THICKNESS SWELLING AND ITS RELATIONSHIP TO INTERNAL BOND STRENGTH LOSS OF COMMERCIAL ORIENTED STRANDBOARD

QINGLIN WU†
CHENG PIAO†

ABSTRACT

Samples from two types of mixed hardwood oriented strandboard (OSB) and two types of southern pine OSB were tested to study thickness swelling (TS) and its relationship to internal bond (IB) strength loss of the products. The treatment conditions included four equilibrium moisture contents and 24-hour water soaking at room temperature. It was shown that both high humidity and water-soaking treatments led to significant TS for all materials tested. Residual IB strength for all OSBs decreased linearly with an increase in non-recoverable TS. Regardless of the way OSB absorbed moisture, there was an average IB strength loss of about 0.0138 MPa for every percent of non-recoverable TS in the specimens. In-plane density variation and non-uniform resin application due to curled flakes were found to play a significant role for the large TS and IB strength loss in these products.

Thickness swelling (TS) of wood composites in relation to moisture content (MC) change and panel manufacturing parameters has been extensively studied. It was shown (1,8) that total thickness swelling (TTS) has two components: recoverable thickness swelling (RTS) and non-recoverable thickness swelling (NTS). RTS is the swelling of the wood due to MC change within the hygroscopic range, while NTS is a result of the combined effect of the compression stress release from the pressing operation and differential swelling potential due to inherent in-plane density variation. The latter results in normal swelling stresses between high and low density areas in the plane of the panel. These stresses are often large enough to break the adhesive bonds, leading to significant NTS (3,5).

A large negative consequence of the NTS is the reduction of strength properties of wood composites. Lehmann (2) studied the effects of single or multiple water-exposure and drying cycles on the strength and stability of a series of structural flakeboards of varying resin and wax contents. It was shown that bending stiffness and strength and internal bond (IB) strength all decreased after various treatments were applied to the test panels. Resin content was shown to have a significant effect in reducing TS and maintaining panel strength. Winstorfer and DiCarlo (6) tested randomly formed flakeboard made of mixed hardwoods for the effects of furnish MC, resin non-volatile content, and assembly time on stability and strength retention properties. The study demonstrated that an oven-dry-vacuum/pressure/soak treatment led to significant IB strength loss of the panels due to the large TS involved. Suchsland and Xu (5), using a model consisting of thin veneer strips, demonstrated the development of large TS and severe reduction of IB strength due to in-plane density variation in laboratory-made flakeboards.

Limited work has been done directly relating strength loss to TS (especially NTS) in commercial OSB currently marketed. The product is normally made with relatively large flakes and low resin content. Its flake alignment level and mat structure are significantly different from those of laboratory panels. Thus, test data on TS and its relationship to strength loss from laboratory panels may not directly apply to commercial OSB products. Wu and Suchsland (8) demonstrated that commercial OSBs can suffer significant stiffness and strength at higher MC conditions. The study showed that both strength and stiffness losses were directly proportional to the amount of TS in the panel. It was speculated that the strength...
loss in OSB was mainly due to breakage of adhesive bonds in the panel, which causes NTS. Therefore, studies on the relationship between IB strength and TS may shed more light on how OSB products lose strength when they get wet. The objectives of this study were to: 1) characterize the TS behavior of OSB in relation to high humidity exposure and short-term water soaking; 2) determine residual IB strength after various treatments; and 3) examine the relationship between IB strength loss and permanent TS as influenced by product type and manufacturing parameters.

**Materials and Methods**

**Material Selection and Specimen Preparation**

Four types of commercial OSB were selected for the study (Table 1). These included two OSBs made of mixed hardwoods for sheathing (MHS) and two OSBs made of southern pine for sheathing (SPS) and for flooring (SPF). Two 122- by 122-cm panels for each OSB were directly obtained from the OSB manufacturers. It is known that all panels were made with liquid phenol-formaldehyde adhesive at a face-to-core flake weight ratio of approximately 50:50. Other manufacturing variables were not known.

