Classification of Finger Joint Timber Based on Strength Index

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Abstract

At present, off-cut wood pieces are dumped by sawmills as they are considered to be wastes in the wood industry. Inadequate length of sawn timber material is also reported to be a limiting factor for fully utilization of timbers. Finger joint, a method which connects two small pieces of timber together is identified as a sound technique to minimize the wastage. As there is no classification system applicable for finger joint timber in Sri Lanka, the present study focused on developing a classification system for selected 32 timber species based on their strength properties. The relationship between the strength properties and density of selected timber species was also investigated. Strength properties of finger jointed timber species were evaluated by three-point bending and compression tests according to BS 373:1957 using Universal Testing Machine (UTM-100).Factors were identified through an analysis to determine the strength index for the selected samples. The strength index values were grouped into five strength classes as very low, low, medium, high and very high. Cluster analysis was used in grouping the species with similar strength properties. Regression analysis was performed to identify the strength index of compression parallel to grain, compression perpendicular to grain, modulus of elasticity and modulus of rupture varies on density. A significant correlation (p=0.05) between the strength index and timber density was observed.

Key words: Finger joint, timber classification, universal testing machine, strengthindex

1. Introduction

Timber has high demand in construction industry. Though it is one of the oldest building materials in Sri Lanka, it is widely used as a structural element in construction industry and furniture manufacturing industry.Waste sawn timber material of furniture factories and shorter sections of sawn wood are common problems associated with the timber industry in Sri Lanka as they are dumped by sawmills despite the fact that the timber is considered to be a scare resource.

Some of these timber wastes is used to fuel kiln dried boilers. Joining the shorter sections of timber together is considered to be another option in minimizing the wastage. Finger joints are described as interlocking end joints formed by machining a number of similar tapered symmetrical fingers in the ends of timber members using a finger joint cutter and then bonded together (BSI, 2014). Finger joint is a sustainable, eco-friendly and economically sound technique in furniture industry. It ensures the sustainable utilisation of small wood cut pieces which removed as waste (Sandika et al, 2017).

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Timber properties differ from species to species. Every matured timber species possesses a unique density range. Strength also varied with timber species. Mechanical properties most commonly measured and represented as "strength properties" for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain. (Forest product laboratory, 2010).

When finger joints expose to different stress conditions, their properties such as the strength varies from one timber species to another. As a consequence, some failures may occur when different timber species are mixed to produce finger joint production. There is no timber classification system in Sri Lanka based on their strength properties. Therefore, the main objective of this study was to develop a user-based timber classification system considering the strength properties of 32 timber species available in Sri Lanka and to find out the relationship between the strength index and the density of selected timber species.

2. Methodology

2.1 Timber sample selection

Locally available 32 timber species were selected for the study. The selected timber species are commonly used for structural and non-structural purposes in Sri Lanka and represent all the classes in the timber classification chart of the State Timber Corporation of Sri Lanka.

Table 1: Selected timber species.

No.	Common name	Scientific name	No.	Common name	Scientific name
1	Albizia	*Albizia molucana*	17	Mahogany	*Swietenia macrophylla*
2	Cypress	*Cypressus macrocarpus*	18	Mango	*Mangifera indica*
3	Ebony	*Diospyros ebenum*	19	Margosa	*Azadirachta indica*
4	Ehela	*Cassia fistula*	20	Mi	*Modhuca longifolia*
5	Microcorys	*Eucalyptus microcorys*	21	Milla	*Vitex pinnata*
6	Ginisapu	*Michelia champaca*	22	Na	*Mesua ferrea*
7	Grandis	*Euclayptus grandis*	23	Nedun	*Pericopsis mooniana*
8	Halmilla	*Berrya cordifolia*	24	Palu	*Manilkara hexandra*
9	Havarinuga	*Alstonia macrophylla*	25	Pine	*Pinus caribaea*
10	Hora	*Dipterocarpus zeylanicus*	26	Paramara	*Samanea saman*
11	Jack	*Artocarpus heterophyllus*	27	Robusta	*Eucaliptus 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*

2.2 Timber sample preparation

Selected timber species were collected from different saw mills of State Timber Corporation. The matured heartwood of the timber pieces was machined and trimmed to obtain standard sized samples. Samples were prepared based on a code of practice BS:373-1957 and BS EN 15497:2014 and then those were screened for timber defects. Five samples from each species were used for each test.

