Effect of adhesive applied to the tooth-wood interface on metal-plate connections loaded in tension

Leslie H. Groom

Abstract

The structural behavior of metal-plate connections (MPCs) is affected not only by the isolated properties of the adjoining wood members and metal plate but also by the interfacial region between individual teeth and the surrounding wood. This study looked at maintaining a good interface by applying an epoxy adhesive to metal-plate teeth immediately preceding joint assembly. Addition of an adhesive layer between the teeth and wood substantially increased MPC stiffness, critical slip, and ultimate load for tensile specimens.

The underlying purpose of metal-plate connections (MPCs) is to adequately transfer stress among adjoining wood members. MPC research has focused primarily on the mechanical properties of individual wood members and metal plates. Of equal importance is the amount and quality of the interfacial region because the interface dictates how stresses are transferred. Moisture hysteresis affects the quality of the interface by forcing the metal plate to back out of the wood members (3,4). Moisture hysteresis, along with load duration, contribute to MPC degradation due to localized fatigue of the wood surrounding individual teeth.

The two general tensile failure modes for MPCs with metal plate and wood grain oriented parallel to the applied load are tooth withdrawal and metal plate tensile failure. Metal plate tensile failure is an indication of adequate wood mechanical properties and good interfacial integrity between the teeth and wood. In contrast, the tooth withdrawal failure mode may indicate a poor interface with undesirable characteristics such as low stiffness and strength. Sliker (5) showed that an adhesive applied to nails prior to being driven into wood provided an improved interface, thus increasing withdrawal-related mechanical properties such as nail joint stiffness and strength. MPCs should behave similarly. The objective of this study was to investigate the effect of an adhesive applied to metal-plate teeth before joint assembly on MPCs.

Materials and procedure

Lumber

MPCs were constructed from 20 boards representing a narrow range of specific gravities. These boards were 2 by 4 No. 2 grade KD15 Southern Pine 18 feet in length. The boards were sampled from a local lumber retailer in central Louisiana.

Metal plates

The die-punched metal plates used in this study were Gangnail GN20 plates. They were made of 20-gauge ASTM A446 grade C galvanized steel and were 3 inches wide and 4 inches long, with an average tooth density of 8.0 teeth per square inch. Average tooth length was 0.360 inch.

Joint construction and testing

Figure 1 shows a typical MPC used in this study. In accordance with TPI-85 (6), all teeth were removed within a lumber end distance of 0.5 inch. The teeth were removed with a milling bit that cut the teeth at the plate surface. Thirty-six pairs of teeth were present in the upper member and 24 pairs of teeth were present in the lower member. This type of construction was done to ensure failure in the lower member, which was equipped with linear variable differential transformers (LVDTs).

The lumber used for the glued and unglued specimens was matched by overall board specific gravity (SG), modulus of elasticity as determined by simple bending, and ratio of pith- versus nonpith-associated wood. Several 10-inch wood segments clear of any

The author is a Research Technologist, USDA Southern Forest Expt. Sta., Forest Products Util., 2500 Shreveport Hwy., Pineville, LA 71360-5500. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the USDA of any product or service.
This paper was received for publication in July 1990.

Forest Prod. J. 41(4):33-35.

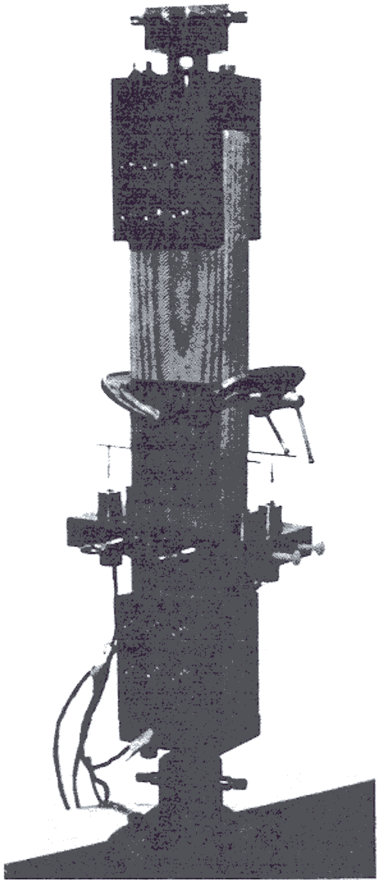

Figure 1. — Typical MPC tensile specimen used in this study.

