THE EFFECT OF SPECIES AND SPECIES DISTRIBUTION ON THE LAYER CHARACTERISTICS OF OSB

Siqun Wang†
Paul M. Winistorfer†

ABSTRACT
Southern pine and aspen are widely utilized species for oriented strandboard (OSB) production in North America. In general, aspen with a relatively low specific gravity and uniform cell structure arrangement is considered more suitable for composite panel manufacture than is southern pine. Aspen OSB typically is lower in density and has better dimensional stability when compared to pine OSB. The purpose of this study was to investigate the effects of species use and distribution within OSB panels on the formation of the vertical density profile, resulting layer thickness swelling, and end-product layer characteristics. Five species configurations were used in this study (by weight): all pine, all aspen, 50/50 percent mixture, 25 percent aspen faces/50 percent pine core, and 25 percent pine faces/50 percent aspen core. Results show that the shape of the vertical density profile was considerably affected by species and species distribution. Resulting shapes of the vertical density profile were described as steep or gradual, referring to the densification of the face layers relative to the core. A steep profile has high density surface layers relative to the core and a gradual profile exhibits less difference between the face and core layers. The face density region of the density profile was further described as either a narrow density peak or a wide density peak, referring to the degree of density change within the face itself. The all-aspen panel had a steep density profile with a very narrow density peak. The 25 percent pine faces/50 percent aspen core panel had a more gradual density profile with a wide density peak. There was a strong relationship between layer density and layer thickness swelling. Physical and strength properties for all species combinations of panel types are reported.

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ince the inception of the oriented strandboard (OSB) industry, only a few wood species have been utilized in large quantities for commercial OSB manufacture. The history of waferboard originating in the Lake States from the abundant aspen resource is well known. As the industry has expanded to almost all geographic areas of North America, and now off-shore, other species have been and are continuing to be investigated and utilized (7). However, there still remains a limited number of preferred commercial timbers for OSB manufacture, and aspen (Populus spp.) and southern pine (Pinus spp.) are the leading species. An existing challenge for the OSB industry is to effectively utilize more of the abundant dense hardwood species readily available in the Eastern hardwood forests. Prior research suggests this is not an easily solved utilization problem (7).

There have been a large number of research reports published that describe the utilization of different species and species mixtures (1-9,11-13). The basic premise of most of this research has been to establish that OSB can be manufactured from other species, species combinations, and species-board configurations. Most of this work has been empirical in nature, i.e., a recipe approach to achieving acceptable OSB performance without detailed investigation of the underlying effects of species utilization on the fundamental formation of panel characteristics that ultimately influence panel performance.

Rice's (9) work on compaction ratio effects begins to explore some of the fundamental material characteristics of alternative species utilization on panel performance. He examined species utilization based on the parent material
density compared to the final panel density, commonly referred to as compaction ratio (5). Useful information about compaction or densification through the panel thickness was perhaps never extracted from Rice's experiments because at the time in which the work was conducted scientific equipment to easily analyze the vertical density profile through the panel thickness was not available. Techniques recently developed to further analyze the impact of densification through the panel thickness on panel properties were also not fully explored at that time (14-19).

The fundamental impact of species utilization from a material-processing perspective (excluding wood surface chemistry and bonding effects) is that species density will affect the stress-strain relationship in the mat during hot-pressing and consequently result in changes in the vertical density distribution, ultimately having a considerable impact on panel performance. The purpose of this study was to investigate the effects of species use and species distribution within the mat on the layer characteristics of the resulting laboratory panels. The objectives of this study were to:

1. Quantify the layer density and layer thickness swelling of aspen OSB and pine OSB.
2. Evaluate the effect of mat structure (single-layer and three-layer species combinations) on the end-product layer characteristics.
3. Model the layer density and layer thickness swelling relationship.

