Effect of Finger Joint on Flexural Strength of Teak Wood

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***Abstract* - This paper presents the flexural properties of rectangular Burma teak wood beam without finger joint and with finger joint. Finger joints enable full utilization of wood. Finger jointing technique is also used to eliminate wood defects which weaken the strength of wood. This paper considers finger joint as defined defect and its effect on the flexural strength is determined. Teakwood is hard and heavy, seasons rapidly and has good durability. The specimens were studied under three point bending test. Both edge wise and flat wise tests were carried out. It is observed that Burma teakwood beam without finger joint is stronger than beams with finger joints. Because of finger jointing the flexural strength reduces. It can be concluded that the strength loss can improved upon by selecting suitable geometry of finger joint and a suitable adhesive. It is recognized that further studies are necessary on jointing techniques of wood and type of adhesive so as to equal the flexural strength properties of clear teak wood beams.**

Keywords – Burma teak wood, finger Joint, flexural strength, three point bending.

I. INTRODUCTION

Wood is widely used material because of its low cost, high specific strength, high stiffness and high toughness. It is the oldest and most commonly used building and structural material in the world. It is a renewable resource, and its production requires low energy input. Wood is fiber-composite material with complex overall structure [1].

Teakwood is moderately hard, heavy and has good machining properties. It is naturally durable and possesses high dimensional stability. It is most valuable and best known tropical timber species and highly valued for use in outdoor equipment, ship building, furniture, rural housing and general carpentry [2].

Finger joints enable full use of wood. By cutting out the defects and joining them with finger joint increases the utilization of wood. From the research carried out on the strength of finger jointed woods of various species it is observed that this technique reduces the strength of the member [3]-[5].

In a recent study on evaluation of tensile strength performance of both vertically and horizontally finger-jointed laminate with 3 different lengths of finger profiles for 5 softwood species. Douglas fir finger-jointed lumber showed the best joint efficiency at 74.1%, followed by spruce-pine-fir (SPF) groups, at 65%, among the 5 wood species. Both Japanese cedar and southern pine finger-jointed lumber had lower joint efficiencies due to weak finger profiles causing early failure in tension. Southern pine finger-jointed lumber was found to have the highest tensile strength, 116.6% higher than the lowest Japanese cedar group, followed by the Douglas fir group which was 65.9% higher. The hemlock and SPF groups had similar tensile strengths, and they were also higher than the Japanese cedar group by 46.8 and 40.7%, respectively. The tensile strength of lumber joined with a 21-mm long finger profile showed a significantly lower value than those with 18- and 24-mm finger profile groups by 11.3 and 8.5%, respectively, due to the wide finger tips. The results show that there was no significant difference in tensile strength of finger-jointed lumber between horizontal and vertical finger formation. With the exception of the 21-mm finger-jointed group, slightly higher tensile strength (7.4%) for the 18- and 24-mm finger length groups with vertical finger-joints was obtained, compared to those with horizontal joints [3].

In an experiment conducted to study flexural properties and joint efficiencies of Finger joints from three tropical African hardwoods such as Obeche, Makore and Moabi were prepared using three finger profiles, three end pressures and resorcinol-formaldehyde adhesive, to assess the effect of the study variables on the performance of the joints. Finger profile geometry was found to have a statistically significant influence on Modulus of Elasticity and Modulus of Rupture of Finger joints from the three tropical African hardwoods. Finger joints from the low density Obeche exhibits highest joint efficiency, high flexural performance and wood failure followed by that from the medium density Makore. Finger joints from the high density Moabi exhibited the lowest joint efficiency and wood failure[4].

