The evaluation of bending moment resistance of single wood-plate corner joints in particleboard and lodgepole pine

Tsair-Bor Yen*
Hans R. Zuuring
Edwin J. Burke*

Abstract

Wood-plates and dowels are used increasingly as connectors in furniture, wood cases, and cabinet joints. Little information is available, however, for the strength of the wood-plate joint design. This study was designed to obtain background information on bending moment resistance of single wood-plate joints in particleboard and solid lodgepole pine lumber, and to also formulate equations for predicting the bending moment resistance of wood-plate corner joints in particleboard and lodgepole pine lumber. Results indicated that the bending-moment resistance was positively related to the size (surface area) of the wood-plate. The average bending-moment resistance increased from the #0 (smallest) to the #S-6 (largest) plates in both substrates. Wood-plate joints averaged 21 percent higher resistance under compression loading for lodgepole pine than those under tension loading for this substrate. Wood-plate joints did not exhibit significant differences in mean resistance between tension and compression loading for particleboard except for the largest #S-6 plates. The lodgepole pine group also exhibited larger variation in bending-moment resistance than the particleboard group. In all the wood-plate joints, the substrate was the point of failure. This study provides a preliminary database of strength values for the engineering wood-plate joint constructed of both lodgepole pine and particleboard.

Elliptical wood-plate-connected joints were developed in the mid-1950s by Swiss cabinetmaker Herman Steiner. A beech (Fagus spp.) wood-plate, or biscuit, as it is often referred to in the United States, is fitted into a circular kerf made in the material to be joined with a carbide-tipped circular saw or router bit. Upon installation in the tight-fitting slot, the plate swells with the intake of water from the aliphatic resin adhesive applied after the slot is cut, and “self clamps” in the mating slots. Results of informal tests as well as anecdotal reports of overall joint strength praise this technology as a fast, accurate, and strong method of joining wood in numerous applications. The diagonally grained, compressed wood biscuit has the potential of replacing dowels as the principal mechanical fastening member for many types of joints in panels, case-goods, counter tops, and door and window frames. Several secondary forest product manufacturers have been using these beech wood plate joints because they more easily provide precise joint alignment than doweled joints, and generally allow the use of thinner stock. When compared with the preparation and assembly time of the dowel joint, the wood-plate joint is often faster and less expensive to produce.

While many different wood trade journals and magazines (Speas 1993, Wagner 1995, Hanson 1996) have reported on the wood-plate, only vague statements regarding the strength of wood-plate joints have been made. The review of literature found no citations pertaining to the strength of compressed wood-plate joints in refereed research journals. A comparison of several joints including the wood-plate carried out by Wagner (1995) indicated that the double wood-plates having parallel-face arrangement gave the strongest joint. Two number

The authors are, respectively, Assistant Professor, Dept. of Tropical Agriculture and Inter. Cooperation, National Pingtung Univ. of Sci. and Tech., Pingtung, Taiwan (tbyen@mail.npust.edu.tw); Professor of Biometrics and Professor of Wood Sci. and Technology (eburke@forestry.umt.edu), College of Natural Resources and Conservation, Univ. of Montana, Missoula, MT. This study was derived from part of an MS thesis by Tsair-Bor Yen (1997) supported by College of Natural Resources and Conservation, Univ. of Montana. This paper was received for publication in July 2004. Article No. 9905.

*Forest Products Society Member.
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20 wood-plates were used in the L-shape hinge of the doorframe. Each wood-plate was inserted into the kerfs with a 0.5-inch distance from the borders of the substrates to the centers of the dowels. The results showed that the double wood-plate joint failed at 2,800 pounds in compression loading. Besides the Wagner study, the results of an uncontrolled experiment carried out by Hanson (1996) suggest using the largest wood-plates and as many wood-plates as possible to obtain the maximum joint strength; this statement provides no precise or accurate estimate of the load-carrying capacity of any specific joint design. These articles were contained in trade and popular journals, and none of the references to joint strength were made using statistically controlled investigation.

Concerning the gluing methods, Speas (1993) recommended the single-spread glue method. The adhesive was placed in the kerf first, and the wood-plate then inserted into the kerf to avoid the enlargement of the wood-plate’s thickness after bonding with the adhesive. Conversely, Hanson (1996) found that the wood-plate joints were strengthened by spraying with water before applying the adhesive because the water enlarged the wood-plate’s thickness, and therefore fit the kerfs better than the wood-plates without pretreatment with water.

