Staple holding strength of furniture frame joints constructed of plywood and oriented strandboard

Y.Z. Erdil*
J. Zhang*
C.A. Eckelman*

Abstract

Staples are common in the construction of upholstered furniture. Staples are most common for the attachment of fabric to the frame, but they are also now being used in the construction of the frame itself because they provide a rapid and convenient method of constructing joints. The primary objective of these tests was to develop basic strength data for staple holding strength in both plywood and oriented strandboard (OSB) that could be used in the product engineering of furniture frames constructed of these materials. Results of the tests showed the staple holding strength from the face was at least 50 percent higher than that from the edge of plywood and OSB. The results of lateral holding of staples on edge of plywood and OSB indicated that the number of staples was nearly proportional to the strength. In the gusset plated stapled moment resisting joints, results showed that the larger gusset dimension and higher number of staples were the key factors in increasing the overall strength of joints. Furthermore, application of glue in the gusset plates could at least double the moment resisting strength of such joints.

Staples are common in the construction of upholstered furniture for both attaching fabric to the frame and in joining the frame. Taken individually, staples are generally acknowledged to have limited holding strength, but there is a pervasive feeling that the low holding strength of individual staples can be offset by their use in multiples. This idea does, in fact, hold in such applications as the attachment of plywood gussets to the sides of other members with staples. In these cases, the staples are loaded in lateral shear rather than tension, and sufficient staples may develop the strength required. However, when staples are the sole means of attaching members together with non-gusseted joints, it is questionable whether enough staples can be used to develop the strength required.

The conclusion to be drawn is that the strength requirements of each joint in a sofa frame should be determined first and rational procedures then followed to determine if a staple-based joint can provide the strength required. Sound furniture frames can be and have been constructed with staples as the sole load bearing fasteners when this practice has been followed.

Past research[1,2] concerning the holding strength of staples is helpful in designing staple-based joints. Chow et al.[3] investigated the direct withdrawal strength of staples and nails in structural wood-based panels such as oriented strandboard (OSB) and plywood. The results of the study showed that panel type, fastener type, and exposure conditions affected the withdrawal strength. Yadama et al.[4] investigated typical up-

[1] Albert, T.J. and J.W. Johnson. 1967. Lateral holding capacity of power-driven fasteners. Forest Prod. J. 17(9):59-67.

[2] Johnson, J.W. and T.J. Albert. 1962. Tests of power-driven fasteners for plywood. Forest Prod. J. 12(12):589-595.

[3] Chow, P., J.D. Mcnatt, S.J. Lambrechts, and G.Z. Gertner. 1988. Direct withdrawal and head pull-through performance of nails and staples in structural wood-based panel materials. Forest Prod J. 38(6):19-25.

[4] Yadama, V., B.M. Syed, P.H. Steele, and D.E. Lyon. 1991. Effects of leg penetration on the strength of staple joints in selected wood and wood-based materials. Forest Prod. J. 41(6):15-20.

The authors are, respectively, Assistant Professor of Wood Science, Mugla Univ., Faculty of Technical Education, Kotekli/Mugla/48000, Turkey; Assistant Professor, Forest Prod. Lab., Mississippi State Univ., Mississippi State, MS 39762-9820; and Professor, Dept. of Forestry and Natural Resources, Purdue Univ., West Lafayette, IN 47907. Approved for publication as J. Article No. FP 223 of the Forest and Wildlife Res. Center, Mississippi State Univ. This paper was received for publication in August 2001. Reprint No. 9353.
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Table 1. — Description of panels for the tests.