Fifty 50.8- by 50.8-mm specimens were cut from each of the four OSBs for TS and IB strength tests in this study. The 50 specimens from each OSB were randomly separated into 5 groups with 10 samples in each group. Each specimen was labeled on one edge according to OSB type, group number, and replication number for easy identification during the conditioning room and specimen preparation. The labeled specimens for a given group from each OSB. A total of five sets were prepared. They were stored in an air-conditioned room at 55 percent relative humidity (RH) and 25°C before testing.

**Test Condition and Procedure**

During testing, one of the five sets of specimens was selected. They were tested according to the following scheme: oven-drying → treatment → oven-drying → IB strength testing. The treatment conditions included four RH exposures corresponding to four target EMCs (5, 10, 15, and 25%) and 24-hour water soaking at room temperature. The objectives of this study were to: 1) characterize the TS behavior of OSB in relation to high humidity exposure and short-term water soaking; 2) determine residual IB strength after various treatments; and 3) examine the relationship between IB strength loss and permanent TS as influenced by product type and manufacturing parameters.

**Materials and Methods**

**Material Selection and Specimen Preparation**

Four types of commercial OSB were selected for the study (Table 1). These included two OSBs made of mixed hardwoods for sheathing (MHS) and two OSBs made of southern pine for sheathing (SPS) and for flooring (SPF). Two 122- by 122-cm panels for each OSB were directly obtained from the OSB manufacturers. It is known that all panels were made with liquid phenol-formaldehyde adhesive at a face-to-core flake weight ratio of approximately 50:50. Other manufacturing variables were not known.

Fifty 50.8- by 50.8-mm specimens were cut from each of the four OSBs for TS and IB strength tests in this study. The 50 specimens from each OSB were randomly separated into 5 groups with 10 samples in each group. Each specimen was labeled on one edge according to OSB type, group number, and replication number for easy identification during the conditioning room and specimen preparation. The labeled specimens for a given group from each OSB. A total of five sets were prepared. They were stored in an air-conditioned room at 55 percent relative humidity (RH) and 25°C before testing.

**Test Condition and Procedure**

During testing, one of the five sets of specimens was selected. They were tested according to the following scheme: oven-drying → treatment → oven-drying → IB strength testing. The treatment conditions included four RH exposures corresponding to four target EMCs (5, 10, 15, and 25%) and 24-hour water soaking at room temperature. The test procedure at each EMC condition was as follows. A group of 40 pre-prepared specimens was selected (10 samples from each OSB). They were first oven-dried at 105°C for 24 hours. Specimen weight and size (length, width, and thickness) were measured after the oven-drying. The specimens were then placed in a climate-controlled room, which was set at the target EMC, until equilibrium was reached. They were removed from the conditioning room and specimen weight and size (length, width, and thickness) were re-measured. The specimens were then subjected to a second oven-drying and their weight and size measured again. Finally, all specimens were tested for IB strength. Specimen thicknesses after the first oven-drying, after conditioning, and after the second oven-drying were used to calculate total, recoverable, and non-recoverable TS (8).

Tests under water-soaking condition were conducted as follows. After the first oven-drying, specimens were submerged 25.4 mm below the surface of water at room temperature. To determine the swelling rate as a function of time, specimens were submerged after 1, 2, 3, 5, 10, 15, and 24 hours of water soaking. Their

**Table 1. Summary of test data on the commercial OSBs tested.**

<table>
<thead>
<tr>
<th>OSB type</th>
<th>Specific gravity</th>
<th>MC</th>
<th>TTS (%)</th>
<th>NTS (%)</th>
<th>IB (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHS1</td>
<td>0.70 (0.06)</td>
<td>4.75 (0.06)</td>
<td>1.93 (0.72)</td>
<td>0.52 (0.71)</td>
<td>0.458 (0.13)</td>
</tr>
<tr>
<td>MHS2</td>
<td>0.70 (0.06)</td>
<td>4.79 (0.09)</td>
<td>1.96 (0.54)</td>
<td>0.21 (0.48)</td>
<td>0.416 (0.13)</td>
</tr>
<tr>
<td>SPS</td>
<td>0.69 (0.03)</td>
<td>4.99 (0.08)</td>
<td>2.15 (0.23)</td>
<td>0.10 (0.12)</td>
<td>0.509 (0.15)</td>
</tr>
<tr>
<td>SPF</td>
<td>0.61 (0.03)</td>
<td>4.88 (0.34)</td>
<td>4.88 (0.15)</td>
<td>0.13 (0.10)</td>
<td>0.348 (0.08)</td>
</tr>
</tbody>
</table>

