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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.

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).

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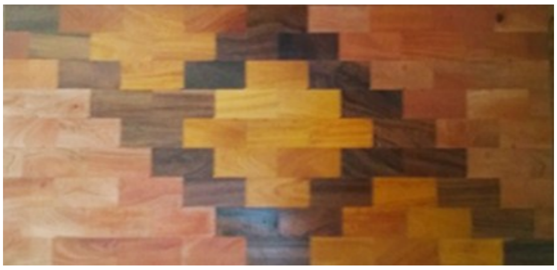


Figure 1. The appearance of finger-joint board, prepared by using different timber species

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). 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

Table 1: Selected 32 timber species

No.	Common Name	Botanical Name	Family	Origin	STC class	Floristic region
1	Albizia	*Albizia falcataria*	Fabaceae	Exotic	C-III LG	UC/ LCWZ
2	Caribbean Pine	*Pinus caribaea*	Pinaceae	Exotic	C-III	UC/ LCWZ
3	Cypress	*Cypressus macrocarpa*	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	*Michelia champaca*	Magnoliaceae	Exotic	C-II	WL
7	Grandis(red)	*Eucalyptus grandis*	Myrtaceae	Exotic	C-II	UC
8	Halmilla	*Berrya cordifolia*	Malvaceae	Indigenous	L	LCDZ
9	Havarinuga	*Alstonia macrophylla*	Apocynaceae	Exotic	C-II	LCWZ
10	Hora	*Dipterocarpus zeylanicus*	Dipterocarpaceae	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	Lunumidella	*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	*Tectona 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

properties (mean ray height, mean vessel diameter, vessels per square millimetre), mechanical properties (modulus of rupture, modulus of elasticity, compression parallel to the grain, compression perpendicular to the grain) workability and dimensional effects of wood species in three environmental conditions were investigated. Timber species were then grouped based on wood properties.

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,

Table 2: Standard sizes for specimens

Sample test	Standard Size (mm) W x H x L
Shrinkage test	25x25x100
Density test	25x25x30
Bending test	20 x 20 x300
Compression parallel to the grain	20 x 20 x 60
Compression perpendicular to the grain	50 x 50 x 50

W-width of the specimen, H-height of the specimen, L-length of the specimen

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

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.

Timber samples were seasoned to reduce the moisture content down to 12 %. This study was conducted at the wood laboratory in State Timber Corporation in Rajamalwatta Road, Battaramulla, Sri Lanka. All the tests were performed according to BS 373 (1957).

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 0 C for 48 hours (BS 373,1957).

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

$$Density = \frac{W}{V} \dots\dots\dots\dots (1)$$

W- Weight of oven-dried wood (kg)
V- Volume of wood (m^3)

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

$$r = \frac{Mr-M0}{M0} \times 100 \dots\dots\dots..(2)$$

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.

$$Bending\ strength = \frac{3F_1L_1}{2bd^2} \dots\dots\dots\dots..(3)$$

Where, F1= Serviceability Force (N), L1 = Length of the span (mm), b = Width of the specimen (mm) and d = Depth/Thickness of the specimen (mm)

$$MOR = \frac{3F_2L_1}{2b\,d^2} \dots\dots\dots\dots.(4)$$

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)

$$MOE = \frac{F_3 L_1^3}{4\delta b d^3} \dots\dots\dots\dots(5)$$

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 = 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).

$$Serviceability\ Ccompressive\ Strength = \frac{F3}{A} \dots\dots\dots(6)$$

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).

$$Volumetric\ Shrinkage = \frac{(l_{t\,max} \times l_{r\,max} \times l_{a\,max}) - (l_{t\,min} \times l_{r\,min} \times l_{a\,min})}{(l_{t\,max} \times l_{r\,max} \times l_{a\,max})} \times 100 \dots(7)$$

Where,
$l_{t\,max}$ *- Maximum length of tangential plane*
l_{rmax} *- 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/m^3)	MRH (mm)	MVD (mm)	VSQMM (no.)	Sh 35 (%)	Sh27 (%)	Sw 16 (%)	CPAG (N/mm^2)	CPERG (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)	W (0-100 %)
Albizia falcataria	Albizia	425	529.4	200	5	1.5122	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
Cypressus macrocarpa	Cypress	502	367.6	0	0	2.2511	-0.2643[a]	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	Ginisapu	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
Berrya cordifolia	Halmilla	796	234.6	80	23	1.0910	0.6208	0.4763	43.84	8.78	8141.70	91.14	80
Alstonia macrophylla	Hawarinuga	651	503.8	81	44	3.5924	0.4298	1.2319	40.06	8.53	9836.82	84.56	60
Dipterocarpus zeylanicus	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 arjuna	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

