The withdrawal strength of screws from a commercially available medium density fiberboard

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Abstract

Tests carried out to determine the holding strengths of various sizes of sheet metal type screws in the face of a commercially available medium density fiberboard (MDF) indicated that withdrawal strength could be predicted by means of the following expression:

$$f = 39(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

where:

f = withdrawal strength (lb.)
IB = internal bond strength (psi)
D = diameter of the screw (in.)
L = depth of embedment of the screw (in.)

Similarly, tests carried out to determine holding strength in the edge of the MDF included in the tests indicated that withdrawal strength could be predicted by the following expression:

$$f = 18.4(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

Withdrawal strengths were about 13 percent higher when optimum pilot holes were used than when pilot holes were not used.

The rational design of furniture to meet specified strength and durability requirements demands that methods be available for predicting the holding strength of the fasteners used in its construction. In the case of screws, there is little information available that can be used to predict holding strength in medium density fiberboard (MDF), which is used almost exclusively in furniture, although considerable information is available concerning screw holding strength in solid wood and particleboard (3-7). Specifically, expressions are lacking to predict the holding strength of screws as a function of screw diameter and depth of embedment and one or more mechanical properties of the board. A study was carried out in order to obtain background information concerning the holding strength of screws in a typical commercially available MDF and then to formulate empirical expressions that could be used to estimate face and edge screw holding strengths in this material. As part of this study, tests were also carried out to determine optimum pilot hole diameters for screws in the face of the board.

Scope of the study

The following topics were included in this study:

1. Optimum pilot hole diameters for number 4A, 6A, 8A, 10A, 10AB, 12A, 14A, and 16A screws for face withdrawal;
2. Face withdrawal strength versus seven depths of penetration for 10A screws in 5/4-inch-thick board;
3. Face withdrawal strength of 10A screws embedded through five thicknesses of MDF;
4. Face withdrawal strengths of 4A, 6A, 8AB, 10A, 10AB, 12A, 14A, and 16A screws embedded through 7/8-inch-thick board;
5. Optimum pilot hole diameters for 6A, 8AB, 10A, 12A, and 14A screws for edge withdrawal;
6. Edge withdrawal strength versus diameter, depth of embedment, and internal bond strength (IB) for 6A, 8AB, 10A, 12A, and 14A screws embedded to either three or five depths of penetration in five thicknesses of board.

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Materials

The material used in this study was donated by a commercial producer and corresponded to ANSI Standard A208.2 (1). The material was conditioned to a moisture content of about 6 percent before use. Other material properties of each of the boards are given in Table 1.

The screws used in this study were also obtained from commercial suppliers. All of the screws were of the sheet metal type.

Test methods

Withdrawal tests were carried out on a universal testing machine. The specimens were held in place by means of the jig shown in Figure 1 for face withdrawal and by the jig shown in Figure 2 for edge withdrawal. In general, the use of these jigs ensured that loads were applied along the longitudinal axes of the screws, free of eccentricity. A rate of loading of 0.05 inches per minute of crosshead travel was used. Ten replications were used in the face withdrawal of 10A screws from five thicknesses of boards and the withdrawal of 4A, 6A, 8AB, 10A, 10AB, 12A, 14A, and 16A screws embedded through 7/8-inch-thick board. Five replications per sample were used in the remainder of the tests.

IB was determined by means of standard tests for tensile strength perpendicular to the surface (ASTM D 1037). Ten specimen replications were used for each board type.

Results

Optimum pilot hole size

Results of holding strength versus pilot hole diameter tests are given in Table 2. These results indicate that holding strength increases gradually as pilot hole size is increased, until the pilot hole nears the root diameter of the screw. Above this point, holding strength decreases, gradually at first and then rapidly, as the pilot hole diameter nears the nominal screw diameter.