Material code	Board description	Wood species	Density	Thickness
			(pcf)	(in.)
OSB-1	Oriented strandboard	Mixed softwoods	46.9	3/4
OSB-2	Oriented strandboard	Mixed softwoods	39.1	3/4
OSB-3	Oriented strandboard	Mixed softwoods	48.5	7/8
OSB-4	Oriented strandboard	Mixed softwoods	42.5	7/8
OSB-5	Oriented strandboard	Mixed softwoods	47.0	3/4
SPLY-1	5-ply, C-C	Southern pine (*Pinus elliottii*)	35.9	23/32
SPLY-2	6-ply, 2 center plies, furniture grade	Southern pine (*Pinus elliottii*)	36.3	23/32
SPLY-3	5-ply, structural sheathing	Southern pine (*Pinus elliottii*)	36.8	23/32
HPLY	6-ply, 2 center plies, furniture grade	Sweetgum (*Liquidambar styraciflua*)	36.3	3/4
DFP-3/8	4 ply	Douglas-fir (*Pseudotsuga menziesii*)	31.1	3/8
DFP-1/2	4 ply	Douglas-fir (*Pseudotsuga menziesii*)	34.4	1/2
DFP-5/8	5 ply	Douglas-fir (*Pseudotsuga menziesii*)	32.1	5/8
DFP-3/4	7 ply	Douglas-fir (*Pseudotsuga menziesii*)	32.8	3/4

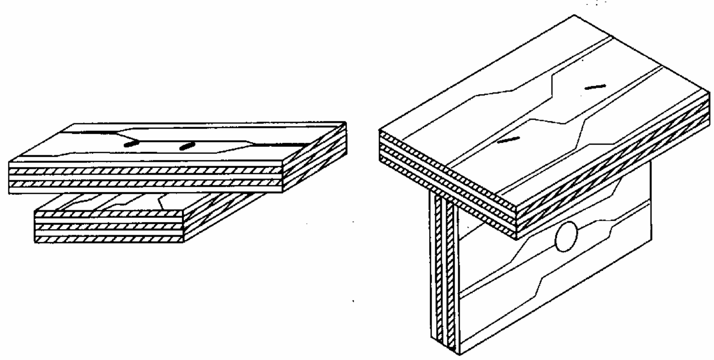

Figure 1. — General configuration of face (left) and edge (right) withdrawal specimens.

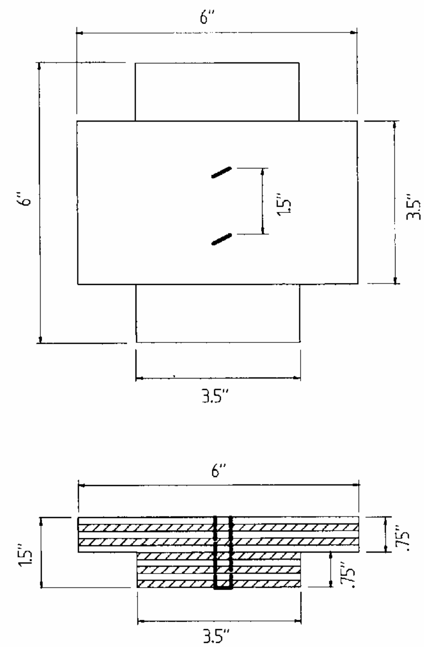

Figure 2. — Geometric dimensions of face withdrawal specimens.

holstered furniture frame joints constructed with staples. They investigated both the direct staple withdrawal and the shear (lateral holding) properties of red oak, cottonwood, medium density fiberboard, and OSB. Results of this study indicated that depth of staple penetration positively affected the holding strength of the joints. This information is helpful, but as plywood and OSB emerge as the most common upholstered furniture framing material, additional information is needed concerning the holding strength of staples in upholstered frame joints fabricated with these materials.

The primary objective of these tests was to develop basic strength data for staple holding strength in both plywood and OSB that could aid the product engineering of furniture frames constructed of these materials. The first purpose of this study was to determine the direct withdrawal strength of staples in plywood and OSB. The second purpose was to determine the lateral holding strength of staples in the edge of plywood. The third and final purpose was to determine the moment resistance of T-shaped joints constructed with plywood gusset plates that were either stapled or stapled/glued in place.