Table 3 continued

Botanical name	Common name	D (kg/m^3)	MRH (mm)	MVD (mm)	VSQMM (no.)	Sh 35 (%)	Sh27 (%)	Sw 16 (%)	CPAG (N/mm^2)	CPERG (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)	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	4.4166	-0.1784[a]	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
Mesua ferrea	Na	1087	757.4	96	5	2.4098	-0.9707[a]	0.6438	56.37	10.69	12175.20	140.65	20
Pericopsis mooniana	Nedun	795	307.6	123	5	1.8703	-0.8473[a]	1.0745	34.22	12.75	8715.65	111.88	40
Manilkara hexandra	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	274.2	176	8	2.7212	0.7212	0.1279	38.22	7.36	9723.76	98.85	60
Hevea brasiliensis	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	Suriyamara	840	529.6	73	10	1.4561	0.2798	0.7630	43.74	11.95	5454.79	102.79	40
Tectona grandis	Teak	720	555	185	10	1.7672	0.5297	0.2620	49.31	10.08	8478.26	90.77	40
Eucalyptus microcorys	Tallow wood	910	220.8	108	13	3.0746	0.5749	0.9497	62.48	11.47	14919.83	127.34	60
Pterospermum suberifolium	Welan	640	376.6	102	22	1.5833	0.8101	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 ^{0}C, Sh 27 – Volumetric shrinkage at 27 ^{0}C, Sw 16 ^{0}C, – Volumetric Swelling at 16 ^{0}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 ^{0}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 kgm^{-3}) was recorded in Ebony while the least was recorded in Lunumidella (400 kgm^{-3}) (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 Nmm^{-2}) and the least was recorded in Albizia (17.36 Nmm^{-2}). The highest MOE value was showed in Tallow wood (14919.83 Nmm^{-2}) and the least was recorded in Albizia (1939.81 Nmm^{-2}). The highest compression perpendicular to grain value was showed in Ebony (20.97 Nmm^{-2}) and the least was recorded in Albizia (3.50 Nmm^{-2}). The highest compression parallel to grain value was showed in Tallow wood (62.48 Nmm^{-2}) and the least was recorded in Albizia (10.43 Nmm^{-2}).

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.

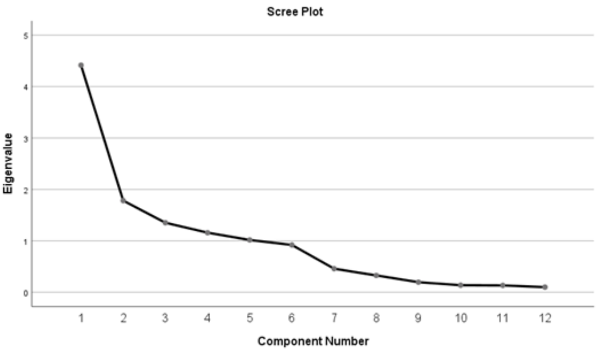


Figure 2: Scree plot for all wood variables

Table 4: Rotated Factor Loadings and Communalities (Varimax Rotation)

	Component					
Variables	**1**	**2**	**3**	**4**	**5**	**Communality**
D	**.896**	.121	.173	-.198	-.093	.895
MRH	**.085**	.053	.851	.234	.116	.802
MVD	-.030	**-.654**	.126	.049	.608	.816
VSQMM	.117	**.899**	.053	.038	-.003	.827
Sh 35	.006	.033	.189	**.935**	.007	.911
Sh 27	-.108	.012	-.004	-.021	**.899**	.820
Sw 16	.135	.405	**-.464**	.107	.263	.478
CPAG	**.846**	.050	-.110	.172	.004	.761
CPERG	**.815**	.093	.312	-.148	.084	.799
MOE	**.828**	.010	-.259	.299	-.087	.850
MOR	**.875**	.185	-.191	.070	-.182	.874
W	**-.773**	.100	-.295	.440	-.056	.891
% of Variance	35.715	12.280	11.033	11.029	10.997	
Total % of variance						81.052

Table 5: Component score co-efficient matrix

	Component				
	1	2	3	4	5
D	**.194**	.035	.115	-.134	-.033
MRH	**-.014**	.125	.657	.156	.046
MVD	.066	**-.391**	-.010	.074	.379
VSQMM	-.050	**.678**	.133	-.041	.139
Sh 35	.021	-.030	.130	**.710**	-.020
Sh 27	.003	.161	-.053	-.038	**.727**
Sw 16	.034	.279	**-.346**	.059	.309
CPAG	**.218**	-.061	-.127	.159	.044
CPERG	**.177**	.059	.212	-.102	.094
MOE	**.225**	-.130	-.245	.264	-.030
MOR	**.207**	.010	-.163	.076	-.077
W	**-.174**	.067	-.188	.311	-.046

