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Withdrawal Strength of Dowels in Plywood and Oriented Strand Board

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Abstract: Plywood and oriented strand board (OSB) are being used increasingly in the construction of upholstered furniture frames. Yet there is little information available concerning the holding strength of various fasteners, and, in particular, dowels in these materials. A study was conducted accordingly, to obtain basic information about the holding strength of dowels in both plywood and oriented strand board. Results of the tests were incorporated into predictive expressions that allow designers to estimate withdrawal strength as a function of the diameter of the dowels, their depth of embedment and the density of the composite material. Given the variability of the composite materials, significant differences between predicted and observed values must be expected. The maximum differences observed in the tests amounted to no more than 44 percent, however, so that the expressions developed nonetheless provide reasonable first estimates of dowel withdrawal strength. Coefficients of determinations for the expressions varied from 0.868 to 0.623. The results indicated that the generous use of adhesives tends to compensate for inherent material problems such as delamination.

Key Words: Plywood, OSB, dowel, withdrawal, strength

Oriented Strand Board (OSB) Kontraplak'in Kavela ile Tutma Mukavemeti

Özet: OSB (Oriented Strand Board) ve kontrplakın döşemeli mobilya iskeletlerinin konstrüksiyonunda kullanımı gün geçtikçe artmaktadır. Ancak, bu tür kompozit malzemelerin değişik bağlantı elemanları ve özellikle kavela ile tutma mukavemeti hakkında yeterli veri yoktur. Bu çalışmada kavelanın kontrplak ve OSB ile tutma mukavemeti hakkında gerekli temel veriler sağlanmaya çalışılmıştır. Test sonuçları sayısal formüller haline getirilerek ürün tasarımcılarının kavela tutma mukavemetini kavela çapı, derinliği ve kompozitin yoğunluğunun fonksiyonu olarak tahmin etmeleri amaçlanmıştır. Kompozit malzemedeki degiskenlik gözönüne alındığında, test sonuçları ile istatistiksel tahminlerden elde edilen sonuçlar arasında buyuk bir fark olmasi beklenir. Buna karşın, test değeri ile istatistiksel tahmin arasındaki en büyük farkın % 44 olması, elde edilen formullerin kavela mukavemetini makul bir düzeyde tahmin ettiğini göstermektedir. Formüllerin determinasyon katsayıları .868 ile .623 arasında seyretmiştir. Ayrıca, test sonuçları fazla miktarda tutkal kullanımının delaminasyon gibi kompozite ilişkin bazı problemlerin ortadan kaldırılmasına yardımcı olduğunu göstermiştir.

Anahtar Sözcükler: Kontraplak, OSB, kavela, mukavemet

Introduction

The rational design of furniture frames constructed of plywood (PLY) or oriented strand board (OSB) requires that quantitative information be available concerning the strength of joints constructed with these materials. In the case of dowels, information is needed concerning both the withdrawal and lateral strength of single pin dowel joints along with the strength of multiple-pin joints. Ideally, the strength of multiple pin joints can be predicted from a consideration of single pin joint strength and joint geometry once the fundamental strength characteristics of single pin joints are understood and the geometrical interactions functionalized. Quantitative information concerning the withdrawal strength and lateral strength of single pin dowel joints is, accordingly, of primary interest. This paper treats the withdrawal strength, that is, the axial strength, of dowel pins in both the face and edge of plywood and OSB. The intent of this study was both to obtain quantitative information concerning the holding strength of dowel pins, and, as far as possible, to develop generalized expressions to estimate their strength. Presumably, the information obtained for these boards could then be extrapolated to cover other similar boards offered to the furniture industry.

A substantial number of studies of the holding strength of dowels in solid wood have been conducted over the years by Eckelman (1969, 1971, 1979). Substantial information has also been published concerning the holding strength of dowels in composites such as particleboard and medium density fiberboard (Eckelman and Cassens, 1985; Zhang, 1991). Except for the work of Erdil (1998), however, little information has been published concerning the holding strength of dowels in plywood and OSB.

