Static bending resistance of metal-plated joints constructed of oriented strandboard for upholstered furniture frames

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Abstract

Metal-plate connectors are commonly used to connect critical joints in upholstered furniture frames due to their high load resistance, rapid assembly, and easy connection of members with uniform thickness. To successfully introduce oriented strandboard (OSB) into furniture frames, basic data for metal-plated joints constructed of OSB is needed. In this study, static moment capacity of T-shaped joints with metal-plates was determined experimentally for different configurations. The moment capacity and stiffness of the joint with one pair of metal-plates increased in proportion with the width of the metal-plate up to 6-in (152 mm). When the metal-plate was equal the full width of the OSB member, too many teeth cut into it, making the assembly weaker. Metal-plated joints with two pairs of plates were nearly 50 percent stronger and stiffer than those with a single pair of metal-plates covering the same area.

Metal plate connectors (MPC), commonly called “truss plates,” are widely used for joining wood members, especially in trussed rafters and joists. Introduced by A. Carroll Sanford in 1952, MPC changed the wood construction industry. Prefabricated wood roof and floor trusses, most of which use MPC, are used in 80 percent of light commercial and residential construction in the United States and Canada. The MPC are typically fabricated from rolled metal sheets of 20-, 18-, or 16-gauge steel. The sheet metal is cut into a variety of sizes. The size of MPC depends on the geometry of the joint intended to be held in equilibrium. Requiring little time for joint fabrication and enhancing the strength and stiffness of trusses of almost any shape, MPC reduce fabrication cost and time, and develop a degree of efficiency and architectural flexibility which was not possible before.

The furniture industry is a relatively new area for MPC. Although originally designed for use in structural applications, MPC have gained popularity as connectors for critical joints such as front post to front rail and side rail to back post...
joint in upholstered furniture frame construction (Zhang et al. 2005). As a connector in upholstered furniture, MPC provide high load resistance, rapid joint assembly, and easy connection of members with uniform thickness.

The furniture industry continues to use more and more wood-based panels, but limited information is available on the moment capacities of metal-plated joints constructed of wood composites. The moment capacities of metal-plated and gusset-plated joints constructed of plywood and OSB have been addressed by a few researchers. Tables 1 and 2 show the moment capacities of metal-plated and gusset-plated joints for plywood and OSB found in the literature. Eckelman (1980) studied the performance of T-shaped, end to side-grain joints constructed of red oak, yellow-poplar, soft maple, and Douglas-fir with 18- and 20-gage metal plates of various shapes. Zhang et al. (2005, 2006) expanded Eckelman’s research by using furniture grade 3/4-in-thick 7-ply southern yellow pine plywood as material. They reported that metal-plate and rail widths affected the moment capacity of MPC plywood joints significantly. Generally, there is very little research on connections in oriented strandboard (OSB) furniture frames. Wang et al. (2007a, 2007b) evaluated the feasibility of using OSB as a material for gusset-plated joints in upholstered furniture. The results show that the moment capacity of the joint increased in proportion to the length of the gusset-plate until the strength of the gusset exceeded that of the main member; application of glue changed the failure modes of the joints and increased their strength significantly. The performance of OSB as a frame member in a T-shaped metal-plated joint has not been studied before.

The primary objective of this research was to develop basic data on the static bending resistance of T-shaped, metal-plated joints constructed of OSB. The specific objectives were: 1) to understand how metal-plate width and joint configuration affect moment resistance of T-shaped joints; 2) to determine the stiffness of metal-plated joints constructed of OSB; 3) to understand the behavior of the joints through their failure modes; and 4) to determine an optimum configuration for the bending capacity of metal-plated joints. The data will be further used for fatigue testing of the joints and for optimization of upholstered furniture frame designs.

Materials and Methods

The T-shaped, end-to-side, metal-plated joint specimens were comprised of two principal members, a post and a rail,
joined by one or two pairs of metal-plates symmetrically attached on both sides of the joint, i.e., an equal number of teeth were pressed into both the rail and the post, as shown in Figure 1. For the configurations with two pairs of metal-plates on each side (series G1 and G3), a distance of 0.5 in (12.7 mm) was left between edges of the rails and that of the plates. The two principal members were positioned in such a way that the long side of the post was perfectly centered and aligned with the short side of the rail. The joints were constructed of OSB conforming to CSA 0325 (CSA 2003) produced by Norbord (Canada). The OSB members were 23/32-in (18-mm) thick, 6-in (152-mm) wide, 16-in (406-mm) long. The metal-plates were 2 by 6 in (51 by 152 mm) or 4 by 6 in (102 by 152 mm), SK-20 manufactured and provided by Jager Building Systems Inc. The plates were cut in halves for joint configurations with metal-plates of 1.0-in or 3.0-in (25.4- or 76.2-mm) width.

