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Assessment of the compression strength performance of finger –jointed wood products

C.K. Muthumala[1*], S. De Silva[2], P.L.A.G. Alwis[3] and K.K.I.U. Arunakumara[4]
[1]Research Division, State Timber Corporation, Sri Lanka
[2]Dept. of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Sri Lanka
[3]Dept. of Agric. Engineering, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka
[4]Dept. of Crop Science, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka
ck_muthumala@yahoo.com

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Abstract

Finger joint technique is used to eliminate wood defects which weaken the strength of sawn wood plank. The variation of compression strength of seven wood species commonly used for manufacturing furniture in Sri Lanka was investigated to assess finger joint efficiencies of wood species. Stratified random sampling was applied tomeasure compression tests in un-jointed and finger- jointed samples. BS 373: 1957 was used as the standard for test conducted with one Softwood species Pine (Pinuscaribaea) and Hardwood species; Grandis (Eucalyptus grandis), Jack (Aartocarpusheterphyllus), Kumbuk (Termineliaarjuna), Big leaf Mahogany (Swieteniamacrophylla), Satin (Chloroxylonswietenia) and Teak (Tectonagrandis). Two finger lengths (13 mm and 19 mm) were used and tested by Universal Testing Machine, using polyvinyl acetate adhesive. Data were analyzed by using ANOVA and Duncan's Multiple Range Test at 0.05 significant level. It was observed that the highest joint efficiency was recorded in 19 mm finger -jointed specimen of Grandis followed by 13 mm finger jointed Pine specimen for compression parallel to grain. The least joint efficiency was recorded in 13 mm finger jointed specimen of Kumbuk. Strength of compression perpendicular to grain of 19 mm finger-jointed specimens showed better performance than clear specimens, except Jack and Teak. Limited availability of historical data was a constraint during the study and Sri Lankan context, little effort has so far made on finger jointed manufacturing. The results will be utilized in the commercial application of finger joint manufacturing industry and useful to the traders and planners of timber industry.

Keywords: Compression strength, finger joint, efficiencies, timber.

Introduction

Timber is one of the best material for construction works, roofs, interior decorations, paneling, partition boards, wood carvings, furniture, floorings, window frames, doors, and musical instruments etc. Timber is a renewable resource which can effectively reduce climate change. Sri Lankan forests have about 450 timber species which are used for non-structural and structural purposes[1].

Timber processing operations generate enormous amount of wood residues and effective utilization of them ultimately has the potential of lessening the effect of climate change[2].

Off-cut wood is currently considered to be one of the wastes dumped by sawmills as they failed in finding alternate use of them. Waste sawn timber material of furniture factories and short length of sawn timber are also found to be constraints in timber industry. However, some of this wasted wood is already being used as fuel wood for various boilers and also for bread baking[3]. Another potential use of these wastes is a jointing system which is done through finger jointed techniques. Using this method, waste timber planks, trimmings and edgings can be used as finger jointed boards and furniture in sustainable way.

The two sets of fingers made with finger joint cutters are subsequently bonded together[4]. Finger joint technique is an economically valuable concept for sustainable production of furniture. It ensures use of small wood planks, which removed as waste[5]. The finger jointing technology in timber industry is considered to be a viable solution for minimizing the waste generation in furniture manufacturing and building construction activities. It is a new concept for Sri Lankan furniture industry[6].

Mostly used non-structural applications for finger joints consists of doors, casings and partition boards, which can be produced as value added products[7]. Mechanical properties of wood are important because they can significantly influence for the structural and non- structural applications[8]. The strength of wood depends on its species and some certain growth characteristics[9].

Polyvinyl acetate (PVAc) is one of the most common adhesives used in furniture industry. PVAc is ability to produce durable, strong bonds on wood-derived products in furniture manufacturing processes. PVA cadhesives are not recommended for jointing works under continuous load or subjected to high humidity and high temperature conditions[7,10].

