BENDING MOMENT RESISTANCE OF L-SHAPED TWO-GUSSET-PLATE FURNITURE JOINTS IN ORIENTED STRANDBOARD

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Abstract. Bending moment resistances of L-shaped joints connected with two gusset plates stapled on one side of joint members in oriented strandboard (OSB) were investigated. Factors were joint member material type, rail width, and number of staples. Experimental results showed that ultimate moment resistances of L-shaped, gusset-plate joints ranged from 429 to 842 N-m. Ultimate moment resistance loads of joints connected with 12 staples were 43% higher than those with 8 staples. Ultimate moment resistance loads increased as rail width increased from 152 to 203 mm with an increment of 25.4 mm, but the significance was affected by material type and number of staples. The increase in ultimate moment resistance loads of L-shaped, gusset-plate joints was not sensitive to material density profile change and density increase when 178-mm-wide or less rails were used, but the increase in moment resistances was sensitive to density increase when 203-mm-wide rails were used. Moment load-displacement curves of gusset-plate joints indicated that moment resistance loads at the ultimate point were two times their corresponding moment resistance loads at a proportional limit. The mechanical model was verified experimentally as a valid means for deriving estimation equations of moment resistances of L-shaped, gusset-plate joints in OSB.

Keywords: Bending moment resistance, staple-connected joints, gusset-plate joints, oriented strandboard, density profile, mechanical model.

INTRODUCTION

A gusset-plate joint can be defined as a place in a frame structure where two members meet edge-to-edge and are connected by plates fastened to the member faces with fasteners driven perpendicularly through the plates into the member faces. Gusset plates can be metal, wood, or wood-based composites, such as plywood. Metal gusset plates may vary as a barbed metal gusset plate or a toothed gusset plate attached to the members with their teeth or a nailed metal gusset plate (Wilkinson 1984). One of the most popular wood gusset-plate materials is plywood, which is commonly used for gusset plates because of its great tensile strength and split resistance (APA 1997). Because power-driven staples are fast and easy for assembling gusset-plate joints in upholstered furniture frames, the staples are one of the most commonly used mechanical fasteners for joining structural members (Zhang et al 2002). There are two physical appearance variations of gusset plates commonly seen in upholstery furniture frame construction: one wide gusset plate attached to the

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same face of two connected members alone and two narrow gusset plates attached to the upper and lower part of the same face of two connected members. A gusset plate can be attached to two jointed members using staples alone or staples with adhesive applied on the surfaces of members and gusset plates.

Gusset plates connect highly stressed joints in upholstery furniture frame construction such as stump to front rail joints and bottom side rail to back post joints because staple-connected gusset-plate joints have a high bending moment resistance capacity. Staples as mechanical fasteners resist face lateral shear forces rather than direct withdrawal forces when a joint is subjected to in-plane bending moments (Zhang and Maupin 2005). Therefore, the moment resistance capacity of a staple-connected gusset-plate joint in wood-based composites such as oriented strandboard (OSB) materials is governed by the load resistance capacity of OSB to in-plane shear of staples.

Limited studies have been found concerning the development of mechanical models for predicting bending moment resistance of stapled gusset-plate joints in OSB, especially for joints connected with two narrow gusset plates located on one side of the joint. Developing models of joint moment capacity as a function of relevant variables, such as the load resistance of OSB to in-plane shear of staples and joint member width, can help furniture manufacturers carry out rational strength design of furniture frames.

Eckelman (1971) investigated the bending moment resistance capacity of T-shaped, stapled–glued gusset-plate joints in solid Douglas-fir. The two joint members were connected with two plywood gusset plates symmetrically located on each side of the joint. Experimental results indicated that the moment capacity was not particularly sensitive to construction variables such as the number of staples; rather, it was limited by the strength properties of gusset-plate materials, specifically by the rolling shear strength of the plywood used as gusset plates. The moment capacity of evaluated joints improved considerably when the widths and lengths of the gusset plates increased. The mean ultimate moment resistance ranged from 33 to 1664 N-m with coefficients of variation from 4.2 to 19.0%.

Zhang et al (2001) studied the bending moments of T-shaped, stapled–glued, plywood gusset-plate joints in wood-based composites. Wood-based composites were southern yellow pine plywood, aspen Timberstrand® laminated strand lumber, and aspen engineered strand lumber. Test results showed that joint moment resistance was significantly affected by plywood gusset-plate thickness, width, and length and that plate width affected joint moment resistance the most. Member material type and number of staples had no significant effect on joint moment resistance capacity. The mean ultimate moment ranged from 686 to 2093 N-m with the coefficients of variation ranging from 4.7 to 23.7%.