Description of Materials

The boards included in the study are described in Table 1. In general, the boards were obtained from several different suppliers.

In the case of the 5-ply Southern pine plywood construction, the center ply was aligned parallel to the face plies. Thus, 3 plies were aligned parallel to the face plies and 2 plies perpendicular to the face. In the case of the 6-ply plywood construction, the two center plies were aligned in the same direction; as a result, a total of 4 plies were aligned parallel to the face plies and two plies perpendicular to the face.

All of the boards were conditioned to 7 percent moisture content. Representative groups of specimens were weighed in order to determine the density of the boards.

Specimen Configuration and Construction

The configuration of the specimens used to evaluate face withdrawal strength is given in Figure 1. Similarly, the configuration of the specimens used for edge withdrawal strength is given in Figure 2. In general, each specimen consisted of a plywood test piece (test block) from which the dowel was to be withdrawn, a plywood load block whose purpose was to provide a structure to which the other end of the dowel could be attached, a dowel pin, and a piece of wax paper whose purpose was to prevent the end of the load block from adhering to the test block. The face withdrawal test specimens measured a nominal 100 mm by 150 mm and the edge withdrawal test specimens measured 150 mm square, whereas the load blocks measured 150 mm in length by a nominal 50 mm wide. Specimens were cut from the plywood and OSB panels supplied for the tests in accordance with the procedure previously described.

Dowel holes for the withdrawal tests were drilled to the appropriate depth in the center of each test block perpendicular to the face (Figure 1); similarly, holes for the edge withdrawal tests were drilled in the center of each edge of each specimen perpendicular to the face of the appropriate edge (Figure 2). All the holes were drilled with standard twist drills.

In constructing the specimens, the dowels were first inserted into the hole in the end of the load block and forced into the hole until the free length of the dowel protruding from the test block was exactly equal to the depth of penetration desired in the test block. The specimens were allowed to dry for one day, and the free

Table 1. Description of panels used in the tests.

Material Code	Board Description	Wood Species	Density (N/m^3)	Thickness (mm)
OSB-1	Oriented Strand Board	Southern pine (Pinus elliottii)	7367	19.05
OSB-2	Oriented Strand Board	Southern pine (Pinus elliottii)	6142	19.05
SPLY-1	5-ply, C-C	Southern pine (Pinus elliottii)	5639	18.25
SPLY-2	6-ply, 2 center plies Furniture grade	Southern pine (Pinus elliottii)	5702	18.25
SPLY-3	5-ply, Structural Sheathing	Southern pine (Pinus elliottii)	5781	18.25
HPLY-1	6-ply, 2 center plies Furniture grade	Sweetgum (Liquidambar styraciflua)	5702	19.05
HPLY-2	7 ply	Sweetgum (Liquidambar styraciflua)	6111	19.05
WSPLY-3/8	4 ply	Douglas fir (Pseudotsuga menziesii)	4885	9.525
WSPLY-1/2	4 ply	Douglas fir (Pseudotsuga menziesii)	5404	12.7
WSPLY-5/8	5 ply	Douglas fir (Pseudotsuga menziesii)	5042	15.875
WSPLY-3/4	7 ply	Douglas fir (Pseudotsuga menziesii)	5152	19.05
OSB-3	Oriented Strand Board	Southern pine (Pinus elliottii)	7619	22.225
OSB-4	Oriented Strand Board	Southern pine (Pinus elliottii)	6676	22.225
OSB-5	Oriented Strand Board	Southern pine (Pinus elliottii)	7383	19.05

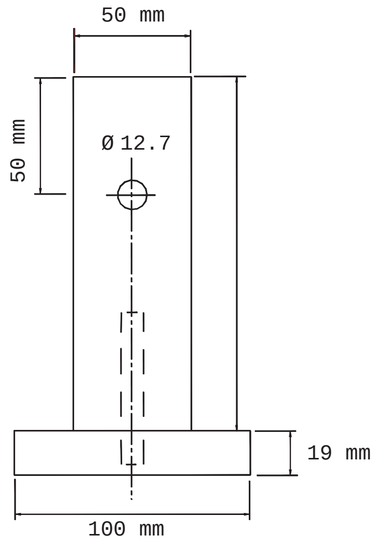

Figure 1. Typical configuration of the specimens used in the face withdrawal test.