For cutting kerf, Speas (1993) recommended that the feed speed of jointers should be rapidly inserted into the substrate with a slow withdrawal. He found this method afforded better control and also reduced the variation of the kerf width. When cutting the kerf, any out-of-plane movement could enlarge the kerf thickness and cause a loose-fitting plate joint (Speas 1993). Lauziere (1995) tested several different brands of the wood-plate jointers and found that the lack of precision of some fences and plunge mechanisms led to imprecise and weak joints.

The work by Burke (1996) is the only preliminary study reporting laboratory-evaluated strength of single wood-plate joints in medium density fiberboard (MDF). It is obvious from this review that definite data for wood-plate joints are completely lacking, and a need for fundamental research of wood-plate joint strength is required.

**Objectives**

The objectives of this study were to obtain background information of bending moment resistance of single wood-plate joints in medium density fiberboard and lodgepole pine lumber, and to formulate equations for predicting the bending moment resistance of single wood-plate corner joints in particleboard and lodgepole pine lumber.

**Materials and methods**

**Substrate preparation**

Both solid lodgepole pine and western softwood particleboard were chosen as substrates in this study. Lodgepole pine (Pinus contorta Doug. Ex Loud.) is a species native to western North America, from New Mexico to north of the Arctic circle and from the eastern foothills of the Rocky Mountains to the Pacific Ocean (Koch 1996). Recently, the secondary product industry has begun increased utilization of this tight-grained wood with characteristically small knots for interior and exposed parts in furniture and cabinets and in solid lumber panels. Mixed western softwood particleboard was used, as it is a major raw material for furniture and cabinet manufacturing.

The industrial-grade particleboard (3/4 in thick) was randomly selected from Louisiana-Pacific Corp., and the dried lodgepole pine lumber was also randomly selected at a local sawmill, being sawn from different trees. For the lodgepole pine, only the heartwood was selected for the test and the growth rate of the specimens was limited to a range of 20 to 35 rings per inch (25.4 mm). In addition, the portion of the stem within 20 rings of the pith was not used in order to limit the amount of juvenile wood in the test specimens. Both the particleboard and lodgepole pine substrates were allowed to equilibrate at 20°C (68°F) and 55 percent relative humidity for 5 days before and after cutting into individual edge and face members, and subsequent final assembly.

Both particleboard and lodgepole pine lumber (50.8 by 203.2 mm [2 by 8 in]) were first cut into 12-inch-wide strips (299.5 by 127.0 by 19.0 mm [11.79 by 5.00 by 0.75 in]). In order to have comparable results, dimensions of the test specimens duplicated those used in previous corner-joint studies (Zhang and Eckelman 1993a, 1993b; Burke 1996). The face member (wood-plate located in the face of the member) was cut to be 158.5 by 127.0 by 19.0 mm (6.25 by 5.00 by 0.75 in) and the edge member (wood-plate located in the edge of the member) was cut to be 139.7 by 127.0 by 19.0 mm (5.50 by 5.00 by 0.75 in) (Fig. 1). For lodgepole pine, all substrates were laid up in a side-grain configuration. Any particleboard and solid wood substrates showing defects, such as knots, splits, checks, etc. were rejected.

**Wood-plate joint preparation**

Compressed beech-wood plates (Lamello Inc.) were used in this study. The four sizes of wood ellipsoids (#0, #10, #20, #S-6) have the same 50.8-mm-(2-in)-radius of curvature with average single-surface areas of 525.36 mm$^2$, 762.26 mm$^2$, 1050.45 mm$^2$, and 1784.02 mm$^2$ (0.814, 1.182, 1.628, and 2.77 in$^2$) (Fig. 2). Thirty plates were randomly selected from a large supply of each size group for computing the means and standard deviations (SDs) of the single surface areas and thicknesses (Table 1). The kerfs (incision) in both face and edge members were made with a DeWalt plate-joint kerfing tool, fixed with a 6-tooth, carbide-tipped, 101.6-mm (4-in) diameter blade with a 3.937-mm-(0.155-in)-thick kerf.

Industry-standard, water-based, fortified polyvinyl acetate adhesive with 65 percent solids content was also used for the wood-plate joints. The holes and kerfs were cleaned with compressed air and an adequate amount of adhesive was applied into the incisions and onto the plates.

In order to ensure a proper bond, a double-spread gluing method was used where the wood-plate and the kerf walls were covered with enough adhesive. The glue-covered plates were first inserted into the kerfs (also coated with adhesive) of face members to ensure that the plates were embedded to the required depth. A layer of waxed paper was placed between the two joint members (Fig. 3) to prevent any excess adhesive.
from forming a bond in the common joint area. All test specimens were cured under light pressure and stored at 20°C (68°F) and 55 percent relative humidity for 5 days prior to testing.