Then the samples were seasoned to reduce the moisture content to 12-15%. A moisture meter was used for measuring the moisture content and Universal Testing Machine (model: OZ-UTM-100PC, Capacity: 100kN, Power: 220-240Hz) was used for testing.

Table 1: Standard sizes for samples.

Sample 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

2.3 Calculation of the dry density

Dry weight of the timber samples was taken by placing at100-105^{o} C in an oven for 48 hours.

$$\text{(BS EN 373:1957) Density} = \frac{\text{Weight of oven dried wood (kg)}}{\text{Volume of wood (m}^3\text{)}} \quad (1)$$

2.4 Flexural strength test

Samples which were placed at normal room temperature showed better structural performance compared to those of at hot and wet conditioned (Vivek et al, 2016).Specimens were tested by three point bending test to obtain bending strength. Span is 280 mm for the test and load was applied on mid span of the specimen with a loading speed of 6mm/min.

2.5 Compression parallel to grain test

Compression parallel to grain test was carried out with loading plate moving speed of 0.5 mm/min and load vs displacement variation was obtained. Maximum load of the elastic limit was used to obtain the serviceability state compressive strength.

2.6 Compression perpendicular to grain test

Failure of the specimens was obtained by loading them perpendicular to grain with loading plate moving speed of 0.5 mm/min. Displacement was obtained with the load applied and load vs. displacement curve was plotted.

3. Results and Discussion

Analysis was done using SPSS 16.0 and Minitab computer software. Factor and cluster analysis were used for interpretation.

3.1 Calculated strength values

The load displacement curves of the mean value of the specimens from each timber species were used to calculate the strength values and showed in Table 3.

Table 3: Calculated strength values (N/mm^2).

	Common Name	Compression parallel to grain	Compression perpendicular to grain	MOE	MOR
1	Ehela	37.64	12.66	9928.79	107.97
2	Micro	62.48	11.47	14919.83	127.34
3	Ginisapu	28.31	9.00	5336.39	65.72
4	Grandis	47.23	4.92	8026.14	68.48
5	Halmilla	43.84	8.78	8141.70	91.14
6	Havarinuga	40.06	8.53	9836.82	84.56
7	Hora	44.36	15.46	13603.85	83.03
8	Jack	42.75	14.48	5872.66	63.93
9	Kolon	34.13	6.17	6196.25	66.46
10	Kumbuk	34.56	8.74	5719.41	60.59
11	Lunumidella	16.71	3.80	4206.02	25.61
12	Madan	23.72	9.62	5211.13	48.87
13	Mahogany	29.88	8.56	6140.01	66.22
14	Margosa	48.00	12.26	7438.61	76.76
15	Mi	37.06	10.25	5810.99	64.17
16	Milla	51.24	16.97	6736.23	74.76
17	Na	56.37	10.69	12175.20	140.65
18	Palu	53.10	17.21	11349.94	82.72
19	Paramara	29.94	4.99	3974.98	38.42
20	Pinus	48.50	4.11	6910.60	69.86
21	Rubber	29.60	5.71	7911.07	75.79
22	Satin	45.19	16.00	11489.57	142.66
23	Suriyamara	43.74	11.95	5454.79	102.79
24	Teak	49.31	10.08	8478.26	90.77
25	Welan	26.49	7.31	5760.22	59.88
26	Cypress	24.92	3.41	4491.91	53.13
27	Amba	28.96	10.10	5033.35	55.92
28	Albizia	10.43	3.50	1939.81	17.36
29	Khaya	37.09	11.78	8879.29	81.50
30	Ebony	52.90	20.97	8676.39	136.05
31	Robusta	38.22	7.36	9723.76	98.85
32	Nedun	34.22	12.75	8715.65	111.88

3.2 Classification of timber according to compressive strength parallel to grain values.

Figure 1 illustrates the dendrogram which was based on the compression strength parallel to grain values.

