An optical technique for determination of layer thickness swell of MDF and OSB

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Abstract

A nondestructive optical technique was developed to determine thickness swell of discrete layers within intact samples of wood composites. Layer thickness swell of commercial medium density fiberboard (MDF) and oriented strandboard (OSB) are presented. Layer swell within the sample is important in understanding the swell phenomena of wood composites. Results from standard specimens show edge layer thickness swell after 2-, 8-, and 24-hour water soak and include measures of precision and variation for this technique. The relative difference for overall thickness swelling compared between the optical technique and the traditional method decreased as water exposure time increased and was less than 3.44 percent after 24-hour water exposure. The contributions of high-density surface layers to overall MDF thickness swell were 95.76, 75.50, and 61.77 percent after 2-, 8-, and 24-hour water exposure, respectively. The contributions of high density surface layers to overall OSB thickness swell were 74.36, 64.39, and 57.30 percent after 2-, 8-, and 24-hour water exposure, respectively. Thickness swell for both products was dominated by the high density surface layers throughout the 24-hour soak cycle. However, dense surface layers contributed more to the overall swell measurement during the early period of the soak cycle compared to the swell measurement at the completion of the 24-hour soak cycle. The relative contribution of the core layers to overall thickness swell increased with length of exposure period. This optical technique is recommended for the measurement and study of in-situ layer swell properties for all wood composite panel materials.

We have been studying the phenomenon of thickness swell in wood-based composites as part of our overall research program to address composite product manufacture and performance (Xu and Winistorfer 1995a, 1995b; Wang and Winistorfer 2000a, 2001). We purport that one of the key variables in understanding the thickness swell phenomenon is recognition of the density profile through the panel thickness. The density profile results from the complex interaction of heat, pressure, and temperature and their combined impact on the consolidation characteristics of the mat during pressing. The interaction of these variables results in non-uniform stress development and relaxation through the thickness of the mat during pressing. We have designed an in situ system for measuring the density profile of the mat during pressing (Winistorfer et al. 1998, Wang and Winistorfer 2000b) and are studying the relationship between consolidation characteristics and panel performance, particularly thickness swell. Improved dimensional stability performance, primarily thickness swell, would enhance performance of current panel products in a wide range of applications.

Suchsland (1973) suggested that the density profile of particleboard samples would lead to internal swelling stresses as the low density layers in the panel re-
strain the higher density layers from swelling to their full potential. This restraint would result in initial internal swelling. At higher moisture contents, tensile stresses in the lower density areas would cause tension failures that allow the thickness swelling to be dominated by the higher density portions. This would be evidenced by the actual thickness swelling exceeding the average potential swelling. Thickness swell is now recognized as having two components: 1) the normal swelling characteristics of the wood itself; and 2) the swell component that develops from the release of compression stresses in the mat. The swell originating from the wood itself is considered recoverable; the swell originating from the release of compressive stresses is considered non-recoverable, and is commonly called spring-back.

We previously introduced two techniques to determine thickness swell characteristics of individual layers within a wood composite panel (Xu and Winistorfer 1995a, 1995b). We developed an intact specimen algorithm to determine thickness swell distribution across the board thickness based on vertical density distribution changes measured before and after the water exposure treatment. The procedure uses a linear relationship between adjacent density data points in the vertical density profile and assumes a constant weight of an individual horizontal layer after swell. An algorithm was developed to make the estimation. A thin, horizontal layer within a sample has a known volume and mass from radiation measurement. After water exposure, the same known volume expands some unknown amount. As the thin layer expands due to swelling stresses, the mass of the original volume decreases as material moves out of the original volume (expands) due to swelling pressures. For thickness swell, the algorithm uses the original mass of the known layer thickness and solves for the new unknown volume of the expanded layer. For water absorption, the algorithm uses radiation absorption principles involving two elements to separate the wood mass from the water mass. The second technique is a layer slicing procedure in which thin horizontal layers are sectioned from composite samples and subsequently tested for thickness swell after 24-hour water soak. Both techniques show that discrete layer thickness swell is positively correlated to the layer density and suggest efforts to improve thickness swell should focus on treatments or processes that impact the more dense surface layers of composite panels.

Both techniques have some limitations that may restrict their widespread use as a standard protocol. The intact algorithm method requires the nondestructive measurement of layer density through the sample thickness. While our laboratory densitometer, utilizing a gamma source, may be used to make layer measurements on standard 150- by 150-mm thickness swell samples, current commercial densitometers for the panelboard industry utilize the standard 50- by 50-mm internal bond sample for density profile measurement. The same limitation applies to the layer slicing technique in that only 50- by 50-mm samples can be prepared with the technique and the standard thickness swell sample is 150 by 150 mm. Other limitations to the layer slicing technique include the removal of sawkerf material as an additional source of measurement error, and that individual layers once removed from the intact specimen more easily absorb water and swell more or less than the intact whole sample without the influence of internal stress. We consider the nondestructive optical technique an improvement over the first two techniques we developed.