Erdil et al (2003) investigated the effects of number of staples and gluing on the bending moment of T-shaped, gusset-plate joints in 19-mm-thick Douglas-fir plywood. The joint members were connected with two 5-mm-thick three-ply Douglas-fir plywood gusset plates symmetrically located on each side of the joint specimen. Test results showed that the larger gusset-plate dimensions and higher number of staples were the key factors for the increase in the joint overall moment resistance capacity. The mean ultimate moment of joints connected with stapled gusset plates ranged from 134 to 308 N-m with the coefficients of variation from 5 to 10%. The mean ultimate moment of joints connected with stapled and glued gusset plates ranged from 425 to 508 N-m with the coefficients of variation from 10 to 20%.

Wang et al (2007) evaluated the bending moment capacity of T-shaped joints connected with two OSB gusset plates symmetrically attached on both sides of joint members using adhesive and staples. The mean ultimate moment resistance load of the joints with staples only ranged from 2980 to 4591 N with coefficients of variation from 4.9 to 9.4%, whereas with staples and adhesive, it was from 3025 to 5649 N with coefficients of variation ranging from 7.0 to 11.8%. The joint moment capacity increased in proportion with the length of gusset plates until the strength of the plate exceeded that of the joint members. Application of adhesive to the connection surface increased the joint moment resistance capacity. The moment capacity of an unglued stapled gusset-plate joint in OSB can be reasonably estimated using analytical equations if the load capacity of a single staple is known. Mean differences between predicted and observed values differed by less than 16%.

The main objective of this study was to evaluate and compare bending moment resistances of L-shaped, two-gusset-plate joints in three different OSB materials, ie two narrow gusset plates were attached to the upper and lower part of the same face of two connected members. Specific objectives were to 1) study the lateral load-slip behavior of face-to-face OSB joints connected with two rows of staples; 2) investigate effects of OSB materials with different densities and number of staples on ultimate lateral resistance loads of face-to-face two-row multistaple joints; 3) study the effects of joint member material density and size and number of staples on ultimate moment resistance loads of L-shaped, two-gusset-plate joints in OSB materials; 4) develop a mechanical model for analyzing moment resistance of L-shaped, two-gusset-plate joints; and 5) derive equations for estimating the bending moment resistance of L-shaped, two-gusset-plate joints in OSB materials.

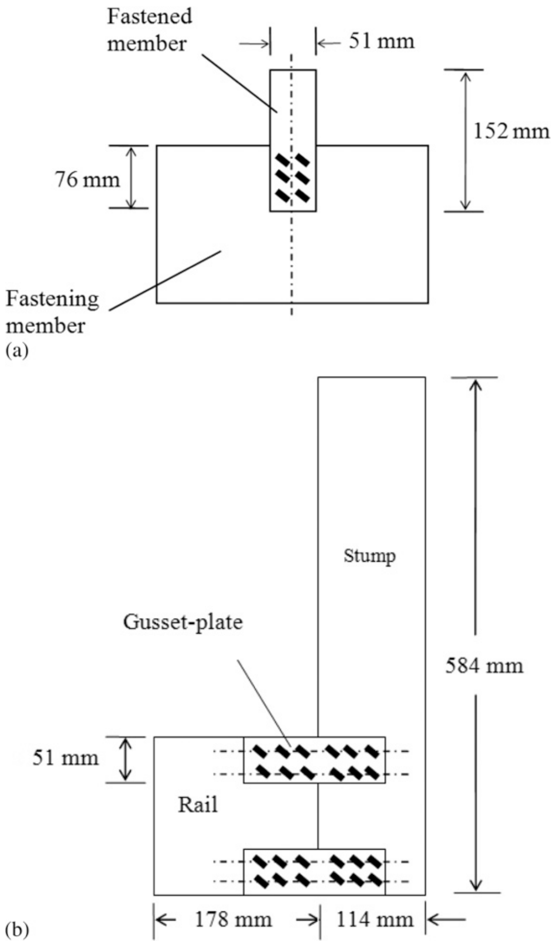

Figure 1. Staple placement of face-to-face oriented strandboard joints connected with two rows of six staples (a) and configuration of an L-shaped two-gusset-plate joint (b).

MATERIALS AND METHODS

Specimen Configurations and Materials

Two-row multistaple joints. The configuration of a face-to-face joint connected with two rows of staples is shown in Fig 1a. Each specimen consisted of two principal structural members, a fastened member and a fastening member, joined together by two rows of staples symmetrically placed with their crowns oriented at an angle of 45° to the lateral load direction. The fastening members were OSB materials and had nominal dimensions of 292 mm long × 178 mm wide × 18 mm thick with their length direction parallel to the full panel (1.2 × 2.4 m) length direction. The fastened member, southern yellow pine plywood, had nominal dimensions of 152 mm long × 51 mm wide × 19 mm thick and was oriented with its length parallel to the face-ply grain direction.

