LATERAL LOADS OF STAPLED–GLUED SURFACE-TO-SURFACE JOINTS IN ORIENTED STRANDBOARD FOR FURNITURE

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Abstract. The additive effects of the number of staples and gluing on ultimate lateral resistance loads of surface-to-surface, multistaple- and glue-connected joints in oriented strandboards (OSB) were investigated. Experimental results indicated that for a stapled–glued OSB joint with a given configuration of surface-to-surface bonding area of two joint members, its ultimate lateral resistance load and stiffness are governed by the number of staples used and gluing, respectively. Applying glue to multistaple-connected OSB joints can alter the effect of the number of staples used on their ultimate lateral resistance loads. Gluing increases joint lateral resistance loads, but this increase will not be significant when the number of staples used reaches a critical number. Applying glue to a stapled OSB joint improves its stiffness when compared with the stiffness of a stapled-only joint. The differences in ultimate lateral resistance loads of stapled–glued joints among three OSB materials evaluated in this study were not significant when the number of staples was six or less, and the differences became significant when the number of staples increased to eight.

Keywords: Joint lateral resistance load, multistaple-connected joints, glued joints, oriented strandboard, fastener additive effects.

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INTRODUCTION

The strength and stiffness performance of an upholstered furniture frame depends heavily on the fastenings that hold its structural members together. The combination of staples and glue to connect frame members is one of the most widely used construction methods in upholstered furniture manufacturing. Figure 1 is a good example where staples and glue are used to connect the front stump to the front rail in a sofa frame using the gusset plate technique, and the joint is subjected to lateral loads when the sofa frame is subjected to a side thrust load test on arms-outward loads (GSA 1998).

As more wood-based composites such as plywood and oriented strandboard (OSB) panel products are used for upholstered furniture frame construction, the engineering data related to the load resistance capacity of stapled–glued joints in wood-based composites becomes increasingly important. With this data, furniture manufacturers can design and reengineer their products to meet product strength and durability requirements.

The load resistance of stapled–glued joints may be influenced by additive effects of staples and the glue (Pellicane 1991; Wang et al 2007). There is limited information available concerning the additive effects of the staples and glue on the load resistance of stapled–glued joints in OSB materials for furniture frame construction, especially about the data related to the lateral load resistance of surface-to-surface stapled–glued joints in OSB materials.

Studies were carried out on lateral and direct withdrawal load resistances of staples-only connected joints in plywood (Zhang et al 2002a, 2002b; Erdil et al 2003; Zhang and Maupin 2004; Zhang et al 2004; Zhang et al 2006) and OSB materials (Yadama et al 2002; Erdil et al 2003; Zhang et al 2006; Demirel and Zhang 2014; Demirel et al 2013). Dai et al (2008) investigated lateral and tensile resistances of glued-only joints in pine plywood and OSB materials.

Wang et al (2007) investigated the moment capacity of OSB gusset plate joints connected with staples and glue and concluded that application of glue to the connection surface increased their moment resistance capacity up to 27%. Pellicane (1991) investigated the lateral load-carrying capacity of nail/glue joints in wood and found out that the use of glue with nails greatly enhanced