**EXPERIMENTAL METHOD**

**Board fabrication**

Commercial southern pine and aspen furnish were procured from cooperating OSB mills. The pine furnish was conditioned to 4.2 percent moisture content (MC) and the aspen furnish was conditioned to 3.93 percent MC. A commercial liquid phenol-formaldehyde resin was applied to the furnish at a rate of 3.5 percent per dry wood weight in a rotating blender. An emulsion wax was applied at a rate of 0.65 percent. The target panel size was 17 by 17 by 1/2 inch (431.8 by 431.8 by 12.5 mm). Similar to industrial OSB production, the target ovendried panel densities were 38 pcf for homogeneous aspen boards and 42 pcf for all pine boards. The ovendried density of the mixed-species board was 40 pcf, the average of the all-aspen board density and the all-pine board density. Five types of OSB panels were manufactured (Table 1), representing various combinations of species use. There were two replications of each OSB panel type.

The panels were produced at a platen temperature of 204°C, a pressing cycle of 320 seconds, and a press closure rate of 20 seconds (from initial contact of mat with upper platen until final position is reached). The top face of each panel was marked immediately after pressing.

**Board testing and analysis**

Four 3- by 14-inch MOR/ MOE specimens, three 6- by 6-inch thickness swell (TS) specimens, and six 2- by 2-inch internal bond (IB) specimens were obtained from each panel. The 24-hour total TS, water absorption (WA), MOR/MOE, and internal bond (IB) tests were performed in accordance with ASTM 1037-92A (1992). A commercial densitometer (QMS Density Profile System QDP-01X) was used to measure the vertical density profile from the six IB samples before testing. Layer TS, WA, total TS, and total edge TS were measured from each specimen after water exposure times of 2, 8, and 24 hours. Total TS was taken at the midpoint of each specimen side 1 inch from the edge. Total edge TS was taken at the same location as the layer thickness measurement.

The nondestructive optical technique was used to determine TS of 13 discrete layers within intact samples of each type of OSB product (14, 15). The technique consists of cutting shallow slots into the sample edge, resulting in a series of “slots” and “bars.” Two of the four sample edges were cut with the slot beginning at the sample face and the other two sample edges were cut with the bar beginning at the sample face. The average TS of any discrete layer was the average of the two bar measurements and two slot measurements. Change in slot and

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**TABLE 1.** — Board fabrication and structure.

<table>
<thead>
<tr>
<th>Board type</th>
<th>Species</th>
<th>Panel structure</th>
<th>Target ovendried density (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100% aspen</td>
<td>Single layer</td>
<td>38</td>
</tr>
<tr>
<td>B</td>
<td>50% aspen + 50% pine</td>
<td>Three-layer: aspen faces/pine core</td>
<td>40</td>
</tr>
<tr>
<td>C</td>
<td>50% aspen + 50% pine</td>
<td>Three-layer: pine faces/aspen core</td>
<td>40</td>
</tr>
<tr>
<td>D</td>
<td>50% aspen + 50% pine</td>
<td>Single layer (mixed)</td>
<td>40</td>
</tr>
<tr>
<td>E</td>
<td>100% pine</td>
<td>Single layer</td>
<td>42</td>
</tr>
</tbody>
</table>

**Figure 1.** — Vertical density profiles of the all-aspen panel A and the all-pine panel E.

**Figure 2.** — Vertical density profiles of panels B (25% aspen faces/50% pine core), C (25% pine faces/50% aspen core), and D (50%/50% mixture).
bar thickness during the exposure cycle was recorded via a microscope and camera. The recorded image is then displayed for measurement of slot and bar thickness and calculation of layer TS.

The relationship between layer density and layer TS for each panel was examined by linear regression analysis. The layer density was calculated from the average density profile data, determined from six IB samples of each panel and divided into 13 zones to correspond to the 13 layers created by the optical TS technique.

**RESULTS AND DISCUSSION**

**VERTICAL DENSITY PROFILES**

The density profiles for the single-specie aspen and pine panels are shown in Figure 1. Both species resulted in panels with a steep profile (high density faces relative to the lower density core). The low density aspen furnish more easily compresses in the core without heating, compared to the pine furnish, resulting in very narrow face densities. The pine panel had a steep profile, with a wider face density and a narrow core density.