L-shaped joints. The general configuration of an L-shaped, two-gusset-plate joint in this study is shown in Fig 1b. The joint consisted of a rail attached to a stump by a pair of plywood gusset plates stapled on the same side of the joint. The rail and stump were constructed of

Table 1. Mean values of physical properties of three tested oriented strandboard (OSB) materials.[a]

Material type	Density (g/cm^3) Overall	Core	Surface	Moisture content (%)
OSB-I	0.463 (8) B[b]	0.389 (11) B	0.654 (16) B	5.0 (6)
OSB-II	0.466 (6) B	0.461 (4) A	0.487 (7) C	5.8 (6)
OSB-III	0.564 (11) A	0.469 (4) A	0.849 (9) A	4.7 (3)
Plywood	0.657 (8)	N/A	N/A	5.6 (5)

[a] Values in parentheses are coefficients of variation in percentage.
[b] Mean comparisons among OSB density values were done in the same column and values with the same upper case letter are not statistically different at a 5% significance level.
N/A, not applicapable.

the same OSB material. The stump had nominal dimensions of 584 mm long × 114 mm wide × 18 mm thick. The rail had nominal dimensions of 178 mm long × 18 mm thick with three widths. The gusset plate, southern yellow pine plywood, had nominal dimensions of 152 mm long × 51 mm wide × 19 mm thick with its length parallel to the face-ply grain direction.

Three different densities of 18-mm-thick commercial southern pine OSB materials (OSB-I, OSB-II, and OSB-III) as shown in Table 1 with their face strands oriented in the direction parallel to the full-sized panel (1.2 × 2.4 m) 2.4-m direction (machine direction) were used as fastening members in two-row multistaple joints and rails and stumps in the L-shaped, two-gusset-plate joints. One type of furniture grade, 19-mm-thick five-ply southern yellow pine plywood, was used for all fastened members. The full-sized sheet of plywood (1.2 × 2.4 m) was constructed with one center ply aligned parallel to the face plies and two even-numbered plies aligned perpendicular to the center ply. The face plies were aligned parallel to the sheet's 2.4-m direction.

The staples were SENCO (Cincinnati, OH) 16-gauge galvanized chisel-end-point types with crown width of 11 mm and leg length of 38 mm. Leg width of the staples was 1.6 mm, and thickness was 1.4 mm. The staples were coated with Sencote coating, a nitro-cellulose-based plastic.

Experimental Design

Two-row multistaple joints. A complete 2 × 3 factorial experiment with 10 replicates per combination was conducted to evaluate factors on the lateral resistance behavior of face-to-face, two-row multistaple joints in OSB. The two factors were fastening member material type (OSB-I, OSB-II, and OSB-III) and the number of staples (four and six).

L-shaped joints. A complete 2 × 3 × 3 factorial experiment with 10 replicates per combination was conducted to evaluate factors on the bending moment resistance of L-shaped, two-gusset-plate joints. The factors were the number of staples (8 and 12 per gusset plate), rail width (152, 178, and 203 mm), and material type (OSB-I, OSB-II, and OSB-III).

Model Development

Figure 2 illustrates the proposed mechanical model for analysis of internal forces at an L-shaped, two-gusset-plate joint subjected to an external moment load and deformed in the elastic range. It is assumed that when the joint is subjected to an external moment load, P, the internal tensile force, F_T, is carried by the upper gusset plate along the centerline of the gusset plate. This tensile force is the resultant force of two tensile forces that act along the upper and lower rows of staples in the upper gusset plate, respectively. It is also assumed that the neutral axis is located at the rail centerline. The area below the neutral axis is in compression with a triangularly distributed stress because of the elastic deformation assumed, ie the resultant of the triangular distributed compression force, F_C, acts at 1/3 of half-rail width from the bottom side of the rail. Summing all the forces and

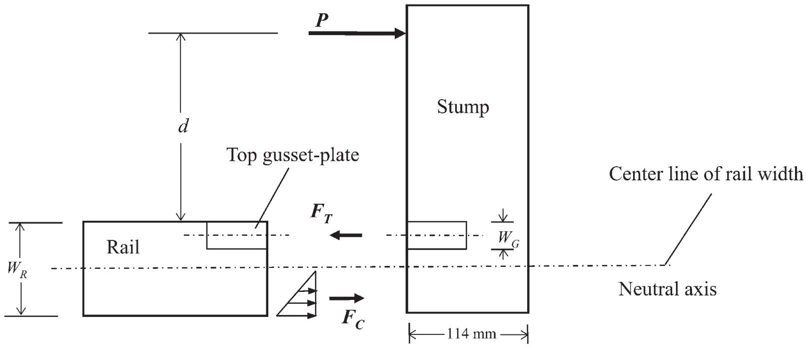

Figure 2. Mechanical analysis models for deriving moment resistance loads of L-shaped two-gusset-plate joints in oriented strandboard materials.

moments on the free-body diagram of the stump in Fig 2 yields the following equations:

$$\Sigma F = 0, F_C + P - F_T = 0 \quad (1)$$

$$\Sigma M = 0, P(d + W_R/2) - F_T(W_R/2 - W_G/2) - F_C(2/3)(W_R/2) = 0 \quad (2)$$

where d is distance from the point at the stump where the external moment load is applied to the rail top edge (mm), W_R is rail width (mm), and W_G is gusset plate width (mm).

