WOOD RESEARCH
54 (3): 2009
99-108

PERFORMANCE OF TURKISH CALABRIAN PINE (*PINUS BRUTIA* TEN.) TIMBER JOINTS CONSTRUCTED WITH METAL PLATE CONNECTORS

Ergün Güntekin
Suleyman Demirel University, Faculty of Forestry,
Department of Forest Products Engineering, Turkey

ABSTRACT

Performance of metal-plate-connected (MPC) wood-truss-joints constructed with Turkish calabrian pine was investigated. Total of 120 joints were constructed using 38 mm by 89 mm lumber and three different sizes of metal plate connectors. Joints ultimate strength, stiffness, and load at critical slip values were evaluated using four-way plate test method. Effect of metal plate size and test method on the ultimate strength, stiffness, and load at critical slip values was also investigated. Results indicate that method of loading and plate size significantly influence the ultimate strength, load at critical slip and stiffness values of the joints. Among the splice joints tested, these was no significant difference between 76 x 102 and 76 x 152 mm plates in strength. AA orientation had higher strength and load at critical slip values than EA orientation, but similar stiffness properties of EA orientation. For the perpendicular joints tested; plate orientation and size did not influence stiffness. Results of this study indicate that Turkish calabrian pine lumber can be used in truss manufacturing.

KEY WORDS: MPC joints, Turkish calabrian pine, performance

INTRODUCION

Metal connector plates have been used for connecting wood truss members at joints, and metal plate connected (MPC) wood truss are commonly used in roofs and floors in residential, industrial, and commercial construction (Gupta et al. 1996). Today wide variety of metal plates is offered to wood truss industry.

Many variables may affect the performance of truss plate joints. These variables include size and number of teeth, plate size, plate thickness and orientation, grain orientation and direction of loading, lumber species, specific gravity of the lumber, moisture content of the lumber, the joint pressing force used to embed the plate, tensile and shear strength of the metal plate, and the time between fabrication and testing (Qualie and Keenan, 1979). Generally, strength and stiffness increase with specific gravity and decrease with moisture content, (Suddarth et al. 1979). Having similar plate properties and specific gravities; different wood species (MacAlister and

Faust 1992) or composite materials (MacAlister 1989) exhibits similar load at critical slip or ultimate strength values. Cyclic loading conditions that simulates seismic events do not cause any strength degradation on MPC heel and splice joints, but cause stiffness degredation (Gupta et al. 2004). According to O'Regan (O'Regan et al. 1998) selecting the plate length by twice the plate width ensures that joint failure will occur in the steel-net section.

MPC truss systems have been used in residential constructions in Turkey since 1999 in which a big earthquake devestated the northwest part of the country. Several imported softwoods, such as SPF (*Picea spp*., *Pinus spp*., and *Abies spp*.) and White Spruce (*Picea abies* Karst), have been used as structural members of the systems. However, Turkish Calabrian pine (*Pinus brutia* Ten.), one of the most important species in Turkey has not been used so far. Turkish Calabrian pine covers the largest area (3,096,064 ha) among the conifers grown in Turkey which corresponds to about 15.3 percent of the total forest area in Turkey. Calabrian pine is one of the fast-growing trees, the wood of which is an important raw material for various fields (such as packacing, furniture making, concrete forming, pulp and paper making) in forest products industries (Bektas et al. 2003).

The purpose of this study was to examine the feasibility of Turkish calabrian pine lumber in truss manufacturing by applying four-way testing method to joints and evaluating the ultimate strength, stiffness, and load at critical slip (0.381 mm) values. Design requirements for MPC wood joints are based on static loading conditions as described by industry standards.

