A PROCEDURE TO DETERMINE THICKNESS SWELL DISTRIBUTION IN WOOD COMPOSITE PANELS

Wei Xu

Post Doctoral Research Associate

and

Paul M. Winistorfer

Associate Professor

Department of Forestry, Wildlife, and Fisheries
Institute of Agriculture
P.O. Box 1071
The University of Tennessee
Knoxville, TN 37901-1071

(Received September 1994)

ABSTRACT

A procedure was developed to determine the thickness swell distribution of wood composite panels, based on the vertical density distributions from before and after the water soak test. The procedure used a linear relationship of the density between adjacent density data points in the vertical density distribution, and it assumed a constant weight of an individual horizontal layer after swell. A computer algorithm was developed for this estimation. The procedure was used to examine the thickness swell distribution of medium density fiberboard, oriented strandboard, and particleboard. Thickness swell distribution in relation to the layer density was discussed.

Keywords: Medium density fiberboard, oriented strandboard, particleboard, thickness swell, vertical density distribution.

INTRODUCTION

The thickness swell (TS) measured by the water soak method (American Society for Testing and Materials 1994) is usually taken as the primary measure of the dimensional stability of wood composite panel materials. Cyclic relative humidity tests are also used to evaluate TS of many interior-use panel materials; the water soak method accelerates TS and is often a preferred procedure for laboratory analysis. A major component of TS comes from the release of the compressive stress (or strain) incorporated into the composite mat during pressing. This release of stress is usually accompanied by some degree of strength loss due to the degradation of adhesive bonds. Large TS influences composite panel performance, both visually and functionally, in many applications involving exposure to weather or high relative humidity. Almost all production or processing parameters have been recognized to influence TS performance (Kelly 1977), and many methods to improve TS have been explored (Halligan 1970; Hsu et al. 1988; Winistorfer et al. 1992; Youngquist et al. 1986).

The vertical density distribution (VDD) within the panel is generally believed to influence TS. While the formation mechanism of VDD was established in the early stages of wood composite panel development (Strickler 1959; Suchsland 1962), interest has recently

This work was supported by the National Research Initiative Competitive Grant program under grant No. 92-37103-8082 and the Tennessee Agricultural Experiment Station under project MS-48.

risen to quantify the shape of the VDD and relate it to TS. By simply overlaying the VDDs of particleboard, before and after a two-hour water soak test, Wang et al. (1988) observed that the TS occurred across the whole thickness of the board. Using a manual iterative technique based on grouping individual VDD data points into similar regions, Davis (1989) divided a 12.7-mm-thick board into five different density zones through the board thickness and performed a correlation analysis between TS and these density zones. Suo (1991) approached a wood composite as a multilayer system and proposed a model to predict the TS behavior based on the properties of each layer. Winistorfer et al. (1995) applied a nonparametric regression technique to model the VDD and a statistical methodology to compare the VDDs resulting from experimental treatments for laboratory-produced oriented strandboard (OSB). Using this technique, Winistorfer et al. (1995) quantitatively reconfirmed that the VDD of wood composites is affected by the press closure rate and furnish moisture content.

A method to determine the TS distribution across the board thickness is clearly needed to relate the VDD to TS. In this paper, a procedure based on the VDD data from before and after the water soak test is developed to estimate the TS distribution (profile) across the thickness of the panel for medium density fiberboard (MDF), OSB, and particleboard.

MATERIALS AND METHODS

The materials consisted of three commercial composite products: MDF (density: 760 kg/m^3, thickness: 20 mm), particleboard (density: 720 kg/m^3, thickness: 25 mm), and OSB (density: 530 kg/m^3, thickness: 17.5 mm). These materials were anonymously procured, and manufacturing processing conditions were not known. For each material, specimens measuring 100 mm × 100 mm were prepared; and their VDDs were measured using the scanning gamma ray densitometer according to the procedures previously described by Winistorfer et al. (1986). The use of a specimen size of 100 mm × 100 mm rather than the standard 150 mm × 150 mm to measure the TS was determined by the configurations of the densitometer. Counts (transmitted radiation at the detector) were taken for 20 seconds at each step, with a scan increment of 0.254 mm. A detector window slit with a width of 0.20 mm and a height of 10 mm was used.