Combining these two equations yields Eq 3, which is a calculation of the moment resistance load of the L-shaped, two-gusset-plate joints with the joint deformed in the elastic range:

$$P = F_T \frac{(5W_R - 3W_G)}{(6d + 5W_R)} \quad (3)$$

Specimen Preparation and Tests

Prior to joint construction, all cut OSB and plywood blanks were conditioned in an 8% equilibrium moisture content chamber. Staples were driven into the specimens with a pneumatic power stapler set to 483 kPa. All tests were performed immediately after stapling. Moisture contents of three OSB materials were measured in accordance with ASTM (2010a). Density and density profiles of OSB samples cut off from joint fastening members were measured using Quintek Measurement Systems' (Knoxville, TN) Density Profiler Model QDP-01X.

Lateral load test. Figure 3 shows the setup for evaluating lateral resistance load of face-to-face, two-row multistaple joints. Joint specimens were tested on a Tinius-Olsen (Horsham, PA) universal testing machine at a loading rate of 2.5 mm/min in accordance with ASTM (2010b). Load-slip (the relative displacement between two members) curves and specimen failure modes were recorded.

Bending load test. Figure 4 shows the setup for evaluating bending moment load of L-shaped, two-gusset-plate joints. All L-shaped joints were

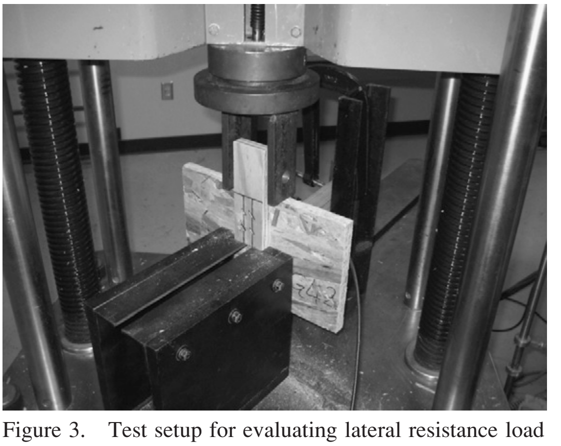

Figure 3. Test setup for evaluating lateral resistance load of face-to-face two-row multistaple joints in oriented strandboard materials.

Figure 4. Test setup for evaluating bending moment resistance of L-shaped two-gusset-plate joints in oriented strandboard materials.

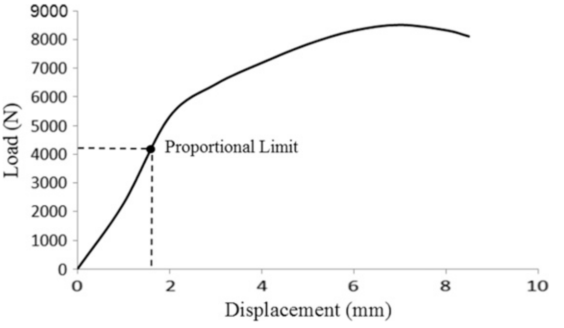

Figure 5. A typical lateral load-slip curve of face-to-face two-row multistaple joints in three oriented strandboard materials.

tested on a hydraulic SATEC (Norwood, MA) universal testing machine at a loading rate of 2.5 mm/min. Loads were applied to the stump 305 mm in front of the rail. Load-displacement curves of tested joints and their failure modes were recorded.

RESULTS AND DISCUSSION

Material Properties

Table 1 summarizes the mean values of physical properties of the three OSB materials evaluated in this study. Mean density comparisons indicated that OSB-III had a significantly higher overall density than the other two materials, followed by OSB-II and then OSB-I (Demirel 2012). Compared with OSB-II, OSB-III had a similar core density distribution, but it had a significantly higher surface density than OSB-II (Table 1), which mainly caused the density difference between the two materials. OSB-I had a significantly higher surface density than OSB-II, but its core density was significantly lower than OSB-II (Table 1).

Two-row Multistaple Joints

Load-slip curve. Figure 5 is a typical load-slip curve of a two-row multistaple joint in OSB when it was subjected to a lateral load. Three regions of linear elastic, curvilinear, and postfailure can be identified. In the linear elastic region, the lateral resistance load increased in proportion to slip increase up to the proportional limit point at which the curve deviated from the straight line. Beyond the proportional limit point, the slip increased at a faster rate than the lateral load and the relationship between the lateral load and slip was no longer linear and became curvilinear. The upper limit of the curvilinear region is the ultimate lateral load that the joint can sustain. After the ultimate load point, the joint starts its postfailure region in which the lateral resistance load starts to drop and the joint fails partially. All joint specimens failed with the mode of staple legs withdrawing from fastening members along with some fine wood particles attached to staple legs and also with staple legs bent and materials crushed underneath staples in the contacting side of both fastened and fastening members.