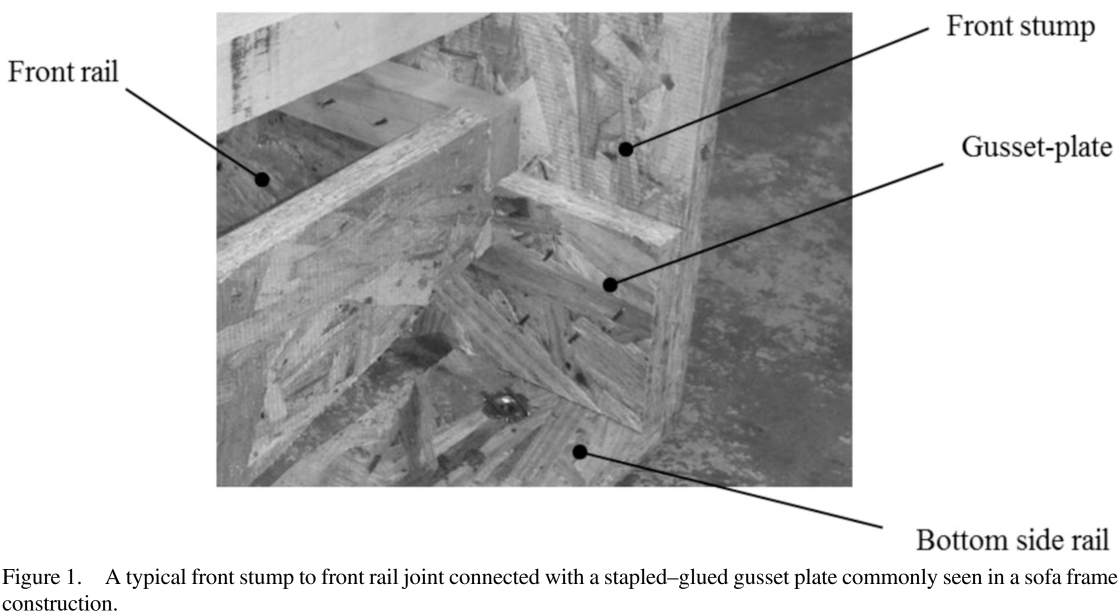


Figure 1. A typical front stump to front rail joint connected with a stapled–glued gusset plate commonly seen in a sofa frame construction.

the connection load-carrying capacity and the average ratio of nail/glue to nail-only joint load-carrying capacity was about 3.7. Therefore, the main objective of this study was to evaluate the additive effect of staples and glue on the lateral load resistance of surface-to-surface, stapled–glued joints in OSB materials.

MATERIALS AND METHODS

The general configuration of a surface-to-surface joint used in this study is shown in Fig 2. Each specimen consisted of two principal structural members, a main member and a side member, joined together by either staples only, glue only, or staples and glue. If staples were used, their crowns were oriented at an angle of 45° to the lateral loading direction. The main members were OSB materials and had nominal dimensions of 292 mm long × 178 mm wide × 18 mm thick. The main members were prepared with their length direction parallel to the full-sized (1.2 m × 2.4 m) panel length direction, ie the applied lateral load was perpendicular to the main member face strand orientation. The side member was southern yellow pine plywood with its face grain parallel to the lateral load direction, and had nominal dimensions of 152 mm long × 51 mm wide × 19 mm thick.

Three types of 18-mm-thick southern pine OSB materials (OSB-I, OSB-II, and OSB-III) with