**Testing methods**

In everyday use, the corner joints of a case or cabinet are exposed to two main forces: compression and tension. Most of these forces are applied through cantilevers (long sides) and can generate sizable bending moments. Compression forces tend to close joints (Fig. 4), while tension forces tend to open corner joints (Fig. 5). Both tension and compression loadings were used to compute the bending-moment resistance ($R$). The relationships between the bending-moment resistance ($R$) and two forces ($F_t$ and $F_c$) were different. Bending-moment resistance values ($R$) were calculated by using the following equations:

<table>
<thead>
<tr>
<th>Size class</th>
<th>Single-surface area</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>#0</td>
<td>525.36 [0.814]</td>
<td>3.91 [0.154]</td>
</tr>
<tr>
<td>#10</td>
<td>762.26 [1.182]</td>
<td>3.13 [0.153]</td>
</tr>
<tr>
<td>#20</td>
<td>1050.45 [1.628]</td>
<td>3.91 [0.154]</td>
</tr>
<tr>
<td>#S-6</td>
<td>1784.02 [2.765]</td>
<td>3.96 [0.156]</td>
</tr>
</tbody>
</table>

**Figure 1.** Layout diagram of specimen members cut from lodgepole pine lumber. Particleboard used the same layout.

**Figure 2.** Four sizes (#0, #10, #20, and #S-6) of wood-plates and means of single-surface area.
where \( R \) = bending-moment resistance (lb-in); \( F_t \) = applied force of tension loading (lb); \( L_t \) = length of two members in tension loading (in); \( F_c \) = applied force of compression loading (lb); \( L_c \) = length of two members in compression loading (in).

A 60,000-pound Tinius-Olson universal testing machine was used to apply a load to each specimen with a crosshead speed of 0.635 mm (0.025 in) per minute (Burke 1996). The arms of tension test specimens rested on roller assemblies so that the two joint members were free to move on the testing machine bed (Fig. 5). Recorded data included loading force, distance between the arms of the two members under compression and tension loading, dry-basis moisture content (MC), specific gravity (SG) of the substrates, and failure mode.

**Sample size determination**

This study used an alpha level of 0.05 and 10 percent allowable error, the desired difference between the sample mean and population mean as a percentage of the sample mean. A pre-test of five samples for each configuration of wood-plate joints yielded an average coefficient of variation (COV) for the bending-moment resistance (dependent variable) of 13.0 percent in tension loading and 12.5 percent in compression loading. Following this, the sample size was determined by using the following equation.

\[
n = \frac{r^2 \times COV^2}{A^2}
\]
where \( n \) = sample size; \( t \) = Student’s \( t \)-value at specified alpha level; \( COV \) = the coefficient of variation (mean/SD); \( A \) = percent allowable error.

As a result, 8 replications of each configuration (2 substrate types by 2 stress loadings by 4 plate sizes) were constructed for a total of 128 specimens.

**Results and discussion**

The SG of particleboard averaged 0.72 with an SD of 0.03. MC percentage of particleboard averaged 8.24 percent with an SD of 0.33 percent. The SG of lodgepole pine averaged 0.50 with an SD of 0.07. The MC averaged 8.92 percent with an SD of 0.5 percent. The MC of the wood-plate averaged 7.02 percent with an SD of 0.06 percent.

**Failure modes**

Most joint failures were traced to fractures within the substrates, as well as the fastener that often carried some material from the bonding surface during withdrawal from the failure zone. The results indicated that the weakest part of the wood-plate joint was the substrate. Two failure modes of wood-plate joints

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**Table 2.** Percentages of failure modes for wood-plate joints by substrate type and loading method.

<table>
<thead>
<tr>
<th>Size class</th>
<th>Lodgepole pine</th>
<th>Particleboard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Face member failure</td>
<td>Edge member failure</td>
</tr>
<tr>
<td>#0</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>#10</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>#20</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>#S-6</td>
<td>75</td>
<td>25</td>
</tr>
</tbody>
</table>

**Table 3.** Ordered means and SDs of bending-moment resistance (lb-in) by loading method and substrate type.

<table>
<thead>
<tr>
<th>Size class</th>
<th>Lodgepole pine</th>
<th>Particleboard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tension</td>
<td>Compression</td>
</tr>
<tr>
<td>#0</td>
<td>106.0 (24.4)(^a)</td>
<td>138.7 (28.1)</td>
</tr>
<tr>
<td>#10</td>
<td>138.7 (23.3)</td>
<td>163.8 (23.1)</td>
</tr>
<tr>
<td>#20</td>
<td>162.6 (22.1)</td>
<td>188.6 (36.5)</td>
</tr>
<tr>
<td>#S-6</td>
<td>170.1 (25.2)</td>
<td>205.5 (31.5)</td>
</tr>
</tbody>
</table>

