Face Lateral Shear Resistance of One-Row Multistaple Joints in Oriented Strandboard

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Abstract

Lateral shear resistance capacities of face-to-face single-staple and one-row vertically aligned multistaple joints in three oriented strandboards (OSB) were investigated and compared. Experimental results from testing single-staple joints indicated that the face strand orientation of OSB materials had no significant effect on their staple holding capacity in resisting lateral shear loads. The OSB-III with a density of 35.19 pounds per cubic foot (pcf; 563 kg/m^3) had a significantly higher lateral shear resistance capacity than OSB-II, with a density of 29.12 pcf (466 kg/m^3). Results of multistaple joints indicated that there was no significant difference in lateral shear load resistance capacities between OSB-II and OSB-III joints. The lateral shear load resistance capacity of multistaple joints increased significantly as the number of staples increased from two to four in increments of one. Two alternative power equations were suggested to estimate the lateral shear load resistance capacity of face-to-face one-row vertically aligned multistaple joints in OSB. One equation requires knowing the lateral shear resistance load of single-staple joints in an OSB material, and the other one requires knowing the density of the OSB material constructing the joints.

The increased use of wood-based panel composites such as oriented strandboard (OSB) as upholstery furniture frame stock is due to several of its inherent advantages compared with solid lumber. Specifically, it eliminates several steps necessary for processing solid lumber as frame stock, such as drying, end-cutting, and planing (Eckelman and Erdil 2000). Therefore, capital investment, raw material costs, handling, and processing costs are reduced. In addition, the use of panel type materials with computer numerical control (CNC) router technology facilitates optimization of cutting schedules with accompanying high yields and accelerated production. Also, CNC router technology allows the design and construction of forms, shapes, and processes that are not feasible with solid lumber construction. Compared with plywood, in general OSB panels are less expensive; therefore, the use of OSB in construction of upholstery furniture frames can reduce material costs.

The rational strength design of upholstery furniture frames constructed of wood-based panel products such as OSB materials requires that fundamental information be available concerning the lateral shear holding capacity of various fasteners such as staples in OSB materials (Zhang and Maupin 2004). It also requires static and fatigue moment resistance capacities of various joints constructed with fasteners such as staple-connected gusset-plate joints. Staples are the most commonly used fasteners to assemble structural members in upholstered furniture frames constructed of wood-based panel composites because power-driven staples are fast and easy for assembling furniture joints (Erdil et al. 2003). It is crucial for furniture manufacturers to know such basic mechanical properties of the materials they are using and understand what each property means to their frame performance, especially for panel products like OSB, which was recently introduced to the upholstery furniture industry (Erdil et al. 2003). The amount of data available on this topic is limited, especially data comparing material properties among different OSB products on the market. Several studies were undertaken at the Forest Products Laboratory of Mississippi State

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University to evaluate and compare static lateral shear resistance capacities of face-to-face staple-connected joints and static and fatigue bending moment capacities of staple-connected gusset-plate joints in different OSB materials. This article reports the results from the study of lateral shear resistance capacities of face-to-face single-staple-connected and one-row multistaple-connected joints in three selected OSB materials.

Yadama et al. (2002) investigated the effects of the number of staples and staple spacing on the lateral shear resistance of stapled joints in selected solid wood and wood-based materials. Wood-based composites were medium-density fiberboard with a specific gravity of 0.78 and OSB with a specific gravity of 0.74. Experimental results indicated that the number of staples positively affected the joint resistance to lateral loads; however, the relationship was not linear for most materials. The mean ultimate lateral load values of the OSB joints in pounds (Newtons) were 212 (943), 385 (1,713), 584 (2,598), and 1,107 (4,924) for one, two, four, and eight staples, respectively. The spacing effect on the lateral resistance of OSB joints was not statistically significant. In general, joints with higher density members provided the most resistance to lateral loads.