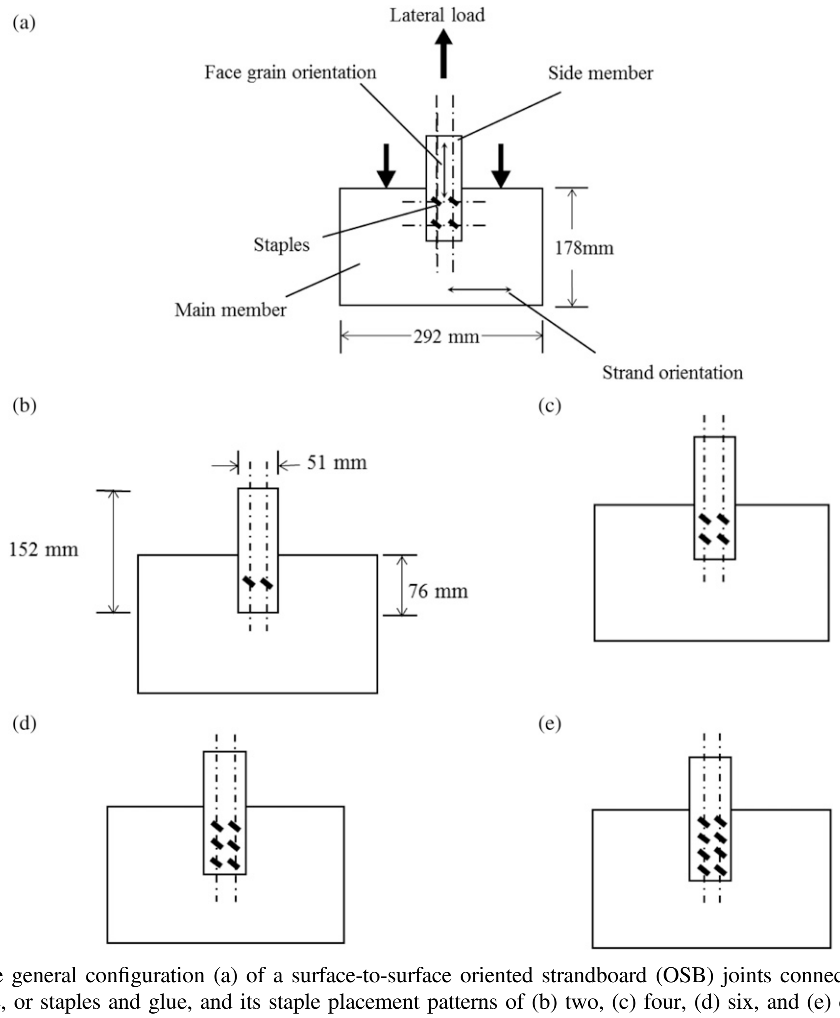


Figure 2. The general configuration (a) of a surface-to-surface oriented strandboard (OSB) joints connected with either staples, or glue, or staples and glue, and its staple placement patterns of (b) two, (c) four, (d) six, and (e) eight.

their face strands oriented in the direction parallel to the full-sized panel length direction were used as the main members. One type of furniture grade, 19-mm five-ply southern yellow pine plywood, was used as side members. The full-sized sheet of plywood (1.2 m × 2.4 m) was constructed with one center ply aligned parallel to the face plies and two even-numbered plies aligned perpendicular to the face. The face plies were aligned parallel to the sheet in the 2.4-m direction. Table 1 summarizes the mean values of the physical properties of the evaluated OSB materials. OSB-III had a significantly higher overall density than the other two, followed by OSB-II and OSB-I which were not significant (Demirel 2012). OSB-III had a significantly higher density of surface layer material than the other two, followed by OSB-I which has a significantly higher surface density than OSB-II. OSB-I had a significantly lower core density than the other two which had no significant difference between themselves.

The staples were SENCO 16-gauge galvanized chisel-endpoint types with a crown width of 11 mm and leg length of 38 mm. The leg width of the staples was 1.6 mm, and thickness was 1.4 mm. The staples were coated with Sencote coating, a nitrocellulose-based plastic. The glue used to connect joint members was polyvinyl acetate with solids contents of 40%.

Experimental Design

Stapled joints. A complete 3 × 4 × 2 factorial experiment with 10 replicates per combination was conducted to evaluate the additive effects of staples and glue on the lateral load resistance of surface-to-surface OSB and plywood joints. The three factors were main member material type (OSB-I, OSB-II, and OSB-III), the number of staples (2, 4, 6, and 8), and fastener type (stapled-only, stapled–glued). Therefore, 240 joint specimens were tested. The evenly spaced multistaple placement patterns for each staple number level are given in Fig 2.

Glued-only joints. In addition to stapled joint evaluation, a one-way factorial experiment with 10 replicates was conducted to evaluate the lateral resistance of surface-to-surface glued-only joints. The factor was main member material type (OSB-I, OSB-II, and OSB-III). Therefore, 30 joints were tested. The glued-only joint specimens had the same configuration illustrated in Fig 2, but without staples.

Testing

Before joint construction, all cut OSB and plywood blanks were conditioned in an 8% EMC chamber for 2 weeks. For staple-connected joints, a Senco 16-gauge pneumatic power staple gun was used to drive the staples into OSB materials with its pressure set to 483 kPa. For glued joints, the glue was applied to the contact surfaces of both main and side members with the glue amount set to 646 g/m^2. All glued-only joint specimens were clamped with the observation of the glue squeezed out. All glued joint specimens were allowed a 48-h curing time before testing.

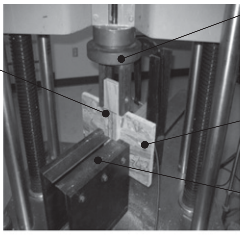
Figure 3 shows the test setup for measuring the lateral resistance load of OSB joints. The side member of a specimen placed on a supporting

Table 1. Mean density and MC of the three oriented strandboard (OSB) materials evaluated in this study.

Material type	Density: Overall (g/cm^3)	Density: Core (g/cm^3)	Density: Surface (g/cm^3)	MC (%)
OSB-I	0.463 (8) 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)

Values in parentheses are coefficients of variation in percent. Comparisons of mean density values were performed in the same column and values with the same capital letter are not statistically different at a 5% significance level.