Study conducted by Muthumala *et al*, have investigated the factors affecting on the glue strength of finger-joint production in Sri Lanka and identified PVAc –SWR as the best PVAc glue type for non- structural finger joint products and investigated that the relationship between finger geometry and finger length, fingertip thickness, finger pitch and slope of the finger[7,11]. Ayhan and Faith[12] was found that since finger joints are often regarded as weak joints and the failure of a finger joint is brittle from a global perspective, it is of great interest to identify the influence of defects in the bondline. Finger joint technology could be recognized as a potential area to expand the timber production in Sri Lanka. Furthermore, the technology ensures maximum utilization of the timber thus minimizing the pressure of forest resources. Majority of customers accept the uniqueness and attractiveness of finger joint products and are thus ready to pay an extra amount for this products'[12,13]. Variation of density, flexural strength and anatomical features of finger jointed wood products in Sri Lanka was studied by Muthumala *et al.*[14]. A recent research was conducted by Bustos *et al* on tension and bending studies of black spruce with different finger joint configurations[15]. Another research study was carried out in Sri Lanka was revealed that no significant differences in strength classes relevant to the grade stresses were observed for finger jointed and clear specimens for Satin, Mahogany, Jack and Grandis[16].

The main objective of this study was to investigate the compression strength performance of finger joints in commonly used timber species in Sri Lanka.

Materials and methods

Wood materials: For the experiment, following timber species which are commonly used for furniture manufacturing processes in Sri Lanka were selected and specimens were collected using stratified random sampling method from Southern and Central province in Sri Lanka (Table-1).

Adhesives: Polyvinyl acetate (PVAc) adhesive type called SWR was used as the bonding material. The highest glue strength was obtained from PVAc-SWR adhesive type for finger joint manufacturing industry in Sri Lanka[11]. The average weight of PVAc is 1.1kg/l. Adhesive was applied only one surface area (250-285g/m^2). The PVAc adhesive was supplied by PIDILITE producer in Mumbai, India[17].

Determination of moisture content: Specimens of 20x20x20 mm were weighed, and oven dried at 103^{0}C until specimens reach a constant weight. The moisture content (r) was determined using Equation-1[18].

$$r = \frac{M_r - M_0}{M_0} \times 100 \qquad (1)$$

where, r is the moisture content of specimen (%), M_r is the moist weight of specimen, M_0 is the fully dried specimen mass before impregnation.

Table-1: Selected timber.

Common name	Botanical Name
Grandis	*Eucalyptus grandis*[1]
Jack	*Aartocarpus heterphyllus*[2]
Kumbuk	*Terminalia arjuna*[2]
Big leaf Mahogany	*Swietenia macrophylla*[2]
Pine	*Pinus caribaea*[1]
Satin	*Chloroxylon swietenia*[2]
Teak	*Tectona grandis*[2]

1-Central Province, 2-Southern province.

Determination of average density: The timber samples were placed in an oven at 105^{0}C for 48 hours and the dry weight was measured. The density values were calculated by using equation-2[18].

$$\text{Density} = \frac{Weightof\ oven\ dry\ wood\ (kg)}{Volume\ of\ wood (m^3)} \qquad (2)$$

Wood density was calculated using oven-dry weight and green volume using water displacement method.

Preparation of test specimens: Wood materials were cut with seasoned wood planks. The specimens were prepared, heart wood portion with average moisture content of 12 ± 3% and 75 ± 5% relative humidity. They were cross cut using a circular saw machine to make the size of 60mm×20mm×20mm. Similar two pieces were made for joining with adhesive after making 13mm finger joint (the length of one joining piece is 36.5 mm). The specimens of the size of 80mm × 20mm × 20mm were cross cut using a circular saw machine into two pieces for joining 19mm finger jointed specimens (length of one joining piece is 40mm). An assembling pressure of 6 MPa was used for this research study[19]. All the specimens were prepared in finger joint manufacturing unit at State Timber Corporation, Galle, Sri Lanka.