Zhang and Maupin (2004) studied the lateral shear resistance of face-to-face single-staple and multistaple joints in pine plywood. Experimental results indicated that the lateral shear resistance of single-staple joints in the plywood ranged from 268 (1,192) to 315 (1,401) pounds (Newtons), with coefficients of variation ranging from 11 to 18 percent, and was affected by staple crown orientation, but not plywood grain orientation. The lateral shear resistance of one-row vertically aligned multistaple joints in the plywood increased significantly as the number of staples increased from two to five in increments of one. Plywood grain orientation affected the lateral shear resistance of the multistaple joints when more than two staples were used. The mean ultimate lateral resistance of the multistaple joints ranged from 569 (2,531) to 1,425 (6,339) pounds (Newtons) with coefficients of variation ranging from 7 to 12 percent. The lateral shear resistance of the multistaple joints can be estimated with the empirical power expression including the single-staple joint resistance value and the number of staples raised to the power ranging from 0.92 and 0.95.

The main objective of this study was to evaluate and compare lateral shear resistance capacities of face-to-face staple-connected joints in three different OSB materials. Therefore, the specific objectives of this study were to (1) evaluate OSB material types and their face strand orientation effects on the lateral shear resistance of single-staple-connected joints; (2) investigate the additive efforts of staples and OSB material type effects on the lateral shear resistance of face-to-face one-row vertically aligned multi-staple joints; and (3) quantify the effect of the number of staples and OSB material density on the lateral resistance capacity of the multistaple-connected joints in OSB materials.

Materials and Methods

Specimen configuration and materials

The general configuration of a face-to-face staple-connected joint specimen in this study is shown in Figure 1. Each specimen consisted of two principal structural members, a fastened member and a fastening member, joined together by staples 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 11.5 inches (292.1 mm) long by 7 inches (177.8 mm) wide by 23/32 inch (18.3 mm) thick. The fastened member, southern yellow pine plywood, had nominal dimensions of 6 inches (152.4 mm) long by 2 inches (50.8 mm) wide by ¾ inch (19.1 mm) thick and was oriented with its length parallel to the face ply grain direction for all joint specimens in this study.

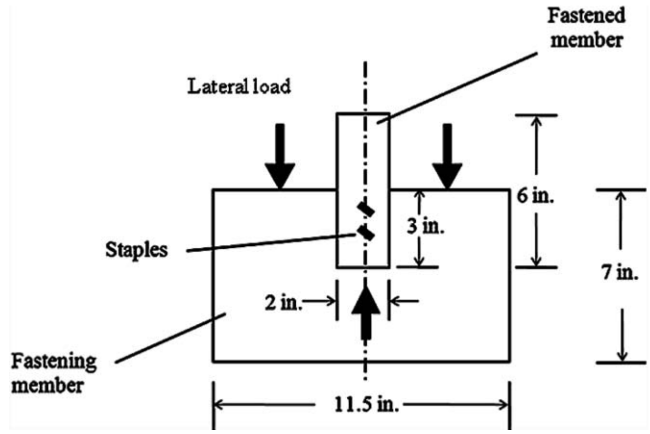

Figure 1.—The general configuration of a face-to-face staple-connected joint specimen. 1 inch = 25.4 mm.

Three different densities of 23/32-inch-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-size panel (4 by 8 ft) 8-foot direction (machine direction) were used as the fastening members to evaluate and compare their resistances to staple lateral shear loads. One type of commercial furniture grade, ¾-inch-thick 5-ply southern yellow pine plywood was used as fastened members. The full-size sheet of plywood (4 by 8 ft) 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 8-foot direction.

The staples were SENCO 16-gauge galvanized chisel-end-point types with a crown width of 7/16 inch (11.1 mm) and leg length of 1.5 inches (38.1 mm). The leg width of staples was 0.062 inch (1.6 mm) and thickness was 0.055 inch (1.4 mm). The staples were coated with Sencote coating, a nitro-cellulose–based plastic.

Experimental design

Single-staple joints.—A complete two-factor 2 × 3 factorial experiment with 30 replicates per combination was conducted to evaluate the factors on OSB material staple holding capacity in resisting lateral shear loads. The factors were fastening member face strand orientation (parallel and perpendicular) and fastening member material type (OSB-I, OSB-II, and OSB-III). Therefore, 180 joints were tested. Parallel referred to joint specimens loaded in the direction parallel to the fastening member face strand orientation, which is the full-size panel length direction. Perpendicular referred to the applied lateral load perpendicular to the fastening member face strand orientation.