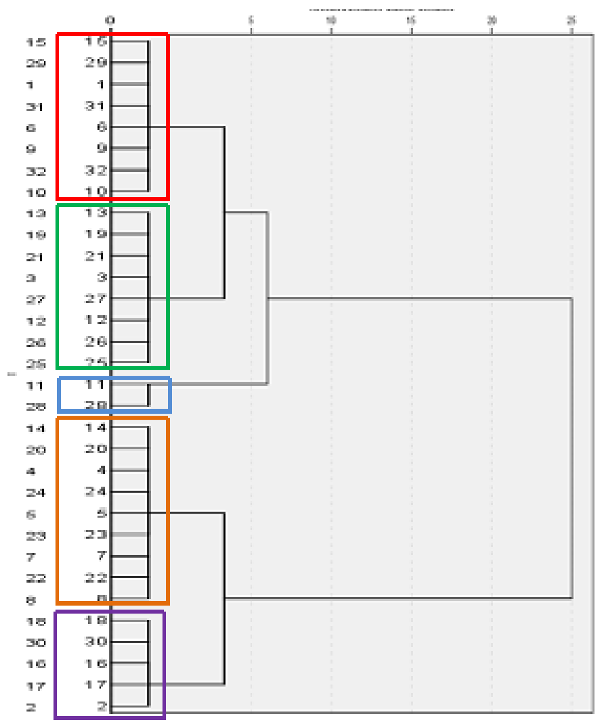

Figure 1. Dendrogram of compressive strength parallel to grain values.

Table 4: Classification of timber species according to compression strength parallel to grain.

Group	Compression parallel to grain	Timber species
Group 1	<20	Albizia, Lunumidella
Group 2	20-29	Ginisapu, Mango, Rubber, Mahogany, Paramara
Group 3	30-39	Kolon, Nedun, Kumbuk,Mi, Khaya, Ehela, Robusta, Hawarinuga
Group 4	40-49	Jak, Suriyamara, Halmilla, Hora, Satin, Grandis, Margosa, Pinus, Teak
Group 5	>50	Milla, Ebony, Palu, Na, Micro

Table 4 reveals that the highest compression parallel to grain value was recorded in Micro (62.48 N/mm^2) timber species. The lowest compression parallel to grain value was showed in Albizia (10.43 N/mm^2) and the second lowest value was recorded in Lunumidella (16.71 N/mm^2) timber species.

3.3 Classification of timber according to compressive strength perpendicular to grain values

Figure 2 represents the dendrogram which was based on the compression strength perpendicular to grain values.

According to table 5, the highest value for compression perpendicular to grain was observed in Ebony (20.97 N/mm^2) timber species and the lowest strength value was recorded in Cypress (3.41 N/mm^2) timber species.

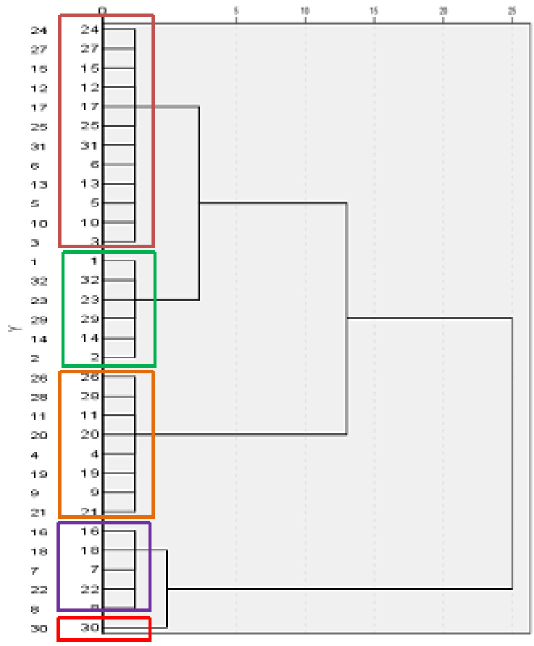

Figure 2. Dendrogram of compressive strength perpendicular to grain values.