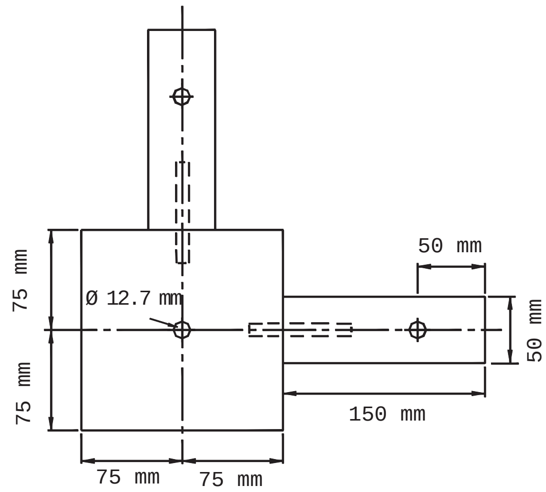

Figure 2. General configuration and dimensions of edge withdrawal specimens.

end of the dowel was then inserted its full depth into the test block.

The surfaces of the holes of the load blocks were liberally coated with adhesive. Dowels were embedded to a depth of 38 mm in the end of the load blocks in order to ensure that the dowels would withdraw from the test block rather than the load block. Dowels were cut into certain measured lengths for all specimens to ensure the protruding length from the load block would be inserted in its full length into the test block. Subsequently, a piece of wax paper with a hole cut in it of the same diameter as the dowel was slipped over the end of each dowel to ensure that the end of the load block did not adhere to the test block. The walls of the holes in the test blocks were coated with adhesive and the ends of the dowels protruding from the load blocks were inserted their full length into the test block. Specimens were allowed to cure at least 5 days before testing.

All of the specimens were constructed with multi-groove Yellow birch (Betula alleghaniensis) dowels and a commercially available aliphatic resin emulsion adhesive. The working properties of the adhesive are as follows:

Aliphatic resin emulsion; State - liquid; Solid content - 46 %; Pot life - not applicable; Application temperature - room temperature; Assembly time - 5 minutes.

The adhesive conforms to ASTM D4236.

Scope of the Study

Specific joint construction parameters along with the number of replicates tested are given in Tables 2, 3a, and 3b. In most cases, 4 replicates were constructed and tested, but in a few cases, 5 were used. The total number of specimens tested is given for each diameter subclass. Thus, in Table 2, for OSB-1, the symbol "8" indicates that 4 specimens were constructed and tested that had 14.3 mm depth of dowel embedment and 4 that had a 19 mm depth of dowel embedment. It should also be noted that, for 19 mm depth of dowel embedment, the dowel holes were drilled completely through the board. For lesser depths of embedment in 19 mm thick boards, "blind" holes were used unless otherwise noted. In the case of the Douglas fir plywood (WSPLY), the dowel holes were drilled completely through the boards.

In the case of the edge withdrawal tests, four replicates were used also; again, the total number of specimens constructed is listed for each diameter subclass. Thus, in Table 3a, the number "8" indicates that 4 specimens were fabricated in which the dowel was embedded in the "side" of the board and in 100 mm specimens the dowel was embedded in the end of the board. As used here, "end" refers to an edge of the specimen that was aligned perpendicular to the "long" axis of the board from which it was cut, and "side" refers to an edge of the specimen that was aligned parallel to the long axis of the board from which it was cut.

