Rubber      | Hevea brasiliensis | Euphorbiaceae | Exotic | C-III | LCWZ/IN |
| 28  | Satin       | Chloroxylon swietenia | Rutaceae | Exotic | L | LCDZ |
| 29  | Suriyamara  | Albizia odoratissima | Leguminosae | Indigenous | SPU | DZ |
| 30  | Teak        | Teectona grandis | Lamiaceae | Exotic | SL | LCDZ |
| 31  | Tallow wood | Eucalyptus microcorys | Myrtaceae | Exotic | SP | UC    |
| 32  | Welan       | Pterospermum suberifolium | Malvaceae | Indigenous | SPU | LCDZ |

LCWZ - Low Country Wet Zone, UC- Upcountry, LCDZ - Low country Dry Zone, IN- Intermediate Zone, LCIZ- Low country Intermediate Zone, WZL- Wet Zone Lowland, DZ- Dry Zone, STC class-State Timber Corporation timber class, SL-Super Luxury class, L – Luxury class, SPU – Special Upper class, SP – Special class, C-I – class I, C-II – class II, C-III – class III, C-III LG – class III lower grade

Timber sample selection
Locally available 32 timber species in Sri Lanka were selected for the study (Table 1). The selected timber species are commonly used for structural and non-structural purposes. Furthermore, they represent all the timber classes that appeared in the timber classification chart of the STC of Sri Lanka. Where timbers are classified as Super luxury,
Preparation of wood specimens
Wood samples from matured trees (30-40 years of age) were collected from Kumbukkana and Boossa timber complexes of the State Timber Corporation in Sri Lanka. Specimens were prepared from defects-free, heartwood pieces from logs with ten replicates for each test. Standard sizes were used for the relevant test as shown in Table 2.

Luxury, Special upper, Special, Class I, Class II, Class III and below Class (STC 2017).

Calculation of the Dry Density and Humidity
The dry weight of the timber specimens was measured after placing them in an oven at 103 ± 2°C for 48 hours (BS 373,1957).

Density values were determined at the moisture content of 12 % using equation 1.

\[
\text{Density} = \frac{W}{V} \quad \ldots \ldots \ldots \ldots (1)
\]

\(W\) - Weight of oven-dried wood (kg)
\(V\) - Volume of wood (m³)

For determination of humidity, specimens were weighed and then oven-dried at 103 0°C until they reach a constant weight. The humidity (r) was determined using equation 2 (BS 373: 1957).

\[
r = \frac{M_r - M_0}{M_0} \times 100 \quad \ldots \ldots \ldots \ldots (2)
\]

Where \(r\) is the humidity of samples(%), \(M_r\) is the moist weight of samples, \(M_0\) is the fully dried specimen mass.

Calculation of the bending and compression strength
Bending tests were conducted using a Universal Testing Machine (UTM-100) with the loading plate moving speed of 1 mm/min.

The specimens were prepared with an average moisture content of 12 ± 3 % and 75 ± 5 % relative humidity. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) values were calculated using equations 3 and 4 (Record 1914) corresponding to test data.

\[
\text{Bending strength} = \frac{3F_1L_1}{2bd^2} \quad \ldots \ldots \ldots \ldots (3)
\]

Where, \(F_1=\) Serviceability Force (N), \(L_1 = \) Length of the span (mm), \(b = \) Width of the specimen (mm) and \(d = \) Depth/Thickness of the specimen (mm)

\[
\text{MOR} = \frac{3F_2L_1}{2bd^2} \quad \ldots \ldots \ldots \ldots (4)
\]

Where \(F_2 = \) Maximum Force (N), \(L_1 = \) Length of the span (mm), \(b = \) Width of the specimen (mm) and \(d = \) Depth/Thickness of the specimen (mm)
\[ MOE = \frac{F_3 L_1^4}{48b d^4} \]  

Where \( F_3 \) = Maximum load at proportionate state (N), \( L_1 \) = Length of the beam between supports (mm), \( b \) = width of the specimen (mm), \( d \) = Depth/Thickness of the specimen (mm) and \( \delta \) = Deflection of timber specimen (mm)