Ten finger jointed specimens were used for each timber species with two finger joint lengths of 13mm and 19mm. Ten clear specimens were used for each timber species as control. Finger jointed wood specimens with same dimensions were made with constant finger geometry as shown in Figure-1 and Table-2.

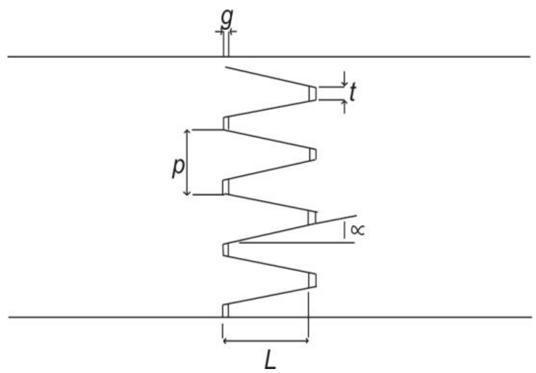

Figure-1: Geometric parameters of finger joint.

Table-2: Selected finger profiles for the finger joints.

Profile Finger	Length (L), mm	Tip width (t), mm	Pitch (P), mm	Slope angle (θ^0)	Gap (g), mm
1	13 mm	1.1	4	70	0.5
2	19 mm	1	4	70	0.5

Experimental procedure: Wood specimens which were placed for the period of two weeks at room temperature (27^0C) showed better strength performance compared to dry (35^0C) and wet (16^0C) temperatures[20]. The testing was done under both laboratory and manufacturing conditions according to BS 373:1957.

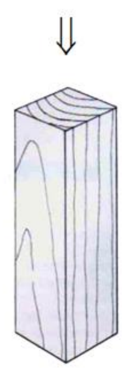

Figure-2a: Force direction to compression parallel to grain specimen.

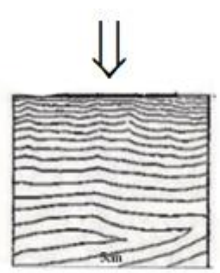

Figure-2b: Force direction to compression perpendicular to grain specimen.

Specimen's testing location was Wood Science Laboratory of State Timber Corporation, Sri Lanka. Compression tests were conducted with prepared specimens using Universal Testing Machine (UTM-100) with moving speed of 0.5 mm/min of Loading plate. Before loading the average density and moisture content were obtained for each species.

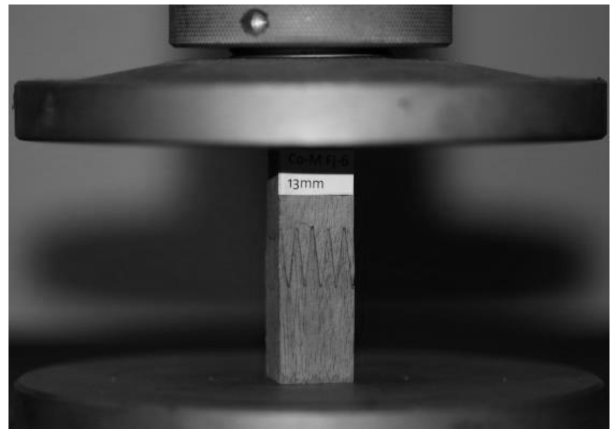

Figure-3a: Set –up for compression parallel to grain test of the finger-jointed specimens.