In a study on the effects of poly vinyl acetate (PVAc) bonding (durability classes D1, D2, and D3 according to EN 204: 2001), finger length (4 and 10 mm), and finger orientation on the bending strength of finger-jointed steamed and un-steamed beech wood (Fagus sylvatica) were studied. Specimens were prepared according to EN 385 (2001) and modulus of rupture (MOR) and modulus of elasticity (MOE) tests were performed according to the procedures detailed in the ISO 10983 (1999) and DIN 52186 (1978) standards. The MOR of un-steamed wood joints ranged from 33.51 to 82.24 N/mm2, whereas the MOR of the steamed wood joints fluctuated from 34.9 to 80.27 N/mm2. In both steamed and un-steamed wood the specimens with a finger length of 10 mm showed higher MOR than the specimens with a finger length of 4 mm. The MOE of the un-steamed specimens was not affected by finger jointing, whereas, the MOE of the steamed specimens increased slightly (by 5.4%) compared to the control solid wood. The MOE values of the un-steamed specimens were approximately the same as those of the control solid wood [5].

The experimental study carried out to study the flexural properties of teakwood filled steel tube, it is observed that the defective teak wood filled specimens are weaker in flexural strength and tearing of steel tube is observed when teak wood beam with knot is tested [6]. It is better to replace such knots by suitable jointing technique and determine the strength properties so as to have better control on design aspects of wood members subjected to different kind of loading.

In the present work an experimental and theoretical study was conducted on the Burma teakwood material procured from local market to incorporate the possible adverse conditions in selection of teak wood material. The source of material is assumed to be Burma, and adhesive used for finger joint is also unknown. The finger joint geometry is obtained by carefully dismantling the joint. The Finger joint is considered to be a defined defect in this case and loss of strength and stiffness is determined in comparison with defect free beam.

II. MATERIALS AND SPECIMENS

A. Burma teak wood properties

Commercially available rectangular shaped finger jointed Burma teak wood material was procured from local market which is manufactured as per ASTM D-5572. Fig. 1 shows the geometry of finger joint of procured material.

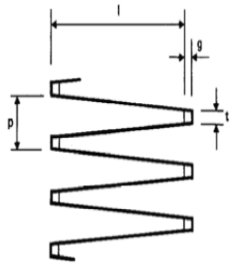

Fig. 1. Geometry of Finger joint profile (l = finger length = 14.8 mm, p = pitch = 4.17 mm, t = tip width = 1.12 mm, g = gap = 2 mm)

The longitudinal modulus of elasticity of the Teak wood material without finger joint was determined experimentally and is equal to 10960.45 MPa with a standard deviation of 863.03 MPa. Similarly longitudinal modulus of elasticity of the Teak wood with finger joint was obtained experimentally and is found to be 11598.22 MPa with standard deviation of 751.51 Mpa. In each case five specimens were tested. The material properties obtained experimentally were verified with already published data from [2], [7]-[12] and fall within the researched data.

B. Test Specimens

Two types of specimens were considered for the testing i. Teak wood beam without finger joint (TWB), and ii. Teak wood beam with finger joint (FJTWB). The geometrical size of the specimens was 22.5mm X 12.2mm X 414 mm. Fig. 2 shows sample specimens which were visually inspected for any distortion and misalignment. In specimen code alphabet 'E' and 'F' are used to describe edge wise and flat wise testing respectively.

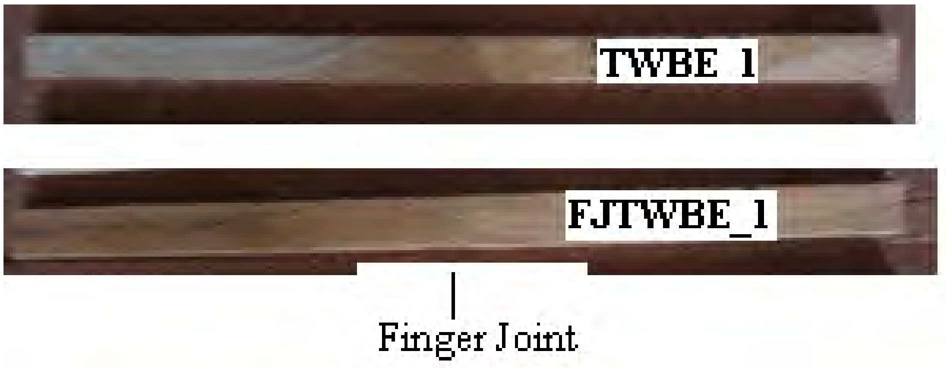

Fig. 2. Teakwood Specimens

C. Geometrical and physical properties of teak wood beam without finger joint

Table I shows the physical and geometrical properties of edge wise teak wood beam without Finger joint (TWB).