Compression tests were conducted with prepared specimens using Universal Testing Machine (UTM-100) with a loading plate moving speed of 0.5 mm/min. The average density and moisture content were obtained for each species. Compressive strength values were calculated using equation 6 (BS 373, 1957).

\[
\text{Serviceability Compressive Strength} = \frac{F_3}{A} \quad \ldots \ldots (6)
\]

\( F_3 \) - Maximum load act on the specimen at a proportionate state  
\( A \) - Load acting area

**Assessment of Workability**

Assessment of workability of 32 heartwood timber planks was done by examining the ease of working properties; hand sawing, nailing, sanding and polishing works, and grouped into five categories as very easy, easy, normal, difficult and very difficult. Wood drying improves workability; hence selected wood specimens to assess workability were dried to 12% moisture content.

**Calculation of the dimensional effects**

The selected samples of the approximately same size were wiped to remove sawdust or any dust materials before the experiment. Radial, tangential and longitudinal planes were marked in every specimen. Critical environmental conditions were selected according to the data taken from the Department of Meteorology of Sri Lanka. Minimum and maximum average temperatures were 16°C (at RH of 90-100%) and 35°C (at the RH of 70-80%) respectively. Room temperature and RH values were 27°C and 80-90% respectively.

Longitudinal shrinkage is usually less than 0.2% (Rowell 2013). Most researchers reported that the dimensional change (swelling or shrinkage) in the longitudinal direction is negligible (Gryc et al. 2007; Usta and Guray 2000). Hence, two primary planes or surface of the wood where shrinkage take place corresponding to radial shrinkage and tangential shrinkage were added. Samples were kept at each environmental condition for 48 hours. Before and after the test, dimensional data were collected. Volumetric shrinkage (or volumetric swelling) was measured according to equation 7 (EAS 2002).

\[
\text{Volumetric Shrinkage} = \left( \frac{l_{t\max} \times l_{r\max} \times l_{a\max} - l_{t\min} \times l_{r\min} \times l_{a\min}}{(l_{t\max} \times l_{r\max} \times l_{a\max})} \right) \times 100 \ldots (7)
\]

Where,

\( l_{t\max} \) = Maximum length of tangential plane  
\( l_{r\max} \) = Maximum length of radial plane  
\( l_{a\max} \) = Maximum length of longitudinal plane  
\( l_{t\min} \) = Minimum length of tangential plane  
\( l_{r\min} \) = Minimum length of radial plane  
\( l_{a\min} \) = Minimum length of longitudinal plane

Digital balance with the accuracy of 0.01g was used to measure the weight of wood specimens. Venire calliper was used to measure dimensional values. The minimum measurement was 0.05mm of the Venire calliper.

**Microscopic examination of wood**

All wood samples were sectioned and macerated according to the standard techniques described by Baas and Zhang (1986) for light microscopic study. Anatomical observations on qualitative and quantitative parameters were made under the light microscope at 4 x 10 magnifications. Measurements were obtained using anatomical photographs and Micro metrics SE.
Table 3 Selected wood properties of the studied timber species