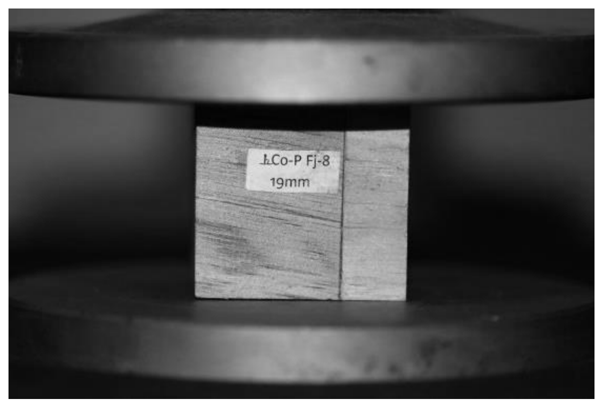

Figure-3b: Set–up for compression perpendicular to grain test of the finger-jointed specimens.

Figure-4a: Failure of the finger-jointed specimen under compression parallel to grain.

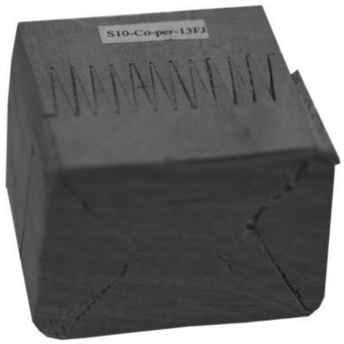

Figure-4b: Failure of the finger-jointed specimen under compression perpendicular to Grain.

Serviceability Limit State (SLS): SLS cannot be identified as a physical characteristic. This can be also identified as the point where the initial crack is occurred. In the timber designing, calculation check is performed at a point located at elastic zone where the structural behavior is purely elastic. Therefore, load at the point of proportion limit is considered as the maximum load of serviceability state. At the SLS, timber member is under the action of characteristic design (un-factored) loads. The compression strength values were calculated using Equation (3).

$$\text{Compressive strength} = \frac{\text{Maximum Load act on specimen at Serviceabiity state}}{\text{Load acting area}} \quad (3)$$

Results and discussion

Table-3 depicted the compression parallel to grain values and compression perpendicular to grain values of finger jointed specimens. The average moisture content of the specimens were 12 ± 3% with the relative humidity of 75 ± 5%.

Table-3: Compression parallel to grain values and compression perpendicular to grain values of finger- jointed specimens of seven timber species.

Timber Species	Finger Length	No of Specimens	Compression Parallel to Grain (N/mm^2)	Standard Deviation	Compression Perpendicular to Grain(N/mm^2)	Standard Deviation
Grandis	0	10	45.19	0.11	4.91	0.00
Grandis	13	10	27.48	0.39	5.85	0.02
Grandis	19	10	32.81	0.49	7.87	0.06
Jack	0	10	41.02	0.16	13.42	0.05
Jack	13	10	29.89	0.40	7.27	0.01
Jack	19	10	29.64	0.13	10.47	0.06
Kumbuk	0	10	33.81	0.16	7.39	0.01
Kumbuk	13	10	19.31	0.06	7.96	0.01
Kumbuk	19	10	20.97	0.23	8.82	0.03
Mahogany	0	10	30.31	0.02	8.20	0.01
Mahogany	13	10	26.42	0.10	7.67	0.06
Mahogany	19	10	25.75	0.12	8.20	0.04
Pine	0	10	45.78	0.51	5.53	0.03
Pine	13	10	27.12	0.19	7.55	0.04
Pine	19	10	31.85	0.04	7.48	0.05
Satin	0	10	46.36	0.09	16.65	0.01
Satin	13	10	35.49	0.44	12.85	0.03
Satin	19	10	36.59	0.84	17.85	0.04
Teak	0	10	47.40	0.24	9.20	0.05
Teak	13	10	32.57	0.34	7.43	0.02
Teak	19	10	33.87	0.13	9.02	0.12

According to the values shown in the Table-3, clear specimen of Teak has the highest compression parallel to grain value (47.40N/mm^2) and finger jointed Satin specimen with 19mm finger length has the highest compression perpendicular to grain value (17.85N/mm^2). Clear specimen of Grandis has the lowest compression perpendicular to grain value (4.91N/mm^2) and Kumbuk specimen with 13mm finger length has the lowest compression parallel to grain value (19.31N/mm^2).