Mean comparisons. Table 2 summarizes mean ultimate lateral resistance loads and lateral resistance loads at proportional limit of face-to-face two-row multistaple joints in OSB materials. Each value represents a mean of 10 specimens tested. A two-factor analysis of variance (ANOVA) general linear model procedure was performed to analyze main effects and their interactions on mean ultimate lateral resistance loads of face-to-face OSB joints connected with two rows of staples at the 5% significance level. ANOVA results indicated that the two-factor

Table 2. Mean ultimate lateral resistance loads and mean lateral resistance loads at proportional limit of face-to-face two-row multistaple joints in three oriented strandboard (OSB) materials.[a]

Material type	Number of staples	Ultimate load (N)	Load at proportional limit (N)
OSB-I	4	3941 (8)	2233 (12)
OSB-II	4	4404 (12)	2233 (13)
OSB-III	4	4813 (9)	2246 (9)
OSB-I	6	6299 (9)	3576 (7)
OSB-II	6	6761 (12)	3452 (5)
OSB-III	6	7540 (7)	3581 (10)

[a] Values in parentheses are coefficients of variation in percentage.

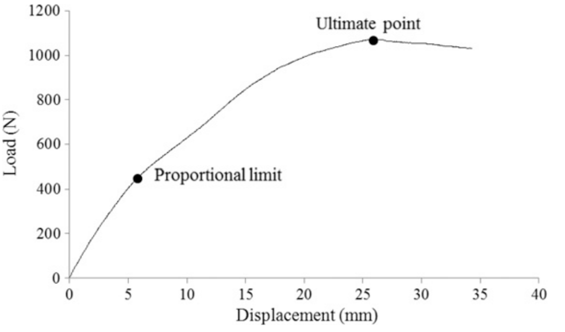

Figure 6. A typical load-displacement curve of L-shaped two-gusset-plate joints in three oriented strandboard materials.

interaction was not significant and two main effects were significant. Mean comparisons of main effect material type indicated that joints with OSB-III had a significantly higher ultimate lateral resistance load than OSB-II, followed by OSB-I, which had a significantly lower ultimate lateral resistance load than OSB-II. The difference in ultimate lateral resistance loads with different OSB materials can be explained by their different densities and density profiles. Significantly higher ultimate lateral resistance of joints with OSB-III was because OSB-III had a significantly higher overall density, especially the surface layer, than OSB-I and OSB-II. A possible explanation for joints with OSB-II material having significantly higher ultimate lateral resistance load than joints with OSB-I material is that OSB-II had a significantly higher core density than OSB-I (Table 1) and a uniform density profile across its thickness. OSB joints connected with six staples had a significantly higher ultimate lateral resistance load than those with four staples.

L-shaped Joints

Moment load-displacement curve. Figure 6 shows a typical bending moment load-displacement curve of L-shaped, two-gusset-plate joints in OSB materials. It has three clear regions of linear elastic, curvilinear, and postfailure that is similar to the lateral load-slip curve of two-row multistaple joints (Fig 5). This might imply that the load-displacement behavior of L-shaped, two-gusset-plate joints is mainly governed by the lateral load-slip behavior of face-to-face two-row multistaple joints that served as the top gusset plate of L-shaped joints. In addition, the joint failure always occurred at the top gusset plate in tension mainly with the modes of staple legs withdrawing from either the rail or the stump or both members along with some fine wood particles attached to staple legs and also with staple legs bent and the material underneath crushed.

Mean comparisons. Table 3 summarizes mean moment resistance loads at the ultimate point and proportional limit of L-shaped, two-gusset-plate joints in three OSB materials. Load ratios of moment resistance loads at the proportional limit to their corresponding values at the ultimate point were calculated. The average ratio of 0.51 indicates that the moment resistance load at the ultimate point is approximately twice that of its corresponding moment resistance load at proportional limit. This implies that if the moment resistance load of the joints at proportional limit can be found, then its ultimate moment resistance can be estimated by doubling the moment resistance load value at the proportional limit.

A three-factor ANOVA general linear model procedure was performed to analyze main effects and their interactions on mean ultimate moment resistance loads at the 5% significance level. ANOVA results indicated that the three-factor interaction was not significant. Among three two-factor interactions, material type by rail width and the number of staples by rail width

Table 3. Bending moment resistance loads of L-shaped two-gusset-plate joints subjected to a bending moment load 305 mm in front of the rail.[a]

Material type	Number of staples	Rail width (mm)	Ultimate load (N)	Load at proportional limit (N)	Load ratio
OSB-I[b]	8	152	1090 (12)	494 (10)	0.46 (15)
	8	178	1205 (14)	618 (21)	0.51 (14)
	8	203	1321 (13)	681 (14)	0.52 (8)
OSB-II	8	152	1054 (12)	516 (14)	0.49 (10)
	8	178	1228 (11)	587 (11)	0.48 (11)
	8	203	1397 (10)	685 (8)	0.49 (13)
OSB-III	8	152	1174 (11)	592 (10)	0.50 (8)
	8	178	1343 (6)	707 (10)	0.53 (12)
	8	203	1793 (10)	850 (7)	0.47 (8)
OSB-I	12	152	1624 (6)	965 (13)	0.59 (12)
	12	178	1721 (11)	983 (8)	0.57 (9)
	12	203	1913 (9)	1072 (12)	0.56 (9)
OSB-II	12	152	1726 (7)	832 (4)	0.48 (7)
	12	178	1837 (11)	974 (9)	0.53 (9)
	12	203	1788 (19)	894 (15)	0.50 (12)
OSB III	12	152	1824 (8)	856 (11)	0.47 (8)
	12	178	1833 (22)	996 (9)	0.54 (13)
	12	203	2068 (16)	1050 (15)	0.51 (9)
				Average	0.51