- MHS1 = mixed hardwood OSB sheathing (span rating: 32/16); MHS2 = mixed hardwood OSB sheathing (span rating: 24/16); SPS = southern pine OSB sheathing (span rating: 24/16); and SPF = southern pine OSB flooring (span rating: 24 OC).
- Specific gravity is based on oven-dry weight and volume.
- Specimen MC at the time of IB strength testing averaged 7.5 percent.
- Values in parentheses are standard deviations based on 10 specimens.
- Data from the soaking group.
Thickness and weight (after wiping off water on the specimen surface) were measured. After a 24-hour soaking, all specimens were ovendried at 105°C for 24 hours. Specimen weight and thickness were measured again. Finally, all specimens were tested for IB strength as described previously. From the data, water absorption (WA, %) and TTS as a function of soaking time were calculated for each specimen. TTS was expressed as a function of WA for each individual specimen of a given OSB and for all specimens from each OSB combined as a group. A linear regression procedure was used to determine the slope (i.e., the swelling rate from water soaking). NTS developed. This can be seen from Figure 1 as data points for TTS and RTS overlap. As MC increased further, however, NTS developed gradually up to the 10 to 12 percent MC level, and then increased quickly with further increases in MC. The observed TS behavior agreed with earlier results on commercial OSBs (8). After the 25 percent EMC treatment, flakes in the panels were practically saturated. The mean TTS reached was 33.0, 32.0, 37.2, and 29.3 percent for the four OSBs as a function of MC. RTS followed the TS-MC data well with a coefficient of determination from 0.93 to 0.99 (Table 2). The combined TTS-MC and NTS-MC relationships for the four OSBs (pooled data) are, respectively:

\[
TTS = 0.83 - 0.52 MC + 0.13 MC^2 - 0.002 MC^3 \quad r^2 = 0.97 \quad [2]
\]
and

\[
NTS = 0.60 - 0.67 MC + 0.10 MC^2 - 0.002 MC^3 \quad r^2 = 0.93 \quad [3]
\]

Equations [2] and [3] can be used to estimate TTS and NTS for commercial OSBs as a function of MC. RTS followed a linear relationship with MC increase for all four OSBs (Fig. 1). The swelling rate, coefficient \(a_1\) in Table 2 under RTS, was practically the same for MHS1, SPS, and SPF, while it was slightly smaller for MHS2.

### Thickness swelling in relation to water soaking

A linear relationship existed between TTS and WA of the OSBs (Fig. 2). Thus, thickness swelling of OSB from short-term water soaking is directly proportional to the amount of water absorbed. The swelling rates (coefficient \(b\) in Table 3: regression slope of the linear TTS-WA curve) of the three sheathing products are practically the same: 0.31. Since the first two OSBs were made of mixed hardwoods and the third one made of southern pine, wood species seemed to show insignificant effects on the swelling rate from short-term water soaking.

### Results and discussion

#### Thickness swelling in relation to high-humidity exposure

Test data on TS, specimen specific gravity (SG), and treatment MC are summarized in Table 1. Table 2 shows regression results on the relationship between TTS, RTS, or NTS, and MC. Typical plots showing TS as a function of MC are shown in Figure 1. In each graph, the area between the RTS line and the TTS line represents NTS.

TTS increased non-linearly with increases in MC (Fig. 1). For MC change up to the 5 to 6 percent level, very little NTS developed. This can be seen from Figure 1 as data points for TTS and RTS overlap. As MC increased further, however, NTS developed gradually up to the 10 to 12 percent MC level, and then increased quickly with further increases in MC. The observed TS behavior agreed with earlier results on commercial OSBs (8). After the 25 percent EMC treatment, flakes in the panels were practically saturated. The mean TTS reached was 33.0, 32.0, 37.2, and 29.3 percent for MHS1, MHS2, SPS and SPF respectively. The corresponding mean RTS was 18.7, 20.2, 24.2, and 17.5 percent for the four products, respectively. SPF had the largest TTS and NTS among the four OSBs. NTS accounted, on average, for 61.2 percent of TTS under this treatment condition. This large component of NTS led to significant IB strength loss in the products as shown later.