Description of materials

The general descriptions of the boards used in the study are given in **Table 1**. A coding system identified the boards in this study: OSB = oriented strandboard; SPLY = southern pine plywood; HPLY = hardwood plywood; DFP = Douglas-fir plywood. The boards were obtained from several different suppliers.

All of the boards were kept in an environmentally controlled testing room set to produce an average of 7 percent equilibrium moisture content (EMC). Representative sections, 48 by 24 inches, were cut from the boards, measured, and weighed in order to determine the density of the boards.

Specimen configuration and construction

Edge and face withdrawal strength

The general configurations of the edge and face withdrawal specimens included in the study are given in **Figures 1**, **2**, and **3**. In general, each specimen consisted of two parts. Each of the two parts of the specimens measured about 3.5 by 6 inches in cross section. In construction of the face withdrawal test specimens, a cross-shaped lap joint was

Table 2. — Withdrawal strength of staples from plywood and OSB.

Material code	Withdrawal from edge				Withdrawal from face			
	1 staple		2 staples		1 staple		2 staples	
	DOP[a]	Force avg./SD[b]	DOP	Force avg./SD	DOP	Force avg./SD	DOP	Force avg./SD
	(in.)	(lb.)	(in.)	(lb.)	(in.)	(lb.)	(in.)	(lb.)
OSB-1	.75	90/25	.75	195/35	.75	100/20	.75	255/35
OSB-2	.75	25/5	.75	120/25	.75	105/30	.75	230/50
OSB-3	.625	95/20	.625	N/A[c]	.625	180/40	.625	445/45
OSB-4	1.0	100/34	1.0	145/34	.625	170/29	.625	280/42
OSB-5	1.0	110/26	1.0	150/31	.75	200/40	.75	390/59
SPLY-1	.78	125/31	.78	175/31	.71	145/47	.71	265/51
SPLY-2	.78	40/15	.78	155/15	.71	160/35	.71	305/55
SPLY-3	.78	165/50	.78	205/95	.71	230/35	.71	315/40
HPLY	.75	222/30	.75	365/35	.75	185/45	.75	525/45
DFP-3/4	.75	117/28	.75	211/42	.75	171/32	.75	298/30

[a] DOP = nominal depth of penetration of staple shanks in the test block.
[b] SD = standard deviation.

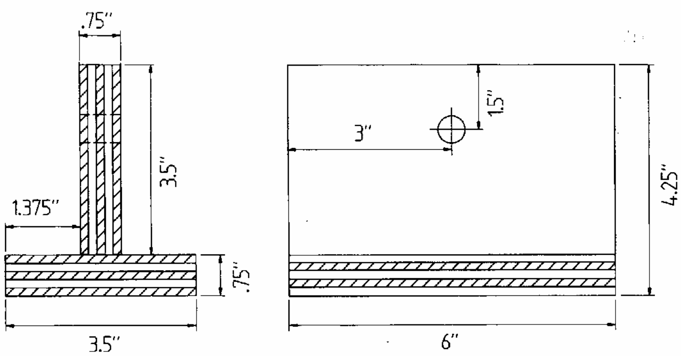

Figure 3. — Geometric dimensions of edge withdrawal specimens.

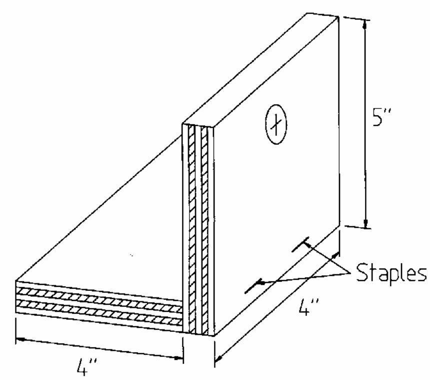

Figure 4. — Geometric dimensions and configuration of lateral holding strength specimens.

formed by placing one part on top of the other. A staple was then driven through the face of the top member into the face of the bottom member to form a face withdrawal joint. A second set of specimens was also prepared in which two staples were used instead of one staple. Four specimens of each joint were constructed from each material.