One-row multistaple joints.—A complete two-factor 3 × 3 factorial experiment with 10 replicates per combination

Table 1.—Mean value of physical and mechanical properties of three tested oriented strandboard (OSB) materials.[a]

Material type	Density (pcf) Overall	Density (pcf) Core	Density (pcf) Surface	MC (%)	MOE (psi) Cross orientation	MOE (psi) Parallel orientation	MOR (psi) Cross orientation	MOR (psi) Parallel orientation
OSB-I	28.88 (8)	24.3 (11) B[b]	40.8 (16) B	5.0 (6)	358,277 (10) B[c]	747,173 (10) A	1,614 (22) B	2,827 (20) A
OSB-II	29.12 (6)	28.8 (4) A	30.4 (7) C	5.8 (6)	308,781 (8) B	769,191 (16) A	2,047 (14) B	3,098 (28) A
OSB-III	35.19 (11)	29.3 (4) A	53.0 (9) A	4.7 (3)	494,103 (7) B	1,007,213 (10) A	2,678 (16) B	4,756 (17) A
Plywood	41 (8)	NA	NA	5.6 (5)	NA	1,291,000 (17)	NA	7,400 (23)

[a] 1 pound per square inch (psi) = 6.895 kPa; 1 pound per cubic foot (pcf) = 16 kg/m^3. Values with the same letter are not statistically different; values in parentheses are percent coefficients of variation. MC = moisture content; NA = not applicable.
[b] Mean comparisons among density values were done in the same column.
[c] Mean comparisons for modulus of elasticity (MOE) and modulus of rupture (MOR) were done in the same row.

was conducted to evaluate the additive effects of staples on the lateral shear resistance of face-to-face OSB joints connected with one row of vertically aligned staples. The two factors were fastening member material type (OSB-I, OSB-II, and OSB-III) and the number of staples (two, three, and four). Therefore, 90 joints were tested. The multistaple placement patterns of each staple number level are shown in Figure 2. In the multistaple joint study, all specimens were loaded parallel to staple alignment direction and perpendicular to their fastening member face strand orientation.

Physical and mechanical property testing

Physical properties of moisture content (MC) and density were evaluated in accordance with Method B—Secondary Oven-Drying Method (ASTM International 2010a) and Method A—Volume by Measurement (ASTM International 2010b), respectively. Density profile measurement was carried out in Quintek Measurement Systems' Density Profiler Model QDP-01X. Mechanical properties, modulus of rupture (MOR) and flatwise modulus of elasticity (MOE), were measured in accordance with Method A—Center-Point Flexure Test (ASTM International 2010c). For each OSB material, 30 replicates of each of two specimen groups, parallel and cross, were tested. Parallel specimens were defined as their length direction parallel to the full-size panel length direction, i.e., their face strand orientation. Cross specimens were defined as their length direction perpendicular to the full-size panel length direction.

