Influence of Moisture, Fastening Direction and Wood Species on Screw Withdrawal Load of Furniture-grade Plywood

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ABSTRACT

Ultimate screw withdrawal loads (USWLs) from panel face and edge of furniture-grade southern pine (*Pinus spp.*) and sweetgum (*Liquidambar styraciflua L.*) plywood were evaluated at five moisture contents (MCs). Both face and edge USWL decreased in general with increases in MC within the hygroscopic range. The effect of moisture on edge USWL was more pronounced than on face USWL. For each plywood, USWL from panel face was significantly larger than the USWL value from the panel edge. At higher MC levels, edge screw-holding capacities deteriorated more rapidly than face screw-holding capacities. For plywood with comparable properties (e.g. panel thickness, bending stiffness and strength), wood species (pine versus sweetgum) had an insignificant effect on USWL. Thus, sweetgum plywood is as good as pine plywood in screw-holding strength.

Interior-type plywood is widely used in construction of furniture and cabinets. The integrity of such construction is frequently dependent upon the connections between its components. For maximum strength and stability, each connection requires a design which is adapted to the fastener type and to the strength properties of the individual structural members [1].

Ultimate fastener withdrawal loads for plywood joints depend on fastener type (screw or nail), fastening direction (face or edge), panel moisture content (MC) and wood species used to manufacture the plywood. The ASTM standard [2] specifies that screw withdrawal tests be conducted in both dry and soaked conditions for wood-based panels. However, for interior-type plywood used for furniture and cabinet manufacturing, plywood joints or constructions at complete water soaked condition are rare. On the other hand, MC of the panel does fluctuate within the hygroscopic range depending on geographic location, season of the year, etc. This fluctuation in MC can significantly alter the screw-holding capacity of the panel and its structural integrity. Very little information exists, however, on effects of moisture, fastening direction, and wood species on the ultimate screw withdrawal load (USWL) for furniture-grade plywood. The information is greatly needed for manufacturing, buying and selling plywood panels and for better construction of plywood joints in furniture and cabinets.

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[1] Anonymous. 1995. Fastener loads for plywood - screws. APA Technical Note Number E830C. APA, Tacoma, WA. 4 pp.

[2] American Society for Testing and Materials (ASTM). 1996. Standard methods for evaluating properties of wood-based fiber and particle panel materials. ASTM D 1037-96. pp:137-166. Philadelphia, PA.

The purpose of this study was to measure and quantify the influence of moisture, fastening direction and wood species on ultimate screw withdrawal load of interior-type plywood manufactured for furniture, cabinet, and millwork markets.

Materials and Methods

Interior-type southern pine (*Pinus spp.*) and sweetgum *(Liquidambar styraciflua L.)* plywood panels were used in the study. Six 4-ft by 4-ft (1.22 x 1.22-m) panels of each type of plywood were obtained from a plywood manufacturer in the South. The panels had a 5-ply construction with a panel thickness of 23/32-inch (18-mm). The product was developed for the furniture and cabinet industry in the South.

Five specimens along both material directions from each of the panels were cut for bending modulus of elasticity (MOE) and modulus of rupture (MOR) tests according to the ASTM standard [2]. Specimens were conditioned at 25.5 °C and 55% relative humidity for about two weeks before the tests. Immediately after testing, the failed specimens were oven-dried to determine their moisture content.

Forty 3 x 6 x 23/32-inch (76 x 152 x 18-mm) specimens for edge screw withdrawal tests were cut from each of the six panels of both pine and sweetgum plywood . Twenty-five specimens with no apparent voids along both 6-inch (152-mm) long sides were selected from the forty specimens of each panel. The specimens were randomly divided into five groups with five specimens in each group. They were labeled according to species, panel number, group number and replication number.

Fifty 3 x 4 x 23/32-inch (76 x 102 x 18-mm) specimens were cut from each of the panels for face screw withdrawal tests. Twenty-five groups of two 23/32-inch thick specimens were randomly selected from the fifty specimens of each panel. They were laminated together to form 25 specimens of approximately 1.4375-inch (36-mm) of thickness. The twenty-five 1.4375-inch thick specimens from each panel were randomly divided into five groups with five specimens in each group. They were labeled according to species, panel number, group number and replication number, similar to the edge screw withdrawal specimens.