Table 5: Classification of timber species according to compression strength perpendicular to grain.

Group	Compression perpendicular to grain	Timber species
Group 1	Very low (<6.5)	Cypress, Albizia, Lunumidella, Pinus, Grandis, Paramara, Rubber, Kolon
Group 2	Low (6.5-11)	Welan, Robusta, Hawarinuga, Mahogany, Kumbuk, Halmilla, Ginisapu, Madan, Teak , Mango, Mi, Na
Group 3	Medium (11-15.5)	Micro, Khaya, Suriyamara, Margosa, Ehela, Nedun, Jack, Hora
Group 4	High (15.5-19.5)	Satin, Milla, Palu
Group 5	Very high (>19.5)	Ebony

3.4 Classification of timber according to modulus of rupture

Figure 3 represents the dendrogram which was based on the modulus of rupture values. The Modulus of rupture (MOR) of tested samples ranged from 17.36 N/mm^2 to 142.66 N/mm^2. Table 6 reveals that the highest modulus of rupture value was recorded in Satin (142.66 N/mm^2) timber species. The lowest modulus of rupture value was showed in Albizia (17.36 N/mm^2) and the second lowest value was recorded in Lunumidella (25.60 N/mm^2) timber species.

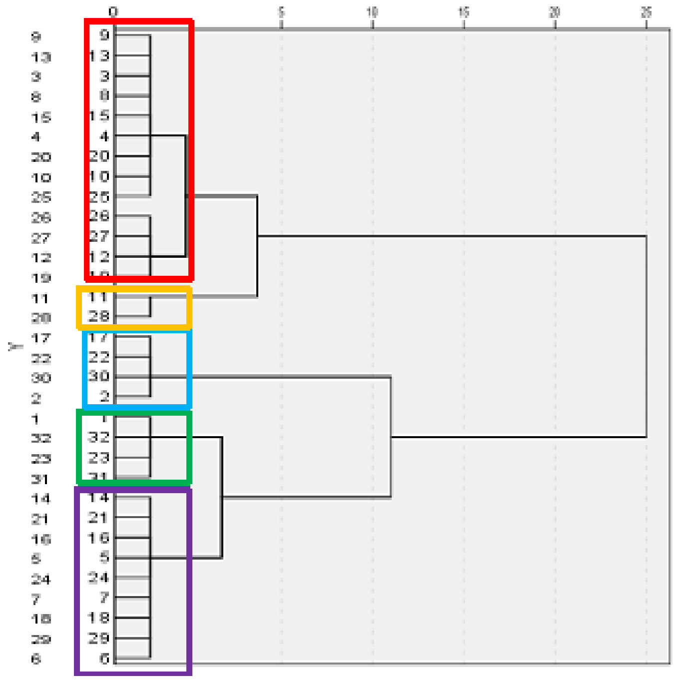

Figure 3. Dendrogram of Modulus of rupture.

Table 6: Classification of timber according to modulus of rupture.

Group	MOR (N/mm^2)	Timber species
Group 1	Very low (<49)	Albizia, Lunumidella
Group 2	Low (49-70)	Paramara, Madan, Cypress, Mango, Welan, Kumbuk, Jack, Mi, Ginisapu, Mahogany, Kolon, Grandis, Pinus
Group 3	Medium (70-91)	Milla, Rubber, Margosa, Khaya, Palu, Hora, Hawarinuga,Teak, Halmilla
Group 4	High (91-112)	Robusta, Suriyamara, Ehela, Nedun
Group 5	Very high(>112)	Ebony Micro, Satin, Na

3.5 Classification of timber according to modulus of elasticity.

Figure 4 represents the dendrogram which was based on the modulus of elasticity values. Table 7 shows that the highest modulus of elasticity (MOE) value was recorded in Micro (14919.83 N/mm^2) timber species. The lowest modulus of rupture value was showed in Albizia (1939.81 N/mm^2 timber species.