[a] Values in parentheses are coefficients of variation in percentage.
[b] OSB, oriented strandboard.

were significant. Therefore, these two significant two-factor interactions were further analyzed.

Tables 4 and 5 show the mean comparisons of ultimate moment resistance loads for rail width and material type, respectively. The results were based on a one-way classification with nine treatment combinations of rail width by material type. The protected least significant difference (LSD) multiple comparison procedure at the 5% significance level was performed to determine the mean differences of those treatments using the single LSD value of 214 N.

Tables 6 and 7 show the mean comparisons of ultimate moment resistance loads for rail width and the number of staples, respectively. The results were based on a one-way classification with six treatment combinations of rail width by the number of staples. The protected LSD multiple comparison procedure at the 5% significance level was performed to determine the mean differences of those treatments using the single LSD value of 116 N.

Rail width effect. Table 4 indicates that within OSB-I and OSB-II, the joints with 203-mm-wide rails had significantly higher ultimate moment resistance loads than the 152-mm-wide rail joints but not significantly higher than the 178-mm-wide

Table 4. Mean comparisons of ultimate moment resistance loads of L-shaped two-gusset-plate joints for rail width within each of three oriented strandboard (OSB) materials.[a]

Material type	Rail width 152 (mm)	178 (mm)	203 (mm)
	(N)		
OSB-I	1361 B	1468 AB	1615 A
OSB-II	1392 B	1530 AB	1592 A
OSB-III	1490 B	1619 B	1931 A

[a] Values with the same upper case letter are not statistically different at 5% significance level.

Table 5. Mean comparisons of ultimate moment resistance loads of L-shaped two-gusset-plate joints for material type within each of three rail widths.[a]

Rail width (mm)	Material type OSB-I[b]	OSB-II	OSB-III
	(N)		
152	1361 A	1392 A	1490 A
178	1468 A	1530 A	1619 A
203	1615 B	1592 B	1931 A

[a] Values with the same upper case letter are not statistically different at 5% significance level.
[b] OSB, oriented strandboard.

Table 6. Mean comparisons of ultimate moment resistance loads of L-shaped two-gusset-plate joints for rail width within each of two numbers of staples.[a]

Number of staples	Rail width 152 (mm)	178 (mm) (N)	203 (mm)
8	1103 C	1259 B	1503 A
12	1717 B	1819 AB	1922 A

[a] Values with the same upper case letter are not statistically different at 5% significance level.

Table 7. Mean comparisons of ultimate moment resistance loads of L-shaped two-gusset-plate joints for number of staples within each of three rail widths.[a]

Rail width (mm)	Number of staples 8 (N)	12
152	1103 B	1717 A
178	1259 B	1819 A
203	1503 B	1922 A

[a] Values with the same upper case letter are not statistically different at 5% significance level.

rail joints, and there were no significant differences in ultimate moment resistance loads between the 152- and 178-mm-wide rail joints. Within OSB-III, 203-mm-wide rail joints had significantly higher ultimate moment resistance loads than the 152- and 178-mm-wide rail joints, and there were no significant differences in ultimate moment resistance loads between the 152- and 178-mm-wide rail joints.

Table 6 indicates that when 8 staples were used, the ultimate moment resistance load of L-shaped, two-gusset-plate joints increased significantly as the rail width increased from 152 to 203 mm in increments of 25.4 mm. When 12 staples were used, 203-mm-wide rail joints had a significantly higher ultimate moment resistance load than 152-mm-wide rail joints but were not significantly higher than 178-mm-wide rail joints in ultimate moment resistances.

Based on mean comparisons in Tables 4 and 6, it can be concluded that within OSB-I (Table 3), if 8 staples were used, the ultimate moment resistance load of L-shaped, two-gusset-plate joints increased as rail width increased from 152 to 203 mm with an increment of 25.4 mm each time but the increase in the ultimate moment resistance load was not significant; the significant increase in the ultimate moment resistance load was obtained when rail width increased from 152 to 203 mm. If 12 staples were used, the ultimate moment resistance load increased as rail width increased from 152 to 178 but not significantly, whereas the increase in ultimate moment resistance loads was significant when rail width increased from 178 to 203 mm.

Within OSB-II (Table 3), if 8 staples were used, the ultimate moment resistance load of L-shaped, two-gusset-plate joints increased significantly as rail width increased from 152 to 203 mm with an increment of 25.4 mm each time, but if 12 staples were used, the ultimate moment resistance loads were not significantly different among the joints with three rail widths.