(a)



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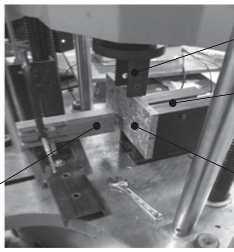

Figure 3. Test setup for evaluating lateral load resistance behavior of surface-to-surface oriented strandboard (OSB) joints connected with either staples, or glue, or staples and glue: (a) front view and (b) back view.

base and a downward load was applied to the main member with a U-shaped loading head attached to the testing machine. A bearing roller fixture placed right behind each main member of the specimens was used as an alignment support because the load applied to the joint specimen was eccentric. All the joint specimens were evaluated on a Tinius-Olsen universal testing machine at a loading rate of 2.5 mm/min in accordance with ASTM D 1761-06 (ASTM 2010a). Load–slip curves and failure modes of all the tested joint specimens were recorded. Moisture contents of three OSB materials were measured in accordance with ASTM D 4442-92 (ASTM 2010b). Density values of the OSB samples cut off from the joint main members after the loading test were calculated based on their density profiles measured using a QMS Density Profiler Model QDP-01X (Demirel and Zhang 2014).

Statistical Analyses

A three-factor analysis of variance (ANOVA) general linear model procedure was performed to analyze significances of the main effects and their interactions on mean ultimate lateral resistance loads of surface-to-surface stapled joints in OSB materials. Mean comparisons were performed using the protected least significant difference (LSD) multiple comparison procedure if any significant interaction was identified, otherwise the main effects might be concluded. All statistical analyses were performed at 5% significance level.

RESULTS AND DISCUSSION

Load–Slip Curves

Figure 4, load–slip curves of OSB-III joints as examples, shows the typical load-slip curves of OSB joints evaluated in this study. The load–slip curve of glued-only OSB joints (Fig 4a) had one peak, ie the lateral resistance load sharply declined immediately after reaching its ultimate loading point where joint glue bonding failed. Stapled–glued joints in general have two peaks, ie the lateral resistance load reaches its first peak where possibly joint glue bonding failed then drops to a certain value where staples were mainly subject to the applied load, and then picks up its value, keeps rising to the second peak, and then declines gradually.

The mean of first and second peak loads that appeared on the load–slip curves of glued joints were summarized in Table 2, and the second peak value for two-staple connected joints was not recognized and hence not recorded in the computer system. The first peak value was considered as the ultimate lateral resistance load for glued-only joints. The second peak value was considered as the ultimate lateral resistance load for stapled–glued joints because the second peak value in general was higher than the first peak value. Stapled-only joints typically have three regions commonly observed in other mechanical fasteners such as bolted joints (Johansen 1949). The peak value was considered as the ultimate lateral resistance load for stapled-only joints.

The load–slip curves of evaluated OSB joints (Fig 4) indicated that glue provides the stiffness to the joints because glued joints tended to be stiffer than stapled-only joints, whereas staples can