Average density values of seven timber species varied as Satin (980kg/m^3), Kumbuk (756kg/m^3), Teak (720kg/m^3), Jack (645 kg/m^3), Grandis (570kg/m^3) Mahogany (570kg/m^3), and Pine (465kg/m^3) in descending order.

According to the Table-4, the highest average compression parallel to grain strength values were obtained from control specimens. Strength of compression parallel to grain of control specimens varied as, Teak > Satin > Pine > Grandis > Jack > Kumbuk > Mahogany in descending order. Compression parallel to grain values of finger jointed specimens with 13 mm finger length varied as, Satin> Teak >Jack> Grandis >Pine > Mahogany > Kumbuk in descending order. Strength of compression parallel to grain of finger jointed specimens with 19mm finger length varied as, Satin> Teak> Grandis Pine > Jack > Mahogany >Kumbuk. Finger-jointed Kumbuk showed the lowest strength in both finger lengths.

Furthermore the highest joint efficiency percentage under compression parallel to grain test was obtained from finger - jointed Mahogany species (87.18%) with 13mm finger length and the least joint efficiency (57.10%) was obtained from finger- jointed Kumbuk species with 13mm finger length. Kishan *et al*[21] investigated the joint efficiency of finger- jointed species and obtained 67.8% in 21mm finger length under compression parallel to grain test from Eucalyptus hybrid. Present study shows nearly similar trends as 72.61% was observed from Grandis (*Eucalyptus grandis*) species with 19 mm finger length.

Considering the compression parallel to grain strength, the joint efficiencies of wood species with 13mm finger length can be placed as Mahogany> Satin> Jack> Teak> Grandis >Pine> Kumbuk in descending order. Joint efficiencies of wood species with 19 mm finger length varied as Mahogany> Satin > Grandis > Jack > Teak > Pine > Kumbuk in descending order. Finger-jointed Kumbuk showed the lowest joint efficiencies both finger lengths.

As depicted in Figure-5, higher joint efficiencies were recorded in19 mm finger-jointed specimens than 13mm finger-jointed specimens under compression parallel to grain tests except Jack and Mahogany.

According to the Table-5, the highest average compression strength perpendicular to grain value (17.85N/mm^2) was obtained from finger jointed specimen of Satin with 19mm longer finger length) and control specimen of Satin (16.64 N/mm^2). Compression perpendicular to grain values of control specimens varied as Satin>Jack>Teak>Mahogany>Kumbuk> Pine > Grandis.

Compression perpendicular to grain values of finger jointed specimens with 13 mm finger length varied as Satin > Kumbuk > Mahogany > Pine > Teak > Jack> Grandis. Compression perpendicular to grain values of finger jointed specimens with 19mm finger length varied as Satin> Jack> Teak> Kumbuk > Mahogany > Grandis > Pine.

Based on the compression perpendicular to grain strength, joint efficiencies of seven timber species with 13mm finger length varied as Pine> Grandis> Kumbuk >Mahogany> Teak> Satin> Jack. Joint efficiencies with 19mm finger length varied as Grandis > Pine> Kumbuk > Satin > Mahogany> Teak> Jack. The highest joint efficiency percentage (160.22%) was shown in Grandis and the least (54.14%) was shown in finger -jointed Jack specimen with 13mm finger length.

Table-4: Joint efficiencies of timber species (Compression parallel to grain).