**Experimental method**

**Specimen preparation**

Commercial medium density fiberboard (MDF) and oriented strandboard (OSB) were acquired from cooperating mills. The MDF was 5/8-inch thickness (sanded), bonded with a urea formaldehyde (UF) resin. The OSB was unsanded, nominal 1/2-inch thickness, bonded with a phenol-formaldehyde (PF) resin. Four specimens measuring 150 mm by 150 mm were used for the layer thickness swell tests for both the MDF and the OSB. Specimen preparation and layer thickness swell tests were based on the procedure described in a U.S. Patent No. 6,396,590 (Wang and Winistorfer 2002).

Each specimen edge was lightly sanded after cutting using a stationary belt sander. Sander dust was blown out of the sample edge using a pressurized air stream. The midpoint of each edge was marked along the 150-mm length, and a black water-based paint was applied with a brush to the sample edge in a band approximately 12-mm wide.

A special cutterhead (Fig. 1) used to mark layer locations on the sample edge was designed and built previously (Wang and Winistorfer 2002). The cutterhead mandrel was secured in a

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**Figure 1.** — The specially designed cutterhead, with alternating blades and spacers, that is used to make a very shallow cut through the thin paint layer on the sample edge (MDF is shown in the figure).
router chuck and the router was then attached to the underside of a fixed router table; the cutterhead protruded up through the router table surface. A fence and vacuum box were attached to the router table. The small cut made into the sample edge by the sawblade is subsequently referred to as the slot; the space between slots created by the use of the shim stock in which no sample material was removed is referred to as the bar. All four edges of each sample were prepared this way. Photographs of prepared edges of MDF and OSB are shown in Figures 2 and 3.

Measurement of layer thickness swell

Layer thickness swell, water absorption, total thickness swell, and edge thickness swell were measured from each specimen after water exposure times of 2, 8, and 24 hours. The total thickness swell was taken at the mid-point of each side 1 inch from the edge using a dial caliper. Water absorption was based on weight changes of the sample at each exposure interval. Total thickness swell and water absorption were performed in accordance with the ASTM 1037-92 A (1992) procedure. Total edge thickness swell was taken at the same mid-point location of each edge, the same location of the layer thickness measurement, using a dial caliper.

Prior to the water soak exposure, a 35-mm camera mounted on the down-tube of a stereo microscope was used to record the image of the slots and bars cut into the edge of each sample on color slide film. A reference measurement device was affixed to the sample edge near the location of the saw cuts. Subsequent photographic images were then taken from each sample edge at the end of the 2-, 8-, and 24-hour exposure periods. The photographic slides of the sample edges were then projected for measurement of each slot and bar width. The reference measurement image was used as a magnification guide for the projected image. The original thickness of each slot and bar were denoted $T_{oi}, i = 1$ to 20. After water soak, the swollen thickness of each slot and bar were measured and denoted $T^{w}_{oi}, i = 1$ to 20. The layer thickness swelling of discrete layers in the sample, measured from the thickness of each slot and bar were calculated as:
The individual layer thickness swelling was calculated from the average of the measurements taken from each sample edge. The total thickness swellings (\(TS_{op}\)) as measured by the optical technique was calculated as:

\[
TS_{op} = \left( \frac{\sum Layer\ TS_i}{\sum T_i} \right) / TS_i
\]

In theory, the total edge thickness swell is equal to the sum of the thickness swell of individual layers:

\[
Edge\ TS = \sum Layer\ TS
\]

**Results and discussion**

**Figure 2** shows a representative MDF sample edge before and after swelling. Before water soak and after water soak, the demarcation of the slots and bars in the sample edge appear very clearly as narrow light and dark bands on the sample edge. There were adequate color and contrast differences between slots and bars on the projected image to easily measure the thickness of each individual layer (slot and bar). MDF exhibits uniform swelling of individual layers in both the surface and core, due to uniform furnish characteristics and uniform mat structure.