In order to construct edge withdrawal test specimens, the two members were first arranged to form a "T." A single staple was then driven through the center of the face of the top member into the edge of the test member placed on the edge below it. A second set of specimens was prepared in alike manner with two staples instead of one staple. Four specimens of each joint were constructed from each material.

All of the staples in the withdrawal tests were plastic coated, 16 gage, 1-1/2 inches long with a 3/8-inch crown. Ten different boards were included in the tests. **Table 2** gives depths of penetration in both the face and edge of the bottom members for each combination of material and number of staples. Different depths of penetration in the test (bottom) members were obtained by changing the thickness of top members in specimen construction.

Lateral edge holding strength

The general configuration and dimensions of the lateral edge strength specimens are shown in **Figure 4**. In general, each specimen consisted of a test block that measured 4 inches square and a load block that measured 4 by 5 inches. The load block was stapled to the edge of the test block with either 1 or 2 staples. All of the staples in the lateral holding tests were plastic coated, 16 gage, 1-3/4 inches long with a 3/8-inch crown. Three different boards were included in the tests: OSB-1, HPLY, and DFP. All of the boards were a nominal 3/4-inch thick. Depth of penetration in the edge of the test block is given in **Table 3**. Different thickness load blocks obtained the desired depth of penetration of the staple in the edge of the test block. For example, 1.125 inches of depth of penetration was achieved with a 5/8-inch-thick DFP board as a load block that would allow only 1.125 inches of the staple legs to penetrate the test block. The sample size was five specimens for each configuration.

Gusset plate moment resisting joint strength

The configurations of the gusseted joints are given in **Figure 5**. Each specimen consisted of a 5- by 10-inch post and a 4- by 12-inch rail. The rail was joined to the post by means of gusset

Table 3. — Lateral holding strength of the staples.

	Lateral holding force avg./SD[b]							
DOP[a] (in.)	1	1.125	1.25	1.375	1	1.125	1.25	1.375
Material code	1 staple				2 staples			
	(lb.)							
OSB-1	178/22	189/25	166/21	152/24	296/43	363/28	337/16	353/23
HPLY	183/30	190/44	176/40	179/16	279/107	351/75	359/35	330/47
DFP-3/4	179/31	158/31	154/21	176/33	270/36	254/51	242/19	226/57

[a] DOP = depth of penetration of staple shanks in the test block.
[b] SD = standard deviation.

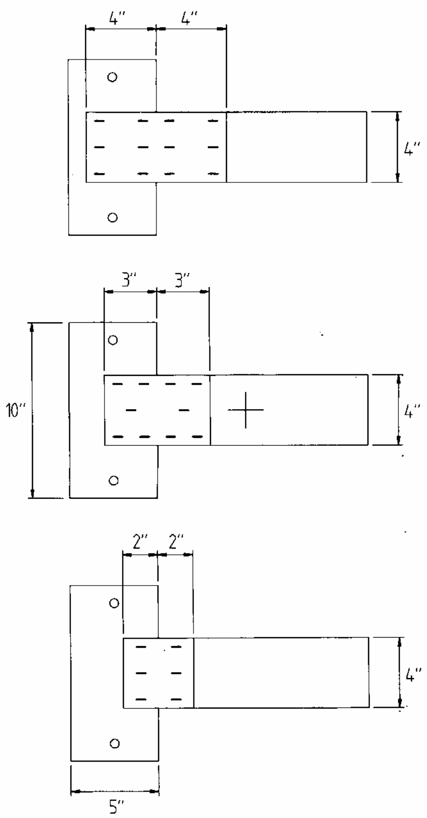

Figure 5. — Geometric dimensions of bending specimens.

