**SCREW-HOLDING CAPACITY OF TWO FURNITURE-GRADE PLYWOODS**

QINGLIN WU†

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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 the 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 vs. sweetgum) had an insignificant effect on USWL. Thus, sweetgum plywood is as good as pine plywood in screw-holding strength.

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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 that is adapted to the fastener type and to the 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 standard² 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 the 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.

The purpose of this study was to measure and quantify the influence of moisture, fastening direction, and wood species on USWL 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- by 4-foot (1.22- by 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 19- by 3- by 23/32-inch (483- by 76- by 18-mm) 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 giving a total of 30 specimens for each type of plywood. Specimens were conditioned at 25°C and 55 percent relative humidity before testing.

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relative humidity for about 2 weeks before the tests. Immediately after testing, the failed specimens were ovendried to determine their MC.

Forty 6- by 3- by 23/32-inch (152- by 76- by 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 40 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- by 4- by 23/32-inch (76- by 102- by 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 50 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 the middle span of each specimen. The midpoint 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 to a penetration of 5/8 inch (16 mm). The prepared specimens were conditioned to one of the four equilibrium MCs (7%, 12%, 16%, and 20%) at 25°C (77°F). After conditioning, screw withdrawal tests were performed according to the ASTM standard. Screw withdrawal tests were also conducted on specimens soaked for 24 hours for comparison purposes. In these tests, screws were embedded before the specimens were soaked. Finally, all specimens were ovendried to determine their MC at the time of testing.

Linear regression analysis was carried out to determine the relationship between USWL 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

<table>
<thead>
<tr>
<th>Properties</th>
<th>Southern pine plywood</th>
<th>Sweetgum plywood</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOE - parallel</td>
<td>1,343,944.6 (26925.5)</td>
<td>1,085,248.2 (107162.5)</td>
<td>0.290</td>
</tr>
<tr>
<td>MOR - parallel</td>
<td>9,312.2 (2100.8)</td>
<td>9,217.9 (1174.1)</td>
<td>0.870</td>
</tr>
<tr>
<td>MOE - perpendicular</td>
<td>429,627.5 (76531.6)</td>
<td>378,736.6 (46324.5)</td>
<td>0.005</td>
</tr>
<tr>
<td>MOR - perpendicular</td>
<td>4,279.7 (1331.5)</td>
<td>4,719.1 (1054.5)</td>
<td>0.200</td>
</tr>
</tbody>
</table>

* Specific gravity (based on oven dry weight and volume at about 6% MC) averaged 0.59 for southern pine plywood and 0.57 for sweetgum plywood. Values in parentheses are standard deviations based on 30 specimens.

b 1 psi = 6894 Pa.
ear 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 percent with a standard deviation of 0.3 percent. 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 USWLs are listed in Table 2 for the two types of plywood. The data are plotted in Figure 1 for the pine plywood and Figure 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 percent 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 percent 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 the USWL-MC relationship was fairly low due to large data variability, similar to other mechanical properties of wood and wood-based products. USWL at 0 percent MC from regression analysis (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 the linear regression line (USWL vs. MC within the hygroscopic range) and the mean USWL from the water-soaked group varied from 23.2 to 29.2 percent. 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 (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 glueline 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 APA3 separates southern pine and sweetgum into species Group 1 and Group 2, respectively. Most of the USWL 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 USWL, 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 the panel face ($F = 0.00$) and the panel edge ($F = 0.03$) at the 0.05 significance level. Thus, it seems that interior-type sweetgum plywood can hold screws as well as pine plywood does.

**Summary and Conclusions**

USWLs of interior pine plywood panels and sweetgum plywood panels were measured on both the panel face and the panel 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 for 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.

### Table 3

<table>
<thead>
<tr>
<th>USWL</th>
<th>Constant (lb.)</th>
<th>Slope (lb.% MC)</th>
<th>$r^2$</th>
<th>Intersecting MC (lb.)</th>
<th>Water soaked Mean USWL (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine - edge</td>
<td>454.32</td>
<td>-9.33</td>
<td>0.37</td>
<td>26.9</td>
<td>203.1</td>
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<tr>
<td>Pine - face</td>
<td>496.68</td>
<td>-7.04</td>
<td>0.26</td>
<td>29.2</td>
<td>291.6</td>
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<tr>
<td>Sweetgum - edge</td>
<td>463.48</td>
<td>-9.67</td>
<td>0.60</td>
<td>26.2</td>
<td>209.9</td>
</tr>
<tr>
<td>Sweetgum - face</td>
<td>495.55</td>
<td>-7.51</td>
<td>0.49</td>
<td>23.2</td>
<td>321.7</td>
</tr>
</tbody>
</table>

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