**Results and discussion**

**Figure 3** shows a representative OSB sample edge before and after swelling. Before water soak, slots and bars appear as straight bands. After 2 hours of water exposure, the surface layers (1, 2, 12, 13) exhibit a non-uniform swell response within the individual layers. While individual slots and bars are easily seen on the projected image, the non-uniform swell response within an individual layer requires that careful attention must be taken during the actual measurement to ensure consistent measurement of the layer change during the exposure cycles. At 2 hours of exposure, core layers exhibited little change in thickness or in uniformity of swell. After 8 hours of water exposure, the core layers exhibited the same non-uniform swell response as did the surface layers. After 24 hours of water exposure, most layers exhibited non-uniform layer swell. Excessive thickness swell occurred in the high-density surface layers. Areas A and B in Figure 3 show much greater swell than the other layers of the sample. The non-uniform layer swell of the OSB samples is likely due to the mat structure characteristics of OSB, heterogeneous furnish characteristics, and non-uniform mat formation. A heterogeneous mat structure likely causes additional stress development within the mat during pressing and results in non-uniform stress release during water exposure.

**Comparing thickness swell data using traditional and optical measurement methods**

Table 1 shows a comparison of the average dimensional stability of the commercial MDF and OSB samples, after 2, 8 and 24 hours of water soak exposure, using the traditional method (ASTM) and the optical technique for thickness swell determination.

After 2, 8, and 24 hours of water exposure, total MDF thickness swell taken at the midpoint of each side, 1 inch from the edge, was 1.43, 3.03, and 5.74 percent, respectively. Thickness swell at the sample edge was 3.40, 7.78, and 13.65 percent for the 2-, 8-, and 24-hour exposures, respectively, which were about twice as great as the swell 1 inch from the edge. Total thickness swell (\(TS_{op}\)) measured with the optical layer swell technique was 3.06, 8.35, and 14.12 percent after 2, 8, and 24 hours of water exposure, respectively. The standard deviations of \(TS_{op}\) were 0.67 to 0.88 percent and were larger than the standard deviations of traditional edge thickness swell.
measurement. The relative differences of $TS_{op}$, compared to the traditional measurement, were 10.00 to 3.44 percent and decreased as water soak time increased.

After 2, 8, and 24 hours of water soaking, total OSB thickness swell taken at the midpoint of each side, 1 inch from the edge, was 3.71, 8.20, and 14.62 percent, respectively. The edge thickness swell measurements were 8.91, 16.77, and 23.81 percent, which are much larger than total OSB thickness swell as measured at the midpoint of each side, 1 inch from edge. Total thickness swell ($TS_{op}$) measured with the optical layer swell measurement technique was 9.24, 17.57, and 24.16 percent after 2, 8, and 24 hours of water exposure, respectively. The standard deviations of $TS_{op}$ were 1.00 percent to 2.34 percent, and were almost the same as the standard deviations for the edge thickness swell. The relative differences of $TS_{op}$, compared to the traditional thickness swell measurement, were 1.47 to 4.77 percent and were the least after the 24-hour water soak exposure.
Typical layer thickness swell of commercial MDF and OSB

**MDF.**—The development of average actual layer thickness swell in relation to the water exposure time and layer location for commercial MDF samples is shown in **Figure 4**. Layer thickness swell increased with prolonged water exposure. Maximum thickness swell is reached after 24 hours of water exposure. There were large differences in thickness swell between surface layers and core layers. There was 40.72 percent thickness swell in layer 20 (Table 2) after 2 hours of water exposure. Even after 8 hours of water exposure, the data of layers 8, 10, 12, and 14 were still negative. During specimen preparation with the cutterhead, layers 4, 6, 8, 10, 12, and 14 became slots on the sample edge. We have noted that the bars tend to swell slightly more than the slots ([Fig. 6](#)), due to the lack of material restraint that results as an artifact from cutting slots and bars in the sample edge. We have made the depth of cut of the cutterhead as shallow as is practical to still allow detecting a difference in the slot and bar demarcations. The small differences in the swell response between slots and bars can be minimized by alternating the location of the slot and bar cuts in the sample edge, i.e., two of the four sample edges can be cut with the slot beginning at the sample face, the other two sample edges can be cut with the bar beginning at the sample face. Average thickness swell of any discrete layer will be the average of two bar measurements and two slot measurements.

The contribution of individual layers to total thickness swell of commercial MDF was calculated and is shown in **Table 2** and **Figure 7**. The contribution of layer 1 to total thickness swell was about 37.34 percent after 24 hours of water exposure. Even after 2 hours of water exposure, the data of layers 8, 10, 12, and 14 were still negative. During specimen preparation with the cutterhead, layers 4, 6, 8, 10, 12, and 14 became slots on the sample edge. We have noted that the bars tend to swell slightly more than the slots ([Fig. 6](#)), due to the lack of material restraint that results as an artifact from cutting slots and bars in the sample edge. We have made the depth of cut of the cutterhead as shallow as is practical to still allow detecting a difference in the slot and bar demarcations. The small differences in the swell response between slots and bars can be minimized by alternating the location of the slot and bar cuts in the sample edge, i.e., two of the four sample edges can be cut with the slot beginning at the sample face, the other two sample edges can be cut with the bar beginning at the sample face. Average thickness swell of any discrete layer will be the average of two bar measurements and two slot measurements.