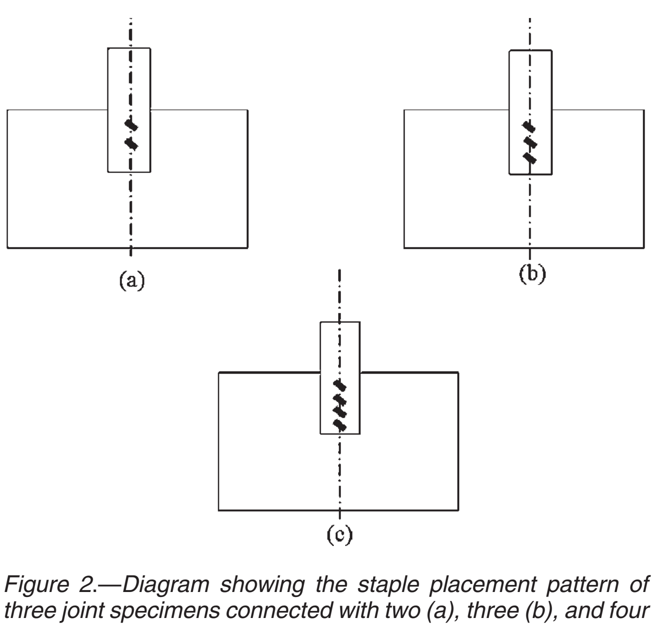

Figure 2.—Diagram showing the staple placement pattern of three joint specimens connected with two (a), three (b), and four (c) one-row vertically aligned staples.

Joint specimen preparation and test

Prior to joint construction, all cut OSB and plywood blanks were conditioned in an equilibrium MC chamber controlled at 65°F ± 4°F (18°C ± 2°C) and 40 ± 2 percent relative humidity. The staples were driven into the specimens with a pneumatic power stapler set to 70 pounds per square inch (psi; 483 kPa). All tests were performed right after the stapling in the testing room with the temperature at 76°F (24°C) and 35 percent relative humidity. Figure 3 shows the test setup for evaluating the lateral shear resistance load of face-to-face staple-connected joints. All joint specimens were tested on a Tinius-Olsen universal-testing machine at a loading rate of 0.10 in./min (2.54 mm/min) in reference with the Lateral Nail, Staple, or Screw Resistance Test (ASTM International 2010d). Ultimate lateral shear loads and specimen failure modes were recorded.

Results and Discussion

Physical and mechanical properties

Table 1 summarizes the mean values of physical and mechanical properties of three OSB materials evaluated in this study. Mean density comparisons indicated that OSB-III had a significantly higher density than the other two materials, followed by OSB-II and OSB-I (Demirel 2012).

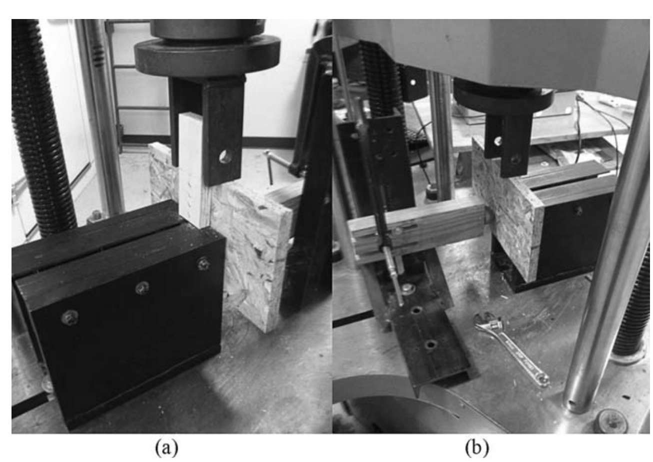

Figure 3.—Test set-up for evaluating lateral shear load resistance of face-to-face, staple-connected joints: (a) front view and (b) back view.

Typical density profiles of three OSB materials shown in Figure 4 indicate that OSB-II had a flat density profile indicating a uniform density across its thickness. 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), which mainly caused the difference in density between the two materials.

MOE and MOR values of each of the three OSB materials tested in flatwise and with their face strands oriented in parallel were significantly higher than their corresponding values in cross orientation. This indicated that flake orientation had a significant effect on OSB static bending properties, and flakes were oriented mainly in the direction parallel to the full-size panel length direction.

Mean ultimate lateral shear loads and comparisons

Single-staple joints.—Table 2 summarizes the mean ultimate lateral shear loads and their coefficients of variation (COV) of face-to-face single-staple-connected joints in OSB materials. Each value represents a mean of 30 replicates. In general, all single-staple 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 in the contacting side of both fastened and fastening members.