To prepare OSB components, 4- by 8-ft (1.22 by 2.44-m) OSB panels were cut into 6-in (152-mm) strips along the 8-ft (2.44-m) direction, then crosscut into 16-in-long blanks and randomized. The metal-plates were installed using a hydraulic press at a pressure of 70 psi (483 kPa). To ensure tight contact between the rail and the post, the joint was preassembled with two staples. To hold metal-plates and members in alignment,

<table>
<thead>
<tr>
<th>Test</th>
<th>Initial loads (lbf)</th>
<th>Load increments (lbf)</th>
<th>Number of loads</th>
<th>Light-service acceptance level</th>
<th>Medium-service acceptance level</th>
<th>Heavy-service acceptance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclic vertical load test on – Front rail</td>
<td>100</td>
<td>100</td>
<td>3</td>
<td>300</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>– Back rail</td>
<td>100</td>
<td>100</td>
<td>3</td>
<td>200</td>
<td>300</td>
<td>500</td>
</tr>
</tbody>
</table>

*1,000 lbf = 4,448 N.

Figure 2. — Configurations of metal-plated joints tested.
two opposite corners of each metal-plate were hammered into the two members. Metal-plates were pressed one at a time until full contact between the plate and the panel. Six series of tests on the T-shaped, end-to-side MPC joints were conducted. The configurations of the specimens are shown in Figure 2. Density, MC, internal bond strength and flexural properties of the OSB were determined in accordance with ASTM D 1037 (ASTM 2005) before testing the assemblies.

In order to conform to durability performance test standards such as the General Services Administration (GSA) test regimen FNAE-80–214 A (GSA 1998), design strength of upholstered furniture frames require information about the performance of each joint in a typical sofa frame. According to the GSA, the bending moment acting on the back rail to back post joint is considered. For a 72-in (1.83-m) long three-seat sofa of light-duty category, three concentrated vertical loads of 200 lbf are applied to the back-rail with a total of 600 lbf (Table 3). If the back-rail has two rigid joints with back posts, each joint carries a bending moment of $200 \times \frac{72}{8} + 200 \times \frac{12}{72} = 3800$ lbf-in in fatigue test. To estimate the static load capacity, the load is doubled resulting in a target static moment capacity of 7600 lbf-in. With a 14-in (356-mm) long arm used in the tests, the target static load on the joint is approximately 7600/14 = 543 lbf.

All specimens were tested using a Tinius–Olsen universal testing machine. The post of the joint was bolted to the test fixture with 0.67-in (17-mm) aluminum spacers so that the metal-plates could deform freely during the test. Vertical upward load was applied to the rail at a rate of 0.2 in/min (5 mm/min), and recorded using a load cell with accuracy of 0.2 percent. As can be seen in Figure 1, joint slip at top and bottom between two points (A and B) was measured using two linear variable differential transducers (LVDTs).

**Calculation of the rotational stiffness of the joint**

As shown in Figure 3, the two points of LVDTs were originally located at A and B at a distance of 8.78 in (223 mm) from each other, which remained constant. During the test, the LVDT at point A contracted the distance $AA' = a$; the LVDT at point B retracted the distance $CB' = b$. The angle of rotation of the arm, $\alpha$, can be expressed from:

$$\tan \alpha = \frac{a}{x} = \frac{b}{223 - x}$$  \[1\]

Then, it can be calculated from displacements $a$ and $b$ as follows:

$$\tan \alpha = \frac{a + b}{223}$$  \[2\]

Moment-rotation curves (as shown in Fig. 4) were used to calculate the rotational stiffness of the joints as a slope between 10-lbf and 40 percent of ultimate load (Gebremedhin et al. 1992).

**Results and Discussion**

**Physical and mechanical properties of OSB**

Table 4 shows the physical and mechanical properties of OSB panels used in the tested specimens.