Compression parallel to grain (N/mm^2)					
Timber species	Control specimen	Specimen with 13 mm finger length	Joint Efficiencies %	Specimen with 19 mm finger length	Joint Efficiencies %
Grandis	45.19	27.48	60.81	32.81	72.61
Jack	41.02	29.89	72.86	29.64	72.24
Kumbuk	33.81	19.31	57.10	20.97	62.01
Mahogany	30.31	26.42	87.18	25.75	84.95
Pine	45.78	27.12	59.25	31.85	69.58
Satin	46.36	35.49	76.54	36.59	78.92
Teak	47.40	32.57	68.71	33.87	71.46

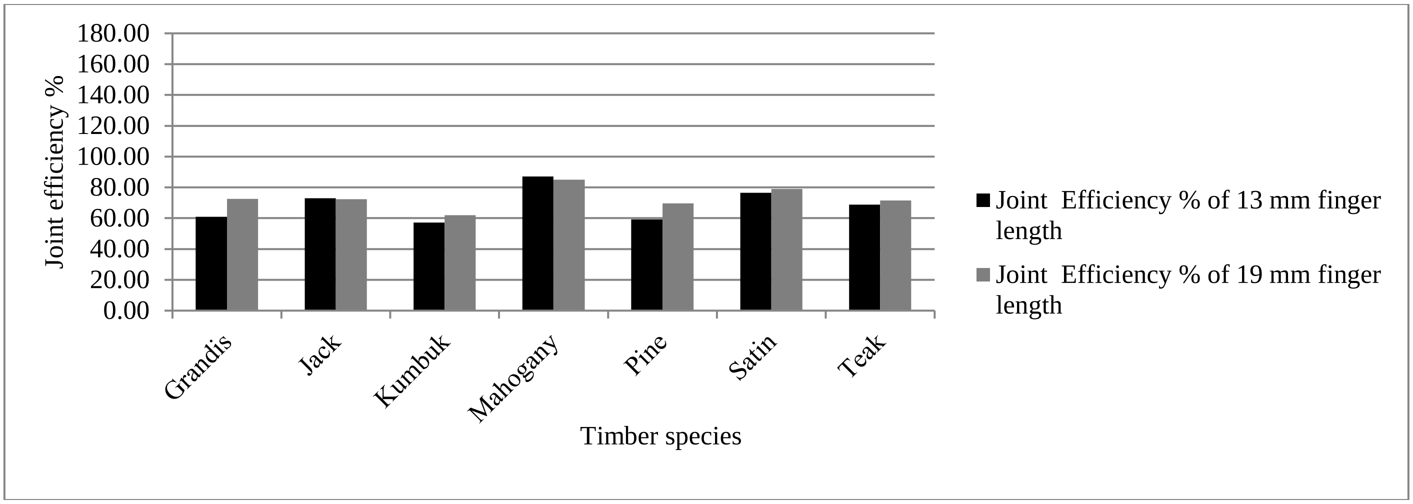

Figure-5: Variation in joint efficiencies of timber species under compression parallel to grain (CPAG) test.

Table-5: Joint efficiencies of timber species (Compression perpendicular to grain).

Compression perpendicular to grain (N/mm^2)					
Timber species	Control specimen	Specimen with 13 mm finger length	Joint Efficiencies %	Specimen with 19 mm finger length	Joint Efficiencies %
Grandis	4.91	5.85	119.06	7.87	160.22
Jack	13.42	7.27	54.14	10.47	77.95
Kumbuk	7.39	7.96	107.72	8.82	119.40
Mahogany	8.20	7.67	93.61	8.20	100.00
Pine	5.53	7.55	136.62	7.48	135.33
Satin	16.65	12.85	77.16	17.85	107.23
Teak	9.20	7.43	80.72	9.02	98.03