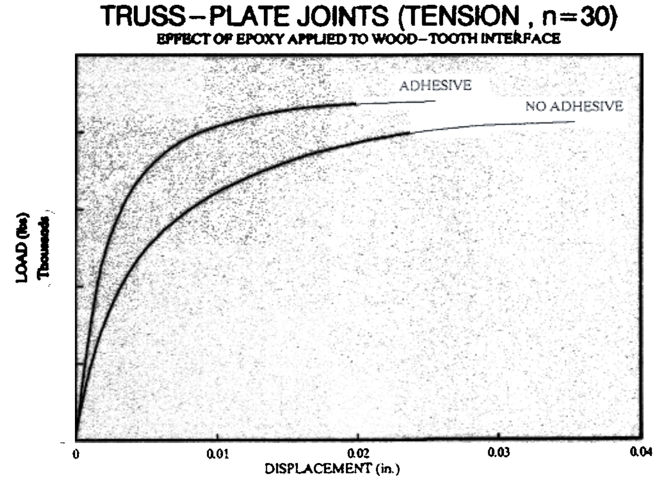

Figure 2. — Average load-displacement traces for 30 metal-plate connections with and without adhesive. (Note: displacement represents relative slip between the metal plate and the active wood member.)

visible defects were removed from each board for assembly into joint specimens.

An epoxy resin with a cure time of 15 minutes was applied with a sponge to the tips of the metal-plate teeth immediately before pressing into the wood members. An average of 0.0031 g of epoxy was applied to each tooth. The resin was spread along the tooth length during pressing. Metal plates were pressed into the wood members to make firm contact but not so much that the plate surfaces became embedded into the wood. The joints were placed in a hygrothermally controlled room at 79°F and 66 percent relative humidity with an equilibrium moisture content (EMC) of approximately 12 percent after assembly for at least 3 weeks before testing to allow for relaxation of stresses induced by pressing.

The load was applied in tension by a 30,000-lb. capacity, screw-driven crosshead testing machine (Fig. 1). A constant displacement rate of 0.015 in./min. was applied to the load and produced failure in 5 to 10 minutes. The specimen was attached to the testing machine with universal joints to eliminate potential moments produced by misalignment. Joint slip, which in this study is defined as the relative slip between the center of the metal plate and the active lower wood member, was taken as the average of four LVDT readings located in pairs at the two opposite sides of the wood-wood juncture. The passiveness of the upper member was insured by attachment of two C-clamps. Load was monitored with a 10,000-lb. capacity load cell. A computer-controlled data acquisition system operating at approximately four readings per second acquired the load and displacement readings.

Specimen SG and moisture content (MC) were determined on a block of wood (approximately 1.5 by 1.5 by 3.5 in.) that was adjacent to the metal plate after testing.

Metal plate backout is defined in this study as the dimensional difference between the wood member thickness and the wood-plus-plate thickness. This method was adopted to minimize errors due to stress relaxation or small wood dimensional changes related to minor MC fluctuations. Plate backout was based on the wood-plus-plate thickness difference measured 30 minutes after joint assembly and immediately preceding testing. The dimension was based on the average of two locations, located on each side of the long axis centerline of the metal plate and midway between the rows of teeth. Wood member dimensions were recorded at the same time.

Results and discussion

Physical and mechanical properties of the tensile tested MPCs are summarized in Table 1. Each test group consisted of 30 specimens, and exhibited almost identical MC and SG.

The load-slip traces for MPCs with and without epoxy were averaged and are shown in Figure 2. All MPCs failed by tooth withdrawal. Visual examination of the failed joints showed that approximately 5 to 10 percent of the surface of teeth with epoxy was covered with wood, indicating there was some degree of bonding between the metal plate and the wood member.

