Utilization of waste timber for construction industry using finger joint technique

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1. Introduction Timber was man's first structural material and today is as important as ever for this purpose, it is likely, too through difficult to prove conclusively, that timber is used for a greater number of products than any other material [1]. While using timber in construction industry, waste timber materials and shorter section of timber which are dumped by sawmills is significant problem. Therefore, timber utilization is essential and timber utilization is urgently called by local timber industry due to the scarcity of timber species. In this case, the residues produced when using timber needs to be absorbed for suitable industries. Wastage of timber can be minimized by using proper machines and adopting new technology [2].

Finger joints (FJ**)** are described as interlocking end joint 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 [3]. Using this method, wastes can be used as Finger jointed beams, boards and furniture in sustainable, eco-friendly way [4].
Normally manufacturing process goes to cutting a whole tree, the finger joint process saves trees through a sustainable and eco-friendly approach. At the present as the environmental pollution occurs highly and forest plantation reduces fast, this finger joint concept is more suitable to the nature. According to the literatures, most of strength evaluation of finger jointed timber sections has been done on softwoods and there are limited numbers of studies on hardwoods. When consider the local timber species, most of them are hardwoods. Required mechanisms and machineries to perform FJ on hardwoods are available in Sri Lanka. Therefore, FJ is already used locally for non-structural timber products. Previous studies investigated that 19 mm finger length [5]and Polyvinyl acetate SWR adhesive is the most suitable adhesive for finger jointed timber species in Sri Lanka [6]. Further it can be recommended for the hardwood and hardwood off-cuts to be used as indoor structural component in construction industry in Sri Lanka by considering the mechanical properties.
There are some findings on the structural performance of the FJ in order to manufacture finger jointed timber products such as studs, trusses, columns, beams etc. Major objective of this study is, evaluate the flexural, compressive strength properties and MOE of finger jointed sections of Teak, Jack, Mahogany, Grandis, Satin, Pine and Kumbuk to suggest strength grade for structural applications by using small clear specimens method. To evaluate the FJ under actual loading conditions, structural scale specimens are used. Applications of FJ were investigated and it ensures the utilization of timber waste.

2. Experimental

2.1 Sample Collection

Teak, Jack, Mahogany, Grandis, Satin and Kumbuk were selected representing hardwoods and Pine was selected as softwood mostly used timber species in Sri Lanka. Waste timber relevant to each matured timber species which are discarded by STC saw mill in Boossa, Galle, Sri Lanka were collected. Sufficiently long pieces for joining purposes were cut from the waste timber and ensured that they are defect free portions by visual inspection.

2.2 Specimen Preparation

Specimens were prepared according to British standard BS 373:1957. Clear timber specimens take as control specimen and finger jointed timber specimen with same dimensions were made with constant finger geometry with the parameters shows in Image 1.

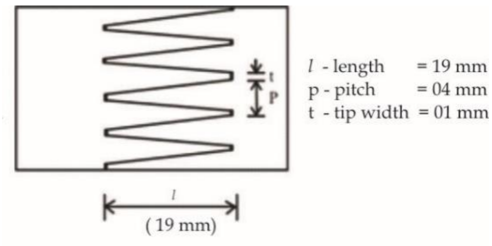

Image 1. Finger Geometry

Specimens were prepared (M.C. ~ 12%) at Finger joint factory, State Timber Corporation, Boossa, Galle, Sri Lanka.

2.3 Specimens for three-point bending test and compression test

Cross section of the timber specimen was 20mm×20mm and length are 300 mm for both finger jointed and clear timber specimens were prepared for three – point bending test and specimen was square shaped with 50mm length, width and depth for both clear and finger jointed timber species were prepared for compression perpendicular to grain. Cross section of the timber specimen was 20mm×20mm and length are 60mm for both finger jointed and clear timber specimens were prepared for compression parallel to grain [7].

2.4 Experimental procedure

Sample testing location was laboratory of STC, Battaramulla, Colombo, Sri Lanka. Tests were conducted on prepared specimens by using Universal Testing Machine (UTM) according to BS 373:1957 and before loading by UTM average density and natural moisture content were obtained for each species. Samples which were placed in normal room temperature (27 ^{0}C) conditioned showed good structural performance compared to hot and wet conditioned [8]. Strength classes identified according to BS 5268-2:2002 standard [9].

2.5 Average Density and Moisture Content

Moisture content was measured by using moisture meter just before test and average density of timber species were calculated using equation 1. Dry weight of the timber samples was taken by placing in 105^{0}C oven for 48 hours.