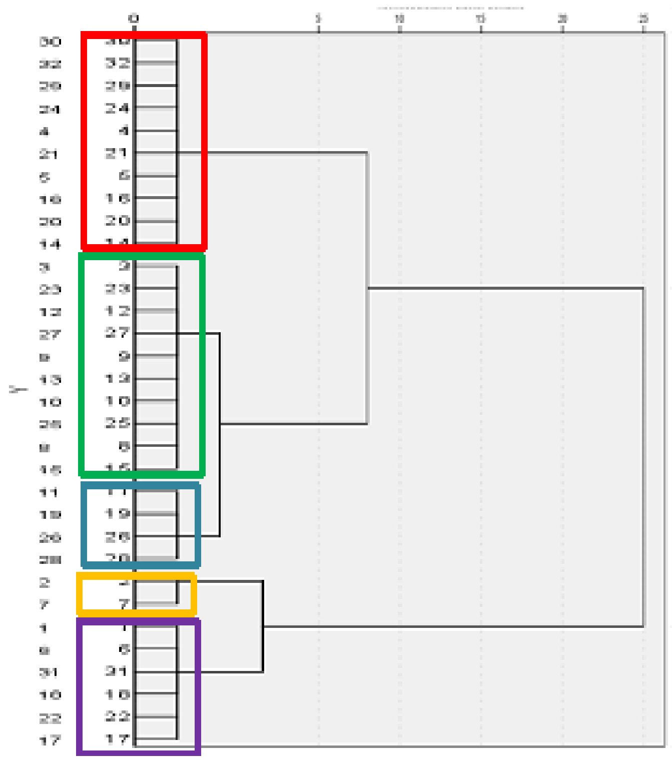

Figure 4. Dendrogram of Modulus of elasticity.

Table 7: Classification of timber according to modulus of elasticity.

Group	MOE (N/mm^2)	Timber species
Group 1	Very low	Albizia, Paramara, Lunumidella, Cypress
Group 2	Low	Mango, Madan, Ginisapu, Suriyamara, Kumbuk, Welan, Mi, Jak, Mahogany, Kolon
Group 3	Medium	Milla, Pinus, Margosa, Rubber, Grandis, Halmilla, Teak, Ebony, Nedun, Khaya
Group 4	High	Robusta, Hawarinuga, Ehela, Palu, Satin, Na
Group 5	Very high	Hora, Micro

3.6 Factor analysis

Factor analysis was performed using the Compression strength- parallel to grain, Compression strength-perpendicular to gain, Modulus of Elasticity, Modulus of Rupture in N/mm^2 to develop a strength index.

3.7 Calculation of strength index

Factor score was calculated using factor loading coefficients and the 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. Factor weight of each factor was multiplied by their factor scores and then added together to develop the strength index. Strength index was calculated according to Equation 2.