Within OSB-III (Table 3), if 8 staples were used, the ultimate moment resistance load of L-shaped, two-gusset-plate joints increased significantly as rail width increased from 152 to 203 mm with an increment of 25.4 mm each time. If 12 staples were used, the ultimate moment resistance load increased as rail width increased from 152 to 178 mm but not significantly, whereas the increase in ultimate moment resistance loads was significant when rail width increased from 178 to 203 mm.

Material effect. Table 5 indicates that there were no significant differences in ultimate moment resistance loads among the joints constructed of three OSB materials when rail widths were 152 and 178 mm wide, although results from the mean comparisons among ultimate lateral resistances of face-to-face two-row multistaple joints in three OSB materials indicated that the ultimate lateral resistances among three OSB materials were significantly different. When 203-mm-wide rails were used, L-shaped OSB-III joints showed significantly higher ultimate moment resistance loads than OSB-I and OSB-II joints, and there was no significant difference in ultimate moment resistance loads between OSB-I and OSB-II joints.

Staple number effect. Table 7 shows that, in general, the L-shaped, two-gusset-plate joints

Table 8. Mean differences between ultimate moment resistance loads of L-shaped two-gusset-plate joints with 8 and 12 staples.

Material type	Rail width (mm)	Number of staples 8 (N)	Number of staples 12 (N)	Ratio 12/8
OSB-I	152	1090	1624	1.49
	178	1205	1721	1.43
	203	1321	1913	1.45
OSB-II	152	1054	1726	1.64
	178	1228	1837	1.50
	203	1397	1788	1.28
OSB-III	152	1174	1824	1.55
	178	1343	1833	1.36
	203	1793	2068	1.15
			Average	1.43

OSB, oriented strandboard.

connected with 12 staples had significantly higher ultimate moment resistance loads than those with 8 staples within each of three rail widths. This is consistent with results from lateral loading tests of two-row staple joints, which were OSB joints connected with two rows of six staples that had a significantly higher ultimate lateral resistance load than those with two rows of four staples. Table 8 indicates that the ultimate moment resistance load of L-shaped joints connected with 12 staples was 43% higher on average than 8-staple-connected joints.

Model verification. Estimated moment resistance loads at proportional limit, P_{PL}, were calculated with Eq 3 and shown in Table 9 under the Estimated column. The F_T value in Eq 3 was estimated using the mean ultimate lateral resistance load at proportional limit of face-to-face two-row multistaple joints given in Table 2. The ratios of estimated moment resistance load values to observed load values were calculated and shown in Table 9. The ratios range from 0.80 to 1.17, which indicates that, in general, the derived Eq 3 based on the proposed mechanical analysis model reasonably estimates bending moment resistance loads at proportional limit of L-shaped, two-gusset-plate joints in OSB materials.

Therefore, the ultimate moment resistance load, P_{ult}, of L-shaped, two-gusset-plate joints in OSB materials can be estimated using the following equation because Table 3 indicates that the moment resistance load at ultimate point is approximately twice its corresponding moment resistance load at proportional limit, P_{PL}:

$$P_{ult} = 2P_{PL} \tag{4}$$

Table 10 shows the ultimate moment resistance loads of L-shaped, two-gusset-plate joints estimated with Eq 4 and their corresponding observed

Table 9. Comparisons of observed moment resistance loads at proportional limit of L-shaped two-gusset-plate joints in three oriented strandboard (OSB) materials with their corresponding values estimated using Eq 3.

Number of staples	Material type	W_R (mm)	W_G (mm)	d (mm)	F_T (N)	Estimated (N)	Observed (N)	Ratio
8	OSB-I	152	51	305	2233	523	494	1.06
		178	51	305	2233	605	618	0.98
		203	51	305	2233	677	681	0.99
	OSB-II	152	51	305	2233	523	516	1.01
		178	51	305	2233	605	587	1.03
		203	51	305	2233	677	685	0.99
	OSB-III	152	51	305	2246	526	592	0.89
		178	51	305	2246	609	707	0.86
		203	51	305	2246	681	850	0.80
12	OSB-I	152	51	305	3576	838	965	0.87
		178	51	305	3576	969	983	0.99
		203	51	305	3576	1083	1072	1.01
	OSB-II	152	51	305	3452	809	832	0.97
		178	51	305	3452	935	974	0.96
		203	51	305	3452	1046	894	1.17
	OSB-III	152	51	305	3581	839	856	0.98
		178	51	305	3581	970	996	0.97
		203	51	305	3581	1085	1050	1.03

Table 10. Comparison of observed ultimate moment resistance loads of L-shaped two-gusset-plate joints in oriented strandboard (OSB) materials with their corresponding values estimated using Eq 4.