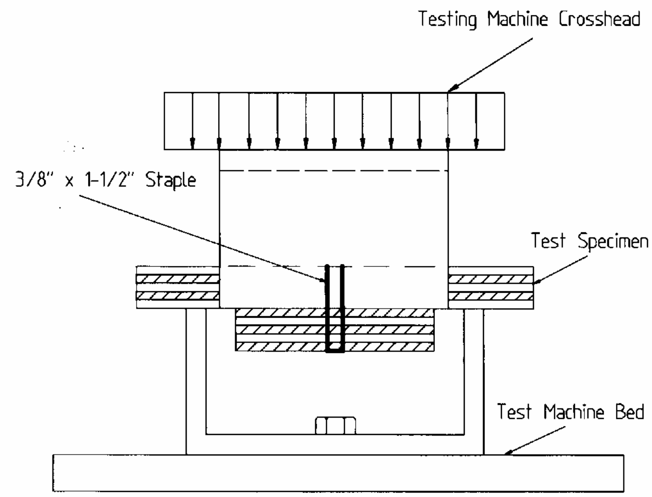

Figure 6a. — Apparatus for evaluating face holding strength of staples.

plates and staples. All of the staples in these tests were plastic coated, 16 gage, 1-inch-long with a 3/8-inch crown. Three plate sizes were included in the study: 4 by 4, 4 by 6, and 4 by 8 inches. All of the plates were constructed of 3/16-inch-thick 3-ply DFP. The posts and rails were constructed of 3/4-inch-thick DFP. The gusset plates were symmetrically located on the joints so that half of the plate was attached to the post while the other half was attached to the rail. Plates were applied on both sides of the specimens. Each 4-inch-long plate was attached with a total of 6 staples symmetrically arranged as shown in **Figure 5**. Likewise, the 6-inch plates were attached with a total of 10 staples and the 8-inch plates with 12 staples. Eight replications were constructed for each plate size. One set of specimens was constructed with staples alone. An identical set was constructed in which the plates were both glued and stapled to the posts and rails. Staples were allowed to penetrate through the whole thickness of the board in all cases.

General method of tests

It must be noted that the following test set-ups are not standards that are used to evaluate the property of joints. Set-ups were made in order to simulate the typical loading conditions that are encountered while these types of joints are used in furniture frame constructions.

Face and edge withdrawal strength

All of the tests were carried out on a universal testing machine. Face withdrawal tests were carried out with a fixture allowing the two parts of the specimen to be forced apart as loads were applied to the top of the jig by the top crosshead of the testing machine (**Fig. 6a**). Rate of loading was 0.1 inch per minute of crosshead travel.

In the case of the edge withdrawal specimens, the arm of the "T" was held in a slotted fixture (**Fig. 6b**). Straps were attached to the post of the specimen by means of a pin that fit through the straps and the post of the specimen. The other end of each strap, in turn, was pinned to a fixture attached to the other crosshead of the testing machine. Rate of loading was 0.1 inch per minute of crosshead travel.

Lateral edge holding strength

The lateral edge holding tests were carried out with the fixture shown in **Figure 7**. In this procedure, the test block of the specimen was clamped to the bed of the testing machine by means of 0.5- by 2- by 8-inch-long steel bar and two bolts. The specimen was first placed

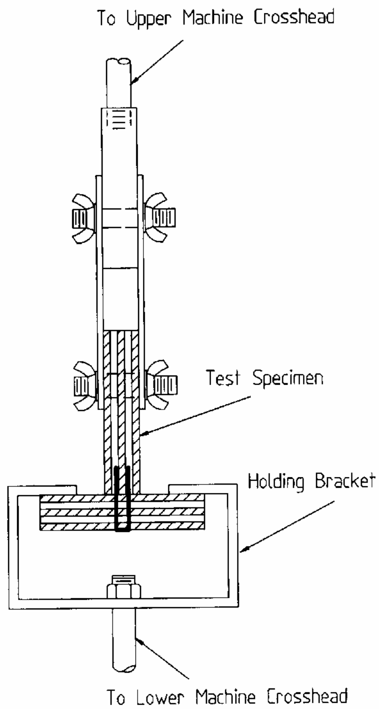

Figure 6b. — Method of testing the edge withdrawal strength of staples.