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

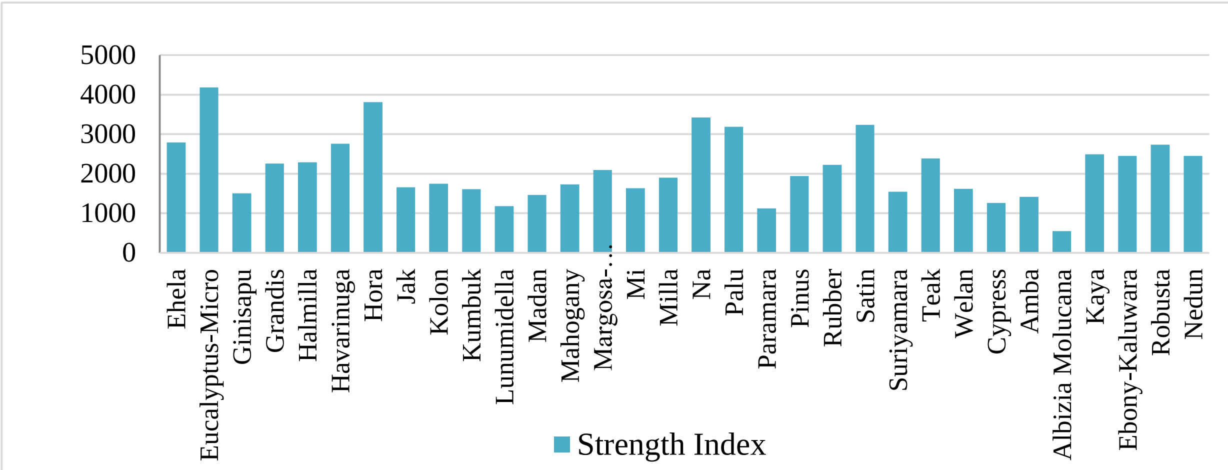

Figure 5. Strength indexes of timber species.

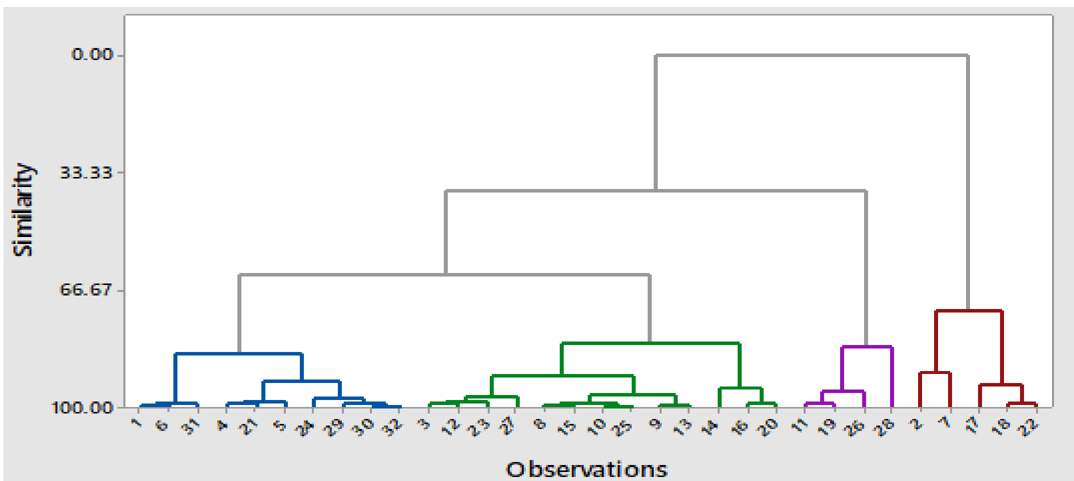

Figure 6. Dendrogram of strength index.

Cluster analysis was used for grouping the species which are similar to each other by their strength properties, modulus of rupture, modulus of elasticity, compression parallel to grain and compression perpendicular to grain which made the internal structure of data. Ward's hierarchical clustering method was used since it uses minimum variance and Euclidean distance measure was used. Figure 7 represents the dendrogram which was created using the strength index.

Table 8: Strength classification according to strength index.

Group	Index value	Timber species
Group 1	Very low(<1400)	Albizia, Paramara, Lunumidella, Cypress
Group 2	Low(1400-2200)	Mango, Madan, Ginisapu, Suriyamara, Kumbuk, Welan, Mi, Jack, Mahogany, Kolon, Milla, Pinus, Margosa
Group 3	Medium (2200-3000)	Rubber, Grandis, Halmilla, Teak, Ebony, Nedun, Khaya, Robusta, Hawarinuga, Ehela
Group 4	High (3000-3800)	Palu, Satin, Na
Group 5	Very High (>3800)	Hora, Micro