General Method of Testing

All of the tests were carried out in a Tinius Olsen universal testing machine. In the case of the face withdrawal tests, the test block in which the dowel was embedded was held in a slotted fixture which supported the face of the block on two sides of the block (Figure 3). This fixture was attached to the lower load head of the testing machine. The load block was held by a second fixture attached to the upper cross head of the testing machine. This fixture consisted of two straps that fit on either side of the load block. Holes were drilled through the flat face of each strap near the ends. A 12.7 mm diameter pin was inserted through one strap, then through the hole in the load block, and finally through the hole in the second strap in order to anchor the load block in place. The test fixtures were aligned so that the line of action of the force applied to the joint by the testing machine coincided with the longitudinal axis of the dowel in the joint. The rate of loading was 1.27 mm per minute of cross head travel.

In the case of the edge withdrawal tests, the test block was held in place by straps in the same manner as the load block (Figure 4). A 15.9 mm diameter hole was drilled through the center of the test block perpendicular to its face for this purpose. The rate of loading was again 1.27 mm per minute of cross head travel.

Results and Discussion

A description of the boards used in the study is given in Table 1. The specimen construction schedule for the face withdrawal specimens along with average face holding strengths and standard deviations are given in Table 2. Similarly, the specimen construction schedule for the edge withdrawal specimens and average holding strengths and standard deviations are given in Tables 3a and 3b. Finally, a list of the predictive expressions fitted to the test results is given in Table 4.

Results of the tests indicate that the holding strength of dowels in both the face and edge of plywood and OSB may vary considerably from board to board. This variability is likely more closely related to process variables than basic wood properties, since boards manufactured from the same species may still exhibit significantly different holding strengths. In general, therefore, these results indicate that exact predictive expressions must be based on tests results derived from a larger population of boards and must include pertinent process variables. The problem that exists for the practicing furniture engineer, however, is that it is unlikely that the processing information needed will be available.

The results also indicate that, in addition to other factors, the holding strength of adhesive-based fasteners such as dowels likely depends on the amount of adhesive

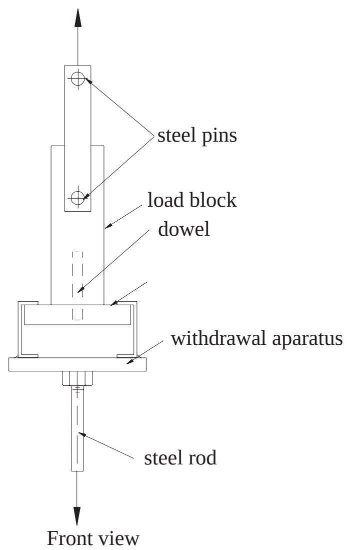

Figure 3. Apparatus used to hold specimens for testing in the face withdrawal tests.

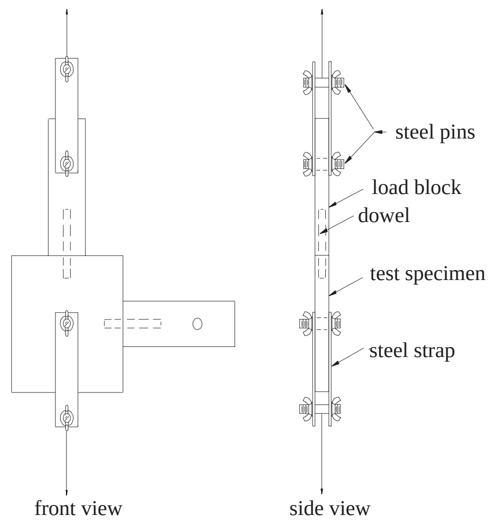

Figure 4. Apparatus used to hold specimens for testing in the edge withdrawal tests.

Table 2. Withdrawal strength of dowels in the face of plywood and OSB.