The polynomial function (Eq. [1]) fitted the TS-MC data well with a coefficient of determination from 0.93 to 0.99 (Table 2).

### Table 2: Regression results on the relationship between thickness swelling and MC. Model: TTS, NTS, or RTS = \(a_0 + a_1 MC + a_2 MC^2 + a_3 MC^3\).

<table>
<thead>
<tr>
<th>OSB type(^a)</th>
<th>Regression coefficients</th>
<th>Coefficient of determination, (r^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a_0)</td>
<td>(a_1)</td>
</tr>
<tr>
<td>Total TS (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHS1</td>
<td>0.34</td>
<td>0</td>
</tr>
<tr>
<td>MHS2</td>
<td>0.53</td>
<td>0</td>
</tr>
<tr>
<td>SPS</td>
<td>0.20</td>
<td>0.410</td>
</tr>
<tr>
<td>SPF</td>
<td>0.14</td>
<td>0.380</td>
</tr>
<tr>
<td>Non-recoverable TS (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHS1</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>MHS2</td>
<td>0.24</td>
<td>0</td>
</tr>
<tr>
<td>SPS</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>SPF</td>
<td>0.12</td>
<td>0</td>
</tr>
<tr>
<td>Recoverable TS (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHS1</td>
<td>-0.936</td>
<td>0.565</td>
</tr>
<tr>
<td>MHS2</td>
<td>-0.404</td>
<td>0.493</td>
</tr>
<tr>
<td>SPS</td>
<td>-0.507</td>
<td>0.522</td>
</tr>
<tr>
<td>SPF</td>
<td>-0.516</td>
<td>0.566</td>
</tr>
</tbody>
</table>

\(^a\) MHS1 = mixed hardwood OSB sheathing (span rating: 32/16); MHS2 = mixed hardwood OSB sheathing (span rating: 24/16); SPS = southern pine OSB sheathing (span rating: 24/16); and SPF = southern pine OSB flooring (span rating: 24 OC).

...
SPF (southern pine OSB for floor underlayment) had the lowest swelling rate in response to water soaking. This was thought to be due to its lower panel density.

Density variation exists within a given OSB panel and among different products. Earlier work in the field (7) showed that density had a large influence on the TS properties of OSB. To show the effect of specimen density on the swelling rate of the products tested, the swelling rate of each individual specimen from all four OSBs was combined. A linear regression analysis was performed to establish the relationship between the swelling rate and specimen specific gravity (Eq. [4]).

\[
\text{TS Rate (\%TTS/\%WA)} = -0.137 + 0.65 \text{ SG} \quad r^2 = 0.41
\]  

It can be seen from Equation [4] that the swelling rate increased with increase in specimen density. This implies that for a given OSB panel, large in-plane density variation can lead to different rates of swelling. This would create out-of-plane swelling stresses between high and low density areas, which, in turn, lead to internal damage of the panel. Thus, improving the forming process for uniform properties would greatly improve the moisture resistance of the panel.

After the 24-hour soaking, the flakes were not fully saturated. Average TTS reached 17.6, 22.8, 17.5, and 16.3 percent for MHS1, MHS2, SPS, and SPF, respectively (last row under each OSB in Table 3). The corresponding average NTS was 16.2, 18.5, 12.7 and 8.8 percent for the four OSBs. The overall mean NTS among the four OSBs accounted for 75.5 percent of the TTS. Compared with the long-term exposure condition at 25 percent EMC, both TTS and NTS were smaller. Since NTS is directly related to the breakdown of adhesive bonds between the flakes in the panel, the smaller TS, especially NTS, after 24-hour water soaking would lead to less severe damage to the strength properties of OSB.