TABLE I.
Physical and geometrical properties of edge wise teakwood beam without finger joint

Specimen Code	**Width, B, mm**	**Depth, D, mm**	**Span, L, mm**	**Density, ρ, kg/m³**	**Second Moment of Area, I, mm⁴**
TWBE 1	12.83	21.50	368.00	579.27	10535.43
TWBE 2	12.93	22.61	368.00	701.80	12463.01
TWBE 3	12.73	21.45	368.00	662.90	10586.78
Average	12.83	21.85	368.00	647.99	11195.07
Std. Dev.	0.08	0.54	0.00	51.12	896.81

Table II shows the physical and geometrical properties of flat wise teak wood beam without Finger joint.

TABLE II.
Physical and geometrical properties of flat wise teak wood beam without Finger joint

Specimen Code	**Width, B, mm**	**Depth, D, mm**	**Span, L, mm**	**Density, ρ, kg/m³**	**Second Moment of Area, I, mm⁴**
TWBF 1	22.00	13.06	368.00	634.15	4160.59
TWBF 2	22.10	12.81	368.00	597.01	3874.34
TWBF 3	22.06	12.94	368.00	609.05	3983.15
Average	22.05	12.94	368.00	613.40	4006.03
Std. Dev.	0.04	0.10	0.00	15.47	117.98

D. Geometrical and physical properties of teak wood beam without finger joint

Table III shows the physical and geometrical properties of edge wise teak wood beam with finger joint (FJTWB).

TABLE III.
Physical and geometrical properties of edge wise teak wood beam with finger joint

Specimen Code	**Width, B, mm**	**Depth, D, mm**	**Span, L, mm**	**Density, ρ, kg/m³**	**Second Moment of Area, I, mm⁴**
FJTWBE1	13.37	22.03	368.00	598.67	11914.68
FJTWBE2	12.95	22.15	368.00	605.97	11735.93
FJTWBE3	13.14	22.08	368.00	624.20	11787.22
Average	13.15	22.09	368.00	609.61	11812.61
Std. Dev.	0.17	0.05	0.00	10.74	75.15

Table IV shows the physical and geometrical properties of flat wise teak wood beam with finger joint (FJTWB).

TABLE IV.
Physical and geometrical properties of flat wise teak wood beam with finger joint

Specimen Code	**Width, B, mm**	**Depth, D, mm**	**Span, L, mm**	**Density, ρ, kg/m^3**	**Second Moment of Area, I, mm^4**
FJTWBF1	22.55	13.54	368.00	632.73	4665.36
FJTWBF2	22.37	12.23	368.00	617.76	3412.36
FJTWBF3	22.43	12.93	368.00	624.31	4044.31
Average	22.45	12.90	368.00	624.93	4040.68
Std. Dev.	0.09	0.66	0.00	7.50	626.51

III. EXPERIMENTAL METHOD

Experimental setup is shown in Fig. 3. The specimens of rectangular teakwood without Finger joint and rectangular teakwood with Finger joint were tested to study the behavior under 3-point bending. Both Edgewise and flat wise bending was carried out with the span of 368 mm.

Fig. 3 Experimental setup

The beams were tested using universal testing machine under the three point arrangement. The universal testing machine consists of a setup for testing the specimen under three point bending along with the digital data acquisition system. Load was applied at slow rate using hydraulic cylinder the values of load applied, deflection are digitally recorded directly onto the data acquisition system. Further the load data was connected with the computer and a plot of load vs. deflection was directly generated by computer which was taken as the output. The applied load increased up to the breaking point or the failure of the material.