The effect of panel structure on the vertical density profile is shown in Figure 2. The average densities of panels B, C, and D were 50.5, 49.5, and 48.4, respectively, which were not the same due to experimental variation. In order to investigate the effect of mat structure on the vertical density profile, the profiles of panels B, C, and D were adjusted based on the average density of three panels. Figure 2 shows the adjusted profiles. Panels B, C, and D consisted of the same materials (50% aspen flakes and 50% pine flakes based on weight). The panel B structure, consisting of an aspen face and pine core, resulted in the steepest profile among the three panels. The panel C structure, consisting of an aspen core and pine face, resulted in the most gradual profile among the three panels. The panel D structure, consisting of a mixture of both species, had a profile shape between panels B and C. The density of aspen is lower than pine and aspen can therefore be more easily compressed. The low density aspen considerably increases face or core density if aspen furnish is positioned in the face or core of three-layer OSB. It is expected then that a high compression rate will result from the aspen face area of panel B.

**PANEL PERFORMANCE**

Table 2 shows major property test results for all panels. The highest IB strength was 58.9 psi for the all-pine panel (panel E), likely due to the high core density. The lowest IB strength was 37.5 psi for the all-aspen panel (panel A), certainly due to the very low overall and core density of the aspen panel.

The MOR and MOE values of the all-aspen panel A were greater than the values of the all-pine panel E, likely due to the greater face density of the all-aspen panel. There was little difference in bending properties between panels B and D.

The TS and WA values after a 24-hour water soak are also shown in Table 2. Both total edge TS and total TS are reported. While the all-aspen panel A showed more WA than the mixed-species panels, the TS response was generally less than almost all other species mixture configurations. The all-pine panel E showed the largest WA and the
greatest TS relative to all other species mixtures. For panels B to D, placement of aspen furnish in the face of the panel (panel B) resulted in the lowest TS response. Both the pine face panel (panel C) and the homogeneous mixture of both species in the furnish (panel D) showed greater TS response than any of the aspen configuration panels. These results concur with our earlier study on mixed-species panel configurations (16).

**LAYER THICKNESS SWELLING**

Layer TS in relation to water exposure time and the vertical density profile of each panel are plotted in Figures 3 to 7. The top side of the panel represents layer #1 and the bottom side represents layer #13. The data are positioned on the ordinate of the x-axis for all panels.

The development of average actual layer TS in relation to the water exposure time, layer location, and the vertical density profile for panel B are shown in Figure 3. Layer TS increased with increased water exposure time. Maximum TS was reached after 24 hours of water exposure. There were large differences in TS results between the surface layers and the core layers. Layer #13 exhibited 41.6 percent TS after 24 hours of water exposure. The minimum TS was 14.1 percent for the core layer #5 after 24 hours of water exposure. Maximum TS after 2, 8, and 24 hours of water exposure always occurred at outside layers #1 and #13, the densest layers of the vertical density profile of that panel. Layer #6 in Figure 3 shows much greater TS than the other adjacent layers after 24 hours of water exposure. The non-uniform layer swell of the OSB is likely due to mat structure characteristics of OSB, heterogeneous furnish characteristics, and non-uniform mat formation. The large TS of layer #6 after 24 hours of water exposure was a result of non-uniform stress release during water exposure.