\(^a\)Values in parentheses are SDs.
can be identified in terms of the location of the failure and are classified as follows:

**Type 1. The face member’s edge failed alone.** — For lodgepole pine in tension and compression loadings, the face member’s edge crushed as a linear-shape, parallel to the wood grain through the edge of the face member (Fig. 6). The failure percentage of Type 1 failures in wood-plate joints increased from 12 to 75 percent in compression loading and from 50 to 88 percent in tension loading as the size (single surface area) of the wood-plate increased from #0 to #S-6 (0.814 in\(^2\) to 2.765 in\(^2\)) (Table 2). The larger sized wood-plate joints having a larger portion of kerf nearly parallel to the growth ring at the face member and the tension stress perpendicular to the grain caused the most Type 1 failures in both tension and compression loadings.

For particleboard, the face member’s edge crushed in the form of a half elliptical shape (bell-shaped with 2- to 4-in width) from the center of the joint area (Fig. 6). The failure percentage increased from 25 to 88 percent in both compression and tension loadings as the size of wood-plate increased from 0.814 in\(^2\) to 2.765 in\(^2\).

**Type 2. The edge member’s edge failed alone.** — The failures on the edge member of lodgepole pine and particleboard were similar to those on face members. For lodgepole pine, the edge member’s edge crushed as a linear-shaped region parallel to the wood grain through the edge of the edge member. The failure percentage decreased from 88 to 25 percent in compression loading and from 50 to 12 percent in tension loading as the size of the wood-plate increased from #0 to #S-6 (0.814 in\(^2\) to 2.765 in\(^2\)) (Table 2).

For particleboard, the edge member’s edge crushed as a half elliptical shape (bell-shaped with 2- to 4-in width) from the center of the joint area. The failure percentage decreased from 75 to 12 percent in both compression and tension loadings as the size of the wood-plate increased from 0.814 in\(^2\) to 2.765 in\(^2\) (Table 2).

The wood-plate joints in particleboard having the higher density exterior layer and the lower density interior layer altered the change from Type 2 to Type 1 failures when the wood-plate size increased. The larger sized wood-plate joints had a lower percentage of their total glue-surface area in the higher density exterior layer of the face members compared to those of the smaller wood-plate joints.

**Bending-moment resistance**

The #S-6 plate (2.765 in\(^2\)) showed the greatest strength in both compression and tension loadings for lodgepole pine and particleboard, while the #0 (0.814 in\(^2\)) plate had the lowest average strength (Table 3).

**Tension loading.** — The average bending-moment resistance under tension loading in lodgepole pine increased in a slight curve fashion from #0 to #S-6 (0.814 in\(^2\) to 2.765 in\(^2\)) plates (Table 3 and Fig. 7). The average bending-moment resistance under tension loading in particleboard also increased as the plate size increased from #0 to #S-6 plates (Table 3 and Fig. 8).

**Compression loading.** — For lodgepole pine, the average bending-moment resistance increased from #0 to #S-6 plates with a similar curve tendency as the tension loading, and averaged 21 percent larger than those in tension tests (Table 3 and Fig. 7). For particleboard, #0 and #10 plates showed nearly identical bending resistances to those in tension tests, but the average bending resistances in compression increased more dramatically from #20 to #S-6 plates than those in tension tests (Table 3 and Fig. 8).

**Data analysis**

Two-way analysis of variance (alpha level = 0.05) indicated that the size of the wood-plate was the most important factor that significantly influenced the bending-moment resistance.
Table 4. — The F-ratio values and significance probabilities (p) of two-way analysis of variance (alpha level = 0.05) for the log10 (bending-moment resistance) due to size of wood-plate and loading method and their interaction.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Lodgepole pine</th>
<th>Particleboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-ratio</td>
<td>p-value</td>
<td>F-ratio</td>
</tr>
<tr>
<td>Size class</td>
<td>18.893 0.000</td>
<td>114.930 0.000</td>
</tr>
<tr>
<td>Loading method</td>
<td>18.847 0.000</td>
<td>9.870 0.003</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.464 0.709</td>
<td>5.180 0.003</td>
</tr>
</tbody>
</table>

Table 5. — Regression coefficients and associated statistics for wood-plate joints.