Material Code Spec.	Total No. of (mm)	Dowel Diameter	Mean Withdrawal Strength/Standard Deviation (Newton)					
			Depth of Embedment in Face (mm)					
			9.525	12.7	14.288	15.875	19.05	22.225
OSB-1	8	6.35			1976/445		2083/325	
	8	7.938			1851/374		2145/401	
	8	9.525			2906/89		3409/138	
OSB-2	8	6.35			1504/209		2051/276	
	8	7.938			1268/285		2247/165	
	8	9.525			1882/169		3160/191	
OSB-3	20	9.525		2407/196				3093/561
	5	9.525[1]						4508/182
OSB-4	20	9.525		2287/151				3262/521
	5	9.525[1]						3876/481
OSB-5	20	9.525		2318/174			2808/596	
	5	9.525[1]					3823/343	
SPLY-1	8	6.35			1811/85		1931/187	
	8	7.938			1549/307		2074/209	
	8	9.525			2403/458		2875/325	
	15	9.525[1]	935/182		1856/187		2270/267	
SPLY-2	8	6.35			1531/227		1918/436	
	8	7.938			1477/125		2051/347	
	8	9.525			2545/218		2750/111	
	15	9.525[1]	1010/98		2016/205		2554/240	
SPLY-3	8	6.35			1949/89		1651/347	
	8	7.938			1464/383		2038/258	
	8	9.525			2516/40		2501/463	
	15	9.525[1]	1015/138		2003/196		2599/147	
HPLY-1	8	6.35			2074/111		2804/147	
	8	7.938			2661/263		3160/111	
	8	9.525			2719/31		3378/142	
HPLY-2	8	6.35			2229/214		2519/240	
	8	7.938			2599/405		2474/156	
	8	9.525			2572/236		3115/178	
WSPLY-3/8	4	6.35	1055/187					
	4	7.938	1055/245					
	4	9.525	1304/147					
WSPLY-1/2	4	6.35		1308/209				
	4	7.938		1308/138				
	4	9.525		1513/53				
WSPLY-5/8	4	6.35				1882/218		
	4	7.938				1954/49		
	4	9.525				2261/271		
WSPLY-3/4	4	6.35					1994/303	
	4	7.938					2461/102	
	4	9.525					2715/178	

[1]Hole drilled through specimen.

Table 3a. Withdrawal strength (in Newtons) of dowels in edge of plywood and OSB.

			Depth of Penetration (mm)								
			19.05			25.4			31.75		
Material Code	Total No. of Spec.	Dowel Diam. (mm)	Random or End & Side Combined	End	Side	Random or End & Side Combined	End	Side	Random or End & Side Combined	End	Side
OSB-1	8	6.35				2194/432	2207/374	2181/543			
	8	7.938				3386/556	3516/645	3262/512			
	8	9.525				2933/1010	2755/1024	3111/1117			
	24	9.525	4561/503	4535/672	4584/360	5718/712	5741/899	5696/610	5834/886	5643/1188	6030/565
OSB-2	8	6.35				1776/432	1647/490	1905/396			
	8	7.938				2519/774	2007/245	3026/801			
	8	9.525				2385/699	2421/823	2350/672			
	24	9.525	4116/405	4285/316	3952/463	5420/788	5318/454	5518/1099	5109/725	5064/1006	5149/467
OSB-3	10	9.525				4966/810					
	5	9.525*				5674/863					
OSB-4	10	9.525				4975/534					
	5	9.525				4601/334					
OSB-5	10	9.525				5051/240					
	5	9.525*				5438/178					
SPLY-1	8	6.35				2999/401	3160/512	2879/320			
	8	7.938				3502/854	3373/570	3631/1153			
	8	9.525				3667/881	3618/828	3720/1059			
	24	9.525	3787/423	3760/556	3818/329	4441/774	5060/449	3823/423	5531/694	5558/414	5509/975
SPLY-2	8	6.35				3168/587	3262/481	3075/739			
	8	7.938				3694/716	3342/587	4045/725			
	8	9.525				3529/970	3137/921	3920/966			
	24	9.525	3805/401	3751/316	3863/512	4819/708	4713/899	4931/578	6074/859	5945/752	6203/1055
SPLY-3	8	6.35				2941/463	3062/538	2848/463			
	8	7.938				3511/886	3364/1041	3653/832			
	8	9.525				3289/1077	3053/1108	3529/1153			
	24	9.525	4134/583	3734/414	4535/436	4957/663	4441/485	5478/267	5972/952	6212/894	5732/1077