TABLE 1. — *Description of the properties of the boards used in the study.*

Thickness	Density	MOR	IB
(in.)	(pcf)	------------ (psi) ------------	
0.750	43.6	5,760	80
0.875	44.5	6,830	118
1.000	44.7	6,910	103
1.125	43.5	6,390	86
1.250	45.1	7,800	105

An interesting finding in these tests was that holding strength did not decrease as much as might have been expected when pilot holes were not used. For the four screw types for which comprehensive test results were available, holding strength was at worst only 13 percent less when pilot holes were not used as compared to when the optimum size holes were used. These findings should be of considerable significance to product engineers.

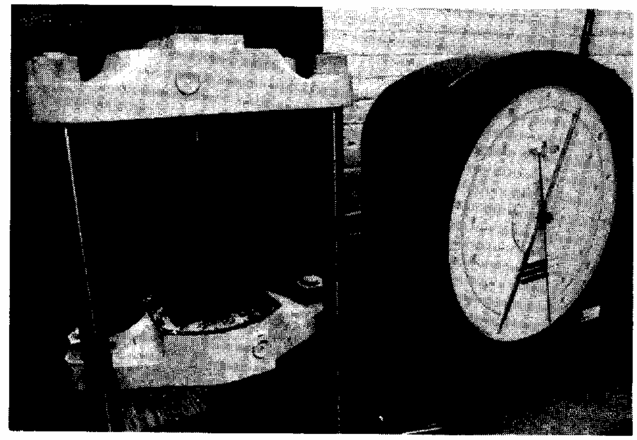

Figure 1. — Photograph showing the apparatus used to hold the face withdrawal specimens during testing.

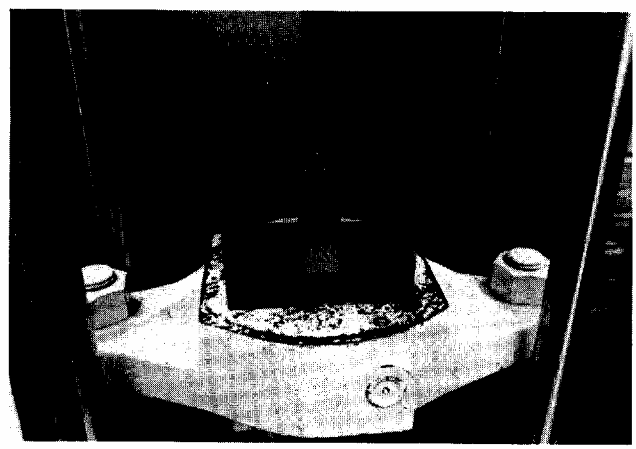

Figure 2. — Photograph showing the apparatus used to hold the edge withdrawal specimens during testing.

TABLE 2. — *Pilot hole withdrawal tests.*

Screw size	Pilot hole diameter (in.)										
	0/64	3/64	4/64	5/64	6/64	7/64	8/64	9/64	10/64	11/64	12/64
	Withdrawal force										
	(lb.)										
4A 7/8	--	609	618	600	--	--	--	--	--	--	--
6A 7/8	635	633	632	685	--	--	--	--	--	--	--
8AB 7/8	700	721	763	772	751	768	715	698	321	--	--
10A 3/4	418	445	452	451	444	448	445	430	420	--	--
10AB 3/4	432	470	472	490	490	487	--	475	437	--	--
12A 7/8	715	--	--	--	800	825	817	--	818	821	733
14A 7/8	--	--	--	--	--	806	827	812	--	--	--
16A 7/8	--	--	--	--	--	--	906	945	905	--	--

Based on the data presented in Table 2, the following are suggested optimum pilot hole sizes for face withdrawal for the various screw sizes:

Screw size and type	Optimum pilot hole	No hole percent optimum
	(in.)	
4	4/64	
6	5/64	
8 AB	5/64 to 6/64	90
10A	4/64 to 5/64	88
10AB	5/64 to 6/64	92
12A	7/64 to 11/64	87
14A	8/64[a]	
16	9/64[a]	

[a]Results based on limited data.