The same procedure was repeated for all the specimens, further the investigation is carried out to determine load at proportionality limit, Peak load, and corresponding deflections. Modulus of Elasticity, Modulus of Rupture, and Bending Moment is computed using beam theory relations.

$$Second\ Moment\ of\ Area = I = B * D^3/12 \quad (1)$$

$$Modulus\ of\ Elasticity = MoE = Ppl*L^3/48*\Delta pl*I \quad (2)$$

$$Modulus\ of\ Ruptur = MoR = 1.5*Pmax*L/B*D^2 \quad (3)$$

$$Bending\ Moment\ = Mb = Pmax * \frac{L}{4} \quad (4)$$

IV. RESULTS AND DISCUSSION

A. *Results of teak wood beam without finger joint*

Flexural strength properties obtained experimentally for edge wise teak wood beam without Finger joint (TWB) are shown in Table V.

TABLE V

Flexural strength properties of edge wise teakwood beam without finger joint

Specimen Code	Load at Proportionality Limit, Ppl, KN	Deflection at Proportionality Limit, Δpl, mm	Max. Load, Pmax, KN	Deflection at Max. Load, Δmax, mm	MoE, Mpa	MoR, MPa	Moment, Mb, KN-mm
TWBE1	0.12	1.10	0.78	14.30	10750.74	72.77	71.76
TWBE2	0.24	2.00	0.82	15.40	9996.79	68.48	75.44
TWBE3	0.16	1.40	0.72	14.40	11208.06	67.86	66.24
Average	0.17	1.50	0.77	14.70	10651.86	69.70	71.15
Std. Dev.	0.06	0.46	0.05	0.61	611.66	2.67	4.63

Load Vs Deflection curves for edge wise teak wood beam without finger joint (TWB) are shown in the Fig. 4.

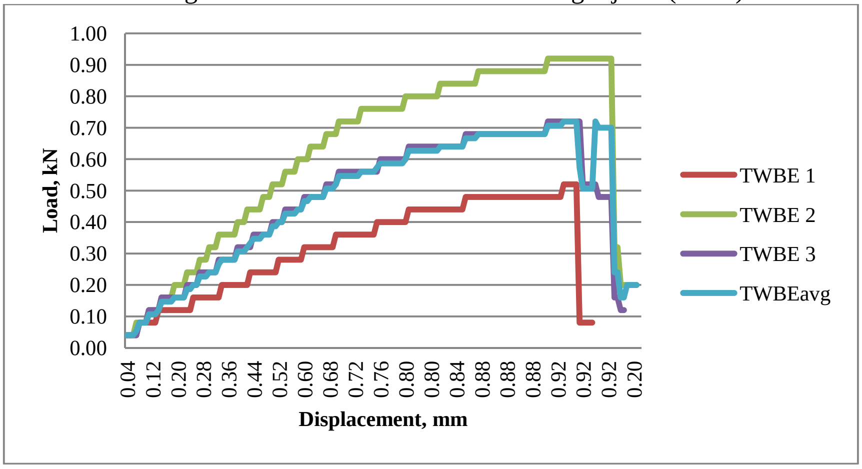

Fig. 4. Load Vs Deflection curves for edge wise teak wood beam without finger joint

The natures of failure of specimens without finger joint in case of edge wise testing are shown in the Fig. 5

Fig. 5. Failed specimens of teakwood beam without finger joint - edgewise test

Flexural strength properties obtained experimentally for flat wise teak wood beam without finger joint (TWB) are shown in Table VI.

TABLE VI

Flexural strength properties of flat wise teakwood beam without finger joint

Specimen Code	Load at Proportionality Limit, Ppl, KN	Deflection at Proportionality Limit, Δpl, mm	Max. Load, Pmax, KN	Deflection at Max. Load, Δmax, mm	MoE, Mpa	MoR, MPa	Moment, Mb, KN-mm
TWBF1	0.2	4.1	0.48	17.7	12172.88	70.61	44.16
TWBF2	0.12	3.2	0.39	17.9	10049.3	59.36	35.88
TWBF3	0.12	2.7	0.39	17.7	11584.92	58.28	35.88
Average	0.15	3.33	0.42	17.77	11269.03	62.75	38.64
Std. Dev.	0.05	0.71	0.05	0.12	1096.47	6.83	4.78

Load Vs Deflection curves for flat wise teak wood beam without finger joint (TWB) are shown in the Fig. 6.