During testing, one group of edge screw-withdrawal specimens and one group of face screw-withdrawal specimens were selected from each panel of both plywood types. For the edge screw-withdrawal specimens, a line was drawn across a 6-inch edge at middle span of each specimen. The mid-point of the line was marked. For face screw-withdrawal specimens, two diagonal lines were drawn on one surface of each specimen. The intersecting point between the two lines was marked. A 1/8-inch (3.2-mm) diameter lead hole was drilled at the marked position for both edge and face screw withdrawal specimens. One 1.5-inch (38-mm), number 10 wood screw (13 pitches per inch) was screwed into each specimen with to a peneration of 5/8-inch (0.625-mm). The prepared specimens were conditioned to one of the four equilibrium moisture contents (7, 12, 16, and 20%). After conditioning, screw withdrawal tests were performed according to the ASTM standard [2]. Screw withdrawal tests were also conducted on specimens soaked for 24 hours for comparison purpose. Finally, all specimens were oven-dried to determine their MC at time of testing.

Linear regression analysis was carried out to determine the relationship between ultimate screw withdrawal load and MC within the hygroscopic range. Values of both face and edge USWLs from the soaked group were averaged for each plywood type. The linear regression line between USWL and MC within the hygroscopic range was forced to meet the average USWL from the soaked group. This was done by adjusting the MC such that the predicted USWL value was equal to the average USWL from the soaking test. The MC at the intersecting point was taken to be the MC approximating the fiber saturation point.

Results and Discussion

MOE/MOR value

Table 1 lists measured MOE and MOR data for the two types of plywood. The mean MC for all specimens was about 5.7% with a standard deviation of 0.3%. As shown in Table 1, both MOE and MOR values for the two types of plywood were comparable. The southern pine plywood had significantly higher MOE values in the perpendicular direction compared to the sweetgum plywood. However, there were no significant differences in all other properties between the two types of plywood.

Effect of Moisture

Both face and edge ultimate screw withdrawal loads are listed in Table 2 for the two types of plywood. The data are plotted in Fig. 1 for the pine plywood and Fig. 2 for the sweetgum plywood.

USWL generally decreased with increases in panel MC within the hygroscopic range. For face USWL of pine plywood, an MC change between 7% and 16% led to an insignificant USWL reduction. Further increases in panel MC, however, led to a significant decrease in the USWL values. For face USWL of the sweetgum plywood, there was no significant difference between 21% and 62% MC levels. Significant differences in edge USWL existed at all MC levels for both pine and sweetgum plywood. In general, effect of MC on edge USWL was more pronounced than on face USWL.

The coefficient of determination (r^2) for USWL-MC relationship was fairly low due to large data variability (Table 3), similar to other mechanical properties of wood and wood-based products. USWL at 0 % MC from regression analysis (Constant in Table 3) was higher for the panel face than for the panel edge. The sweetgum plywood showed slightly higher face and edge USWL reduction rates compared to the pine plywood.

The intersecting MC between linear regression line (USWL versus MC within the hygroscopic range) and mean USWL from water soaked group varied from 23.2% to 29.2 %. These values approximated the fiber saturation point for the plywood. It was assumed that USWL remained a constant above the intersecting MC. Test data (e.g. Fig. 2b) supported such an assumption.

Effect of Fastening Direction

At a fixed MC level, edge USWL was significantly lower than face USWL for both pine and sweetgum plywood. Furthermore, the reduction rate in edge USWL associated with MC increases was significantly higher compared to the reduction rate of face USWL (Slope in Table 3). Thus, panel edges not only had lower screw-holding capacities, but deteriorated more rapidly at higher MC levels. As a result, fastening into a plywood panel edge is not normally recommended. For some purposes, however, edge fastening may be necessary. Edge screw-withdrawal load is normally needed by plywood manufacturers and retailers for comparing properties of different products. The larger rate of reduction in edge USWL at higher MC levels may be due to the deterioration of the glue line between individual plies as a result of moisture-related swelling. Thus, improving edge screw holding capacity remains a challenge for the plywood industry.