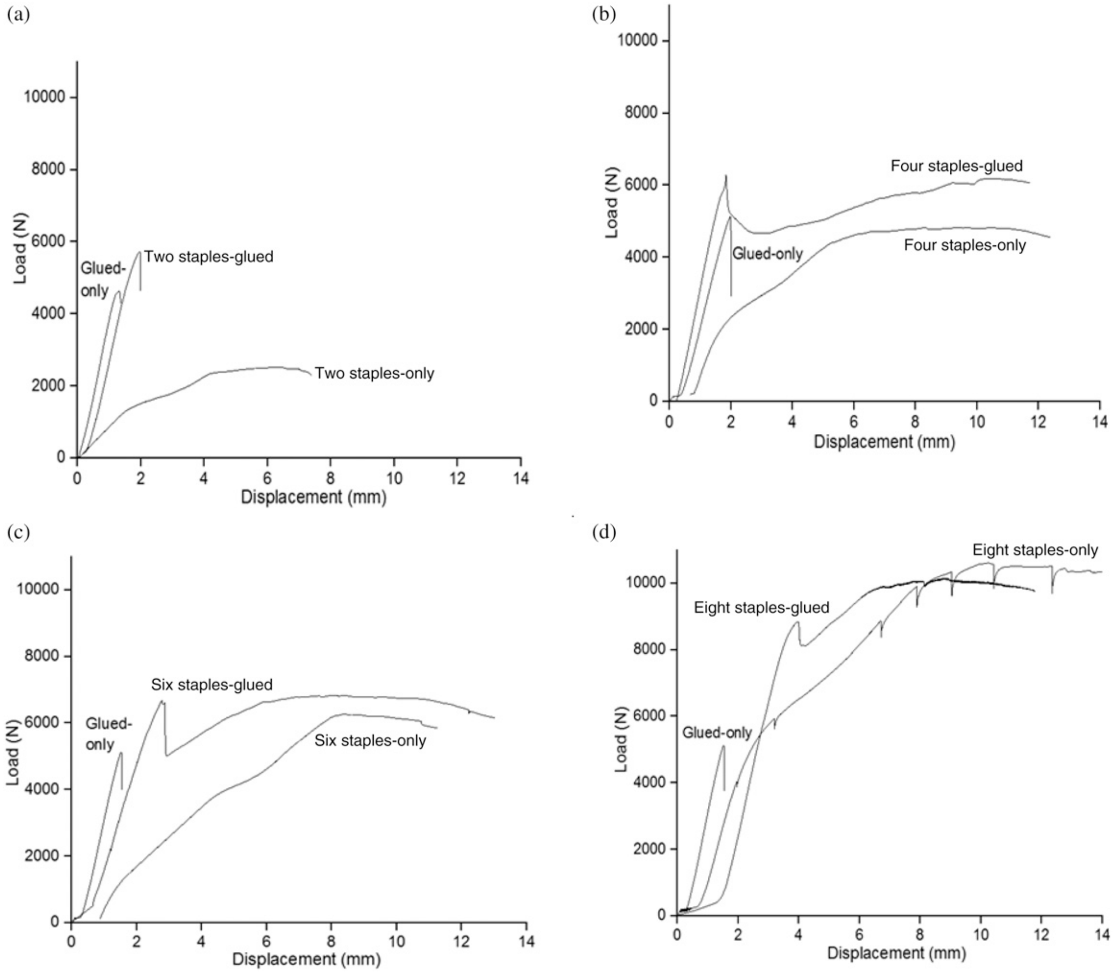

Figure 4. Load–slip curves of OSB-III joints, as examples, illustrate typical load–slip curves of evaluated joints connected with (a) two staples, (b) four staples, (c) six staples, and (d) eight staples, respectively.

provide secondary holding resistance to external loads through holding joint members together after glue-line fractured. The load–slip curves also indicated there was an additive effort of glue and staples not only on joint stiffness, but also on lateral resistance loads of OSB joints. For two- or four-staple connected joints (Fig 4a and 4b), glued joints had higher peak values than glued-only and stapled-only joints. For six-staple connected joints, the second peak value of a stapled–glued joint was higher than the peak value of a stapled-only joint. For eight-staple connected joints, the second peak value of a stapled–glued joint was not higher than the peak value of a stapled-only joint. These observations might imply that with less number of staples used, for instance, in this study, two- and four-staple connected OSB joints, glue and staple additive effects on lateral resistance loads of stapled–glued joints are more obvious. But this additive effect is not for the case where more number of staples is used, for instance six- and eight-staple connected joints. In another words, for a given configuration and sized joint, if the glue and staples are used for the connection of joint members, there is a critical turning point where its ultimate lateral resistance load will not be significantly increased by applying glue when enough number of staples is used, but the joint

Table 2. Summary of mean lateral resistance load values of first and second peaks of glued joints in three oriented strandboard (OSB) materials.

		Number of staples				
Peak	Material type	0	2	4	6	8
1st	OSB-I	5170 (18) D	5868 (12) C	6719 (8) B	6953 (11) B	7625 (16) A
	OSB-II	5237 (12) E	6035 (13) C	6907 (14) B	7229 (8) B	8227 (9) A
	OSB-III	5330 (12) C	5770 (13) C	7322 (8) B	6677 (7) B	8557 (8) A
2nd	OSB-I	n/a	n/a	6773 (8)	7021 (10)	7917 (12)
	OSB-II	n/a	n/a	6907 (15)	7429 (5)	8626 (5)
	OSB-III	n/a	n/a	7322 (8)	7071 (4)	9904 (10)

Values in parentheses are coefficients of variation in percent. Values with the same capital letter in the same row are not statistically different at a 5% significance level.

stiffness will be enhanced with glue applied. The significances among these mean peak values of lateral resistance loads of evaluated OSB joints were discussed in the following mean comparison section.