on the bed of the testing machine; the steel bar was then placed on top of the test block with its longitudinal axis parallel to the front edge of the block but with the edge of the steel bar positioned 1/2 inch from the front edge of the test block; bolts were then inserted through holes drilled through the steel bar (at 1 in. from each end of the bar) and threaded into corresponding holes located in the bed of the testing machine. Straps were then attached to the load block by steel pins that passed through the hole drilled in the block (**Fig. 7**). A steel fixture that contained a threaded hole at one end and a cross hole near the other end was then attached to the other end of the straps with a steel pin. A length of threaded rod was then screwed into the threaded end of the fixture. The other end of the threaded rod passed through the center of the ball seat of the upper crosshead and was fastened in place with a washer and nut. Rate of loading was 0.1 inch per minute.

Gusset plate moment resisting joint strength

The tests were carried out in a universal testing machine as shown in **Figure 8**. The post of each specimen was first clamped to the post of a test fixture that

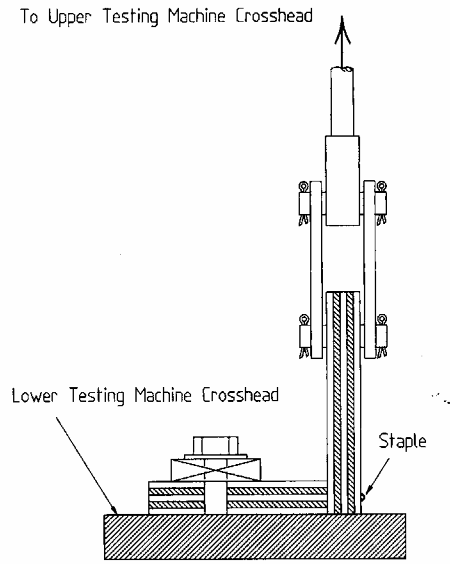

Figure 7. — Method of testing the lateral holding strength of staples.

in turn was attached to the bed of the testing machine. Vertical loads were then applied to the rail at a point 10 inches distant from the rail to post joint so that the moment acting on the joint was equal to 10 times the applied load. Rate of loading was 0.25 inch per minute of crosshead travel.

Results and discussion

Edge and face withdrawal strength

Results of the tests are given in **Table 2**. As expected, edge withdrawal strengths in both plywood and OSB were lower and more variable than face withdrawal strengths. Differences among the type of boards were statistically significant with a 0.05 level of confidence ($p < 0.001$). Ignoring material differences, edge holding strengths varied from a low of 25 to a high of 222 pounds for one staple and from a low of 120 pounds to a high of 365 pounds for two staples. Face holding strengths, on the other hand, varied from a low of 100 to a high of 230 pounds for one staple and from a low of 230 to a high of 525 pounds for two staples. On average, therefore, face withdrawal strength was higher than edge withdrawal strength by 52 percent for one staple and 71 percent for two staples. Statistically, the differences between edge and face withdrawal strengths were significant ($p < 0.003$; $\alpha = 0.05$).

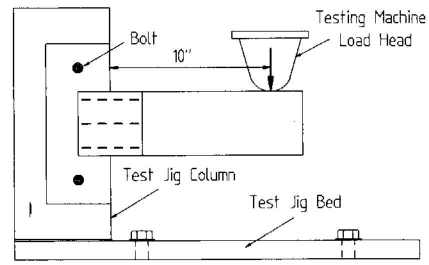

Figure 8. — Method of testing the bending strength specimens.