<table>
<thead>
<tr>
<th>Property</th>
<th>Units*</th>
<th>Average</th>
<th>COV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of elasticity flatwise MOE</td>
<td>psi $\times 10^6$</td>
<td>918</td>
<td>8.2</td>
</tr>
<tr>
<td>Modulus of elasticity edgewise MOE</td>
<td>psi $\times 10^6$</td>
<td>687</td>
<td>5.4</td>
</tr>
<tr>
<td>Modulus of rupture flatwise MOR</td>
<td>psi $\times 10^3$</td>
<td>4.67</td>
<td>12.1</td>
</tr>
<tr>
<td>Modulus of rupture edgewise MOR</td>
<td>psi $\times 10^3$</td>
<td>3.25</td>
<td>11.7</td>
</tr>
<tr>
<td>Density</td>
<td>lb/ft$^3$</td>
<td>37.1</td>
<td>6.8</td>
</tr>
<tr>
<td>MC</td>
<td>%</td>
<td>6.8</td>
<td>7.7</td>
</tr>
<tr>
<td>Internal bond</td>
<td>psi</td>
<td>61.8</td>
<td>18.2</td>
</tr>
</tbody>
</table>

*1000 psi = 6.89MPa.
tooth pull-out, crushing at the top corner of OSB rail, in-plane shear of OSB member, and rupture of OSB member. In the test assemblies with two pairs of metal-plates (G1 – 2 @ 1 in by 6 in and G3 – 2 @ 2 in by 6 in), mixed failure modes were observed. However, metal-plate yielding in tension (Fig. 5a) was the dominant failure mode in narrow metal-plates (G1 – 2 @ 1 in by 6 in, G2 – 1 @ 2 in by 6 in, and G4 – 1 @ 3 in by 6 in). Metal-plate tooth pull-out (Fig. 5b) was most often observed in the joints with wider metal-plates (G5 – 1 @ 4 in by 6 in, and G3 – 2 @ 2 in by 6 in). In test assemblies with the widest metal-plate (G6 – 1 @ 6 in by 6 in), OSB member rupture on the tension side (Fig. 5f) was evident, because too many teeth cut into the OSB, weakening the member. The discussion of bending strength presented below confirms this conclusion.

**Moment capacity**

Mean values and coefficients of variation (COV) of the moment capacity of OSB metal-plated assemblies are summarized in Table 5. Statistical comparisons of results were performed using an analysis of variance (ANOVA) general linear model and the Tukey’s multiple tests.

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### Table 5. — Moment capacity, rotational stiffness, and failure modes of tested joints.

| Joint configuration | Metal-plate size (in) | Pairs of metal plates | Number of specimens tested | Moment capacity Average (kip-in) | Moment capacity COV (%) | Rotational stiffness Average (kip-in/rad) | Rotational stiffness COV (%) | Mode of failure
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>1 by 6</td>
<td>2</td>
<td>10</td>
<td>8.05 C&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7</td>
<td>1677 A&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29</td>
<td>50% PY, 20% PY+TP, 10% TP, 20% CR</td>
</tr>
<tr>
<td>G2</td>
<td>2 by 6</td>
<td>1</td>
<td>10</td>
<td>5.38 D</td>
<td>9.1</td>
<td>252 D</td>
<td>31</td>
<td>100% PY</td>
</tr>
<tr>
<td>G3</td>
<td>2 by 6</td>
<td>2</td>
<td>10</td>
<td>11.2 A</td>
<td>8.3</td>
<td>1852 A</td>
<td>35</td>
<td>50% TP, 30% TP+S, 10 % CR, 10% MR</td>
</tr>
<tr>
<td>G4</td>
<td>3 by 6</td>
<td>1</td>
<td>10</td>
<td>7.59 C</td>
<td>6.0</td>
<td>558 C</td>
<td>34</td>
<td>90% PY, 10% TP</td>
</tr>
<tr>
<td>G5</td>
<td>4 by 6</td>
<td>1</td>
<td>10</td>
<td>9.76 B</td>
<td>5.8</td>
<td>1295 B</td>
<td>10</td>
<td>100% TP</td>
</tr>
<tr>
<td>G6</td>
<td>6 by 6</td>
<td>1</td>
<td>10</td>
<td>10.9 A</td>
<td>9.3</td>
<td>1391 B</td>
<td>8</td>
<td>90% MR, 10% TP</td>
</tr>
</tbody>
</table>

<sup>a</sup>PY = Metal-plate yield in tension; TP = Metal-plate tooth pull-out; CR = OSB crushed on the top corner of rail member; S = In-plane shear of OSB; MR = OSB member rupture.

<sup>b</sup>Values with the same letter index are not statistically different at 95 percent significance level.