MATERIAL AND METHODS

The testing procedure for this study was carried out in accordance with the ANSI-TPI 95 specifications. Total of 120 splice joint specimens were prepared using calabrian pine lumber which were supplied from a local lumber company. The lumber specimens were 300 cm long and 38 by 89 mm in the cross section. Lumber pieces were cut into 50 cm pieces and used in the joint constructing. Pieces with knots, checks, etc. were excluded in the study. The lumber's specific gravity (SG) and moisture content (MC) were based on representative sections cut from each specimen near the joint. Sections were approximately 20 x 20 mm in cross-section and 25 mm in length. The MC and SG values for all tests were based on oven-dry conditions. Modulus elasticity (MOE) and modulus of rupture (MOR) of the lumber were calculated from the adjacent pieces that were used in joint construction assuming these values should be similar.

Three different sizes of metal plates; 76 by 76 mm – 36 tooth (S), 76 by 102 mm-48 tooth (M), and 76 by 152 mm-72 tooth (L) used in the study were supplied by a commercial plate manufacturer (Mitek Inc). M and L sizes are standard plates utilized in the industry, and S plates were cut from L plates. Some properties of the plates are summarized in Tab. 1. Only one plate was pressed each time using hydraulic press. All joints were tested in seven to fourteen days after fabrication. A screw-driven testing machine with a capacity of 50 kN was used in the evaluation of performance parameters. A constant testing speed of 1 mm / minute was applied to reach maximum load in 5 to 8 minutes. Slip between the joint members was measured by means of two displacement transducers placed on the sides of the test specimen. General configuration of the loading is shown in Fig. 1. Four-way plate testing quantifies the performance of the metal connector plates in four primary orientations by testing of joint samples in these four orientations:

AA: Plate slots run parallel to load and parallel to wood grain.

EA: Plate slots run perpendicular to load and parallel to wood grain.

AE: Plate slots run parallel to load and perpendicular to wood grain.

EE: Plate slots run perpendicular to load and perpendicular to wood grain.

Tab. 1: Metal plate properties

Manufacturer and type	Mitek, wave plate M20
Thickness	1 mm
Teeth configuration	wave
Width	76 mm
Length	76-102-152 mm
Plate area	57-77-115 cm2
Slot width	3 mm
Slot length	12 mm
Tooth depth	8 mm
Yield strength	275. 790 MPa
Tensile strength	379. 211 MPa
Allowable tensile stress	165. 474 PMa
Allowable shear stress	110.316 MPa

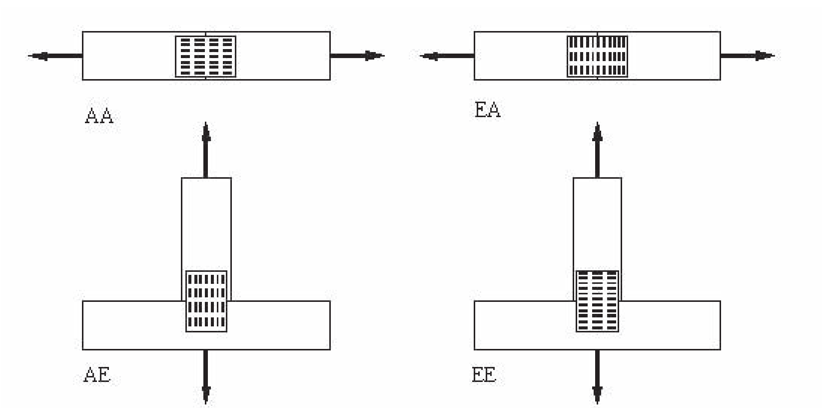

Fig. 1: General configuration of testing

The main parameters for defining performance of the joints are the ultimate strength, load at critical slip, and stiffness. The load-slip curves (Fig. 2) were used to determine the performance of the joints. Load-slip curves exhibited a nonlinear relationship. Most of the curves' beginning sections can reasonably be characterized as linear and the slope of the load-deformation curve also seems to go toward zero at the ultimate strength. A model developed by Foschi (1977) was first fitted to the load-slip curve for each joint tested, then stiffness values obtained. Foschi's parameters were determined for each of these load-slip curves using non-linear least square regression. The three parameter nonlinear model describes the load displacement behavior of a truss plate joint.

$$P = (M_0 + M_1 |\Delta|)\left[1 - e^{-K|\Delta|/M_0}\right]$$

Where;

P = Load

Δ = Displacement

K, M_0, M_1, are constants which depend on the properties of the plate and the wood as well as their orientation to the load.