**INTERNAL BOND STRENGTH**

Test data on IB strength are summarized in Table 1. Specimen MC at the time of testing averaged at about 7.5 percent for all groups. There were variations in IB values (i.e., large standard deviation as shown in Table 1) at a given treatment condition for all OSBs. This was caused by density variation among specimens within a group and problems associated with curled flakes, which is a common problem for most commercial OSB mills. Commercial flakes are fairly large (up to 101.6 mm long and 76.2 mm wide). Some wide flakes curled after they lost moisture in drying. During resin application, the inner surface of the curled flakes did not receive any adhesive. As a result, no gluebond was developed on the inner surface of these flakes. Those specimens often failed along the unbound places.

IB strength for all OSBs varied with treatment conditions applied. The strength values were the highest from the specimens treated with the first two EMC conditions. For all four OSBs, statistical comparison showed no significant differ-

![Figure 1. Thickness swelling as a function of MC. Lines show the regression fit of the data.](image-url)

**TABLE 3. Regression results on TTS-WA relationship from water-soaking test with a linear model (TTS = a + b WA).**

<table>
<thead>
<tr>
<th>OSB type</th>
<th>Regression coefficients</th>
<th>Coefficient of determination, $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHS1</td>
<td>0.42</td>
<td>0.32</td>
</tr>
<tr>
<td>MHS2</td>
<td>-0.71</td>
<td>0.31</td>
</tr>
<tr>
<td>SPS</td>
<td>2.26</td>
<td>0.32</td>
</tr>
<tr>
<td>SPF</td>
<td>0.46</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* MHS1 = mixed hardwood OSB sheathing (span rating: 32/16); MHS2 = mixed hardwood OSB sheathing (span rating: 24/16); SPS = southern pine OSB sheathing (span rating: 24/16); and SPF = southern pine OSB flooring (span rating: 24 OC).
There seemed to be no particular trend on the percent of IB reduction as influenced by wood species and product type.

Although specimens reached higher MCs during water soaking (last row under each OSB in Table 1), these specimens were not completely saturated with water. Also, water penetrated into the specimens from the sides and filled the internal voids within the specimen. Therefore, the specimens from water soaking did not swell as much as the specimens from the 25 percent EMC treatment. As a result, higher residual IB strength remained in the specimens from soaking tests. The average IB strength loss after 24-hour soaking were 45.7, 50.8, 42.3, and 38.2 percent for MHS1, MHS2, SPS, and SPF respectively. This result provides direct evidence that the strength loss in OSB is directly related to the amount of NTS, not the amount of water in the panel.

IB strength is plotted against NTS in Figure 3. Since the decrease in IB strength is directly related to the degree of internal gluebond damage due to excess TS, IB strength for all OSBs decreased almost linearly with increase in the amount of NTS in the specimens. The regression analysis (Table 4) indicated that for every percent of NTS that occurred in the specimens, there was, on average, about 0.0138 MPa IB strength loss. The average rate of IB strength reduction for the two hardwood OSBs was about 0.002 MPa higher compared with that of the two southern pine products. Curled flakes were found to play a significant role in causing the IB strength reduction of the hardwood OSBs. The large amount of IB strength reduction would certainly lead to reduction in the bending strength and stiffness of OSBs as demonstrated in the earlier studies (8). The NTS can occur through exposing the panels to high-humidity conditions and directly contacting with water. Therefore, efforts to improve durability properties of OSB should be concentrated on developing techniques to reduce the amount of NTS in the panel.

**Summary and conclusions**

Four types of commercial OSB were tested to investigate their swelling behavior and its relationship to IB strength losses. It was shown that the OSBs swelled, on average, 32.8 percent over an EMC change of 23.8 and 18.6 percent...
after 24-hour water soaking. The corresponding non-recoverable TS was 20.1 percent and 14.0 percent, respectively. Both high-humidity and water-soaking treatments led to significant IB strength reduction. There was, on average, 0.0138 MPa IB strength loss for every percent of NTS that occurred in the specimens. Wood species and product type showed no obvious effects on the IB reduction rate. Better mat formation and more uniform resin application seem to be some of the keys for improving the long-term durability properties of OSB.

LITERATURE CITED

Figure 3. — Internal bond strength as a function of nonrecoverable thickness swelling. Lines show a linear fit of the data. (1 psi = 6894 Pa.)