In the case of edge withdrawal, tests indicated that maximum holding strength would presumably be obtained with pilot hole sizes that were normally smaller than what was needed to prevent splitting of the edge of the board. Since splitting is largely a function of IB, optimum pilot hole diameters presumably must be determined for each specific board used. For the boards used in this study, it may be said that the following pilot hole sizes were found to give maximum values: 6A - 3/32-inch; 8AB - 1/8-inch; 10A - 9/64-inch; 12A - 5/32-inch; 14A - 13/64-inch. Outside of this study, these pilot hole sizes should be used only as first estimates and adjustments should be made as needed for the specific board in question.

Face withdrawal

In order to evaluate the relationship of withdrawal strength to diameter from the face of MDF, an expression of the following form was used:

$$f = aD^b$$

where:

D = diameter of the screw (in.)
f = withdrawal strength of the screw (lb.)
a and b = regression coefficients

This expression was fitted to the results for the withdrawal of screws that passed through the 7/8-inch-thick board (Table 3). Note that IB and depth of penetration were held constant in this analysis. Results of this evaluation yielded the following expression:

$$f = 1511.6D^{0.384}$$

This expression had an R^2 value of 0.8417. As is indicated by the coefficient of the diameter term, there is a weak relationship between screw diameter and withdrawal strength, which is clearly shown in Table 3, i.e., more than doubling the screw diameter results in an increase in holding strength of only about 50 percent.

To obtain a relationship between depth of penetration and withdrawal strength, an expression of the following form was used:

$$f = a(L - D/3)^b$$

where:

L = depth of penetration of the screw in the board material (in.)
b = a regression coefficient.

This expression was fitted to the results for tests in which 10A screws were embedded to varying depths in 5/4-inch-thick boards (Table 4). IB and screw diameter were held constant in this analysis. The factor, $D/3$, is used to take into account the decreased holding strength of the tapered tip of the screw as suggested in a previous study (4). This analysis yielded the following expression:

$$f = 812.2\ (L - D/3)^{1.267}$$

This expression had an R^2 value of 0.9443.

Similarly, an expression was fitted to the tests in which 10A screws passed through boards of different thicknesses that had different IBs (Table 5). Here, an attempt was made to relate holding strength to IB because previous work with threaded metal inserts and dowels had demonstrated a strong relationship between holding strength and IB (2,7). Again, screw diameter was held constant. The following expression resulted:

$$f = 14.66L^{1.4625}(IB)^{0.8796}$$

where:

IB = internal bond strength (psi)

This expresion had an R^2 value of 0.9606.

Depth of embedment coefficients were relatively close for the two different test sets, 1.4625 versus 1.267. These results indicate a strong relationship between holding strength and depth of embedment.

Finally, an expression that took into account IB, screw diameter, and depth of embedment was fitted to all of the face withdrawal data in the three test sets. The quantity, $D/3$, was set equal to zero in those cases where the screw completely penetrated the board. The following expression resulted:

$$f = 29.09(IB)^{0.8737}D^{0.3889}(L - D/3)^{1.2756}$$

This expression had an R^2 value of 0.8985.

TABLE 3. — *Withdrawal strengths/standard deviations for screws of various diameters inserted through a 7/8-inch-thick board.*

Screw size							
4A	6A	8AB	10A	10AB	12A	14A	16A
Withdrawal force/Standard deviation							
(lb.)							
621	700	784	810	834	837	847	878
12	18	18	19	29	31	39	44

TABLE 4. — *Withdrawal strengths/standard deviations for screws inserted to various depths in the face of 5/4-inch-thick boards.*

Screw size	Depth of embedment (in.)						
	1/2	5/8	3/4	7/8	1	9/8	5/4
	Withdrawal force/Standard deviation						
10A	344	412	474	593	745	806	1,081
	11	16	22	31	26	36	69