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

$$\text{TWI} = \text{Index 1} + \text{Index 2} + \text{Index 3} + \text{Index 4} + \text{Index 5}$$

$$\text{TWI} = \sum_{i=1}^{5} Index\ i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where,

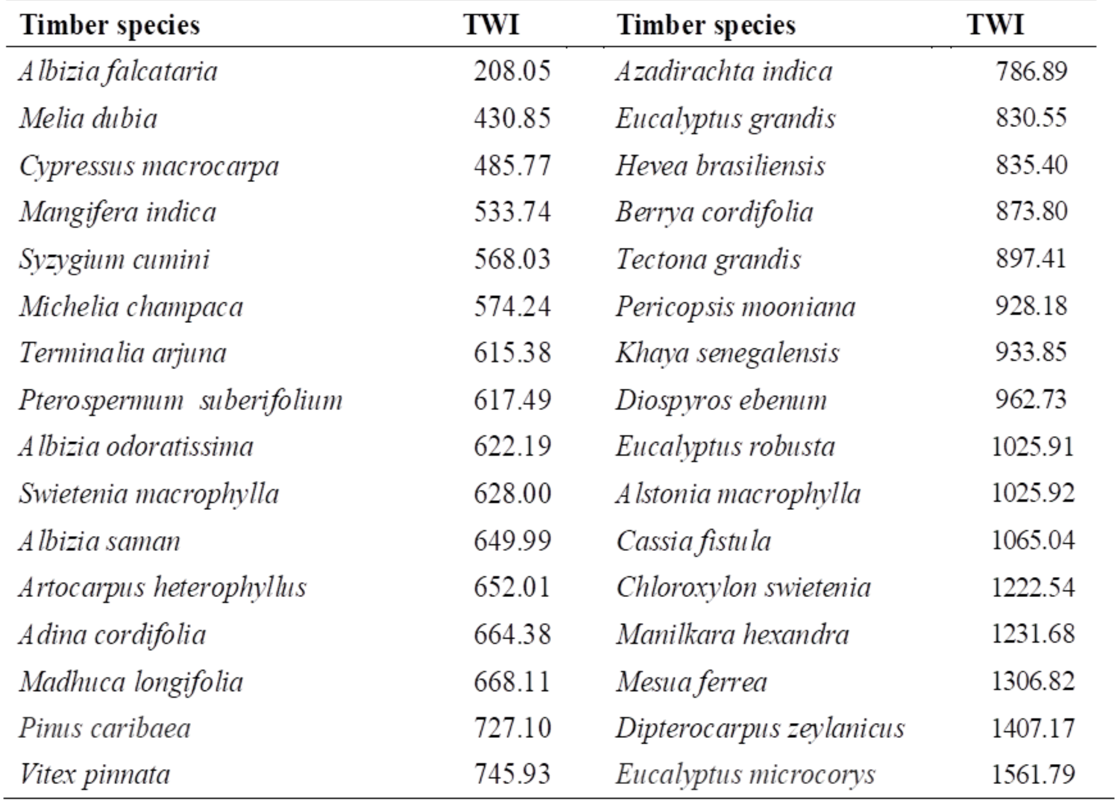
$$\text{Index 1-} \frac{\text{(cum. value of timber species x factor coefficient) x \% of variance of factor 1}}{\text{Total \% of variance}}$$

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

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

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

Table 6: Calculated TWI values of timber species



Timber species	TWI	Timber species	TWI
Albizia falcataria	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 suberifolium	617.49	*Diospyros ebenum*	962.73
Albizia odoratissima	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 zeylanicus*	1407.17
Vitex pinnata	745.93	*Eucalyptus microcorys*	1561.79