K = Initial stiffness

M_0 = Stiffness at large displacement

M_1 = Intercept of the asymptote with slope M_1

Ultimate strength and load at critical slip values were read from the load-slip curves. According to TPI the load at critical slip (0.381 mm) and ultimate strength determines the behavior of the joint that means TPI does not consider the stiffness of the joint. Per tooth values were also calculated to make comparisons with other studies.

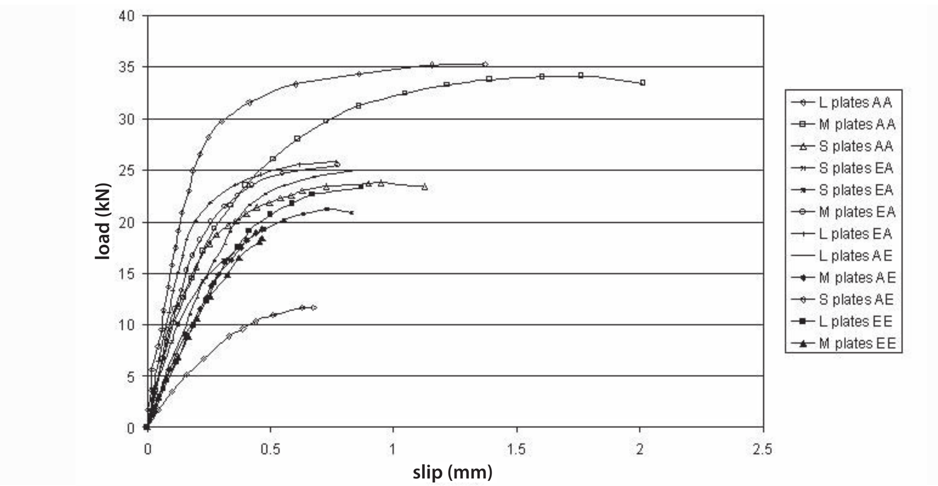

Fig. 2: Average load-slip diagrams obtained from tests

RESULTS AND DISCUSSION

Some physical and mechanical properties of the lumber utilized in the study are summarized in Tab. 2. MC ranged from 10 % to 11 % , while SG ranged from 0.43 to 0.60.

Tab. 2: Some physical and mechanical properties of the lumber used in the study

Property	Mean	Minimum	Maximum	Standard Deviation	Coefficient of variation (%)
SG	0.52	0.43	0.60	0.047	9
MC (%)	10.05	9.47	11.32	0.31	3
MOE (MPa)	8460	5740	11273	1322	16
MOR (MPa)	102	65	135	17	17

The average results of ultimate strength (kN), load at critical slip (kN), and stiffness (kN. mm^{-1}) for each joint type are presented in Tab. 3. A two-way analysis of variance (ANOVA) general linear model procedure was run for data with SAS statistical analysis software to interpret principal and interaction effects on the performance of the joints. The results (Tab. 4) indicate that testing method and plate size have significant effects ($p<0.0001$) on ultimate strength, load at critical slip, and stiffness at the 5 % significance level. This shows that differences in average strength, load at critical slip, and stiffness were observed when method of loading and plate size changed. The coefficients of variations were between 1.2 % to 19.96 % within the reasonable limits that make results of the experiment rather reliable.