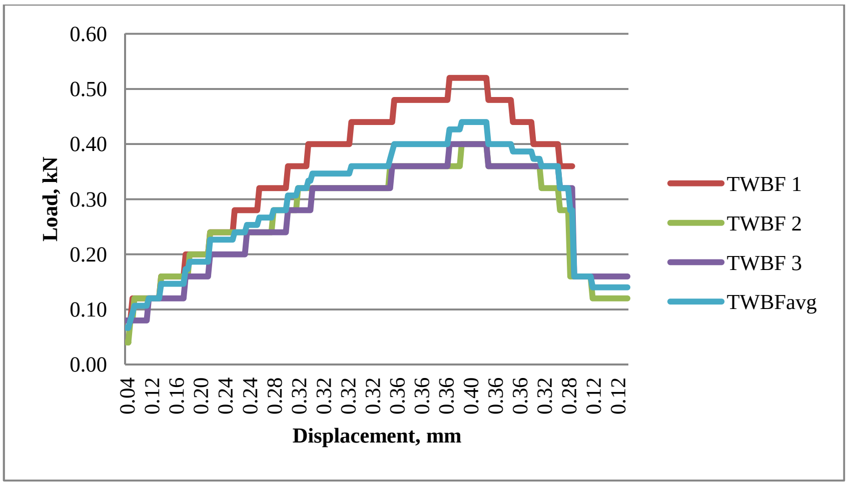

Fig. 6. Load Vs Deflection curves flat wise teakwood beam without finger joint

The natures of failure of specimens without finger joint in case of flat wise testing are shown in the Fig. 7.

Fig. 7. Failed specimens of teakwood beam without finger joint- flat wise test

B. Results of teak wood beam with finger joint

Flexural strength properties obtained experimentally for edge wise teakwood beam with finger joint (FJTWB) are shown in Table VII.

TABLE VII
Flexural strength properties of edge wise teak wood beam with finger joint

Specimen Code	**Load at Proportionality Limit, Ppl, KN**	**Deflection at Proportionality Limit, Δpl, mm**	**Max. Load, Pmax, KN**	**Deflection at Max. Load, Δmax, mm**	**MoE, Mpa**	**MoR, MPa**	**Moment, Mb, KN-mm**
FJTWBE1	0.44	3.10	0.52	4.00	12368.32	44.24	47.84
FJTWBE2	0.44	3.30	0.52	5.30	11795.69	45.18	47.84
FJTWBE3	0.40	2.90	0.52	4.00	12149.34	44.81	47.84
Average	0.43	3.10	0.52	4.43	12104.45	44.74	47.84
Std. Dev.	0.02	0.20	0.00	0.75	288.94	0.47	0.00

Load Vs Deflection curves teak wood beam with finger joint (FJTWB) incase of edgewise testing are shown in the Fig. 8.

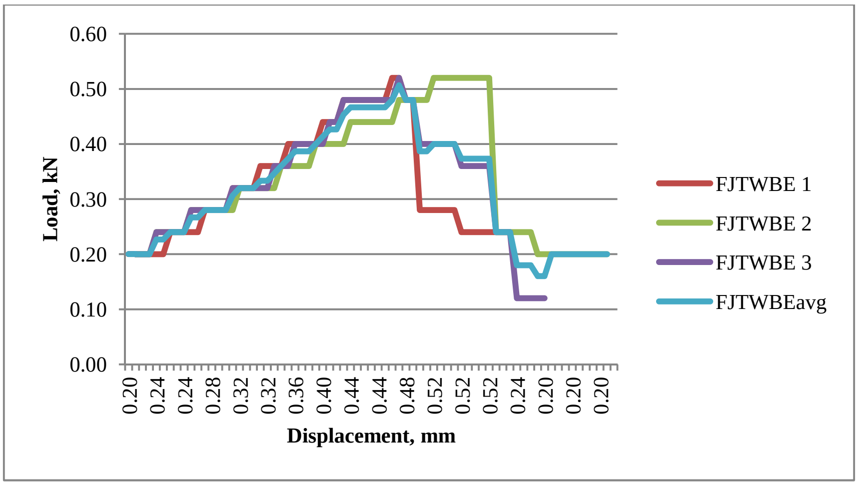

Fig. 8. Load Vs Deflection curves for edge wise teak wood beam without finger joint

Flexural strength properties obtained experimentally for flat wise teakwood beam with finger joint (FJTWB) are shown in Table VIII.