Three individual specimens of MDF, OSB, and particleboard were subjected to water soak exposure times of 12, 24, and 168 h, respectively. The VDD of each specimen was remeasured after the water soak exposures when the specimen had equilibrated to presoak weight. Based on the VDD data, a procedure was developed to estimate the TS distribution across the board thickness for each material. It should be noted that the TS reported in this paper only represents the component (a major component) that resulted from the release of compressive stress; this limitation is necessitated by the mathematical model used in this investigation. The recoverable swell due to the moisture uptake could be superimposed to this distribution by utilizing the wood-moisture relationship.

Procedure

The rationale followed is to calculate the swollen thickness of each layer, layer by layer, based on the premise that each layer will weigh the same before and after swell (obviously, the layer volume will be different before and after swell). Let the curve $f(x)$ in Fig. 1a represent part of the measured VDD in a specimen before swell. X_1, X_2, and X_3 are the three actual density values provided by the scanning densitometer at the locations of x_1, x_2, and x_3. Curve $g(z)$ in Fig. 1b represents part of the measured VDD after swell in the same specimen. Z_1, Z_2, Z_3, Z_4 are the four actual density values at z_1, z_2, z_3, and z_4. Further, suppose that the point z_1 in Fig. 1b corresponds to the point x_1 in Fig. 1a, and the thin horizontal layer Lx_1x_2 before swell becomes lz_1z' after swell, where z' is the point somewhere in between z_2 and z_3. From here, the task to determine the thickness swell of the layer Lx_1x_2

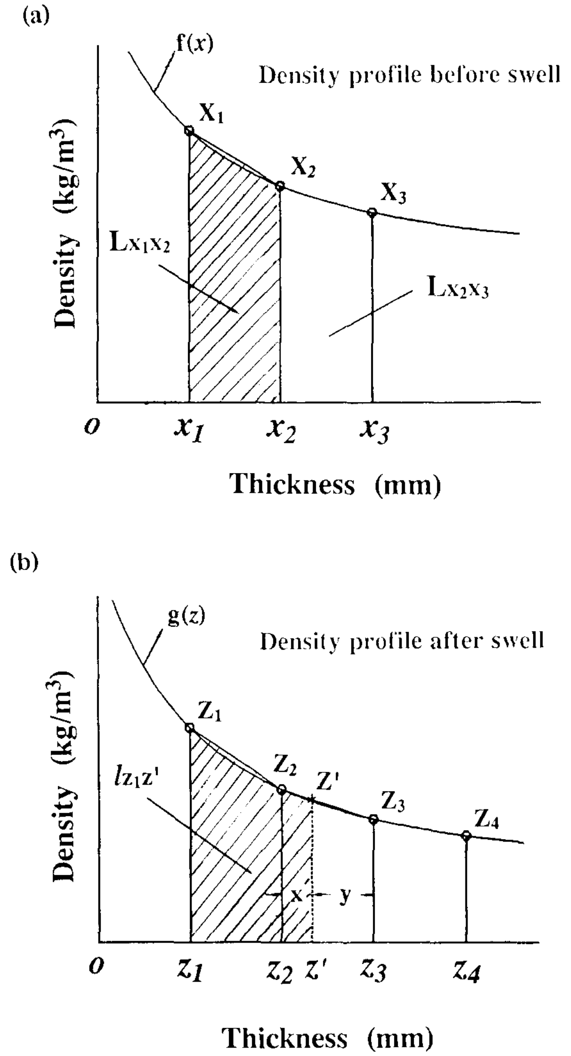

FIG. 1. A schematic showing the procedures of estimating the thickness swell distribution in wood composites.

becomes a geometric problem. We need to estimate the thickness of the layer lz_1z'.