Tab. 3: Descriptive statistical values and comparison of means for strength (kN), load at critical slip** (kN), and stiffness*** (kN/mm) of the joints tested*

Method of Loading	Plate size	N	Mean	Std. dev.	Min.	Max.	Cov (%)
AA	Large	10	*34.76A	0.53	33.91	35.60	1.52
			**30.83A	0.45	30.25	31.52	1.45
			***197.24A	16.05	174.60	225.20	8.13
	Medium	10	34.41A	0.87	32.92	36.65	2.52
			20.45B	1.89	17.36	23.04	9.24
			108.99BIJ	13.24	91.50	128.20	12.14
	Small	10	23.64BE	2.07	20.61	26.20	8.75
			19.15BC	1.49	17.52	21.33	7.78
			98.58BJ	4.19	90.55	104.40	4.25
EA	Large	10	25.34B	0.81	23.98	26.64	3.19
			23.16F	0.80	21.98	24.35	3.45
			173.85H	14.67	155.40	208.30	8.43
	Medium	10	25.31B	0.99	23.50	26.76	3.91
			21.30BF	0.92	20.15	22.99	4.31
			117.29BI	6.88	110.20	133.50	5.86
	Small	10	21.74E	1.47	20.21	25.02	6.76
			17.17CDG	0.83	16.17	18.16	4.83
			98.18BJ	9.81	86.40	115.00	9.99
AE	Large	10	25.98B	2.32	22.19	29.79	8.92
			20.13BC	0.88	19.01	21.51	4.37
			73.79CK	10.02	57.22	93.68	13.57
	Medium	10	18.42C	1.97	15.60	22.24	10.69
			16.33D	1.15	14.39	17.51	7.04
			59.93CK	5.30	51.33	67.80	8.84
	Small	10	11.95D	1.66	10.17	14.69	13.89
			11.20E	1.16	9.51	12.92	10.35
			51.40CK	6.89	43.20	64.54	13.40
EE	Large	10	23.07BE	1.74	19.46	24.99	7.54
			18.50BCG	1.24	17.27	20.05	6.74
			67.61CK	13.50	51.21	82.73	19.96
	Medium	10	18.50C	1.46	15.75	21.17	7.89
			16.36DG	1.40	14.90	18.65	8.55
			63.29CK	4.79	56.52	69.8	7.56
	Small	10	13.76D	1.78	9.64	16.11	12.93
			12.22E	1.44	9.78	14.11	11.78
			53.94CK	6.66	45.54	65.79	12.34

Values followed by the capital letter are not significantly different

Tab. 4: Analysis of variance (ANOVA) table for test parameters

Source of variation	F-value	p-value
Strength	198.28	<0.0001
Method of loading	416.13	<0.0001
Plate Size	380.85	<0.0001
Method of loading*Plate Size	28.50	<0.0001
Load at critical slip	202.60	<0.0001
Method of loading	330.44	<0.0001
Plate size	522.03	<0.0001
Method of loading*Plate Size	32.20	<0.0001
Stiffness	238.55	<0.0001
Method of loading	539.55	<0.0001
Plate size	319.80	<0.0001
Method of loading*Plate Size	60.96	<0.0001