Figure 4 shows development of average actual layer TS in relation to water exposure time, layer location, and the vertical density profile for panel C. Maximum TS of 24.9 percent, after 2 hours of water exposure, occurred at the outside bottom layer #13. The second largest TS after 2 hours of water exposure among layers was 16.2 percent, which occurred at the outside top layer #1. The minimum TS was only 3.06 percent for the core layer #6 after 2 hours of water exposure. The TS of outside layer #13 was more than eight times that of core layer #6. After 8 hours of water exposure the minimum TS at core layer #6 increased to 5.35 percent and maximum TS at the top surface layer #13 increased to 39.2 percent, which was more than seven times that of the core layer #6. However, TS at the top of the face layer #1 was not a maximum; maximum TS was exhibited at layer #3. Maximum TS after 24 hours of water exposure was exhibited at layers #3 and #12, which were 45.1 and 44.8 percent, respectively. The TS of layers #3 and #12 were significantly higher than the 36.0 percent swell.

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![Figure 4](image_url)

**Figure 4.** Actual layer TS of panel C (25% pine faces/50% aspen core) in relation to water exposure times and the vertical density profile.

![Figure 5](image_url)

**Figure 5.** Actual layer TS of panel D (50%/50% mixture) in relation to water exposure times and the vertical density profile.
of layer #1 and the 42.1 percent swell of layer #13. The minimum TS was 11.8 percent for the core layer #8 after 24 hours of water exposure.

The development of average actual layer TS in relation to water exposure time for panel D (Fig. 5) was similar to the trend of panel B. The difference was that the top side maximum TS of 35.0 percent after 24 hours of water exposure was exhibited at layer #4. Layer #4 had already shown a high swell trend after 2 hours of water exposure. Layer #10 at the top side of panel had also shown a high swell trend after 2 hours of water exposure.

The contribution of individual layers to total TS of the all-aspen panel A was calculated and is shown in Figure 6. The contribution of layer #13 to total TS was 17.2 percent after 2 hours of water exposure, and decreased as exposure time increased. The contribution of layer #13 to total TS was 16.1 and 13.3 percent after 8 and 24 hours of water exposure, respectively. The contribution of core layer #8 to total TS was 3.19 percent after 2 hours of water exposure, and increased as exposure time increased. The contribution of core layer #7 to total TS was only 4.56 percent after 24 hours of water exposure. The high density surface layer contributed more than three times as much to the total cumulative TS as did the low density core layer.

The contribution of individual layers to total TS of the all-pine panel E was calculated and is shown in Figure 7. The contribution of layer #13 to total TS was 30.6 percent after 2 hours of water exposure, and decreased as exposure time increased. The contribution of core layer #8 to total TS was only 3.48 percent after 2 hours of water exposure. The high density surface layer contributed more than eight times as much to the total cumulative TS as did the low density core layer. The contribution of layer #13 to total TS was 23.2 and 17.0 percent after 8 and 24 hours of water exposure, respectively. The contribution of the core layer #10 to total TS was only 4.77 percent after 24 hours of water exposure. The high density surface layer contributed more than three times as much to the total cumulative TS as did the low density core layer after 24 hours of water exposure.

To better understand the contribution of high and low density areas on the total TS, the whole panel thickness was divided into a surface region and a core region. The high density surface region was 47.9 to 48.4 percent of the whole panel thickness and included layers #1 to #3 and layers #11 to #13 from each panel face. The low density core area was 51.6 to 52.1 percent of the whole panel thickness and included layers #4 to #10. The contributions of the high density area to total TS of panels A to E were 66.8, 71.4, 70.5, 71.8, and 73.2 percent after 2 hours of water exposure, respectively (Table 3). The contribu-
### Table 3. Percentage thickness swell of face layers and core layers relative to total thickness swell.