Number of staples	Material type	W_R (mm)	Estimated (N)	Observed (N)	Ratio
8	OSB-I	152	1046	1090	0.96
		178	1210	1205	1.00
		203	1354	1321	1.02
	OSB-II	152	1046	1054	0.99
		178	1210	1228	0.99
		203	1354	1397	0.97
	OSB-III	152	1052	1174	0.90
		178	1218	1343	0.91
		203	1362	1793	0.76
12	OSB-I	152	1676	1624	1.03
		178	1938	1721	1.13
		203	2166	1913	1.13
	OSB-II	152	1618	1726	0.94
		178	1870	1837	1.02
		203	2092	1788	1.17
	OSB-III	152	1678	1824	0.92
		178	1940	1833	1.06
		203	2170	2068	1.05

values, as well as the ratios of these two values for all combinations of the number of staples by material type by rail width. The ratios range from 0.76 to 1.17, which indicates that overall, Eq 4 reasonably estimates ultimate static bending moment resistance loads of L-shaped, one-sided, two-gusset-plate joints in OSB materials.

Figure 2 indicates that the moment arm, L_{PL}, and the moment, M_{PL}, of the joint at proportional limit in resisting of the moment load, P_{PL}, applied at a distance of d to the rail top edge, and the ultimate moment can be calculated using the following formulas, respectively:

$$L_{PL} = d + W_R/2 \tag{5}$$

$$M_{PL} = P_{PL} \times (d + W_R/2) \tag{6}$$

$$M_{ult} = 2M_{PL} \tag{7}$$

Table 11 summarizes the estimated ultimate moment values of L-shaped, two-gusset-plate joints in OSB materials using Eq 7 and their corresponding observed value, as well as the ratios of these two values for all combinations of the number of staples by material type by rail width. The ratios ranged from 0.76 to 1.17. The ultimate moment resistance values ranged from 429 to 842 N-m.

Table 11. Comparisons of observed ultimate moment resistance values of L-shaped two-gusset-plate joints in three oriented strandboard (OSB) materials with their corresponding values estimated using Eq 7.

Number of staples	Material type	W_R (mm)	d (mm)	Estimated P_{PL} (N)	Estimated M_{ult} (N-m)	Observed P_{ult} (N)	Observed M_{ult} (N-m)	Ratio
8	OSB-I	152	305	523	399	1090	415	0.96
		178	305	605	477	1205	475	1.00
		203	305	677	550	1321	537	1.02
	OSB-II	152	305	523	399	1054	402	0.99
		178	305	605	477	1228	484	0.99
		203	305	677	550	1397	568	0.97
	OSB-III	152	305	526	401	1174	447	0.90
		178	305	609	480	1343	529	0.91
		203	305	681	554	1793	729	0.76
12	OSB-I	152	305	838	639	1624	619	1.03
		178	305	969	764	1721	678	1.12
		203	305	1,083	880	1913	778	1.13
	OSB-II	152	305	809	616	1726	658	0.94
		178	305	935	737	1837	724	1.01
		203	305	1046	850	1788	727	1.17
	OSB-III	152	305	839	639	1824	695	0.92
		178	305	970	764	1833	722	1.06
		203	305	1085	882	2068	841	1.05

CONCLUSIONS

The ultimate bending moment resistance of L-shaped furniture joints connected with two gusset plates stapled on one side of joint members in three OSB materials was investigated. Factors evaluated on the moment resistance of L-shaped gusset-plate joints were joint member material type, rail width, and the number of staples.

Experimental results indicated that face-to-face two-row multistaple joints with OSB-III had significantly higher ultimate lateral resistance loads than those with OSB-II, followed by OSB-I joints that had significantly lower ultimate lateral resistance loads than OSB-II joints. OSB density and density profile play important roles that affect these differences in lateral resistance loads of face-to-face two-row multistaple joints in OSB materials. The face-to-face OSB joints connected with six staples had significantly higher ultimate lateral resistance loads than those with four staples.

Experimental results showed that the ultimate bending moment resistance of L-shaped two-gusset-plate joints evaluated in this study ranged from 429 to 842 N-m. There were no significant differences in ultimate moment resistance loads among the joints constructed of the three OSB materials used in this study when rail widths were 152 and 178 mm wide. When 203-mm-wide rails were used, OSB-III joints showed significantly higher ultimate moment resistance loads than OSB-I and OSB-II joints, and there was no significant difference in ultimate moment resistance loads between OSB-I and OSB-II joints. In general, the L-shaped two-gusset-plate joints connected with 12 staples had significantly higher ultimate moment resistance loads than the ones with 8 staples. The ultimate moment resistance load of L-shaped, two-gusset-plate joints increased as the rail width increased from 152 to 203 mm with an increment of 25.4 mm, but the significance was affected by material type and the number of staples used.

The study on the moment load-displacement curve of L-shaped two-gusset-plate joints in OSB materials indicated that the moment resistance load at the ultimate point is about two times its corresponding moment resistance load at proportional limit. The proposed mechanical model was verified experimentally as a valid means for deriving the estimation equation of the bending moment resistance of L-shaped two-gusset-plate joints in OSB materials.

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