| Botanical name       | Common name | D (kg/m³) | MRH (mm) | MVD (mm) | V SQM | Sh 35 (%) | Sh 27 (%) | Sw 16 (%) | CPAG (N/mm²) | CPERG (N/mm²) | MOE (N/mm²) | MOR (N/mm²) | W (0-100 %) |
|----------------------|-------------|-----------|----------|----------|-------|-----------|-----------|-----------|---------------|---------------|-------------|-------------|-------------|
| Albizia falcata     | Albizia    | 425       | 529.4    | 200      | 5     | 1.512     | 0.3340    | 1.2443    | 10.43         | 3.50          | 1939.81     | 17.36       | 100         |
| Pinus caribaea      | Pine       | 465       | 210.6    | 0        | 0     | 3.0621    | 0.7705    | 0.3322    | 48.50         | 4.11          | 6910.60     | 69.86       | 100         |
| Cupressus macrocarpa| Cypress    | 502       | 367.6    | 0        | 0     | 2.2511    | -0.2643² | 0.4791    | 24.92         | 3.41          | 4491.91     | 53.13       | 100         |
| Diospyros ebenum    | Ebony      | 1120      | 808      | 55       | 24    | 2.1047    | 0.7865    | 0.9106    | 52.90         | 20.97         | 8676.39     | 136.05      | 20          |
| Cassia fistula      | Ehela      | 960       | 269.6    | 203      | 6     | 1.8512    | 0.3685    | 0.5310    | 37.64         | 12.66         | 9928.79     | 107.97      | 20          |
| Michelia champaca   | Giniispu   | 570       | 650.8    | 74       | 28    | 3.5067    | 0.4566    | 0.4014    | 28.31         | 9.00          | 5336.39     | 65.72       | 100         |
| Eucalyptus grandis  | Grandis    | 570       | 294.3    | 161      | 9     | 2.8586    | 1.5233    | 1.6915    | 47.23         | 4.92          | 8026.14     | 68.48       | 100         |
| Borya carafolila    | Halmilla   | 796       | 234.6    | 80       | 23    | 1.0910    | 0.6208    | 0.4763    | 43.84         | 8.78          | 8141.70     | 91.14       | 80          |
| Alstonia macrophylla| Hawarinuag | 651       | 503.8    | 81       | 44    | 3.5024    | 0.4298    | 1.2319    | 40.06         | 8.53          | 9836.82     | 84.56       | 60          |
| Dipterocarpos zeulenicus | Hora    | 806       | 682.6    | 265      | 5     | 2.9596    | 0.2832    | 0.4121    | 44.36         | 15.46         | 13603.85    | 83.03       | 40          |
| Artocarpus heterophyllus | Jack      | 645       | 666.4    | 215      | 2     | 2.8369    | 1.7288    | 0.3404    | 42.75         | 14.48         | 5872.66     | 63.93       | 40          |
| Khaya senegalensis  | Khaya      | 600       | 450.8    | 119      | 8     | 2.4505    | 0.7010    | 0.4603    | 37.09         | 11.78         | 8879.29     | 81.50       | 60          |
| Adina cordifolia    | Kolon     | 708       | 372.6    | 55       | 45    | 2.4706    | 1.5780    | 0.4790    | 34.13         | 6.17          | 6196.25     | 66.46       | 80          |
| Terminalia aethiaca | Kumbuk    | 756       | 277.8    | 257      | 4     | 1.9871    | 0.3602    | 0.3479    | 34.56         | 8.74          | 5719.41     | 60.59       | 20          |
| Melia dubia         | Lunumidella | 400     | 586.5    | 215      | 3     | 2.4201    | 1.1770    | 0.4151    | 16.71         | 3.80          | 4206.02     | 25.61       | 100         |
| Syzygium cumini     | Madan     | 720       | 394      | 112      | 7     | 1.1886    | 1.2728    | 0.3424    | 23.72         | 9.62          | 5211.13     | 48.87       | 20          |