Effect of Wood Species

The Voluntary Product Standard PS1-95 published by APA [3] separates southern pine and sweetgum into species Group 1 and Group 2, respectively. Most of the ultimate screw withdrawal load data are based on plywood panels of all Group 1 construction [1]. For plywood panels of other species groups, correction factors must be applied to the tabulated values. For ultimate screw withdrawal load, a correction factor of 0.6 needs to be applied for species group 2, including sweetgum. For interior-type plywood, however, test data under the specific conditions used in this study showed that there was no significant difference between the two species in USWL from both panel face (F=0.00) and panel edge (F=0.03) at the 0.05 significance level. Thus, it seems that interior-type sweetgum plywood can hold screws as good as pine plywood does.

Summary and Conclusions

Ultimate screw withdrawal loads of interior pine plywood panels and sweetgum plywood panels were measured on both panel face and edge at five MC levels. It was shown that face and edge USWL decreased with increases in panel MC. The effect of MC was more pronounced on edge USWL. Fastening direction had a significant effect on the USWL with the face USWL values being significantly higher than the edge USWL values for both pine and sweetgum plywood panels. Wood species (pine and sweetgum) did not show significant effects of both face and edge USWL values. The data are useful in developing correction factors for the effect of moisture, fastening direction and species on USWL in practical applications of furniture-grade plywood.

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[3] Anonymous. 1995. PS1-95 Construction and industrial plywood. APA, Tacoma, WA. 40 pp.

Table 1. A comparison of MOE and MOR values for the southern pine and sweetgum plywood.

Properties [a]	Southern pine plywood [b]	Sweetgum plywood [b]	P-value
MOE - parallel (psi)	1343944.6 (26925.5)	1085248.2 (107162.5)	0.290
MOR - parallel (psi)	9312.2 (2100.8)	9217.9 (1174.1)	0.870
MOE - perpendicular (psi)	429627.5 (76531.6)	378736.6 (46324.5)	0.005
MOR - perpendicular (psi)	4279.7 (1331.5)	4719.1 (1054.5)	0.200

[a]. 1 psi = 6894 Pa.
[b]. Values in parentheses are standard deviations based on five specimens.

Table 2. Ultimate screw withdrawal load at various MC levels for the southern pine and sweetgum plywood.

Southern pine plywood				Sweetgum plywood			
Face withdrawal		Edge withdrawal		Face withdrawal		Edge withdrawal	
MC [a] (%)	USWL[b] (Lb)	MC (%)	USWL (Lb)	MC (%)	USWL (Lb)	MC (%)	USWL (Lb)
7.1 (0.2)	431.9 (48.6) A	6.6 (0.3)	382.5 (78.3) A	6.6 (0.8)	440.4 (40.4) A	6.3 (0.3)	390.4 (44.3) A
12.7 (0.2)	413.7 (52.4) A	13.1 (0.3)	350.9 (52.7) B	12.8 (0.4)	403.9 (45.8) B	13.2 (0.3)	355.3 (38.8) B
16.2 (0.2)	421.5 (46.0) A	16.4 (0.5)	306.9 (45.3) C	15.8 (0.5)	383.7 (39.2) C	16.8 (0.7)	305.2 (38.6) C
19.3 (0.4)	327.9 (46.0) B	19.4 (0.7)	259.2 (45.1) D	20.9 (0.3)	331.7 (32.0) D	20.8 (0.6)	250.8 (38.4) D
58.9 (3.4)	291.5 (31.9) C	57.3 (5.5)	203.8 (31.7) E	62.3 (2.9)	325.9 (33.9) D	54.9 (7.2)	210.0 (28.3) E

[a] Values in parentheses are standard deviations based on five specimens.

[b] The same letter indicates no significant difference and different letters show significant difference based on Duncan's multiple range test at the 0.05 significance level.

Table 3. Results of regression analysis on ultimate screw withdrawal load and MC relationship.