TABLE VIII
Flexural strength properties of flat wise teak wood beam with finger joint

Specimen Code	Load at Proportionality Limit, Ppl, KN	Deflection at Proportionality Limit, Δpl, mm	Max. Load, Pmax, KN	Deflection at Max. Load, Δmax, mm	MoE, Mpa	MoR, MPa	Moment, Mb, KN-mm
FJTWBF1	0.12	2.6	0.28	14	10271.29	37.39	25.76
FJTWBF2	0.2	5.4	0.28	12.1	11268.95	46.19	25.76
FJTWBF3	0.16	3.5	0.28	12.1	11735.72	41.22	25.76
Average	0.16	3.83	0.28	12.73	11091.99	41.60	25.76
Std. Dev.	0.04	1.43	0.00	1.10	748.08	4.41	0.00

Load Vs Deflection curves teak wood beam with finger joint (FJTWB) incase of flat wise testing are shown in the Fig. 9.

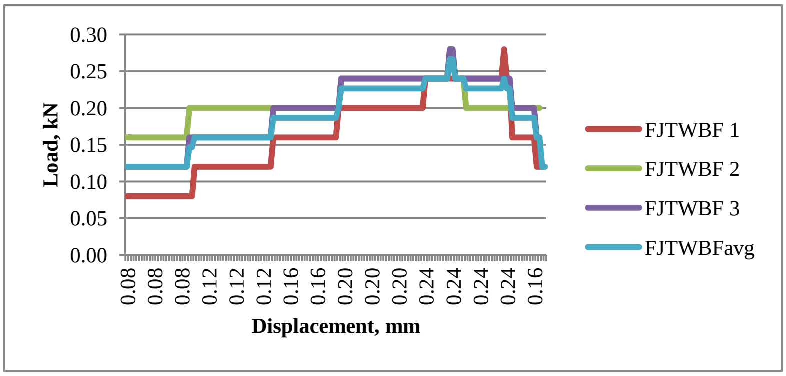

Fig. 9. Load Vs Deflection curves for flat wise teak wood beam without finger joint

The natures of failure of specimens incase of flat wise and edge wise testing are as shown in Fig. 10.

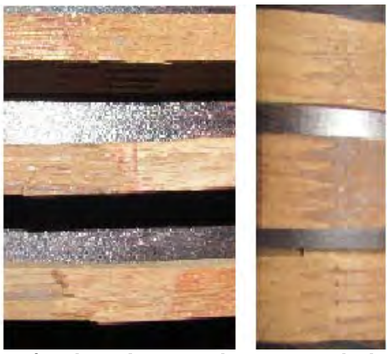

Fig. 10. Failed specimens of Teakwood Beam with Finger joint both flat wise and edge wise

C. Comparison of results with and without finger joints

A Summary of Load Vs Deflection curve based on average values of teak wood beam with and without finger joint in case of edge wise testing are shown in Fig.11.