A two-factor analysis of variation (ANOVA) general linear model procedure was performed to analyze main effects and their interaction on the mean ultimate lateral shear loads. The ANOVA results indicated that the two-factor interaction, face strand orientation × material type, was statistically significant at the 5 percent level. Hence, the tests for main effects were ignored, and the significant two-factor interaction was analyzed. Tables 2 and 3 summarize mean comparisons of the ultimate lateral shear loads based on a one-way classification with six treatment combinations. The protected least significant difference (LSD) multiple comparison procedure at the 5 percent significance level was performed to determine the mean differences among those treatment combinations using the single LSD value of 26 pounds (116 N).

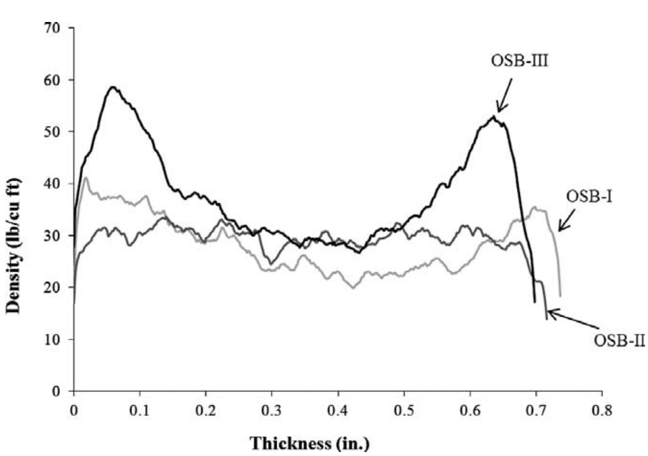

Figure 4.—Typical density profiles of three oriented strandboard (OSB) materials evaluated in this study.

Table 2.—Mean comparisons of ultimate lateral shear loads of face-to-face single-staple-connected joints for material surface strand orientation within each of three oriented strandboard (OSB) materials.[a]

Material type	Parallel orientation (lb)	Perpendicular orientation (lb)
OSB-I	226 (23) A[b]	244 (18) A
OSB-II	268 (22) A	275 (16) A
OSB-III	303 (13) A	321 (19) A

[a] 1 pound = 4.448 Newtons. Values with the same letter are not statistically different. Values in parentheses are percent coefficients of variation.
[b] Mean comparisons were done in the same row.

Table 2 shows that in general there is no significant difference in ultimate lateral shear loads between perpendicular and parallel grain orientations of OSB materials. Table 3 indicates that in general the three OSB materials had significantly different load resistances to single-staple lateral shear. OSB-III had a significantly higher load resistance to staple lateral shear than the other two materials, followed by OSB-II and OSB-I. The ratios of higher ultimate staple lateral loads to lower ones ranged from 1.13 to 1.34 among three OSB materials. The significant differences in staple lateral shear load resistances among three OSB materials can be explained by the significant differences in their densities (Table 1). The analysis of the correlation between lateral resistance load and density indicated that there was a high correlation between the two variables (coefficient of correlation, $r = 0.97$).

One-row multistaple joints.—Table 4 summarizes the mean ultimate lateral shear loads and their COV of face-to-face one-row vertically aligned multistaple-connected joints in OSB materials. Each value represents a mean of 10 replicates. All multistaple joint specimens failed with a similar failure mode of single-staple joints, which was 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 in the contacting side of both fastened and fastening members.

A two-factor ANOVA general linear model procedure was performed to analyze main effects and their interaction on the mean ultimate lateral shear loads. The ANOVA results indicated that the two-factor interaction, material type × staple number, was not statistically significant at the 5 percent level, and the two main effects were significant. Hence, the test for the interaction was ignored, and the

Table 3.—Mean comparisons of ultimate lateral shear loads of face-to-face single-staple-connected joints for material type within each of two oriented strandboard (OSB) face strand orientations.[a]

Orientation	OSB-I (lb)	OSB-II (lb)	OSB-III (lb)
Parallel	226 C[b]	268 B	303 A
Perpendicular	244 C	275 B	321 A
Average	235	272	312

[a] 1 pound = 4.448 Newtons. Values with the same letter are not statistically different.
[b] Mean comparisons were done in the same row.