1in = 25.4 mm; 1kip = 1000 lbf = 4.448 kN.
In joints with one pair of metal-plates, an increase of metal-plate width from 2 in to 3 in, from 3 in to 4 in, and from 4 in to 6 in increased the resistance by 41 percent, 29 percent and 12 percent, respectively. In assemblies with two pairs of metal-plates, significant differences were found. The average moment capacity of joints with two pairs of 2- by 6-in metal plates (G3) was 39 percent higher than that of assemblies with two pairs of 1- by 6-in (G1). Assemblies made with two pairs of 1- by 6-in (G1) were, on average, 50 percent stronger than those with one pair of 2- by 6-in (G2) and 6 percent stronger than those with one pair of 3 by 6-in metal plates (G4). The average moment capacity of assemblies with two pairs of 2- by 6-in metal plates (G3) was 14 percent higher than that of assemblies with one pair of 4- by 6-in (G5) and insignificantly higher than that of assemblies with one pair of 6- by 6-in plates (G6). This again can be explained by the fact that there were too many teeth cutting into the OSB members which made it weaker. The assembly with two pairs of 2- by 6-in metal plates (G3) had the highest bending strength of all configurations as can be seen from Table 5 and Figure 6. It can be concluded that for this joint geometry and size, the two pairs of 2- by 6-in metal-plates (G3) was the optimum design.

Comparisons were made for the moment capacities of tested assemblies (Table 5) with the previously published data on plywood assemblies with metal-plates and OSB with gusset-plates (Tables 1 and 2). The moment capacity (5.38 Kip-in) of the OSB joint with one pair of 2- by 6-in metal-plates (G2) was lower than that of the plywood joint with one pair of 1.6- by 6-in plates (5.98 Kip-in) from Table 1. The moment capacity (7.59 Kip-in) of the OSB joint with one pair of 3- by 6-in metal-plates (G4) was also lower than that of a plywood joint with one pair of 2.4- by 6-in plates (7.73 Kip-in) from Table 1. In OSB assemblies with two pairs of 1- by 6-in metal-plates (G1), the moment capacity (8.05 Kip-in) was somewhat higher than that of the plywood joint with one pair of 2.4- by 6-in plates (7.73 Kip-in) from Table 1. However, the moment capacity of the OSB joints with two pairs of 2- by 6-in metal-plates (G3) (11.2 Kip-in) was similar to those with one pair of 6- by 6-in stapled gusset-plate unglued joints of OSB (11.9 Kip-in) from Table 2 and higher than one pair of 4- by 6-in gusset-plates in both glued and unglued joints (9.52 and 9.38 Kip.-in), respectively.

Rotational stiffness

Moment-rotation curves in Figure 4 demonstrate a nonlinear relationship, but the lower portion of the curves can reasonably be characterized as linear. Therefore, in this study, the slope of the curve between 10-lbf to 40 percent of the ultimate load was used to calculate the rotational stiffness of the joints. Generally, the stiffness of the joints with one pair of metal-plates was much lower than that of the joints with two pairs of metal-plates, as shown in Figure 7. Assemblies with two pairs of 1- by 6-in metal-plates (G1) were even stiffer than those with one pair of 6- by 6-in (G6) metal-plates. Among the joints with one pair of metal plates, the joint with 4- by 6-in metal plates (G5) was much stiffer than that with 3 by 6-in (G4), as shown in Table 5 and Figure 7.

Conclusion

Effects of metal-plate width and number of metal plates on the static bending resistance of T-shaped OSB metal-plated joints were investigated. For the same width of metal plates, the use of two pairs of metal plates was the most important factor that affected the performance of the joints, allowing for strength increase up to 50 percent in comparison with one pair of metal plates of the same total width. Doubling the width of metal plates from 1 to 2 inches in assemblies with two pairs of the plates produced, on average, a 40 percent increase on their moment capacity. An increase in the width of metal-plates from 2 to 4 inches increased the moment capacity of joints with one pair of metal-plates by 80 percent, on average. In assemblies with one pair of 6- by 6-in metal plates, the moment capacity was slightly lower than that for assemblies with two pairs of 2- by 6-in. This can be explained by the weakening of OSB section due to the large number of teeth cutting through the member. The stiffness of the joints with one pair of 4- by 6-in metal plates was 43 percent lower than that of the joints with two pairs of 2- by 6-in. The failure modes observed varied with the size and configuration of the metal plates. Among the tested configurations, the joint with two pairs of 2- by 6-in plates was the strongest and showed the highest stiffness.

Literature Cited