Failure Modes

All glued-only joints failed with the mode of two connected OSB and plywood members separated completely. All stapled–glued OSB joints failed with the mode of member separation; staple legs withdrawing from main members, staple legs bent, and materials crushed in the contacting sides of both main and side members. All stapled-only joints failed with the mode of staple legs withdrawn from main members and staple legs bent and materials underneath of staple legs crushed in main and side members (Fig 5).

Lateral Load Mean Comparisons

Table 3 summarizes mean ultimate lateral resistance load values of surface-to-surface glued-only, stapled-only, and stapled–glued OSB joints evaluated in this study. Each value represents a mean of 10 specimens tested. The ANOVA result (Table 4) indicated that the three-way interaction was not significant, and all two-way interactions and main effects were significant. Further checking the magnitudes of main effects' F values indicated that glue and staple had a similar level of magnitude, whereas material type had a relative lower F value than other two. The influences of these three significant main effects on mean ultimate lateral resistance loads were analyzed by considering the nonsignificant three-way interaction because the nature of conclusions from interpretation of main effects also depends on the relative magnitudes of the interaction and individual main effects (Freund and Wilson 1997), for instance, the magnitudes of F values for each of the three main factors, material type, the number of staples, and fastener type were 30.70, 476.09, and 317.30, respectively.

Mean comparisons for each of three factors were summarized in Tables 5, 6, and 7, respectively. The results were based on a one-way classification with 24 treatment combinations with respect to the three-factor interaction and mean comparisons among these combinations using the protected LSD multiple comparison procedure with a single LSD value of 623 N.

Staple number effect. Table 5 indicates that in general the ultimate lateral resistance load of surface-to-surface stapled OSB joints increased as the number of staples increased from two to eight in increments of two, but the significance was affected by the condition of glue applied or not. When glue was applied, the ultimate lateral resistance load increased significantly as the number of staples increased from two to four and from six to eight, but there was no significant increase in resistance load as the number of staples increased from four to six. In the cases of joints without glue applied, the ultimate lateral resistance load of surface-to-surface stapled OSB joints increased significantly as the number of staples increased from two to eight in increments of two (Demirel and Zhang 2014).