3.8 Classification of timber species according to workability

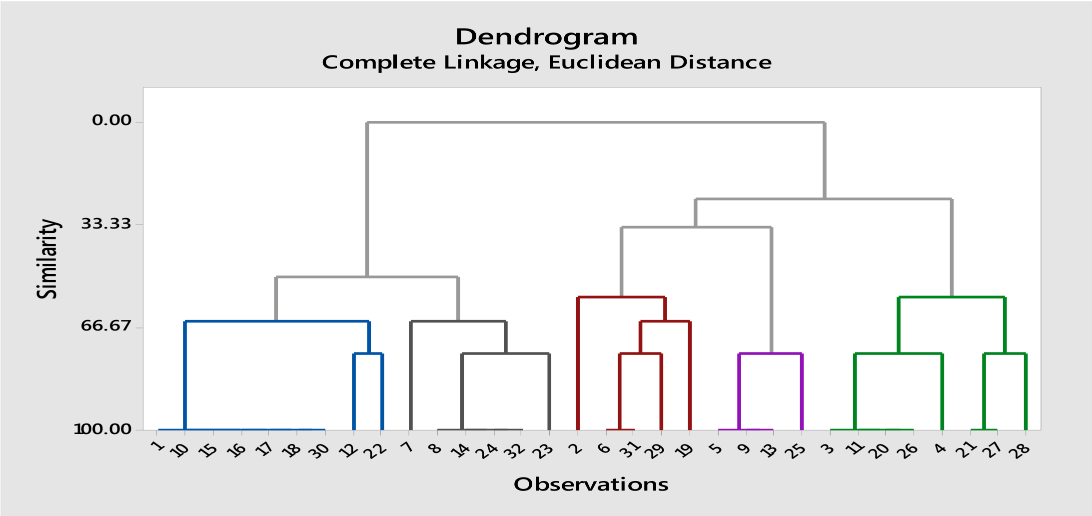

Figure 7. Dendrogram of workability.

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

There is a relationship between the strength index of timber and density values ($p<0.05$). Timber density is statistically significantly predicted the strength index at 33.9%. There is no good to fit into the model of the independent variable. Due to that reason, it should have other affected independent variables which affect to strength index. And also there is a relationship between the density with MOE, MOR, compression parallel to grain and compression perpendicular to grain ($p<0.05$). But R^2 values of these properties are nearly 30%. It means precision prediction could not be done by the model.

Table 9: p values and R^2 values

	p value	R^2%
Compression parallel to grain	0.000	38.00
Compression perpendicular to grain	0.001	32.60
MOE	0.000	33.68
MOR	0.000	33.87
Strength index	0.000	33.88

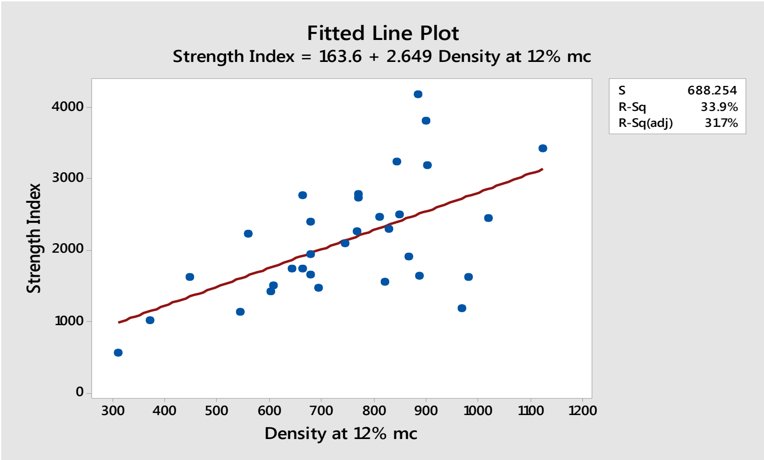

Figure 8. Regression between density and strength index.

Strength index=163.6+2.649 Density (kg/m^3); R^2=33.9%; R^2 (adj)=31.7%

4. Conclusion

Strength properties are considered to be the fundamental factor important for the selection of timber species for different uses. Density, modulus of rupture, modulus of elasticity, compression parallel to grain and compression perpendicular to grain have been used for strength classification.

The strength index values were used to prepare a timber classification system with 5 five strength classes as very low, low, medium, high and very high.

The strength class categories could be effectively used in selecting timber species for finger jointed furniture manufacturing industry. Timber selection based on strength properties could help in minimizing the defects occurring during use.

As revealed by the regression analysis, relationships among the density, MOR, MOE, compression parallel to grain, compression perpendicular to grain and strength index exist though no acceptable model could be developed from the independent variables.

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