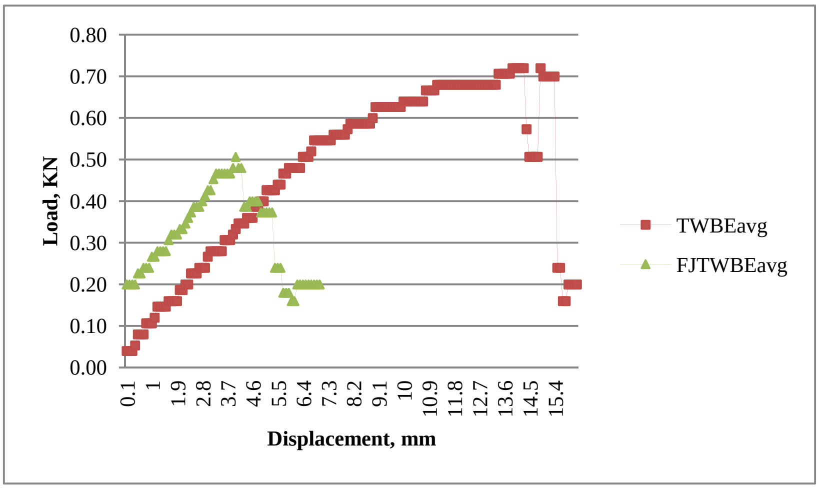

Fig. 12. Summary of Load Vs Deflection curves for edge wise teak wood beam with and without finger joint.

Summary of Load Vs Deflection curve based on average values of teak wood beam with and without finger joint in case of flat wise testing are shown in Fig.12.

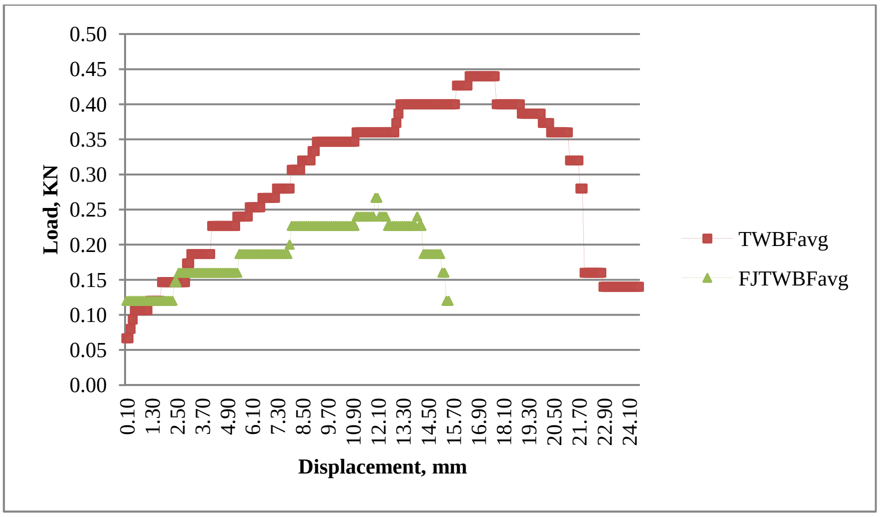

Fig. 12. Summary of Load Vs Deflection curves for flat wise teak wood beam with and without finger joint.

Table IX shows the comparisons of moment capacity of both types of specimens along with the percentage loss. The average loss of strength is 36.62% with standard deviation of 5.67.

TABLE IX
Comparison of Moments of Edge and Flat wise Teakwood without Finger joint, Teakwood with Finger joint specimens

Specimen Code	**Bending Moment, Mb, KN-mm**		**% Loss**
	Without Finger Joint	**With Finger Joint**	
E1	71.76	47.84	33.33
E2	75.44	47.84	36.58
E3	66.24	47.84	27.77
F1	44.16	25.76	41.66
F2	35.88	25.76	28.20
F3	35.88	25.76	28.20
Avg.	54.89	36.80	36.62
Std. Dev.	18.30	12.09	5.67

V. CONCLUSION

Teak wood is costly material compared to other species of wood. Finger jointing technique enhances the utilization of the teak wood but the strength gets reduced. It is evident from the experiment carried out to verify the effect of finger joint on flexural properties. The moment carrying capacity of finger jointed beam is 36.62% less compared to the solid teak wood with standard deviation of 5.67. When a beam with finger joint needs to be used for application the % loss estimated in this paper can safely be used to design small sized beams. It is also recognized from this investigation that further analysis and investigations are required to enhance the flexural properties of finger jointed beam. The length of finger, pitch and width of tip needs to be designed along with known properties adhesives for specific application. Structural adhesives are likely to reduce the loss of moment capacity, hence further tests can be carried with structural adhesive which are available for specific purpose. The properties of the wood vary from species to species hence it is advisable to consider the specific species during design. Modulus of rupture and Modulus of Elasticity of teak wood material with and without finger joint are coherent with published data.

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