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To understand the contribution of high and low density areas to the total thickness swell, the whole panel thickness was divided into surface regions and core regions. The surface area was 31.54 percent of the whole panel thickness and included layers 1 to 3 and layers 18 to 20. The low density core area was 68.46 percent of the whole panel thickness and included layers 4 to 17.

The contribution of the high density area to total thickness swell was 95.76, 75.50, and 60.68 percent after 2, 8, and 24 hours of water exposure, respectively (Table 3). This indicates that thickness swell occurred mainly in the high density surface regions during the early period of water exposure.

The greater thickness swell in the surface layers of MDF suggests that efforts to improve dimensional stability of MDF should be focused on stabilizing the high density surface layers.

OSB. — The development of average actual layer thickness swell in relation to the water exposure time and layer location for OSB samples is shown in Figure 8. Layer thickness swell increased with increased water exposure time. Maximum thickness swell is reached after 24 hours of water exposure. There were large differences in swell results between the surface layers and the core layers. Layer 12 exhibited 47.26 percent thickness swell (Table 4) after 24 hours of water exposure. The minimum thickness swell was 15.14 percent for the core layer 8 after 24 hours of water exposure.

Maximum thickness swell occurred at sub-layers 3 and 12. This result is relative to the vertical density profile of the commercial OSB (Fig. 5) in which the surface layers do not exhibit maximum density within the sample.

Layer 12 was the soft side of the panel. Its layer thickness swell was 47.26 percent and was larger than the 37.57 percent exhibited by layer 3 on the opposite surface of the panel. The lower density of this screen side could be caused by the imprint of the screen on the panel surface, which also likely allows a faster rate of water absorption on that side of the panel. The contribution of individual layers to total thickness swell of commercial OSB was calculated and is shown in Table 4 and Figure 9. The contribution of layer 12 to total thickness swell was about 20.24 percent after 2 hours water exposure and decreased as exposure time increased. The contribution of layer 12 to total thickness swell was 14.84 percent after 24 hours of water exposure. The contribution of the core layer 8 to total thickness swell was 0.14 percent after 2 hours of water exposure and increased as exposure time increased. The contribution of layer 8 to total thickness swell was only 4.66 percent after 24 hours of water exposure. The high density surface layer contributed more than three times as much to the total cumulative thickness swell as did the low density core layer.

To better understand the contribution of high and low density areas on the total thickness swell, the whole panel thickness was divided into surface regions and core region. The surface area was 44.70 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 55.30 percent of the whole panel thickness and included layers 4 to 10. The contributions of the high density area to total thickness swell were 74.36, 64.39 and 57.3 percent after 2, 8, and 24 hours of water exposure, respectively.
cent after 2, 8, and 24 hours water exposure, respectively (Table 3). This shows that thickness swell occurred mainly in the high density surface regions during the early stages of the water soak exposure. While water absorption through the sample edge is one contributing factor to the swell results, the impact of the non-uniform densification that occurs during density profile development is believed to be the contributing causal factor.

**Summary**

The optical technique for determining layer thickness swell, as described in this study, is aimed at identifying the contribution of individual layers to the overall board performance and is a useful tool to understand thickness swell development in relation to the many process variables incorporated during product manufacture. This study revealed the greater contributions of surface layers to thickness swell for both MDF and OSB panel materials. OSB exhibited greater non-uniformity of swell among individual layers, with the greatest non-uniformity in the surface layers. MDF made from a more uniform furnish material and hence a more uniform mat structure, showed uniform swell among the layers. There was larger internal stress within OSB samples during water exposure than MDF samples.

The optical layer swell measurement technique can be used for individual layer measurements, but can also show overall thickness swell. Relative differences for overall thickness swelling compared between the optical technique and the traditional method were 3.40 to 10.00 percent for MDF samples and 1.47 to 4.77 percent for OSB samples. Relative measurement variations decreased as water exposure time increased and were less than 3.4 percent after 24 hours of water exposure.

The contributions of high density surface layers to overall MDF thickness swell were 95.76, 75.50, and 61.77 percent after 2, 8, and 24 hours of water exposure, respectively. It can be concluded that thickness swell occurred mainly in the high density surface areas and was greater for these surface layers than for the core layers. For the high density surface layers, thickness swell was greater during the early period of the water exposure cycle as compared to the end of the 24-hour exposure period.

The optical technique utilized in this study is recommended for the measurement and study of layer swell properties for all types of wood composite panel materials, including OSB, MDF, and particleboard.

**Literature cited**