Table 3b. Withdrawal strength (in Newtons) of dowels in edge of plywood and OSB.

Material Code	Total No. of Spec.	Dowel Diam. (mm)	Depth of Penetration (mm) 19.05 Random or End & Side Combined	19.05 End	19.05 Side	25.4 Random or End & Side Combined	25.4 End	25.4 Side	31.75 Random or End & Side Combined	31.75 End	31.75 Side
HPLY-1	8	6.35				4124/320	4285/436	4143/191			
	8	7.938				4667/552	4971/352	4357/583			
	8	9.525				6217/716	5981/783	6453/659			
HPLY-2	8	6.35				4552/360	4241/325	4864/396			
	8	7.938				5398/285	5433/418	5362/147			
	8	9.525				7271/396	7343/401	7200/387			
WSPLY-3/8	8	6.35				2372/316	1980/289	2759/338			
WSPLY-1/2	8	6.35				3115/409	2826/454	3400/365			
	8	7.938				3493/463	3200/440	3787/485			
WSPLY-5/8	8	6.35				3204/236	3133/360	3271/107			
	8	7.938				3649/414	3636/343	3658/481			
	8	9.525				4414/476	4503/360	4325/587			
WSPLY-3/4	24	6.35	2706/76	3048/9	2581/138	3484/258	3480/427	3489/89	3889/556	4036/579	3758/534
	24	7.938	3253/258	3627/263	2879/254	3796/436	3427/248	4161/623	5371/552	5509/312	5229/792
	24	9.525	3435/280	3489/414	3382/1424	4503/378	4584/369	4423/387	6150/583	6310/654	5985/512

used to construct the joint. More specifically, holding strength is likely a function of the amount of adhesive forced into the substrate surrounding the dowel by hydraulic action as the dowel pin is forced into the hole. The reinforcing effect of the excess adhesive in the surrounding substrate causes uncertainties in determining the true holding strength of a specific composite, but, on the other hand, it offers the possibility of producing strong joints of uniform quality regardless of the properties and process history of the composite simply by forcing adhesive into the surrounding substrate during construction of the joint.

In the case of solid wood, research by Eckelman (1979) has shown that the withdrawal strength of dowel pins may be predicted by means of an expression of the form

$$F_2 = a_0 D L^{a_1} (a_2 S_1 + S_2) a_3 a_4 a_5$$

where F_2 refers to the withdrawal strength of the dowel, D to the diameter of the dowel, L to the depth of embedment in the substrate, S_1 to the shear strength of the substrate and S_2 to the shear strength of the dowel; a_0 to a_2 are regression coefficients, and a_3 to a_5 are dowel surface factor, adhesive factor, and dowel-hole clearance factor, respectively. Dowel surface factor, a_3, is based on the 1971 study by Eckelman; this study suggested that the dowel surface factor should be 0.9 for spiral-groove and multi-groove dowels, and 1.0 for smooth surface dowels. This expression was based on research conducted with dowels that ranged from 6.35 to 12.7 mm in diameter with depths of embedment that ranged from 12.7 to 50.8 mm. Shear strength values ranged from those for the weakest to the strongest woods.

