Effect of Metal Connector Plates on the Bending Strength of Solid Sawn Lumber and LVL: A Pilot Study

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ABSTRACT
Seventy-four bending specimens, with and without metal connector plates (MCPs), were tested to determine the effect of the teeth of MCPs on the bending strength of solid sawn lumber (SSL) and laminated veneer lumber (LVL). The teeth of the MCPs were 3/8 inch long. Based on the results of this pilot study, statistical analysis showed that there was no effect on the bending strength of SSL and LVL.

Metal connector plates (MCPs) are mechanical fasteners commonly used for connecting wood truss members at the joints. The plates are punched from galvanized sheet steel with teeth perpendicular to the plate. There are a wide variety of metal connector plates available for the wood truss industry (Stern 1992). In the four decades since their invention, there has been much improvement in their design, and they have been used successfully for light frame roof and floor trusses. Although many tests have been done (Gupta et al. 1996) to determine the strength and stiffness of metal-plate-connected wood truss joints, there is still some concern that the teeth of MCPs cause damage to the wood fiber and weaken the bending, tension, and shear strength of the wood.

In 1984, McMartin et al. tested long-span, light wood roof trusses and suggested that the long teeth of the metal plates may reduce the effective tensile and shear strength. Gupta et al. (1996) published an extensive review of literature on metal-plate-connected wood joints. However, the authors did not find any study that addressed the influence of the metal plate teeth on wood fiber strength. We therefore designed a pilot study to investigate this issue.

The objective of this study was to determine the effect of MCP teeth on the bending strength of wood. The testing procedure included bending tests of beams 1) with metal plates pressed into both sides (without producing a connection); and 2) without plates. The bending strength of wood members with and without MCPs was compared.

MATERIALS AND METHODS
Solid sawn lumber (SSL) and laminated veneer lumber (LVL) were used for fabricating test specimens. Twenty-two beams of SSL Douglas-fir (Pseudotsuga menziesii), each 14 feet long, were used. The lumber was nominally 2 by 4 inches, and was MSR graded (1800 f - 1.6 E). Thirty pieces of LVL, graded 1.8 E Microlam, were obtained from Trus Joist MacMillan, Junction City, Oregon. The specimens were 8 feet long and 1.8 by 3.87 inches in the cross section. All specimens were stored in a conditioning room, at a constant temperature of about 66°F and relative humidity of 60 percent, until the tests began.

We used two different sizes of metal plates: small (3 in. by 5 in.) and long (3 in. by 10 in.). The long plates were cut from larger (3-in. by 12-in.) plates. The plates were 0.04 inch thick (20 gauge), with an in-line tooth configuration; tooth density was 8 teeth per square inch and tooth length was 3/8 inch. The slot width was 1/8 inch and the slot length was 1/2 inch. All plates were provided by Alpine Engineered Products, Inc. (Pompano Beach, Florida).

The SSL beams were cut into two pieces of equal length to obtain 44 specimens, each 7 feet long. The matching specimens were marked A and B. One of these (A or B) did not receive plates (control group). Metal plates were pressed on both sides of the second piece (A or B). The decision as to which of the matched specimens would receive the plates was not randomly made. On each specimen, we examined the spe-
specific area that would receive the plate (i.e., 3 in. at the center of the specimen for the small plates and 10 in. at the center for the long plates). If there was a large knot directly in the plating area, that specimen did not receive a plate. Knots outside the plated area, including within 24 inches of the center span (i.e., between load heads), were not considered as factors in the selection process. This decision was made to ensure that the beams would fail because of the metal plate’s effect on the wood fibers and not because of the weak spots in the wood.

A hydraulic press was used to press the metal plates into the wood. One plate was pressed at a time. The press was adjusted to close only up to a certain distance between the platens to press the metal connector plates. The teeth of the connector plates had to be completely pressed into the wood, but only so far that the edge of the metal plate did not damage the wood fiber.