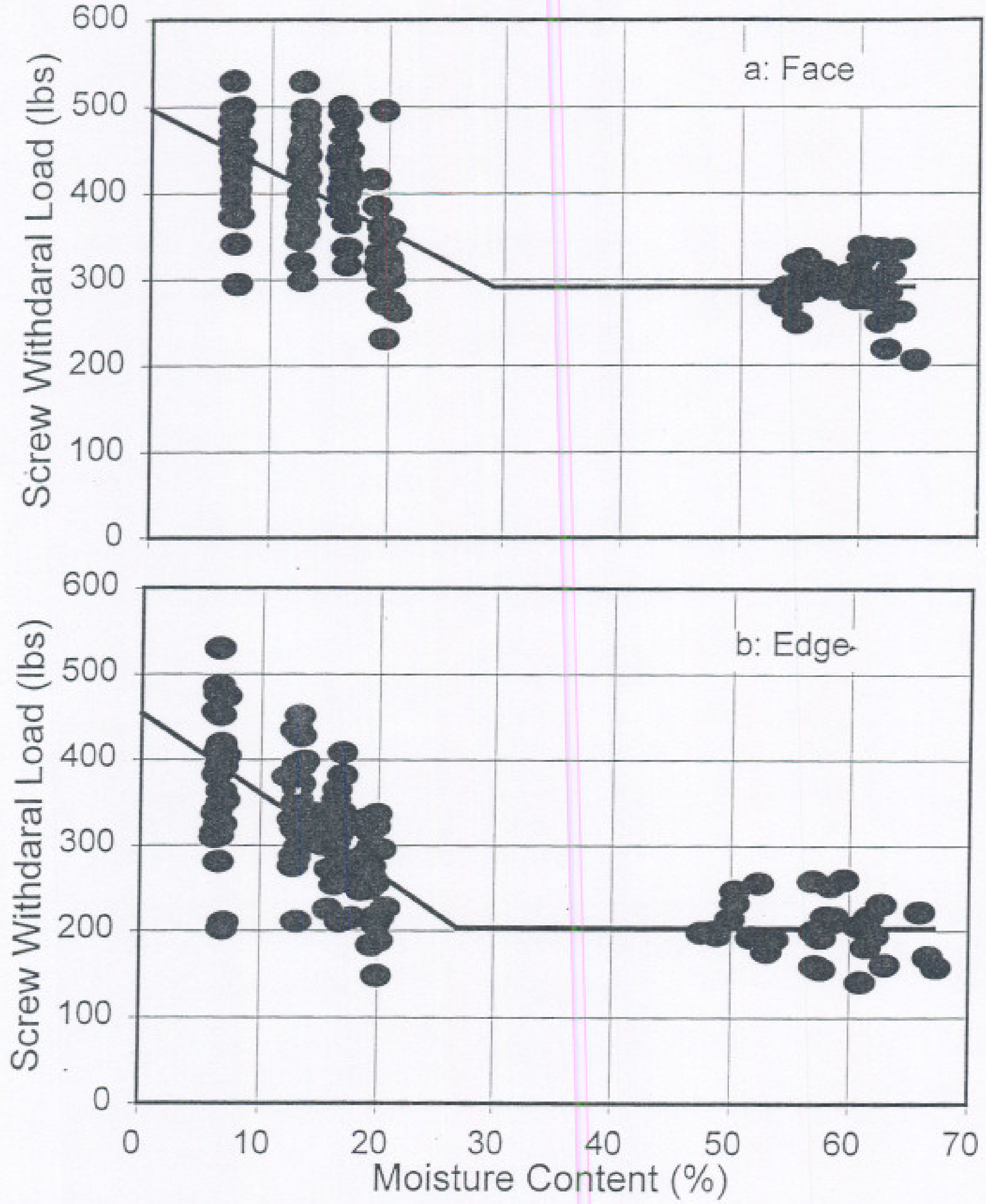
Ultimate Screw Withdrawal Load	Within hygroscopic range			Intersecting MC [a] (%)	Water soaked
	Constant (Lb)	Slope (Lb/%MC)	r^2		Mean USWL (Lb)
Pine - Edge	454.32	-9.33	0.37	26.9	203.1
Pine - Face	496.68	-7.04	0.26	29.2	291.6
Sweetgum - Edge	463.48	-9.67	0.60	26.2	209.9
Sweetgum - Face	495.55	-7.51	0.49	23.2	321.7

[a] MC at which the USWL-MC regression line within the hygroscopic range meets the mean USWL from 24-hour water soak tests.