In the case of composites, research carried out by Eckelman and Cassens (1985) showed that, in general, the holding strength of both medium density fiberboard (MDF) and particleboard tested could be predicted by means of the expression

$$F_2\ (face) = 15.5\ (IB)^{0.85}\ L^{0.85}$$

$$F_2\ (edge) = 15.5\ (IB)^{0.85}\ L^{0.85}$$

where F_2 is the withdrawal strength (lb) of the dowel from face or edge, *IB* is the internal bond strength of the composite (psi), and *L* is the depth of embedment of the dowel (in). Results of this study indicated that there is a near linear relationship between the dowel withdrawal strength and depth of embedment of the dowel; similarly, a near linear relationship between withdrawal strength and internal bond strength of MDF and particleboard was observed. However, this relationship did not hold for the OSB boards tested in the same study.

In the light of the previous studies and preliminary investigations and given the variability of the results obtained, an attempt was made in this paper to derive simple expressions to predict the dowel withdrawal strength in OSB and plywood, based on the one developed for hardwoods (Eckelman, 1979), to represent the data. Accordingly, an expression of the form

$$y = aD^bL^cW^d$$

where *D* refers to dowel diameter (inches), *L* to depth of penetration (inches), and *W* to density (pounds per cubic foot), was used to represent the results. In this expression, the density term, *W*, replaced the shear terms, S_1 and S_2, in the expression developed for solid wood (Eckelman, 1979). Also, since only one type of dowel and one adhesive were used, and the dowel hole clearances were essentially the same for all joints, these factors were not included in the above expression. In each case, this expression was fitted to the results by means of statistical non-linear regression techniques and then simplified, as needed, in accordance with the outcomes of the analyses. Results of the statistical analyses, including the expression developed, the accompanying R^2 value, the maximum and minimum deviations between predicted and observed values, and the standard deviation are given in Table 4.

In the case of face withdrawal, representative linear expressions could be developed for all the materials except hardwood plywood. In the case of edge withdrawal, a representative linear expression could not be developed for OSB, owing to the non-linear dowel diameter and depth of penetration effects.

Table 4. Summary of predictive expressions and related statistics.

		R^2	Over	Under	STD
Material	Expression	Percent			
	Face Withdrawal				
Douglas fir Plywood	y = 2810DLW	81.6	+31	-42	16
Southern pine Plywood	y = 2415 DLW	79.4	+38	-43	16.5
Oriented Strand Board	y = 2415DLW	86.8	+28	-40	16
Sweet gum Plywood	$y = 308D^{0.5}LW$	68.2	+27	-38	16
	Edge Withdrawal				
Douglas fir Plywood	y = 3732DLW	70.5	+44	-31	15
Southern pine Plywood	y = 84.2DW	62.3	+35	-35	17
Oriented Strand Board	$y = 49294\ D^2L^{0.5}W$	78.0	+34	-32	16
Sweet gum Plywood	y = 107DW	68.5	+23	-23	11

D = Dowel diameter (m); L = Depth of penetration (m); W =Density of material (N/m^3);
R^2 = Coefficient of determination; STD = Standard deviation,
over: maximum over-predicted, under: maximum under-predicted

Conclusions

Aside from joint fabrication variables, the withdrawal strength of dowels from the face and edge of plywood and OSB is likely to be a function of the mechanical properties of the base material, the process variables involved in the manufacture of the board, and the geometry of the particles or layers of the board, but most importantly, the amount of adhesive used in construction of the joint. Exact predictive expressions, therefore, must be based on tests of a large population of boards and include process and board geometry variables information-much of which is largely unavailable. Practical predictive expressions, accordingly, necessarily must be based largely on limited mechanical properties data with the result that predicted holding strength may differ significantly from true holding strength for any given board. Fortuitously, however, the generous use of adhesive in the construction of joints largely outweighs the importance of other factors and ensures construction of joints of maximum strength. Thus even though the prediction of strength of any specific joint necessarily will contain some degree of uncertainty owing to lack of information about the mechanical and process variables of the board, the furniture engineer can, in general, ensure that predicted values tend to be conservative through the generous use of adhesive in the construction of the joint.

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