Group-I Group-II Group-III Group-IV

I-------------I---------------I---------------I---------------I

0 Q_1 Q_2 Q_3 Q_4

Q_1 = ¼ th, Q_1 = ¼ * 32 = 8

Q_2 = 2/4 th, Q_2 = 2/4*32 =16

Q_3 = ¼ th, Q_3 = 3/4 * 32 = 24

Q_4 = 2/4 th, Q_4 = 4/4*32 =32

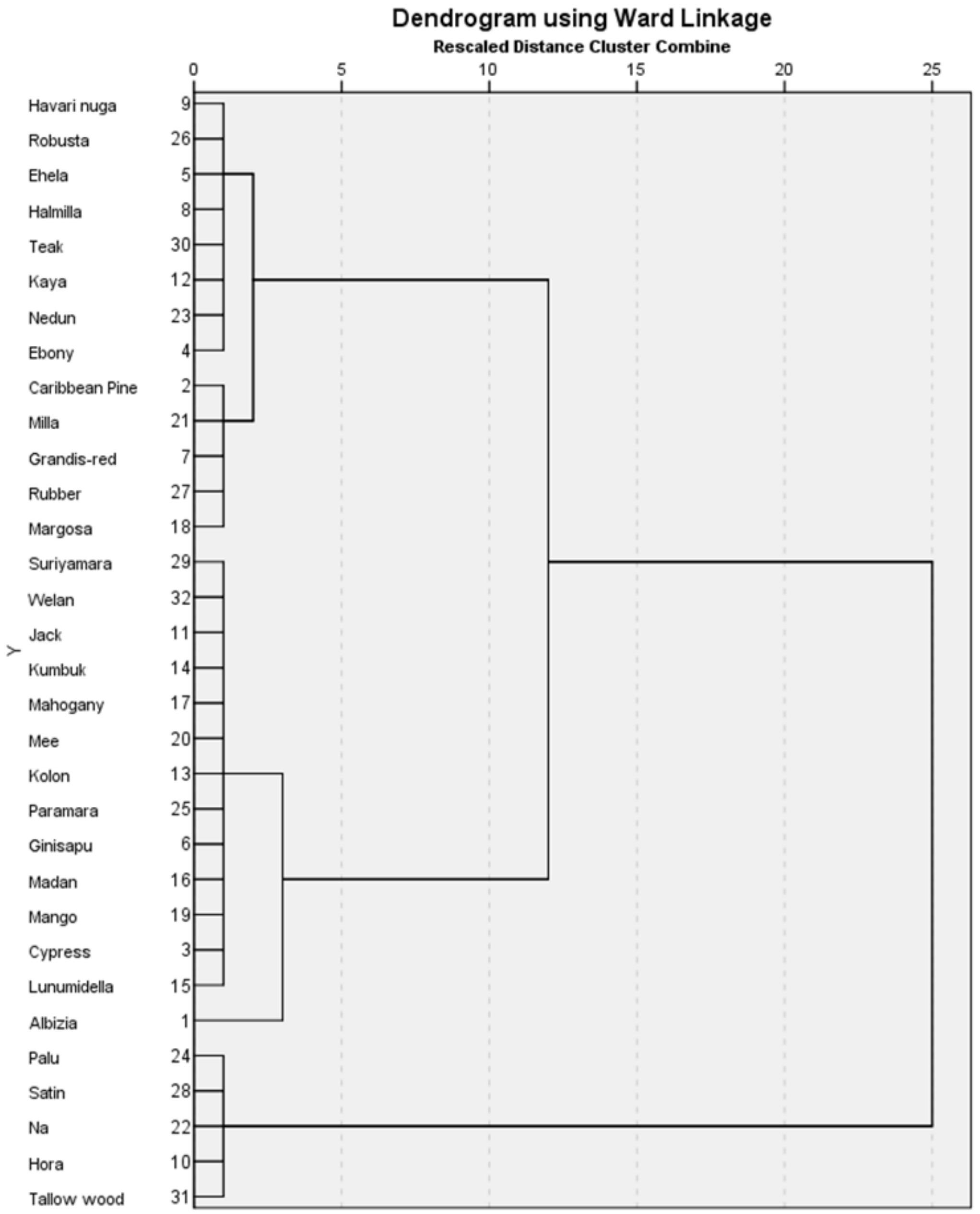


Figure 3: Dendrogram for TWI

Table 7 Timber classification based on TWI

TWI group	Category TWI value range	Timber species
Group I	Low (208.05-617.49)	Albizia, Lunumidella, Cypress, Mango, Madan, Ginisapu, Kumbuk, Welan
Group II	Medium (622.19-745.93)	Suriyamara, Mahogany, Paramara, Jack, Kolon, Mee, Caribbean Pine, Milla.
Group III	High (786.89-962.73)	Margosa, Red Grandis, Rubber, Halmilla, Teak, Nedun, Khaya, Ebony.
Group IV	Very high (1025.91-1561.79)	Robusta, Hawarinuga, Ehela,Satin, Palu, Na, Hora, Tallowwood

dendrogram (Fig.3). 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, 786.89-962.73and 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, Nedun 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, Nedun, 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.