Edge withdrawal strengths of the two-staple joints were 75 percent greater than those of the one-staple joints. Similarly, the face withdrawal strengths of the two-staple joints were 97 percent greater than those of the one-staple joints. Thus, the withdrawal strength of multiple staples in the face of the boards appears to be nearly proportional to the number used, whereas it is somewhat less than directly proportional in the edge of the boards.

Lateral edge holding strength

Results are given in **Table 3**. Results obtained in these tests also reflected the uncertainties and strength variability of stapling into the edge of plywood and OSB. Lateral holding strengths varied from a low of 152 pounds with OSB to a high of 190 pounds with HPLY for one-staple joints. Results for the two-staple joints varied from a low of 226 pounds with DFP to a high of 363 pounds with OSB. General cause of failure in the lateral holding tests was splitting of material and pull-out of staples. No significant difference in lateral holding strength was observed as a function of depth of penetration of staple shank ($p < .48$; $\alpha = 0.05$). Lateral holding strength, as expected, was found to increase significantly ($p < 0.009$; $\alpha = 0.05$) when the number of staples was doubled. Lateral holding strength of single staple joints was essentially half (i.e., 57%) as great as joints with two staples.

Gusset plate moment resisting joint strength

Results of the test are given in **Table 4**. When joints were constructed with staples alone, bending strength increased in a nearly linear manner as the size of the plate along with the number of staples used increased. Furthermore, the increases in strength were quite pronounced; joints of 8-inch plates were 231 percent stronger than those of 4-inch plates. In the joints with both stapled and glued plates, however, increases in strength were less pronounced; the joints of 8-inch plates were only 20 percent stronger than those constructed with 4-inch plates. This result occurred because both the 6- and 8-inch plates failed in tension while 4-inch plates failed in bending and pull-out of the staples. Thicker plates may have had higher strength values.

The difference in strength between the glued and unglued plates is quite striking. For example, the 4-inch plates, staple glued gusset joints were 318 percent stronger than stapled only gusset joints.

Table 4. — Moment resisting strength of Douglas-fir plywood gusseted and stapled joints.

No of staples	Gusset dimension	Moment resisting strength (lb.-in.) avg./SD[a]	
		With adhesive	Without adhesive
		(lb.)	
6	4 by 4 by 3/16-in.	3,763/749	1,183/69
10	6 by 4 by 3/16-in.	4,438/437	2,088/106
12	8 by 4 by 3/16-in.	4,500/742	2,728/268

[a] SD = standard deviation.

Conclusions

Results of the tests showed that the staple holding strength from the face is at least 50 percent higher than that from the edge of plywood and OSB. In the case of lateral holding of staples on the edge of plywood and OSB, results indicated that the number of staples is nearly proportional to the strength. In the gusset plated stapled moment resisting joints, results showed the larger gusset dimension and higher number of staples were the key factors in increasing the overall strength of joints. Furthermore, application of glue in the gusset plates could at least double the moment resisting strength of such joints.

The results obtained in these tests clearly reflect the uncertainties involved in stapling into the edge of plywood or OSB. In plywood, for example, the staple may penetrate end grain or side grain, or, it may encounter a void. Also, it may penetrate between laminae and cause a micro-delamination to occur. Similarly, in OSB, a staple may penetrate into voids and may also cause delamination to occur, depending on the internal bond strength of the board. Although a staple may encounter voids when driven into the face of a board, the other named causes of variability are greatly reduced. It should also be realized that the low number of replications and the well-known variability of the materials used prevented any robust statistical analysis.

In summary, staples provide a rapid and convenient method of constructing joints in upholstered furniture frames fabricated of plywood and OSB. Staples should not be used to replace other fasteners on a one-to-one basis, however. Rather, the strength requirements of each joint should first be calculated and the number of fasteners needed to provide the required level of strength then determined. Ideally, the frame and the joints should be designed so that they will be most effective with staple construction. In some cases, staples should be used with intermediate constructions such as plywood gussets to form joints This practice allows the construction of frames in which staples are the principal load-bearing fasteners.