The weight (Wx_1x_2) of the layer Lx_1x_2 with unit surface area can be estimated by the shaded area in Fig. 1a as

$$Wx_1x_2 = (X_1 + X_2)\cdot 0.254/2 = = (X_1 + X_2)\cdot 0.127 \quad (1)$$

where 0.254 is the increment distance between adjacent density points in millimeters.

In the same fashion and using a linear interpolation, the weight of the layer lz_1z' (Fig. 1b) was estimated by

$$\begin{aligned} Wz_1z' &= (Z_1 + Z_2)\cdot 0.254/2 + \\ &+ (Z_2 + Z')\cdot x/2 = \\ &= (Z_1 + Z_2)\cdot 0.127 + \\ &+ [2\cdot Z_2 + (Z_3 - Z_2)\cdot x/0.254]\cdot \\ &\cdot x/2 \end{aligned} \quad (2)$$

in which Z′ stands for the density value at the location z', while x is the distance from the point z_2 to the point z'.

The unit weight of the horizontal layer Lx_1x_2 before swell should be the same as that of the layer lz_1z' after swell (assuming specimen equilibration after swell). By letting $Wx_1x_2 = Wz_1z'$, a quadratic equation was established as

$$ax^2 + bx + c = 0 \quad (3)$$

here, $a = (Z_3 - Z_2)/0.508$, $b = Z_2$, $c = (Z_1 + Z_2 - X_1 - X_2)\cdot 0.127$.

In general, there were two solutions for x to satisfy Eq. (3). The solution that met the condition of $0 \le x \le 0.254$ was valid, while the other solution was rejected as it was either >0.254 or <0.

The TS of the horizontal layer Lx_1x_2, then, was calculated as

$$TS(\%) = [(0.254 + x) - 0.254]\cdot 100/0.254 = = 100\cdot x/0.254. \quad (4)$$

This process can be manually iterated for the whole thickness of the board from one surface to the other. For example, for the next horizontal layer Lx_2x_3, the point x_2 before swell becomes the point z' after swell. The above procedures can be used except that we need to know the thickness y from z' to z_3. This is calculated by the following relationship (Fig. 1b)

$$y = 0.254 - x \quad (5)$$

In this study, a FORTRAN algorithm was developed to iterate this process. This program

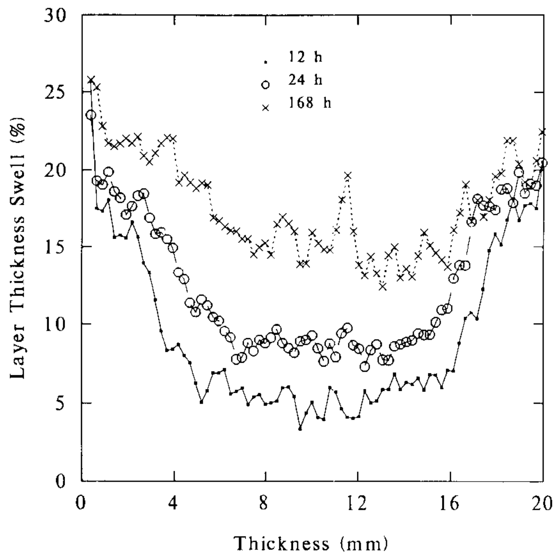

FIG. 2. Thickness swell distributions of the medium density fiberboard after three water soak exposure times.