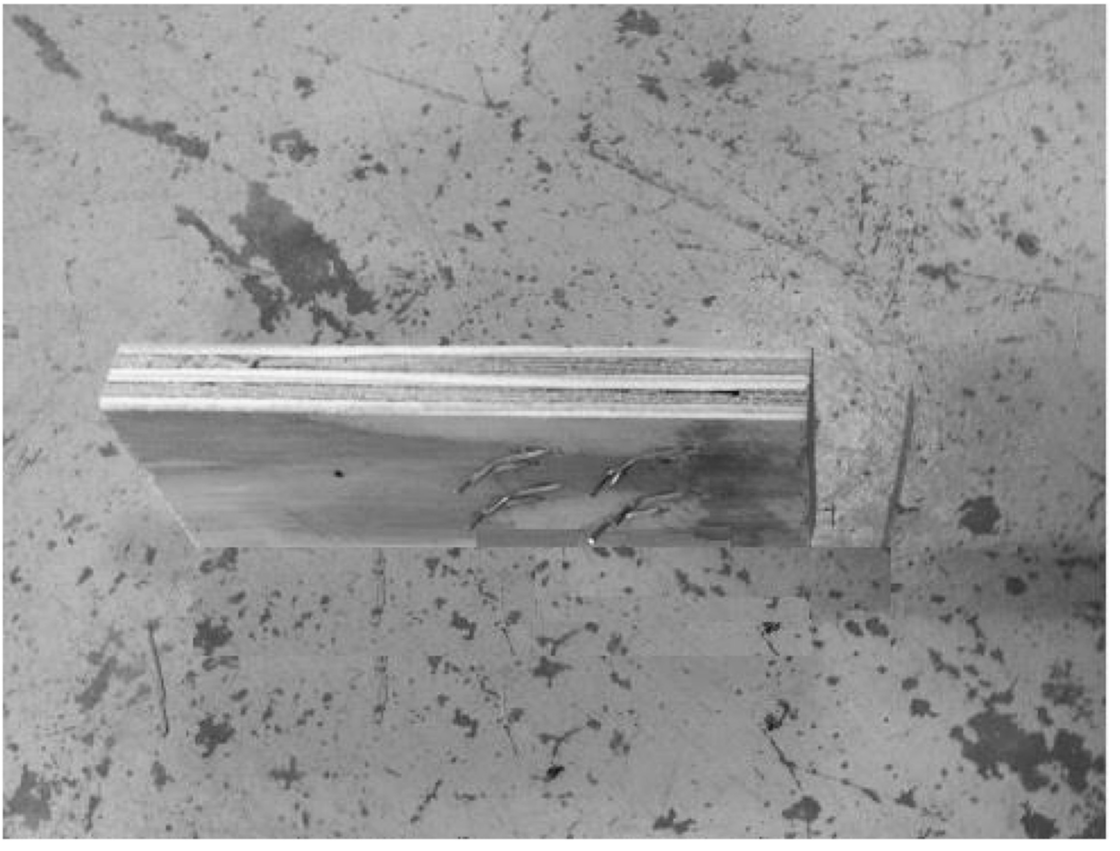

Figure 5. Typical failure modes of surface-to-surface, glued, oriented strandboard (OSB) and plywood joints connected with six staples.

Gluing effects. Table 6 indicates that the ultimate lateral resistance loads of the joints vary with glue applied or not when the same number of staples was applied for all three types of OSB panels. The table tells that with the staples numbered from two to six, applying glue would increase the ultimate lateral resistance load no matter what type of OSB panel was used. When the number of staples reached eight, the additive effect of glue to ultimate lateral resistance loads of the joints was not significant, ie the ultimate lateral resistance load of the joints was mainly

Table 3. Summary of mean ultimate lateral resistance loads of surface-to-surface joints in three oriented strandboard (OSB) materials evaluated in this study.

		Number of staples				
		0	2	4	6	8
Glue applied	Material type	(N)				
Yes	OSB-I	5170 (18)	5868 (12)	6773 (8)	7021 (10)	7917 (17)
Yes	OSB-II	5237 (12)	6035 (13)	6907 (15)	7429 (5)	8626 (6)
Yes	OSB-III	5330 (12)	5770 (13)	7322 (8)	7071 (5)	9904 (10)
No	OSB-I	n/a	2260 (5)	3941 (9)	6299 (9)	7833 (14)
No	OSB-II	n/a	2193 (13)	4404 (12)	6761 (10)	8781 (13)
No	OSB-III	n/a	2620 (11)	4813 (9)	7540 (7)	9862 (7)

Values in parentheses are coefficients of variation in percent.

Table 4. Summary of analysis of variance (ANOVA) results obtained from the general linear model (GLM) procedure performed on three factors.

Source	*F* value	*p* value
Material	30.70	<0.0001
Glue	317.30	<0.0001
Material × glue	3.04	0.0498
Staple	476.09	<0.0001
Material × staple	6.49	<0.0001
Glue × staple	88.95	<0.0001
Material × glue × staple	1.31	0.2559

affected by staples applied when eight staples applied.

The load ratios of glued–stapled joints over stapled-only joints were calculated and are listed in the fifth column (Table 6). The load ratios reduced as the number of staples increased, which further indicates that the additive effect of glue to the lateral resistance load of stapled joint reduced with the increasing number of staples applied. It also tells that applying glue to the joints with the number of staples less than eight was more effective if applying glue to increase the magnitude of ultimate lateral resistance loads was the only concern.

Material type effects. Table 7 indicates that when the glue applied, the differences in ultimate lateral resistance loads of stapled joints among three OSB panels were not significant when the number of staples applied was six or less, and the differences became significant only when the number of staples applied were eight. Glued-stapled joints with OSB-III yielded the highest ultimate lateral resistance load, followed by OSB-II and then OSB-I. This indicates only when the staples number increased to eight, the density outclasses the gluing as the main influencing factor.

In general, stapled-only joints with a higher density OSB panel tend to yield a higher ultimate lateral resistance load than the ones with a lower density OSB panel (Demirel and Zhang 2014). Table 7

Table 5. Comparisons of mean ultimate lateral resistance loads of surface-to-surface stapled joints in three oriented strandboard (OSB) materials for number of staples within each combination of glue applied and material type.

		Number of staples			
		2	4	6	8
Glue applied	Material type	(N)			
Yes	OSB-I	5868 C	6773 B	7021 B	7917 A
Yes	OSB-II	6035 C	6907 B	7429 B	8626 A
Yes	OSB-III	5770 C	7322 B	7071 B	9904 A
No	OSB-I	2260 D	3941 C	6299 B	7833 A
No	OSB-II	2193 D	4404 C	6761 B	8781 A
No	OSB-III	2620 D	4813 C	7540 B	9862 A

Values with the same capital letter in the same row are not statistically different at a 5% significance level.