<table>
<thead>
<tr>
<th>Panels</th>
<th>Position</th>
<th>2 hours (%)</th>
<th>8 hours (%)</th>
<th>24 hours (%)</th>
<th>Proportion of total panel thickness before water soak (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>32.6</td>
<td>34.5</td>
<td>28.1</td>
<td>23.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>A</td>
<td>Top face layers&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.2</td>
<td>35.4</td>
<td>44.8</td>
<td>51.8</td>
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<td></td>
<td>Core layers&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34.2</td>
<td>30.1</td>
<td>27.1</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>Bottom face layers&lt;sup&gt;c&lt;/sup&gt;</td>
<td>32.8</td>
<td>31.9</td>
<td>28.4</td>
<td>23.3</td>
</tr>
<tr>
<td>B</td>
<td>Top face layers</td>
<td>28.6</td>
<td>32.2</td>
<td>39.0</td>
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<tr>
<td></td>
<td>Core layers</td>
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<td>35.9</td>
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<tr>
<td></td>
<td>Bottom face layers</td>
<td>28.6</td>
<td>32.1</td>
<td>32.2</td>
<td>22.9</td>
</tr>
<tr>
<td>C</td>
<td>Face layers</td>
<td>29.5</td>
<td>28.4</td>
<td>34.2</td>
<td>51.8</td>
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<tr>
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<td>Core layers</td>
<td>41.9</td>
<td>39.5</td>
<td>33.6</td>
<td>25.3</td>
</tr>
<tr>
<td></td>
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<td>25.9</td>
<td>27.8</td>
<td>27.7</td>
<td>23.5</td>
</tr>
<tr>
<td>D</td>
<td>Top face layers</td>
<td>28.2</td>
<td>30.9</td>
<td>38.2</td>
<td>51.8</td>
</tr>
<tr>
<td></td>
<td>Core layers</td>
<td>45.9</td>
<td>41.3</td>
<td>34.1</td>
<td>24.7</td>
</tr>
<tr>
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<td>Bottom face layers</td>
<td>27.6</td>
<td>26.7</td>
<td>25.8</td>
<td>22.5</td>
</tr>
<tr>
<td>E</td>
<td>Top face layers</td>
<td>26.8</td>
<td>35.7</td>
<td>42.6</td>
<td>51.6</td>
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<tr>
<td></td>
<td>Core layers</td>
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<td>31.6</td>
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<td>Bottom face layers</td>
<td>27.6</td>
<td>26.7</td>
<td>25.8</td>
<td>22.5</td>
</tr>
</tbody>
</table>

<sup>a</sup> Includes layers 1 to 3.
<sup>b</sup> Includes layers 4 to 10.
<sup>c</sup> Includes layers 11 to 13.
<sup>d</sup> For example, the total thickness of layers 1 to 3 was 23.6 percent of the overall panel thickness before beginning the water-soak TS test.

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Figure 8.—Percentage core layer TS of all five panel configurations with water exposure time.

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With regard to single-specie panels, the contribution of the high density area to total TS of the all-pine panel E was considerably greater than that of the all-aspen panel A after 2 and 24 hours of water exposure, respectively (Table 3). With regard to two-species panels, there were no large differences in the contribution of the high density surface areas to total TS among panels B, C, and D after 2 hours of water exposure.

Figure 8 shows percentage TS development in the low density core area with water exposure time. The percentage TS of the low density core area for any panel was positively and non-linearly correlated with water exposure time. All panels showed the trend of increasing percentage TS of the low density core area as water exposure time increased. After 2 hours of water exposure, each panel showed a slightly different percentage TS of the low density core area, and some differences still remained after 24 hours of water exposure. For example, panel A showed the highest percentage TS of the low density core area after 2 hours of water exposure and also at the conclusion of the 24 hours of water exposure. However, the mixed-species panel D showed a different development in that the low density core area of the panel showed the lowest percentage TS after 2 hours of water exposure and showed the highest percentage TS after 8 hours of water exposure. Panel D showed the second highest percentage TS after 24 hours of water exposure.