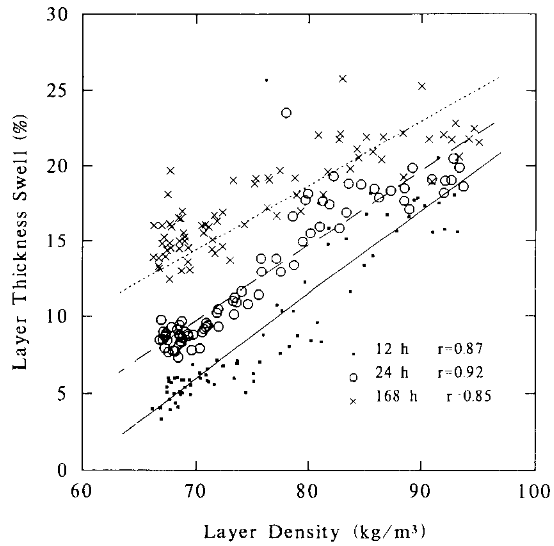

FIG. 3. The relationship between layer density and layer thickness swell of the medium density fiberboard.

was flexible in that the TS distributions can be generated based on different layer thicknesses (resolutions).

RESULTS AND DISCUSSION

Case 1: Medium density fiberboard

The TS distributions of the MDF samples at a layer resolution thickness of 0.254 mm are shown in Fig. 2. The average TS values for these distributions were 9.26%, 12.64%, and 17.64% for the 12-h, 24-h, and 168-h water soak exposures, respectively. These values differed slightly from the measured average TS values (9.20%, 12.40%, and 16.40%, respectively). The small differences in these average TS values suggest that the technique of determining the TS distribution is feasible.

Similar to the VDD (Fig. 5), TS at the surface regions of the board was higher than that in the center. Many processing treatments can contribute to this distribution phenomenon. For example, changing the resin and wax distributions or altering the rheological process across the board thickness can result in a TS distribution. Although process variables for the materials used in this study were not known, the interest of this work was to explore the techniques; the specific influences of processing variables were not examined. However, it is believed the density distribution across the board thickness was the single most important factor in TS development for this study. As more compression set was induced in the high density surface areas due to the hot pressing, the subsequent release of the compressive stress due to the water uptake resulted in more swell in these regions.

Figure 3 shows the scatterplot between the layer density and the layer TS at the same layer thickness of 0.254 mm, together with the result of the correlation analysis (r = linear correlation coefficient). The limited data did indicate that the layer TS was positively correlated to the layer density in these MDF samples. A complete statistical analysis (i.e., regression analysis) would require a larger sample for the analysis of significant effects; and the specific regression equations that depict the relationship between layer density and layer TS would be sensitive to, and dependent on, process variables used during manufacturing. Such an analysis to develop a family of equations was not the objective of this study.

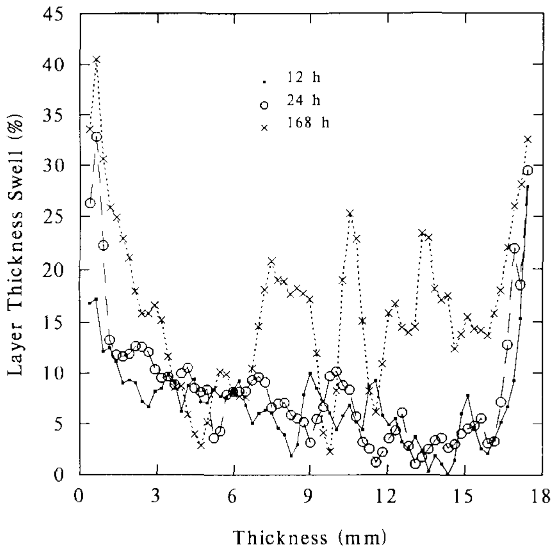

FIG. 4. Thickness swell distributions of the oriented strandboard after three water soak exposure times.

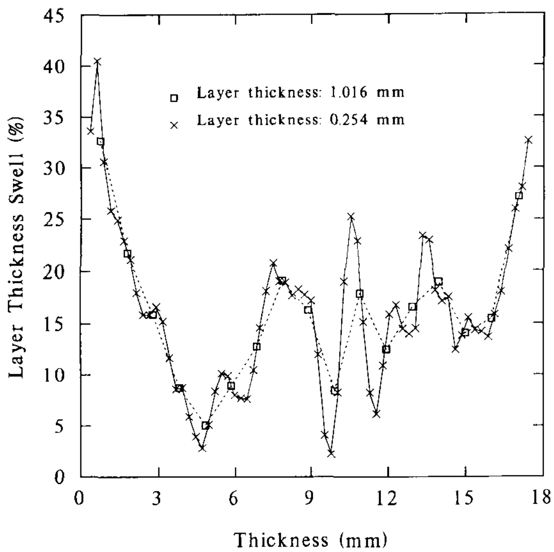

FIG. 6. Thickness swell distributions of the oriented strandboard determined at two resolution thicknesses.