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

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 2 mm/min. Displacement was recorded with the applied load and load vs displacement graph was plotted. Bending strength was calculated for ultimate state (MOR) and serviceability state by using load vs displacement graph. Maximum load represents the ultimate load and maximum load in elastic region represents the serviceability load.

2.6 Modulus of Elasticity (MOE)

Modulus of Elasticity is an indicator for stiffness of the wood and only applies to conditions within elastic limit [10].

2.7 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. Compressive strength of clear timber at ultimate state could be calculated by the maximum load acting on the timber before the failure which can be obtained from the load deflection curve of compression parallel to grain test. Maximum load of the elastic limit was used to obtain serviceability state compressive strength.

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 load applied and load was displacement curve was plotted. Maximum load could be identified on graph to calculate ultimate compressive strength and maximum load of the elastic region was used to calculate serviceability compressive strength.

3. Results and Discussion

Average density, timber class and moisture content percentage of selected timber species are shows in Table I and Table II.

Table I. Average density and timber class of selected timber species

Average Density values of seven timber species are varied between 440-980 kg/m³

Species	Average Density (kg/m³)	Timber Class according to STC Classification
Teak	740	Super Luxury
Satin	980	Luxury
Mahogany	560	Luxury
Jack	640	Luxury
Kumbuk	720	Special Class
Grandis	550	Class II
Pine	440	Class III

Characteristic bending strength was calculated by the following factors to derive grade bending stresses. According to BS5268-2; Section depth less than 72 mm – 0.856, Duration of the load very short term – 0.571

Table II. Average moisture content of tested specimens

Species	Specimen used for bending test (%)		Specimen used for compression parallel to grain test (%)		Specimen used for compression Perpendicular to grain test (%)	
	Clear	FJ	Clear	FJ	Clear	FJ
Teak	10.5	10.28	10.63	10.58	9.98	10.05
Satin	12.13	12.6	11.15	11.1	10.55	10.5
Mahogany	10.85	10.88	10.35	10.33	9.68	10.03
Jack	12.33	12.5	9.38	9.58	10.7	10.65
Kumbuk	11.53	11.15	11.3	12.18	13.83	13.3
Grandis	13.5	13.35	11.35	11.65	12.45	12.1
Pine	11.35	11.38	11.15	11.6	10.43	10.4

3.1 Bending test results

Table III and Table IV shows the Average ultimate bending strength (MOR), average serviceability bending strength of tested specimens and strength reduction percentage.

Table III. Average ultimate bending strength of tested specimens (MOR)

According to Table III, finger jointed Pine and Teak have strength reduction percentage 3.56% and 27.52% respectively as the lowest strength reductions at ultimate state while making the finger joint.

Species	Clear Timber Specimen (N/mm^2)	Finger Jointed Timber Specimen (N/mm^2)	Strength Reduction Percentage %
Teak	77.74	56.34	27.52
Satin	104.57	54.81	47.58
Mahogany	61.38	41.07	33.09
Jack	64.47	42.47	34.12
Kumbuk	60.13	39.74	33.91
Grandis	56.37	38.80	31.16
Pine	58.31	56.23	3.56

Table IV. Average serviceability bending strength of tested specimens

Species	Clear Timber Section (N/mm^2)	Finger Jointed Timber Section (N/mm^2)	Strength Reduction Percentage %
Teak	26.02	23.20	10.84
Satin	27.94	25.28	9.5
Mahogany	24.59	16.64	32.34
Jack	30.58	17.49	42.82
Kumbuk	25.77	13.26	48.54
Grandis	29.39	16.09	45.25
Pine	20.86	16.8	19.43

Table IV shows that characteristic bending strength reduction is less for Satin and it is 9.5% compared to clear timber. Teak and Pine also have strength reduction % less than 20%.

3.2 Modulus of Elasticity (MOE)

Species	Control (N/mm^2)	Finger Jointed (N/mm^2)	MOE Reduction (%)
Teak	8865.07	8796.66	0.77
Satin	9703.65	9493.32	2.17
Mahogany	6208.59	5552.56	10.57
Jack	5537.37	5391.96	2.63

Kumbuk	5225.88	4383.83	16.11
Grandis	5375.64	5286.38	1.66
Pine	5361.99	6657.08	-24.15

Table V. Average MOE for tested species

According to Table V MOE for clear timber and finger jointed timber are approximately same and Pine (soft wood) shows MOE increment and other species have MOE reduction less than 20%.