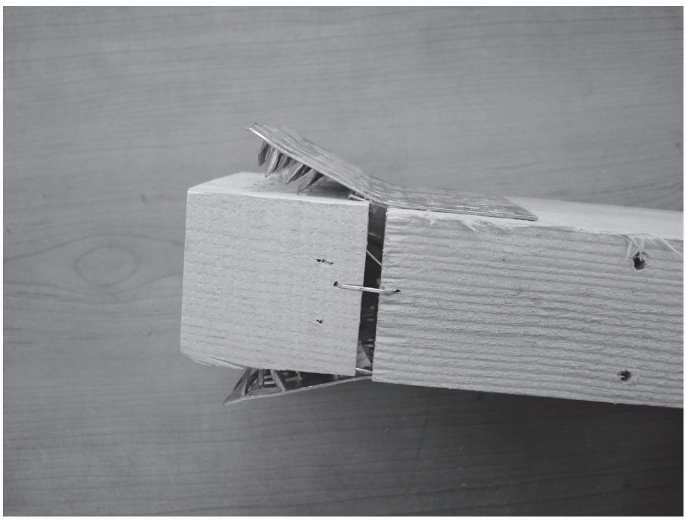

Fig. 3: Tooth withdrawal failure

Comparison of mean values as they were affected method of loading and plate size was made by the T-tests. In general, the mean strength, load at critical slip, stiffness values seemed to be higher in splice joints than perpendicular joints. Joints constructed with L plates and tested in AA position achieved greatest values for ultimate strength, load at critical slip, and stiffness (Tab. 3). The joints with S-plates and tested in AE and EE position reached the smallest values for ultimate strength, load at critical slip, and stiffness (Tab. 3). Among the splice joints tested, plate orientation influenced the strength and load at critical slip values. There was also no significant difference between M and L plates in strength. Stiffness of M and S plates were not significantly different.

It is important to note that plate size did not affect stiffness and method of loading did not changed the strength, and load at critical values of the joints in perpendicular loadings (Tab. 3).

Failure types in the joints were also analyzed. Three types of failure were observed during testing; tooth withdrawal (Fig. 3), plate failure (Fig. 4), and wood failure (Fig. 5). While tooth withdrawal was observed for all the splice joints with S plates, plate failure was typical for M and L plates. Wood split was the only failure type for perpendicular joints. When plates become larger, the split occurred in the wood carried away from the intersection of the joint parts.

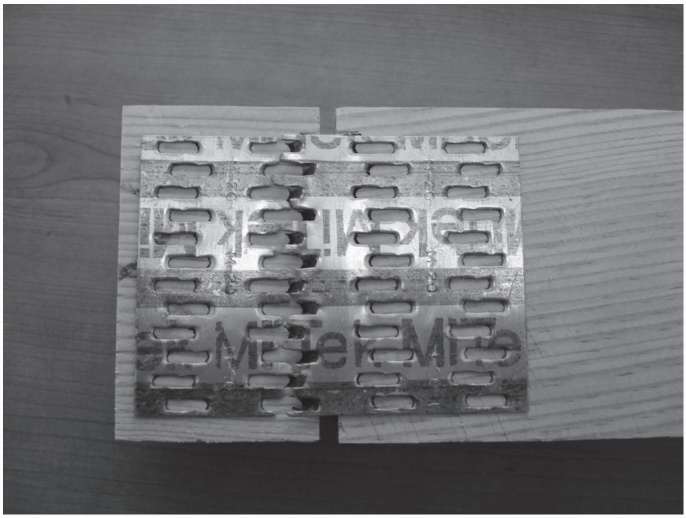

Fig. 4: Metal plate failure

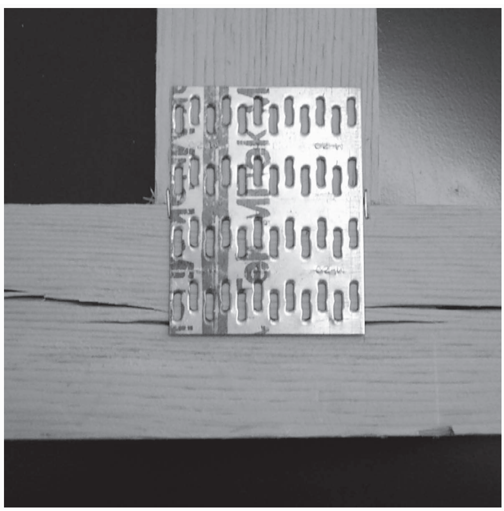

Fig. 5: Wood failure

Because the failure types were not consistent for all type of joints and plates tested, it is expected to find no conclusive relationship between lumber's SG, MOE, MOR and ultimate strength.

Average per tooth values were also compared to with the results available in the literature. Average per tooth strength values ranged from 0.35 kN to 0.71 kN for splice joints and 0.32 kN to 0.38 kN for perpendicular joints. When compared to other studies, they are higher than values found for southern pine (McCarthy and Wolfe 1987, Onat 1999), radiate pine (Lhuede 1992), and Timber Strand LSL (Onat 1999). Average per tooth load at critical slip values ranged from 0.32 kN to 0.53 kN which are higher than values found for southern pine (Onat 1999) and similar to TimberStrand LSL (Onat 1999). When compared to the values found for southern pine (McCarthy and Wolfe 1987), average per tooth stiffness values which varied from 0.93 $kN.mm^{-1}$ to 2.73 $kN.mm^{-1}$ are greater in all orientations. Per tooth stiffness values are similar to those obtained using TimberStrand LSL (Onat 1999).