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Tension loading</th>
<th>Compression loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lodgepole pine</td>
<td>Particleboard</td>
</tr>
<tr>
<td>b0</td>
<td>2.086</td>
<td>2.098</td>
</tr>
<tr>
<td>b1</td>
<td>0.742</td>
<td>0.811</td>
</tr>
<tr>
<td>b2</td>
<td>−0.622</td>
<td>−2.788</td>
</tr>
<tr>
<td>b3</td>
<td>−0.763</td>
<td>4.153</td>
</tr>
<tr>
<td>r²</td>
<td>0.570</td>
<td>0.815</td>
</tr>
</tbody>
</table>

for particleboard, while the method of loading was shown to have less effect on the bending-moment resistance. For lodgepole pine, the results showed both wood-plate size and loading method had equally significant effects on the bending-moment resistance (Table 4).

The regression techniques were applied to determine the functional relationships between bending-moment resistance and single surface area of the wood-plate for lodgepole pine and particleboard in tension and compression tests. Log10 of the bending-moment resistance was used as the dependent variable, while log10 of the single surface area of the wood-plate was used as the independent variable. The results indicated that the polynomial regression was the best fitting model for all configurations in this study. The polynomial regression model had the following form:

\[ Y = b_0 + b_1X + b_2X^2 + b_3X^3 \]

where \( Y = \log_{10} \) of the bending-moment resistance (lb-in); \( X = \log_{10} \) of the single surface area of the wood-plate (in²); \( b_0, b_1, b_2, b_3 \) = regression coefficients. The regression coefficients and associated statistics for equations are given in Table 5.

Discussion

The accuracy of the assembly process could be another important factor affecting the bending-moment resistance of the wood-plate joints. The assembly process of wood-plate joints required the operator to employ precise uniform tool of the plate-jointer. Every effort must be made to eliminate any vertical movement of the blade that would serve to enlarge the width of the kerf and a loose joint. The particleboard’s propensity to swell with water-based adhesives would reduce the loose fit caused by operation errors. The accuracy of the plate-jointer also needs to be monitored to avoid the inaccuracies from a faulty machine.

This study used lodgepole pine and particleboard as substrates and the results indicated that the substrate was the point of failure. The results showed that the strength of the substrate could affect the maximum strength of a corner-joint. For example, medium density fiberboard, northern red oak (Quercus rubra L.), or sugar maple (Acer saccharum Marsh.) may have very different results than those obtained with industrial-grade particleboard and lodgepole pine. For the wood-plate, the mean of bending-moment resistance in particleboard rapidly increased from #20 (1.628 in²) to #S-6 (2.765 in²) plates in particleboard, because the #S-6 plate had a 0.6-inch embedding depth in the face member where bonding surface included two exterior layers on both the plate’s center and border.

The regression analysis revealed that the lodgepole group had lower \( r^2 \) values than those of the particleboard group. The lower \( r^2 \) value indicated that lodgepole pine had higher variations in the wood properties, such as different width of growth rings, and higher variation of SG than particleboard. These variations could contribute to the low prediction percentages of joint strength in the lodgepole pine group.

Conclusions

In general, the bending-moment resistance of wood-plate joints increased from #0 to #S-6 plates in both lodgepole pine and particleboard. Compared with the lodgepole pine group, the bending-moment resistances of the particleboard group increased more rapidly from #0 to #S-6 than did the lodgepole pine group. The results indicated that the #S-6 wood-plate provided the maximum average bending-moment resistance under tension and compression loadings in both lodgepole pine and particleboard, while the #0 plate was the weakest configuration.

The wood-plate joints averaged 21 percent higher resistance under compression loading for lodgepole pine than those under tension loading, while wood-plate joints did not exhibit significant difference of mean resistance between tension and compression loading in particleboard except the largest #S-6 plates.

The substrate was the weakest part in the wood-plate joints for both lodgepole pine and particleboard. The failure percentages increased from edge member to face member as the plate size increased. The lodgepole pine group also exhibited larger variation in bending-moment resistance than did the particleboard group, since the particleboard had more uniform particle structure compared to lodgepole pine. Based on this study, in order to obtain the maximum bending-moment resistance, the #S-6 plate is recommended for use in the corner-joint structures in both lodgepole pine and particleboard.

This study provides information on bending-moment resistances of single wood-plate joints for lodgepole pine and particleboard. However, the wood-plate joints are also widely used in other wood materials such as plywood, solid hardwood, and medium density fiberboard. Little information is available for the wood-plate joints constructed of other wood materials and multiple plates with different arrangements.
The relationships of bending-moment resistance to different wood materials and the optimum plate spacing of multi-plate joints will need further study in order to provide complete engineering information for the wood-plate joint design.

**Literature cited**