Because of the preliminary nature of the study, it was thought that a minimum of 10 specimens per cell would be sufficient to determine the effect of MCPs on the bending strength of SSL and LVL. Therefore, 10 LVL beams did not receive any plates (control group), 10 received small metal plates, and 10 received long metal plates. Similarly, out of 44 SSL specimens, 11 received small plates, 11 received long plates, and 22 received no plates (11 each as the control for the small- and long-plate groups).

After the MCPs were applied, all specimens were kept in the conditioning room for 1 more week.

The bending tests were conducted in accordance with ASTM Standard D 4761-96 (ASTM 1996a). The span-to-depth ratio for lumber was 20.6, with 6 inches of overhang on both sides. The span-to-depth ratio for LVL was 18.6, with 12.5 inches of overhang on both sides. Both ratios were within the ASTM-recommended range of 17 to 21. Figure 1 shows the test set-up for lumber and Figure 2 shows the set-up for LVL. A Tinius Olsen universal testing machine with a maximum capacity of 120,000 pounds was used to apply the load. The speed of testing was adjusted to achieve failure load in approximately 2 to 3 minutes. This is consistent with the ASTM D 4761-93 recommendation that failure should occur between 10 seconds and 10 minutes. The applied load and the deflection were measured once per second and the data were recorded with a computer. The specimens were loaded until failure occurred. Immediately after the test, a small piece, approximately 1 inch long, was cut from every specimen to determine moisture content (MC) and specific gravity (SG), using ASTM standards D 4442-92 (ASTM 1996b) and D 2395-93 (ASTM 1996c), respectively.

**RESULTS AND DISCUSSION**

For SSL, the mean MC was 11.5 percent (COV 8.7%) and mean SG was 0.47 (COV 9.1%); for LVL, the mean MC was 7.4 percent (COV 4.1%) and mean SG was 0.56 (COV 3.2%). MC and SG were in the expected range for the two materials, and the coefficient of variation (COV) was reasonable.

All of the test specimens failed in the wood and no failure was observed in MCPs. Only when the test specimen completely failed in the center area (the area between the two load heads) did some teeth at the edge of the metal plate pull out. This was considered an after-effect of the failure of the beam, rather than a failure due to teeth withdrawal.

All SSL test specimens failed in bending. In 39 tests, the initial failure began at a knot. The knots were located at the compression face on 3 specimens and at the tension face on 36 specimens. The remaining five specimens failed at spots where no knots or other irregularities were observed. In the longitudinal direction, most of the test specimens failed

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**TABLE 1. Summary of test results.**

<table>
<thead>
<tr>
<th>Lumber type</th>
<th>Minimum (psi)</th>
<th>Maximum (psi)</th>
<th>Average (psi)</th>
<th>COV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without MCPs</td>
<td>4,977</td>
<td>11,086</td>
<td>7,012</td>
<td>26.4</td>
</tr>
<tr>
<td>Small MCPs</td>
<td>5,144</td>
<td>10,369</td>
<td>7,521</td>
<td>23.7</td>
</tr>
<tr>
<td>Without MCPs</td>
<td>4,811</td>
<td>12,978</td>
<td>8,095</td>
<td>32.2</td>
</tr>
<tr>
<td>Long MCPs</td>
<td>3,333</td>
<td>11,378</td>
<td>8,359</td>
<td>25.2</td>
</tr>
<tr>
<td>LVL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without MCPs</td>
<td>8,057</td>
<td>10,709</td>
<td>9,699</td>
<td>7.9</td>
</tr>
<tr>
<td>Small MCPs</td>
<td>7,822</td>
<td>11,305</td>
<td>9,427</td>
<td>10.9</td>
</tr>
<tr>
<td>Long MCPs</td>
<td>7,521</td>
<td>16,966</td>
<td>9,000</td>
<td>10.4</td>
</tr>
</tbody>
</table>

*SSL = solid sawn lumber; LVL = laminated veneer lumber; MCPs = metal connector plates.*

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- Figure 1. — Test set-up for SSL.
- Figure 2. — Test set-up for LVL.
between the two load heads; only eight specimens failed outside this 24-inch-long area. The final failure was a combined shear and bending failure. The specimens failed between 71 and 332 seconds. There was no visible difference in failure between test specimens with and without MCPs. Figures 3a through 3c show examples of failure modes of SSL beams.