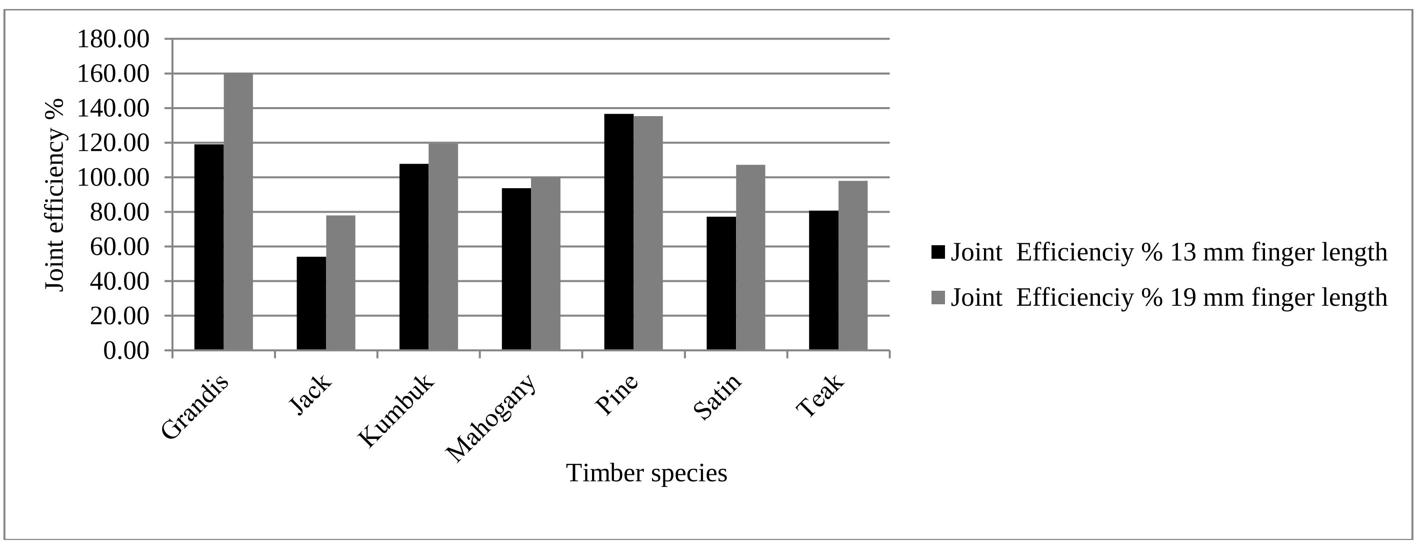

Figure-6: Variation of joint efficiencies with timber species under compression perpendicular to grain (CPEG) test.

Table-6: Mean values of Duncan test results (N/mm^2)

Test	Duncan Grouping	Mean	No.	Finger length (mm)
CPAG	A	41.15	70	0
	B	29.99	70	19
	C	28.11	70	13
CPEG	A	9.73	70	19
	B	8.93	70	0
	C	7.97	70	13

CPAG-compression parallel to grain, CPEG-compression perpendicular to grain.