CONCLUSIONS

Total of 120 MPC joints constructed with calabrian pine and three different sizes of metal plates were tested to determine their ultimate strength, stiffness and load at critical slip values. ANOVA and T-test test were used to compare the strength, load at critical slip, and stiffness values of all the joints. Both plate size and types of loading were found to have effect on the strength, stiffness, and load at critical slip. Splice joints achieved higher values for parameters tested than perpendicular joints. Although plate orientation was an important factor in order to reach higher strength, load at critical slip and stiffness for splice joints, it has no significant affect for perpendicular joints. Based on the findings of the study, it can be concluded that 38 mm x 89 mm calabrian pine lumber can be used with metal-plate fasteners in truss manufacturing.

REFERENCES

1. ANSI/TPI 1-1995: National Design specifications for metal plate connected wood truss construction
2. Bektas, I., Alma, M.H., As, N., Gundogan, R., 2003: Relationship between site index and several mechanical properties of Turkish calabrian pine (*Pinus brutia* Ten.). Forest Prodcuts Journal 53(2): 27-31
3. Foschi, R.O., 1977: Analysis of wood diagrams and trusses. Part II: Truss-plate connections. Canadian Journal of Civil Engineering 43(3): 353-362
4. Gupta, R., Miller, T.H., Redlinger, M.J., 2004: Behavior of metal-plate-connected wood truss joints under wind and impact loads. Forest Products Journal 54(3): 76-84
5. Gupta, R., Vatovec, M., Miller, T.H., 1996: Metal-plate-connected wood joints: A literature review. Research Contribution 13, Forest Research Laboratory, Oregon State University, Corvallis, OR. USA
6. Lhuede, E.P., 1992: Mechano-sorptive creep of punched metal plate timber fasteners. Journal of Institute of Wood Science 12(5): 291-298
7. McCarthy, M., Wolfe, R.W., 1987: Assessment of truss plate performance model applied to Southern pine truss joints. Res.Pap. FPL-RP-483. Madison, WI: USDA, Forest Products Laboratory. 13 pp.
8. McAlister, R.H., 1989: Interaction between truss plate design and type of truss framing. Forest Products Journal, 39(7/8): 17-245
9. McAlister, R.H., Faust, T.D. 1992: Load/Deflection parameters for metal plate connectors in yellow poplar and sweetgum structural lumber. Forest Products Journal 42(3): 60-64
10. Onat, S.M., 1999: Feasibility of Metal-Plate-Connected Timber Strand LSL Joints. Unpublished Master Thesis. Department of Wood Products Engineering. SUNY-ESF Syracuse NY
11. O'Regan, P., Woeste, F.E., Brakeman, D.B., 1998: Design procedure for the lateral resistance of tension splice joints in MPC wood trusses. Forest Products Journal 48 (6): 66-69
12. Qualie, A.T., Keenan, F.J., 1979: Truss plate testing in Canada: Test procedures and factors effecting strength properties metal plate wood truss conference. FPRS Proceedings P-79-28; 1979 November. Madison, WI: Forest Products Society
13. Suddarth, S.K., Percival, D.H., Comus, Q.B., 1979: Variability in tension performance of metal plate connections metal plate wood truss conference. FPRS Proceedings P-79- 28; 1979 November. Madison, WI: Forest Products Society

Ergün Güntekin
Suleyman Demirel University
Faculty of Forestry
Department of Forest Products Engineering
32260 Isparta Turkey
Tel: 90 246 2113144
Fax: 90 246 2371810
E-mail: eguntekin@orman.sdu.edu.tr