Table 4.—Mean comparisons of ultimate lateral shear loads of face-to-face one-row vertically aligned multistaple-connected joints for oriented strandboard (OSB) type within each of the number of staples.[a]

No. of staples	OSB-I (lb)	OSB-II (lb)	OSB-III (lb)
2	476 (13) B[b]	550 (15) A	547 (11) A
3	611 (8) B	771 (9) A	745 (10) A
4	858 (11) B	931 (13) A	985 (15) A

[a] 1 pound = 4.448 Newtons. Values with the same letter are not statistically different. Values in parentheses are percent coefficients of variation.
[b] Mean comparisons were done in the same row.

significant two main effects were analyzed. Tables 4 and 5 summarize mean comparisons of the ultimate lateral shear loads for main effects, material type and number of staples, respectively. The single LSD value of 46 pounds (205 N) determined the mean differences at the 5 percent level.

Table 4 shows that OSB-I joints had a significantly lower ultimate lateral shear load than OSB-II and OSB-III joints. There were no significant differences in ultimate lateral shear loads between OSB-II and OSB-III joints. This implies that the ultimate lateral shear load resistance of one-row multistaple-connected joints might not be sensitive to a material surface density increase (Fig. 4), and may be governed mainly by material core density. This is also evidenced by the fact that OSB-I had a lower core density than OSB-II, with the results that OSB-I joints had a significantly lower ultimate lateral shear resistance load than OSB-II joints. The average ultimate lateral shear load ratios of OSB-II to OSB-I joints were 1.16, 1.26, and 1.09 for two, three, and four staples, respectively. The shear load ratios of OSB-III to OSB-II were 0.99, 0.97, and 1.06 for two, three, and four staples, respectively.

Table 5 indicates that in general the mean ultimate lateral shear load of face-to-face one-row vertically aligned multistaple-connected joints increased significantly as the number of staples increased from two to four.

Estimation equations

To quantify the effect of the number of staples on the lateral shear load resistance of face-to-face one-row vertically aligned multistaple-connected joints in OSB materials, the following power equation was fitted to the individual testing data points of multistaple-connected joints for each of three tested OSB materials using the least squares method:

Table 5.—Mean comparisons of ultimate lateral shear loads of one-row vertically aligned multistaple-connected joints for the number of staples within each of three oriented strandboard (OSB) material types.[a]

Material type	Two staples (lb)	Three staples (lb)	Four staples (lb)
OSB-I	476 C[b]	611 B	858 A
OSB-II	550 C	771 B	931 A
OSB-III	547 C	745 B	985 A

[a] 1 pound = 4.448 Newtons. Values with the same letter are not statistically different.
[b] Mean comparisons were done in the same row.

$$P_N = K_1 \times N^a \tag{1}$$

where

P_N = estimated mean ultimate lateral shear load of one-row multistaple-connected joints (lb),
N = the number of staples, and
K_1 and a = regression constants.

Table 6 gives regression coefficients, coefficients of determination, r^2, and P values of derived equations for each of the three OSB materials. Because K_1 values were very close to the average ultimate lateral shear loads of single-staple joints, P_1, for each OSB material, the regression constants, K_1, in the Equation 1—223, 266, and 301—were replaced by their corresponding single-staple lateral load values of 235, 272, and 312, respectively. This substitution with regression analysis of combining all three OSB material data points yielded the following equation:

$$P_N = P_1 \times N^{0.92} \quad (r^2 = 0.88) \tag{2}$$

where P_1 is the mean ultimate lateral shear load of face-to-face single-staple-connected joints in OSB materials (lb).