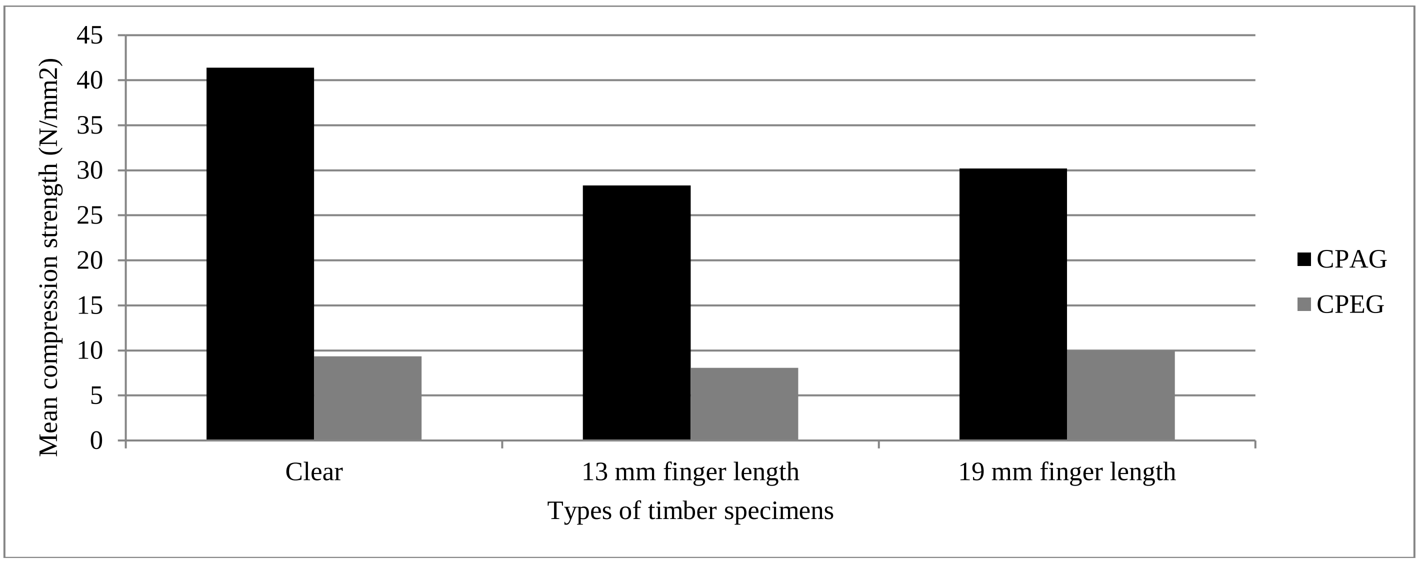

Figure-7: Variation of mean strength under compression tests in clear and two finger lengths.

As shown in Figure-6, higher joint efficiency percentages were recorded in19 mm finger jointed specimens than 13mm finger-jointed specimens under compression strength perpendicular to grain tests except Pine.

According to Table-6, the mean value of compression strength perpendicular to grain of the joints with a finger length of 19 mm was 9.73N/mm^2, which is higher than the corresponding value (7.93N/mm^2) of the joints with a finger length of 13mm. Similarly, the mean value of compression parallel to grain of the joints with a finger length of 19mm was 29.99N/mm^2, which is higher than the corresponding value of the joints (28.11N/mm^2) with a finger length of 13mm which would be duo to larger bonding area with the longer finger lengths.

Figure-7 clearly shows that all the mean strength values of compression parallel to grain were higher than strength values of compression perpendicular to grain. Mean strength values of compression perpendicular to grain varied in limited strength range (7.97–9.73N/mm^2) were significantly lower than compression parallel to grain values (28.11-41.15N/mm^2).

Conclusion

The results of this study conducted to assess the joint efficiencies of finger jointed seven wood species using two finger lengths of big leaf Mahogany (*Swietenia macrophylla*), Pine (*Pinus caribaea*), Satin (*Tectona grandis*), Kumbuk (*Terminelia arjuna*) Teak (*Tectonagrandis*) Grandis (*Eucalyptus grandis*) and Jack (*Aartocarpus heterphyllus*) led to the following conclusions.

In the case of compression parallel to grain strength values, the highest joint efficiency was recorded in 13mm finger jointed specimen of Mahogany followed by 19mm finger jointed specimen of the same species. The least joint efficiency was recorded in 13mm finger jointed specimen of Kumbuk. Considering the compression perpendicular to grain strength values, the highest joint efficiency was recorded in 19mm finger jointed specimen of Grandis followed by 13mm finger jointed Pine specimen. The least joint efficiency was recorded in 13 mm finger jointed specimen of Kumbuk.

Compression perpendicular to grain strength values of 19mm finger jointed specimens showed the highest performance than clear specimens except Jack and Teak. All the mean strength values of clear specimens in compression parallel to grain showed the highest strength values than compression perpendicular to grain values.

The mechanical properties of finger jointed timber vary with the finger geometry and the species of wood from which they have been made. Thus, it can be recommended that finger jointed timber planks with 19mm long fingers can be effectively used in industrial applications.

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