All LVL test specimens failed suddenly. The failure mode was bending failure at the tension face, combined with shear failure. The failure was always followed by a loud bang. Figure 4 shows a typical LVL test specimen after final failure. The failure time varied between 121 and 169 seconds.

A difference was noted between the LVL specimens with and without MCPs. The beams without MCPs failed somewhere in between the two load bearing plates, but not particularly in the center. But for 70 percent of all specimens with MCPs (small or long), failure started at the edge of the metal plate, as shown in Figure 4. This means that 6 out of 10 of specimens with the small MCPs and 8 out of 10 of specimens with the long MCPs failed in the center. The remaining 30 percent of the specimens failed in between the two load-bearing plates.

The COV for average bending strengths for SSL was much higher than the COV for LVL (Table 1), but within the expected range for wood properties. Even between the two control groups of SSL, the COV were quite different; there was a difference of more than 1,000 psi in their average bending strengths. The average bending strength of the test specimens with MCPs in both groups was higher than for groups without MCPs. Because teeth are assumed to weaken the bending strength of the wood, we expected the opposite result. A possible explanation for the results of our study is the decision to apply MCPs to specimens without knots in the area where the plates were pressed. This may have selected the specimens with higher bending strength to receive MCPs. Since this is reflected in our results, MCPs probably did not weaken the specimens.

For LVL, the average bending strength of the specimens with small MCPs decreased by 270 psi when compared with the specimens without MCPs. The average bending strength of the specimens with long MCPs was about 700 psi

Figure 3. — (a) SSL specimen without MCP: bending failure at tension face; (b) SSL specimen with small MCP: bending failure at tension face; (c) SSL specimen with long MCP: bending failure at compression face.
lower than that of the specimens without MCPs. This seemed to indicate that the teeth of the plates might have a weakening effect on bending strength of LVL, especially when it is considered that the specimens failed mainly at the edge of the metal plates. To determine whether MCPs had a real effect on bending strength, we conducted a t-test statistical analysis of the bending strength data.

The t-test showed that the means for bending strength did not differ significantly for any case (Table 2). Applied MCPs did not seem to influence bending strength; however the small number of repetitions may have influenced this result. A larger sample should be used to further confirm the findings of this study.

**Table 2.** Results of t-test.

<table>
<thead>
<tr>
<th>Lumber type</th>
<th>Prob &gt; T</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSL</td>
<td></td>
<td></td>
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<tr>
<td>Group 1, matched specimens without MCPs and with small MCPs</td>
<td>0.5187</td>
<td>0.9010</td>
</tr>
<tr>
<td>Group 2, matched specimens without MCPs and with long MCPs</td>
<td>0.7974</td>
<td>0.5127</td>
</tr>
<tr>
<td>LVL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1, without MCPs and with small MCPs</td>
<td>0.5146</td>
<td>0.3965</td>
</tr>
<tr>
<td>Group 2, without MCPs and with long MCPs</td>
<td>0.0863</td>
<td>0.5766</td>
</tr>
</tbody>
</table>

SSL = solid sawn Douglas-fir lumber; LVL = laminated veneer lumber; MCPs = metal connector plates.

### Conclusions and Recommendations

Bending tests were conducted to determine whether the potential damage caused by the teeth of MCPs affected bending strength of SSL and LVL. Even though the bending strength of SSL with MCPs was higher than the bending strength of SSL without MCPs, there was no statistical difference in the bending strength of the specimens with and without MCPs. The bending strength of LVL with MCPs was lower than the bending strength of LVL without MCPs; however, statistically, there was no difference in the bending strength of the specimens with and without MCPs. All specimens failed in combined bending and shear failure. For SSL specimens, the failure generally started at a knot, but for most of the LVL specimens, the failure initiated near the edges of the metal plate.

### Literature Cited