This indicates that the lateral shear load resistance of face-to-face one-row multistaple-connected joints in OSB materials could be estimated using Equation 2 based on the lateral shear resistance load of single-staple joints and a term of $N^{0.92}$ as a correction factor to consider the multistaple additive effects. This correction factor, $N^{0.92}$, was very close to the correction factor values resulting from the study of lateral shear load resistance of the same type of staples in pine plywood (Zhang and Maupin 2004). The correction factors were $N^{0.92}$ and $N^{0.95}$ for the lateral shear load resistances parallel and perpendicular to plywood face grain orientations, respectively. The correction factor, $N^{0.92}$, also indicates that the lateral shear load resistance of one-row multistaple joints is lower than the product of single-staple lateral shear load and the number of staples. In general, this happens because when multifasteners are used in rows parallel to the loading direction, the total load applied to the joint is unequally distributed among fasteners in the row, and theoretically, the two end fasteners carry a majority of the load (Forest Products Laboratory 2010). This implies that the end staple will reach its maximum shear load capacity and fail first, followed by the failure of the next staple, and then the next staple. This chain reaction of staple failure due to unequal load distribution on staples will yield an actual lateral shear load resistance of face-to-face one-row multistaple-connected joints lower than the product of single-staple lateral shear load capacity and the number of staples.

Table 6.—Regression constants and associated r^2 and P values for derived equations for estimating mean ultimate lateral resistance loads of face-to-face one-row vertically aligned multistaple-connected joints in oriented strandboard (OSB) materials.[a]

Material type	K_1	a	r^2	P value	P_1	K_1/P_1
OSB-I	223	0.97	0.9	<0.0001	235	0.95
OSB-II	266	0.94	0.9	<0.0001	272	0.98
OSB-III	301	0.84	0.94	<0.0001	312	0.96

[a] 1 pound = 4.448 Newtons.

To quantify the effects of the number of staples and material density on the lateral shear load resistance of face-to-face one-row multistaple-connected joints in OSB materials, the following power equation was fitted to the individual testing data points of all three OSB materials including single-staple joints:

$$P_N = K_2 \times N^b \times W^c \tag{3}$$

where

$W =$ material density (pcf), and

K_2, b, and $c =$ regression constants.

Regression analyses yielded the values of 21, 0.92, and 0.73 for the regression constants, K_2, b, c, respectively, with an r^2 value of 0.90. Therefore, the lateral shear load resistance of face-to-face one-row vertically aligned multi-staple-connected joints in an OSB material could also be estimated using Equation 3 if its density is known.

Conclusions

Lateral shear resistances of face-to-face single-staple-connected and one-row multistaple-connected joints in three OSB materials were investigated. Experimental results of single-staple-connected joints indicated that OSB density had a significant effect on the lateral shear resistance capacity of face-to-face single-staple joints. OSB-III with a higher density of 35.19 pcf (563 kg/m^3) had a significantly higher staple holding capacity in resisting lateral shear loads than OSB-II with a density of 29.12 pcf (466 kg/m^3). OSB-I with a lower density of 28.88 pcf (462 kg/m^3) showed a significantly lower staple holding capacity in resisting lateral shear loads than OSB-II. Face strand orientations of OSB materials had no significant effect on their staple holding capacity in resisting lateral shear loads.

Experimental results of multistaple-connected joints indicated that the number of staples increased the lateral shear resistance capacity of face-to-face OSB joints connected with one row of vertically aligned staples. The lateral shear resistance capacity increased significantly as the number of staples increased from one to four in increments of one. The lateral shear resistance capacity of multistaple joints in OSB-I was significantly lower than those in OSB-II and OSB-III joints. There was no significant difference in lateral shear load resistance capacities between OSB-II and OSB-III joints. The lateral shear resistance capacity of multistaple-connected joints might be governed by material core density and might not be sensitive to material surface density changes, because OSB-II and OSB-III had similar core densities and OSB-I had a lower core density than OSB-II and OSB-III materials.

Regression analyses indicated that the lateral shear resistance capacity of face-to-face OSB joints connected with one row of vertically aligned staples can be estimated using two alternative power equations. One equation requires knowing the lateral shear resistance load of single-staple joints in an OSB material. The other equation requires knowing the density of the OSB material constructing the joints.

The conclusions were only limited to the OSB materials and staples evaluated in this study. General conclusions, such as effects of material density and the number of staples on the lateral shear resistance capacity of face-to-face staple joints, could be stated. Therefore, for a specific OSB panel product used as furniture frame stock, a testing method similar to that used in this study could be adapted to understand its staple joint lateral shear load capacity and limitations.

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