REFERENCES

Ali AC, Uetimane JR, Lhate IA & Terziev N. 2008 Anatomical characteristics, properties and use of traditionally used and lesser-known wood species from Mozambique: a literature review. Wood Science and Technology 42:453 –472.

Baas P. and Zhang X. 1986 Wood anatomy of trees and shrubs from China:I. Oleaceae. International Association of Wood Anatomists Bull. n.s.7:195-220

British Standard 1957 BS 373: Methods of testing small clear specimens of timber. British Standards Institution. London.

British Standard institution Eropian Norm:15497 2014 Structural finger-jointed solid timber-Performance requirements and minimum production requirements, European Committee for Standardization. British Standard Institution. B 1000 Brussels.

Chowdhury MQ, Sarker SK, Debjc and Sonet, SS 2013 Timber species grouping in Bangladesh: linking wood. Wood Science and Technology, 797–813. DOI 10.1007/s00226-013-0532-0.

Da´valos, R and Ba´rcenas G 1999 Clasificacio´n de nicas de laspropiedadesmeca´lasmaderasmexicanasencondicio´n ‘‘seca’’. Madera y Bosques 5:61–69.

East African Community 2002 EAS 275: Timber-Determination of volumetric shrinkage, ISO 4858, East African Community.

Gryc V, Vavrčík H and Horáček P 2007 Variability in swelling of spruce wood with the presence of compression wood. Journal of Forest Science 53 (6):243-252.

Hoadley RB 2000 Understanding Wood: A craftsman's guide to wood technology, The Taunton Press, Newtown, USA.

International Association of Wood Anatomists 1989 List of microscopic features for Hardwood identification. Wheeler EA, Baas P and Gasson PE (eds), IAWA, Bui. N.s.: vol 10(3), The Netherlands, Leiden.

Moya R, Tenorio C and Meyer I 2012 Influence of wood anatomy on moisture content, shrinkage and during defects in Vochysiagua temalensis DonnSm, Sxi.For., Piracicaba.94, :249 -258.

Muthumala CK, De Siva S, Arunakumara KKIU and Alwis PLAG 2018 Investigate the most suitable glue type for finger-joints production in Sri Lanka. Research Journal of Agriculture and Forestry Sciences. 6 (11), 6-9.

Ratnasingam J and Tanaka C 2002 Wood Machining Processes: A Managerial Perspective, Tanabe Foundation, Japan.

Record SJ 1914 The Mechanical Properties of Wood, Create Space Independent Publishing Platform, Accessed in 05th

April 2017. http://www.basiccarpentrytechniques.com/

Reinprecht L 2016 Wood Deterioration, Protection and Maintenance, Wiley Blackwell Publishing house, West Sussex, United Kingdom.

Rowell RM 2013 Handbook of Wood Chemistry and Wood Composites. 2nd ed, Moisture properties. CRC Press, Taylor and Francis Group. 6000 Broken Sound Parkway NW.300. p. 77 -85.

Sandika AL, Pathirana GDPS and Muthumala CK 2017 Finger joint timber products for effective utilization of natural resources: An analysis of physical properties, Economic factors and Consumers' perception, International Symposium on Agriculture and Environment, University of Ruhuna, Sri Lanka, pp.109-111.

STC 2017 Timber classification, www.timco.lk. Accessed in 02nd April 2017.

STC 2018 Performance Report, Finance division, State Timber Corporation, Sri Lanka.

Sympson W 1991 Properties of wood related to Drying. In:1991. Dry Kiln Operator's Manual hand Book AH-188. Madison: Forest Products Laboratory.1-41.

Toong W, Ratnasingam J, Roslan MKM and Halis R 2014 The Prediction of Wood Properties from Anatomical Characteristics: The Case of Common Commercial Malaysian Timbers, "Wood anatomy & properties, "Bio Resources 9(3):5184-5197.

Usta I and Guray A 2000 Comparison of swelling and shrinkage characteristics of Corsican Pine (Pinus nigra var. maritima). Turkish Journal of Agriculture and Forestry 24:461-464.

Winandy JE 1994 Effects of long-term elevated temperature on CCA-treated Southern Pine lumber. Forest Products Journal. 44(6): 49–55.

Zobel SY 1995 Effect of growth rate on wood specific gravity and selected mechanical properties in individual species from distinct wood categories," Wood Sci. Technol. 29 (6): 451- 465.

Zobel BJ,and Van Buijtenen JP 1989 Wood Variation. Its Causes and Control, Springer-Verlag, Berlin.