Case 2: Oriented strandboard

The TS distributions across the thickness of the OSB at a layer resolution thickness of 0.254 mm are shown in Fig. 4. These distributions yielded average TS values of 7.03%, 8.43%, and 15.99% for the 12-h, 24-h, and 168-h water soak exposures, respectively, which also differed slightly from the measured values (6.32%, 7.82%, and 14.42%, respectively).

Similar to the TS distributions of the MDF, TS at the surface regions of the OSB was also higher than that in the center. However, these

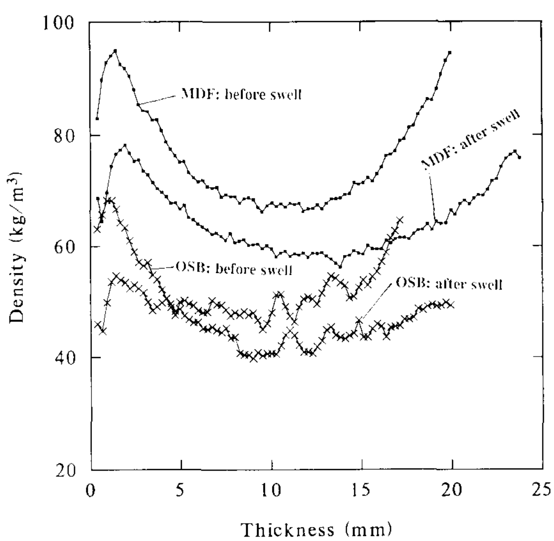

FIG. 5. Vertical density distributions of the medium density fiberboard and oriented strandboard before and after water soak for 168 h.

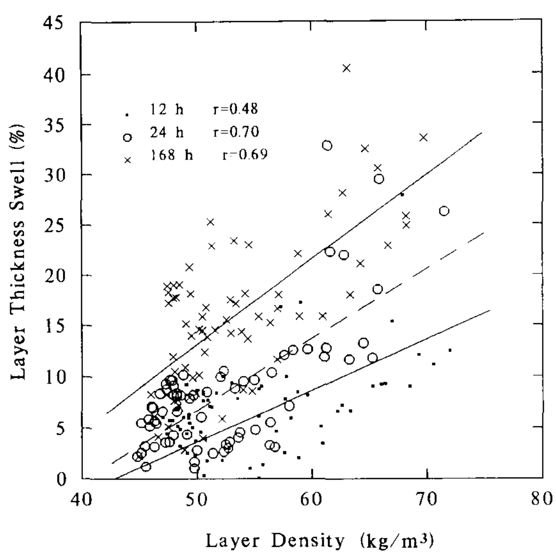

FIG. 7. The relationship between layer density and layer thickness swell of the oriented strandboard.

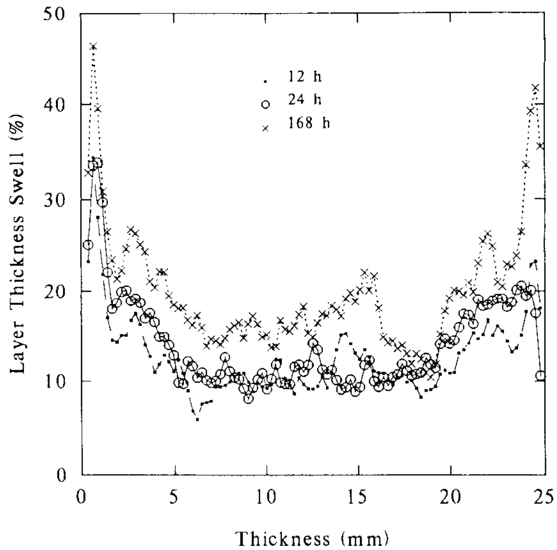

FIG. 8. Thickness swell distribution of the particleboard after three water soak exposure times.