Figures 3 through 7 show a trend that layer TS on the panel bottom side is always higher than layer TS on the panel top side at the same water exposure cycle. The platen press always results in the preheating of the bottom surface of the mat. The preheating on the bottom surface of the mat influences the consolidation and surface resin precure before the press reaches final position. In the most severe cases, we previously reported that flakes on the surface of a sample pressed with a 40- or 60-second closure rate peeled off after the 24-hour water exposure (15). The panels in this study were produced at a press closure rate of 20 seconds. Although these panels did not exhibit flake peel-off after the 24-hour water exposure, poorer bond development on the bottom side of the panels caused the bottom face to swell more than the top face. Figure 9 and Table 3 show that bottom face layers, ex-
cept data for panel A after 8 and 24 hours of water exposure, swell considerably more than the top face layers under any water exposure cycle. There was a larger TS difference between the top face and bottom face after 2 hours of water exposure than after longer water exposure times. For example, the TS of the bottom face of panel D was 45.9 percent, which was 1.77 times that of the top face TS after 2 hours of water exposure. Bottom face TS of panel D was 1.23 times that of the top face TS after 24 hours of water exposure.

**Layer Density and Layer Thickness Swelling Relationships**

The layer TS after three water exposure times is significantly and positively related to layer density in all panels studied (Table 4 and Fig. 10). The correlation coefficient between the layer TS and layer density after 2 hours of water exposure is as high as 0.961 in the all-aspen panel A (Fig. 10). The correlation coefficient between the layer TS and layer density of panel A decreased as water exposure time increased.

The layer TS of the all-pine panel E after three water exposure times, to a differing extent, is less related to layer density. This indicates that layer density strongly affected layer TS and subsequently affected whole sample TS. However, layer density is not the only factor that results in differential layer TS for the pine panel. Internal swelling stress development in the panel during water exposure is an important factor. Suchtsland (10) suggested that the density profile of particleboard samples would lead to internal swelling stresses as the low density layers in the panel restrain the higher density layers from swelling to their full potential. This restraint would result in initial internal swelling. At higher MCs, tensile stresses in the lower density areas would cause tension failures that allow the TS to be dominated by the higher density portions. This would be evidenced by the actual TS exceeding the average potential swell. The internal swelling stress will clearly increase as water exposure time increases. The layer TS of the all-aspen panel A is less related to layer density after longer water exposure times because of the internal swelling stress development. With regard to the two furnish species studied, aspen with relative low density and uniform cell structure, can be compressed uniformly. The internal swelling stress during water exposure would therefore be less for aspen than for a different species with a higher density and non-uniform cell structure. The layer TS appears more closely related to layer density. Pine with relative high density, a non-uniform cell structure, and density variation within the growth ring results in a non-uniform panel density spatial distribution even under a uniform forming process. The layer TS is less related to layer density because of high internal swelling stress development during water exposure.

Among panels B, C, and D, consisting of 50 percent aspen flakes and 50 percent pine flakes, the aspen face and pine core panel B showed the least linear relationship between layer TS and layer density. The correlation coefficient between the layer TS and layer density was 0.665 and 0.676, respectively, after 2 hours and 24 hours of water exposure. The layer TS after 8 hours of water ex-
posure appears more closely related to layer density for those three panels.

**Conclusion**

By exploring species use and distribution within the panel on the critical layer density characteristics through the panel thickness, we were able to show the strong relationship between layer density and layer TS within the panel. More than 65 percent of the total average TS occurred mainly in the high density surface regions during the early stages of water exposure. Even after 24 hours of water exposure, at least 55 percent of the total TS occurred in the high density surface regions. The percentage of the low density core area for any panel was positively and non-linearly related to water exposure time.

The large differences in the density of the parent furnish materials impacted layer compaction characteristics and resulting panel performance. The all-aspen panel exhibited less total TS than the all-pine panel. While the face layers of the all-aspen panel contributed about 14 percent to the total TS of the panel, the face layers of the all-pine panel contributed only about 10 percent to the total TS of the panel. Yet, the all-pine panel exhibited greater total TS than the aspen panel. The placement of the aspen furnish in either the face or the core of the panel resulted in a decreased TS response in that area.

Our interest in this work was most focused on exploring the relationship between layer characteristics and TS of OSB panels manufactured with different species and species mixes. Our long-term research objective is to better understand the TS phenomena in composite panels and ultimately improve the manufacture and performance of wood-based composites.

**Literature Cited**