| Botanical name      | Common name | D (kg/m³) | MRH (mm) | MVD (mm) | VSQMM (no.) | Sh 35 (%) | Sh 27 (%) | Sw 16 (%) | CPAG (N/mm²) | CPERG (N/mm²) | MOE (N/mm²) | MOR (N/mm²) | W (0-100 %) |
|---------------------|-------------|-----------|----------|----------|-------------|-----------|-----------|-----------|-------------|--------------|-------------|-------------|-------------|
| *Swietenia macrophylla* | Mahogany    | 570       | 344.8    | 128      | 11          | 1.3577    | 0.7614    | 0.9029    | 29.88       | 8.56         | 6140.01     | 66.22       | 80          |
| *Azadirachta indica*  | Margosa     | 733       | 480      | 321      | 2           | 2.1349    | 4.9679    | 0.9002    | 48.00       | 12.26        | 7438.61     | 76.76       | 40          |
| *Mangifera indica*   | Mango       | 600       | 433.8    | 243      | 2           | 4.1566    | -0.1784   | 0.7504    | 28.96       | 10.10        | 5033.35     | 55.92       | 100         |
| *Madhuca longifolia* | Mee         | 973       | 868.6    | 166      | 5           | 3.0095    | 0.6806    | 0.8147    | 37.06       | 10.25        | 5810.99     | 64.17       | 20          |
| *Vitex pinnata*      | Milla       | 892       | 236.4    | 117      | 13          | 1.3423    | 0.1288    | 0.1644    | 51.24       | 16.97        | 6736.23     | 74.76       | 20          |
| *Macusa forrea*      | Na          | 1087      | 757.4    | 96       | 5           | 2.4098    | -0.9707   | 0.6438    | 56.37       | 10.69        | 12175.20    | 140.65      | 20          |
| *Pterygota mooreana* | Neehun      | 795       | 307.6    | 123      | 5           | 1.8703    | -0.8473   | 1.0745    | 34.22       | 12.75        | 8715.65     | 111.88      | 40          |
| *Manilkara hancocki* | Palu        | 1100      | 425.5    | 70       | 24          | 2.1778    | 0.3453    | 0.4111    | 53.10       | 17.21        | 11349.94    | 82.72       | 20          |
| *Albizia saman*      | Paramara    | 650       | 316.8    | 204      | 1           | 0.3323    | 0.5681    | 0.6121    | 29.94       | 4.99         | 6241.48     | 59.77       | 60          |
| *Eucalyptus robusta* | Robusta     | 775       | 272.4    | 176      | 8           | 2.7212    | 0.7212    | 0.1279    | 38.22       | 7.36         | 9723.76     | 98.85       | 60          |
| *Hovea brasiilensis* | Rubber      | 680       | 474.4    | 186      | 3           | 2.6770    | 0.8653    | 1.4036    | 29.60       | 5.71         | 7911.07     | 75.79       | 100         |
| *Chloroxylon swietenia* | Satin    | 980       | 258.2    | 74       | 22          | 1.8187    | 0.0955    | 2.8885    | 45.19       | 16.00        | 11489.57    | 142.66      | 20          |
| *Albizia odoratissima* | Suriyarnas | 840       | 529.6    | 73       | 10          | 1.4561    | 0.2798    | 0.7630    | 43.74       | 11.95        | 5454.79     | 102.79      | 40          |
| *Teckota grandis*    | Teak        | 720       | 555      | 185      | 10          | 1.7672    | 0.5297    | 0.2620    | 49.31       | 10.08        | 8478.26     | 90.77       | 40          |
| *Eucalyptus microcarpa* | Tallow wood | 910       | 220.8    | 108      | 13          | 3.0746    | 0.5749    | 0.9497    | 62.48       | 11.47        | 14919.83    | 127.34      | 60          |
| *Eucalyptus subtextusa* | Welanc   | 640       | 376.6    | 102      | 22          | 1.5833    | 0.8010    | 1.1298    | 26.49       | 7.31         | 5760.22     | 59.88       | 80          |