Table 6. Comparisons of mean ultimate lateral resistance loads of surface-to-surface stapled joints in three oriented strandboard (OSB) materials for glue applied within each combination of material type and number of staples.

		Glue applied		
		No	Yes	Ratio
Material type	Number of staples	(N)		—
OSB-I	2	2260 B	5868 A	2.60
	4	3941 B	6773 A	1.72
	6	6299 B	7021 A	1.11
	8	7833 A	7917 A	1.01
OSB-II	2	2193 B	6035 A	2.75
	4	4404 B	6907 A	1.57
	6	6761 B	7429 A	1.10
	8	8781 A	8626 A	0.98
OSB-III	2	2620 B	5770 A	2.20
	4	4813 B	7322 A	1.52
	6	7540 A	7071 A	0.94
	8	9862 A	9904 A	1.00

Values with the same capital letter in the same row are not statistically different at a 5% significance level.

Table 7. Comparisons of mean ultimate lateral resistance loads of surface-to-surface stapled joints in three oriented strandboard (OSB) materials for material type within each combination of number of staples and glue applied.

		Material		
		OSB-I	OSB-II	OSB-III
Number of staples	Glue applied	(N)		
2	No	2260 A	2193 A	2620 A
	Yes	5868 A	6035 A	5770 A
4	No	3941 A	4404 A	4813 A
	Yes	6773 A	6907 A	7322 A
6	No	6299 B	6761 B	7540 A
	Yes	7021 A	7429 A	7071 A
8	No	7833 C	8781 B	9862 A
	Yes	7917 C	8626 B	9904 A

Values with the same capital letter in the same row are not statistically different at a 5% significance level.

indicates that in the case of glued-stapled joints, only after eight staples were applied, OSB-III had a significantly higher ultimate lateral resistance than other two, followed by OSB-II with a significantly higher ultimate lateral resistance than OSB-I. When with two or four or six staples, there is no significant difference between joints with different OSB materials. This implies that applying glue could average material density efforts at a given number of staples, in this case six, because of the additive effort of staples and gluing.

In addition to comparisons of mean loads performed for ultimate lateral resistance loads of stapled joints (including stapled-only and stapled–glued joints), comparisons of means of the first peak loads were also performed for glued-only joints (0 staple) in Table 2. The results were based on a one-way classification with 15 treatment combinations with respect to the two-factor interaction of material type and the number of staples and mean comparisons among these combinations were performed using the protected LSD multiple comparison procedure with a single LSD value of 663 N.

The general trend was that stapled–glued joints had significantly higher ultimate lateral resistance loads than glued-only joints because of the additive effects of the staples and gluing. It might be because the staples bore the applied loads simultaneously with the glue-bonded area.

CONCLUSIONS

The major conclusions from investigating additive effects of the number of staples and gluing on lateral resistance loads of joints varied with three OSB materials are as follows:

1. For a stapled–glued OSB joint with a given configuration of surface-to-surface bonding area of two joint members, its ultimate lateral resistance load and stiffness are governed by the number of staples used and gluing, respectively.
2. Applying glue to a multistaple-connected OSB joint can be additive to the effect of the number of staples used on its ultimate lateral resistance load. The ultimate lateral resistance load of stapled–glued joints increased significantly as the number of staples increased from two to four, but the increase was not significant as the number of staples increased from four to six, and the increase became significant again as the number of staples increased from six to eight. The ultimate lateral resistance load of stapled-only OSB joints increased significantly as the number of staples increased from two to eight in increments of two.
3. Applying glue to a multistaple-connected OSB joint increases its lateral resistance load, but this increase will not be significant when the number of staples used reaches a critical number. In this experiment, the critical number of staples was six, ie beyond this point the ultimate lateral resistance load was mainly affected by lateral resistance loads of staples in OSB materials.
4. Applying glue to a stapled OSB joint improves its stiffness if compared with the stiffness of a stapled-only joint when the number of staples used is less than or equal to six.
5. The differences in ultimate lateral resistance loads of stapled–glued joints among three OSB materials evaluated in this study were not significant when the number of staples was six or less, and the differences became significant when the number of staples increased to eight.

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