Table 1 shows that the effect of the adhesive layer is greater on MPC stiffness than strength. The addition of adhesive increased the ultimate load by about 7

TABLE 1. — *Means, coefficients of variation, and percent change of physical and mechanical properties for standard MPCs tested in tension and for MPCs with an epoxy layer between the teeth and wood.*

		MC	SG	Plate backout	Slope between load levels 300-700	700-1,100	1,100-1,500	1,500-1,900	Load at slip 0.005-in. slip	0.010-in. slip	0.015-in. slip	Maximum load	Slip-at-maximum load
		(%)		(in.)	- - - -	- - (kips/in.) - -	- -	- -	- - - -	(lb.)	- - - -	(lb.)	(in.)
No adhesive	$\bar{x}$	12.10	0.487	0.0023	819	783	742	697	2,486	3,221	3,617	4,128	0.034
(n = 30)	C.O.V.				12.5	12.2	12.2	12.3	7.2	7.2	7.4	10.0	20.7
Adhesive	$\bar{x}$	12.12	0.490	0.0003	1,506	1,480	1,450	1,415	3,551	4,068	4,250	4,404	0.024
(n = 30)	C.O.V.				20.5	20.1	20.2	21.3	9.7	7.7	6.7	5.6	31.4
Percent change					84	89	95	103	42.8	26.9	17.5	6.7	−29.4

percent. However, the slope of the load-slip traces for adhesive MPCs evaluated between load levels of 300 and 1,900 lbs. is about twice that for the MPCs without adhesive. In addition, the adhesive MPCs remain linear to about 50 percent of the ultimate load, whereas the MPCs with no adhesive begin yielding at 25 percent of the ultimate load (Fig. 2). The load at critical slip, which in this study is defined as 0.015 inch because there is only one active member, also increased 17.5 percent by addition of the adhesive layer.

There are several possible explanations for this change in mechanical behavior due to addition of the adhesive layer. The adhesive increased resistance to withdrawal forces as was evidenced by the wood clinging to the adhesive teeth. Also contributing to the change in ultimate load and stiffness was the manner in which stresses were distributed along the length of the tooth. Other research has shown that approximately 90 percent of the lateral load is supported by only the first 1/4 length of the tooth (2). The adhesive layer may redistribute the stresses to more evenly support the applied lateral load.

Plate backout may have also altered the mechanical behavior. The amount of plate backout immediately prior to testing was 0.002 inch for MPCs without epoxy resin at the tooth-wood interface, representing about 0.6 percent of the total tooth length (Table 1). Plate backout for MPCs with an epoxy layer was negligible. This backing out affects the behavior of MPCs by reducing the tooth bearing area acting on the wood member and increasing the moment acting at the base of the tooth (1). However, the small difference in plate backout for MPCs with and without adhesive probably resulted in only a minor effect. Although the mechanistic change in stress transfer due to the adhesive layer is necessary to fully identify fundamental interactions, it is beyond the scope of this study.

Conclusions

Addition of an epoxy resin to the metal-plate tooth-wood interface significantly alters MPC tensile behavior, primarily by increasing resistance to tooth withdrawal and by altering the stress distribution pattern between the tooth and wood. The ultimate load for adhesive MPCs improved by only 7 percent. However, initial stiffness values for adhesive MPCs increased by about 90 percent. The adhesive MPCs also maintained linearity for higher load levels when compared to MPCs without adhesive. The MPCs without adhesive exhibited slight plate backout, but this probably had only a minor effect on mechanical behavior. The real benefit for industry concerning justification of an adhesive interface may depend on the performance of MPCs exposed to cyclic conditions of moisture, as would be commonly encountered in roof and subfloor environments. This will be the focus of a future study.

Literature cited

1. Chou, C. 1988. Modeling of nonlinear stiffness and nonviscous damping in nailed joints between wood and plywood. Ph.D. diss. Oregon State Univ., Corvallis, Oreg.
2. Groom, L.H. 1989. Experimental verification and nonlinear modeling of truss-plate joints by Runge-Kutta numerical technique. Ph.D. diss. Oregon State Univ., Corvallis, Oreg.
3. McAlister, R.H. 1989. Interaction between truss plate design and type of truss framing. Forest Prod. J. 39(7/8):17-24.
4. ________. 1990. Tensile loading characteristics of truss plate joints after weathering and accelerated aging. Forest Prod. J. 40(2):9-15.
5. Sliker, A. 1970. Creep in nailed wood-metal tension joints. Wood Science 3(1):23-30.
6. Truss Plate Institute. 1985. Design specification for metal plate connected wood trusses: TPI-85. Truss Plate Inst., Madison, Wis.