D – Density, MRH – mean ray height, MVD – mean vessel diameter, VSQMM – vessels per square millimeter, Sh 35 – Volumetric shrinkage at 35 °C, Sh 27 – Volumetric shrinkage at 27 °C, Sw 16 – Volumetric Swelling at 16 °C, PARG – compression parallel to grain, CPERG – compression perpendicular to grain, MOE – modulus of rupture, MOE – modulus of elasticity, W – workability, a – swelling specimens at 27 °C.
Premium 4 software available at Wood Science Laboratory at the Research division of the State Timber Corporation. Quantitative wood anatomical features such as mean vessel diameter, vessels per square millimetre and ray height were measured according to the International Association of Wood Anatomists list in 1989. Data analysis was done using the SPSS software version. Factor and hierarchical cluster analysis were used for the interpretation of the results.

RESULTS AND DISCUSSION
Among various wood properties, the highest density value (1120 kg/m³) was recorded in Ebony while the least was recorded in Lunumidella (400 kg/m³) (Table 3). When consider anatomical features, mean ray height, mean vessel diameter and vessels per square millimetre ranged between 210.6~868.6 mm, 55~321 mm and 1~45 respectively. No vessels were seen in Pine and Cypress as they are softwood species (Table 3).

Three critical environmental conditions were selected to assess the dimensional effects of wood specimens at the moisture content of 12 % for 3 days. According to the data taken from the Department of Meteorology of Sri Lanka, selected mean temperature and relative humidity (RH) level of critical environmental conditions were 35°C and 70-80% RH, 27°C and 80-90% RH and 16°C and 90-100% RH. At 35 °C and 27 °C shrinkage effects were observed in timber specimens and at 16 °C, swelling of wood specimens was observed. Volumetric shrinkage of all the specimens ranged between 4.4166~0.3323 % at 35 °C and 4.9679~0.0955 % at 27 °C. The maximum and minimum volumetric shrinkage percentages were showed observed in Mango and shown Paramara respectively at 35 °C. At 27 °C, Margosa and Satin were showed maximum and minimum values for the volumetric shrinkage effect. Four timber species: Cypress, Mango, Na and Nedun were shown to swell at 27 °C (room temperature) and 80-90 % RH. Swelling of all the specimens ranged between 2.8885~0.1279 % at 16 °C.

When it comes to mechanical properties, the highest MOR value was showed in Ebony (142.66 Nmm²) and the least was recorded in Albizia (17.36 Nmm²). The highest MOE value was showed in Tallow wood (14919.83 Nmm²) and the least was recorded in Albizia (1939.81 Nmm²). The highest compression perpendicular to grain value was showed in Ebony (20.97 Nmm²) and the least was recorded in Albizia (3.50 Nmm²). The highest compression parallel to grain value was showed in Tallow wood (62.48 Nmm²) and the least was recorded in Albizia (10.43 Nmm²).

Eight timber species: Albizia, Pine, Cypress, Ginisapu, Grandis, Lunumidella, Mango and Rubber were displayed high workability percentages.

Factor Analysis
Factor analysis was performed to develop a total wood linkage index where the highest common variance from all variables was put into a common score.

Factor 1, 2, 3, 4 and 5 were selected to develop the Total Wood Index (TWI) based on the scree plot shown in Figure 2. Rotated Factor Loadings and Communalities are shown in Table 4.

![Scree Plot](image)

Figure 2: Scree plot for all wood variables
Component score co-efficient values of five factors were used to calculate the strength index (Table 5).

**Calculation of the TWI**

Factor score was calculated using factor loading coefficients. Then variance contribution rate of each factor was divided by the cumulative variance rate of all the selected factors to determine the weights of each factor. The factor weight of each factor was multiplied by their factor scores and then added together to develop a Total Wood Index (Equation 8). TWI values of thirty-two timber species were calculated by using equation 8. TWI values of table 6 were used to develop a...
TWI = Index 1 + Index 2 + Index 3 + Index 4 + Index 5

\[ \text{TWI} = \sum_{i=1}^{5} \text{Index } i \] ...........................(8)

Where,

Index 1- \((\text{cum. value of timber species x factor coefficient } \times \% \text{ of variance of factor 1}) \div \text{Total }\% \text{ of variance}\)

Index 2- \((\text{cum. value of timber species x factor coefficient } \times \% \text{ of variance of factor 2}) \div \text{Total }\% \text{ of variance}\)

Index 3- \((\text{cum. value of timber species x factor coefficient } \times \% \text{ of variance of factor 3}) \div \text{Total }\% \text{ of variance}\)

Index 4- \((\text{cum. value of timber species x factor coefficient } \times \% \text{ of variance of factor 4}) \div \text{Total }\% \text{ of variance}\)

Table 6: Calculated TWI values of timber species

| Timber species          | TWI  | Timber species          | TWI  |
|-------------------------|------|-------------------------|------|
| Albizia falcatoria      | 208.05 | Azadirachta indica     | 786.89 |
| Melia dubia             | 430.85 | Eucalyptus grandis     | 830.55 |
| Cypressus macrocarpa    | 485.77 | Hevea brasiliensis     | 835.40 |
| Mangifera indica        | 533.74 | Berrya cordifolia      | 873.80 |
| Syzygium cumini         | 568.03 | Tectona grandis        | 897.41 |
| Michelia champaca       | 574.24 | Pericopsis mooniana    | 928.18 |
| Terminalia arjuna       | 615.38 | Khaya senegalensis     | 933.85 |
| Pterospermum siibertifolium | 617.49  | Diospyros ebenum       | 962.73 |
| Albizia odoratissina    | 622.19 | Eucalyptus robusta     | 1025.91|
| Swietenia macrophylla   | 628.00 | Alstonia macrophylla   | 1025.92|
| Albizia saman           | 649.99 | Cassia fistula         | 1065.04|
| Artocarpus heterophyllus| 652.01 | Chloroxylon swietenia  | 1222.54|
| Adina cordifolia        | 664.38 | Manilkara hexandra     | 1231.68|
| Madhuca longifolia      | 668.11 | Mesua ferrea           | 1306.82|
| Pinus caribaea          | 727.10 | Dipterocarpus zeylamicus| 1407.17|
| Vitex pinnata           | 745.93 | Eucalyptus microcorys  | 1561.79|
| Group-I | Group-II | Group-III | Group-IV |
|---------|----------|-----------|----------|
| Q₁ = 1/₄ th, Q₁ = 1/₄ * 32 = 8 |
| Q₂ = 2/₄ th, Q₂ = 2/₄ * 32 = 16 |
| Q₃ = 1/₄ th, Q₃ = 3/₄ * 32 = 24 |
| Q₄ = 2/₄ th, Q₄ = 4/₄ * 32 = 32 |