3.3 Compression parallel to grain

Ultimate load and serviceability load can be obtained from the load-deflection curve of compression test to calculate compressive strength. Compressive strength parallel to grain for control and finger jointed specimens of selected species are shown in Table VI and Table VII.

Table VI. Average ultimate compressive strength parallel to grain for tested specimen

Species	Clear Timber Specimen (N/mm^2)	Finger Jointed Timber Specimen (N/mm^2)	Strength Reduction Percentage %
Teak	60.89	43.96	27.8
Satin	60.51	53.66	11.32
Mahogany	37.48	34.89	6.91
Jack	54.53	38.63	29.16
Kumbuk	48.66	33.82	30.49
Grandis	56.75	43.34	23.62
Pine	46.83	38.58	17.63

Mahogany has less strength reduction as 6.91% according to Table VI. Satin and Pine also has strength reduction less than 20% compared to clear timber specimens.

Table VII. Average compressive strength parallel to grain for tested specimen at serviceability state

Species	Clear Timber Section (N/mm^2)	Finger Jointed Timber Section (N/mm^2)	Strength Reduction Percentage %
Teak	24.45	18.2	25.54
Satin	42.21	36.62	13.24
Mahogany	15.62	13.51	13.51
Jack	14.93	14.7	1.53
Kumbuk	29.53	20.17	31.68
Grandis	15.61	13.55	13.22
Pine	15.89	15.40	3.04

Serviceability Compressive strength parallel to grain of Jack is almost similar for clear and finger jointed timber according to Table VII. Satin, Mahogany, Grandis and Pine also have strength reduction less than 20% at serviceability state.

3.4 Compression perpendicular to grain

Results of compression perpendicular to grain test significantly different from bending and compression test results because finger jointed timber strengths have been increased for all the specimens other than Jack compared to clear timber.

Table VIII. Average compressive strength perpendicular to grain for tested specimen at serviceability state

Serviceability Compressive strength perpendicular to grain of Jack is shows 17.90 % Strength Reduction Percentage and other six species are not show Strength Reduction Percentage. The strength values of Finger Jointed Timber specimens of Teak, Satin, Mahogany, Kumbuk, Grandis and Pine are higher than the clear timber specimens.

3.5 Strength class identified

Table IX. Strength class identified according to BS 5268-2:2002

Species	Category	Clear Timber	Finger jointed Timber
Teak	Hard wood	D40	D35/D40
Satin	Hard wood	D40/D70	D40/D70
Mahogany	Hard wood	D30	D30
Jack	Hard wood	D30	D30
Kumbuk	Hard wood	D40	D30
Grandis	Hard wood	D30	D30
Pine	Soft wood	C27	C22/24/27

While they were used as finger jointed timber, Teak shows properties similar to both D35 and D40. Finger jointed Satin, Mahogany, Jack and Grandis timber are almost similar to clear timber in this case. Kumbuk has been changed from D40 to D30 while use as finger jointed timber. Finger jointed Pine shows strength class of C22, C24 and C27.

4. Conclusion

Strength properties of finger jointed seven timber species, commonly used in Sri Lanka were evaluated by three-point bending and compression tests according to BS 373:1957 by using Universal Testing Machine.

Satin timber is the best species to perform finger joint in order to withstand bending in structural element and Jack timber is to withstand compression parallel to grain test by the hardwoods in local industry.

Compression perpendicular to grain test significantly different from bending and compression parallel to grain test results because finger jointed timber strengths have been increased for all the specimens other than Jack compared to clear timber.

Strength classes were identified according to BS 5268-2:2002. 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. Both clear and finger jointed timber specimens obtained D40 for Satin and Teak, D30 for Jack, Mahogany and Grandis. Teak showed properties similar to both D35 and D40 when it was used as finger jointed timber.

Species	Clear Timber Section (N/mm^2)	Finger Jointed Timber Section (N/mm^2)	Strength Reduction Percentage %
Teak	8.53	10.08	-18.13
Satin	15.51	17.16	-10.66
Mahogany	7.85	8.13	-3.66
Jack	13.43	11.03	17.90
Kumbuk	7.71	8.28	-7.31
Grandis	5.14	5.38	-4.72
Pine	6.06	7.72	-27.39

Kumbuk was shown to change from D40 to D30 while it was used as finger jointed timber.

Finger jointed Pine showed properties of C22, C24 and C27. The present findings proved that finger joint technique is useful in effective utilization of off-cut timbers.

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