TABLE 5. — *Test schedule for screws inserted through specimens.*

Screw size	Board thickness				
	3/4	7/8	1	9/8	5/4
	Withdrawal force/Standard deviation				
	(lb.)				
10A	490	819	858	874	1,217
	18	27	37	44	46

In order to develop a more convenient expression for practical use, the regression coefficients associated with IB, diameter, and depth of embedment were fixed at 0.85, 0.5, and 1.25, respectively, and a new leading coefficient for the expression was determined. This resulted in the following expression:

$$f = 39(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

This expression had an R^2 value of 0.8927. Values given by this simpler expression differed from those given by the previous expression by only 0.7 percent over a wide range of diameter, length, and IB values.

Edge withdrawal

In order to obtain an expression for predicting the withdrawal strength of the screws from the edge of MDF, an expression of the following form was used:

$$f = a(IB)^{b}D^{c}(L - D/3)^{d}$$

where:

a, b, c, and d = regression coefficients

This expression was fitted to the data shown in Table 6. As before, the quantity $D/3$ was used to account for the tip effect of the screw. The following expression resulted:

$$f = 24.3(IB)^{0.824}D^{0.64}(L - D/3)^{1.113}$$

This expression had an R^2 value of 0.9669.

In order to obtain a more convenient working expression, the regression coefficients b, c, and d were replaced by the constants 0.85, 0.5, and 1.25, respectively, and a new leading coefficient determined. This resulted in the following expression:

$$f = 18.4(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

This expression had an R^2 value of 0.9592. As is indicated, the multiple correlation coefficient was only slightly reduced by this operation. Values predicted by this expression differed by less than 1 percent from those for the previous expression.

TABLE 6. — *Test schedule for MDF edge specimens.*

Screw size	Depth of embedment	Board thickness 3/4	7/8	1	9/8	5/4
		Withdrawal force/Standard deviation				
	(in.)	(lb.)				
6A	3/4	170	297	226	221	267
		9	17	23	20	15
	1	227	383	330	288	351
		6	25	15	21	8
	5/4	262	505	400	383	467
		13	11	10	35	27
8AB	1/2	48	132	129	102	117
		5	11	8	6	16
	3/4	175	262	209	206	254
		2	9	7	10	11
	1	237	377	313	281	340
		13	12	7	11	7
	9/8	274	427	374	343	--
		17	11	7	33	--
	5/4	298	479	411	398	419
		8	21	10	28	9
10A	1/2	137	188	162	152	181
		7	14	13	9	11
	3/4	211	319	272	243	305
		11	8	20	9	15
	1	272	457	384	372	414
		10	23	12	20	30
	5/4	355	570	475	447	531
		16	16	23	14	15
	3/2	432	714	592	544	647
		12	19	11	7	29
12A	1/2	129	186	161	147	170
		8	7	6	11	8
	3/4	218	340	281	273	315
		5	15	17	8	10
	1	314	477	398	397	473
		14	15	11	16	27
	5/4	379	637	518	513	598
		20	18	15	18	13
	3/2	427	794	634	633	710
		38	19	21	26	54
14A	1	279	465	398	392	438
		15	23	35	29	15
	5/4	351	631	493	513	569
		41	11	25	45	39
	3/2	399	808	638	615	691
		52	17	76	54	21

Summary

Tests carried out to determine the holding strengths of various sizes of sheet metal type screws in the face of a commercially available MDF indicated that withdrawal strength could be predicted by means of the following expression:

$$f = 39(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

where:

f = withdrawal strength (lb.)
IB = internal bond strength (psi)
D = diameter of the screw (in.)
L = depth of embedment of the screw (in.)

Similarly, tests carried out to determine holding strength in the edge of the MDF included in the tests indicated that withdrawal strength could be predicted by the following expression:

$$f = 18.4(IB)^{0.85}D^{0.5}(L - D/3)^{1.25}$$

Finally, it was found that withdrawal strengths were about 13 percent higher when optimum pilot holes were used.

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