Figure 3: Dendrogram for TWI
The highest TWI value was recorded from *Eucalyptus microcorys* (1561.79). The lowest TWI value was recorded from *Albizia falcataria* (208.05).

Critical quartile values ($Q_1$, $Q_2$, $Q_3$ and $Q_4$) were used to classify the Total Wood Index values.

Figure 3 depicts the dendrogram which was created using total TWI values of 32 timber species (Table 6). According to the dendrogram, four clusters have appeared as four branches that occur at different horizontal distances. One outlier shows, timber species number 1, and five timber species numbers, 10, 22, 24, 28 and 31 are fused rather arbitrarily at much higher distances.

**Classification of timber according to TWI**

The tested 32 timber species could be classified into 4 Total Wood Index groups (Table 7). Four different timber groups were prepared based on critical quartile values of TWI.

Chowdhury et al., (2013) have prepared a timber grouping system for timber species in Bangladesh using wood properties. As depicted in the dendrogram derived in the present study, four TWI timber groups were prepared as low, medium, high and very high. *Albizia falcataria* is the only species that belongs to a very low TWI value (208.05). The TWI values of 5 TWI groups ranged from 208.05-617.49, 622.19-745.93, 786.89-962.73 and 1025.91-1561.79 respectively. Each TWR class from I to V had eight species The highest TWI value was recorded from *Eucalyptus microcorys* (1561.79).

Suriyamara, Kolon and Welang were listed in STC classification as special upper group and Mahogany and Jack was listed in luxury class together has obtained a lower grade in the present study. Some timber species; Rubber and Kaya coming under class II in the existing STC classification, have given group III as a superior grade by the present TWI classification. According to the present classification, Robusta, Hawarinuga, Ehela, Satin, Palu, Na, Hora and Tallow wood represent “very high” TWI values and grouped as IV. Timber species; Teak, Nudun and Ebony coming under the super-luxury class in the existing STC classification have been included in group III - “high” TWI values in the present classification.

**CONCLUSION**

Thirty-two timber species were grouped into four categories as low, medium, high and very high based on the values of the Total Wood Index (TWI) which considered physical, mechanical and anatomical properties of wood. Timber species; Robusta, Hawarinuga, Ehela, Satin, Palu, Na, Hora and Tallowwood which recorded very high TWI values (1025.91-1561.79) were grouped into category four whereas Margosa, Red Grandis, Rubber, Halmilla, Teak, Nudun, Khaya and Ebony were grouped into category three with high TWI values (786.89-962.73). Similarly, Suriyamara, Mahogany, Paramara,
Jack, Kolon, Mee, Caribbean Pine and Milla which recorded medium TWI values (622.19-745.93) were included in category II while Albizia, Lunumidella, Cypress, Mango, Madan, Ginisapu, Kumbuk and Welan were grouped into the category I with low TWI values (208.05-617.49). It is recommended to select timber species within the TWI-based groups to ensure the best matching thereby the attractive aesthetic appearance in finger-joint manufacturing.

This classification would be beneficial for finger-jointed furniture manufacturing work using mixed wood species as it could assist in matching different timber species for the production of finger joint boards by minimizing possible wood defects and dimensional effects. Further TWI groups could be used in planning and implementing reforestation and afforestation programs effectively by using different types of waste timber planks.

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