Figure Captions:

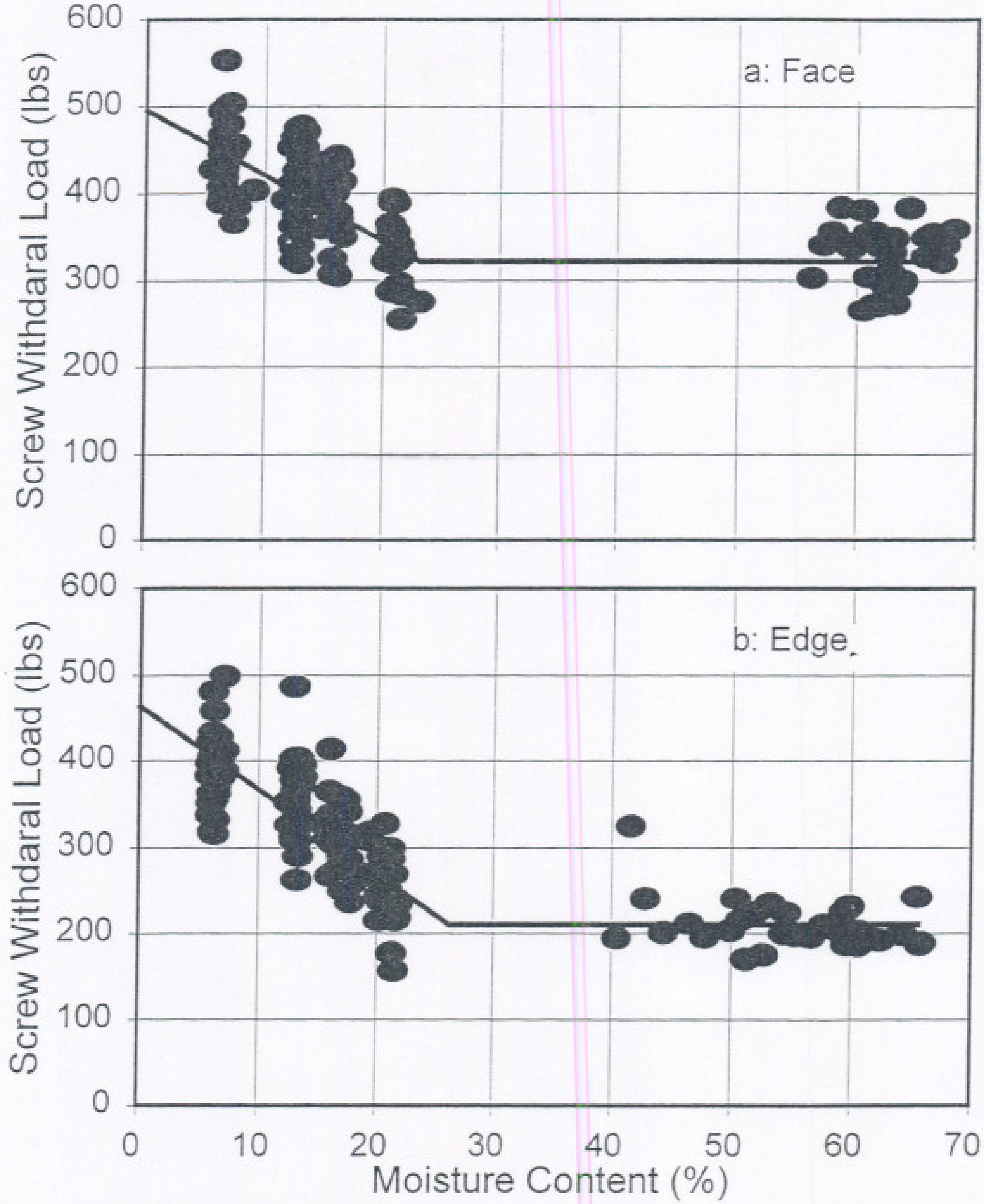
Figure 1. The relationship between ultimate screw withdrawal load and moisture content in southern pine plywood.

Figure 2. The relationship between ultimate screw withdrawal load and moisture content in sweetgum plywood.



600
500
400
300
200
100
0
Screw Withdaral Load (lbs)
a: Face
600
500
400
300
200
100
0
Screw Withdaral Load (lbs)
b: Edge
0
10
20
30
40
50
60
70
Moisture Content (%)

FIG 1.



a: Face
b: Edge
Screw Withdaral Load (lbs)
Screw Withdaral Load (lbs)
0
100
200
300
400
500
600
0
10
20
30
40
50
60
70
Moisture Content (%)

FIG 2.