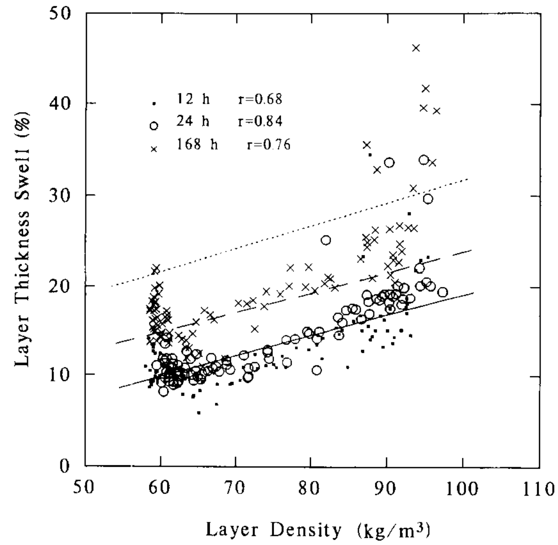

FIG. 9. The relationship between layer density and layer thickness swell of the particleboard.

TS distributions were more erratic for the OSB than for the MDF; the MDF furnish material and resulting density distribution are more uniform than for the OSB. Figure 5 shows the comparison of the VDDs of the MDF and OSB both before and after a 168-h water soak test. Since the TS distribution was determined based on the VDDs, a more erratic TS distribution resulted for the OSB.

The fluctuation in the TS distribution can be alleviated by increasing the layer thickness for the determination. Figure 6 shows the reduction in the fluctuation of TS distribution after a 168-h water soak, determined at a resolution thickness of 1.016 mm for the OSB. The reduction in fluctuation is achieved at the expense of precision or minimum resolution.

The TS distribution of OSB was also believed to be controlled by the density variation across the board thickness. The scatterplot between the layer density and layer TS (Fig. 7) demonstrates a positive correlation ($r > 0$) for the OSB samples.

Case 3: Particleboard

The TS distributions of the particleboard samples at a layer resolution thickness of 0.254 mm are shown in Fig. 8. The average TS values given by these distributions were 12.65%, 14.10%, and 20.02% for the 12-h, 24-h, and 168-h water soak exposures, respectively. These average values also agreed well with the measured values (12.83%, 15.05%, and 18.66%, respectively). The scatterplot and the correlation coefficient (r) between the layer density and the layer TS for the particleboard are shown in Fig. 9. Again, the layer TS was positively correlated to the layer density for the particleboard samples.

SUMMARY AND CONCLUSIONS

Dimensional stability performance, as measured by the thickness swell, is an important material property that helps define end-use application and performance of wood composite panel materials. The technique of determining the thickness swell distribution across the board thickness, as described in this study, is aimed at identifying the layer contributions to the overall thickness swell of composite panel materials and is a useful tool to better understand TS development in relation to the many process variables incorporated during product manufacture. For example, the response of individual layers to the possible distributions of moisture and temperature across the board thickness during manufacture, or the response of incorporating different wood species and particle geometries could also be detected. This information could then be used to improve the design and manufacture of more stable wood composite panels through understanding of layer density influence on the composite as a whole.

The technique was based on the changes in vertical density distributions from before and after the water soak test (we recognize that other test methods could be employed). The thickness swell distribution presented in this study mainly represents the contribution of the unrecoverable TS component due to the release of compressive stress; the removal of the recoverable hygroscopic swell from the total swell may be advantageous in studies aimed at investigating the rheological process during the pressing operation and the relationship to thickness swell performance of wood composite panels. As expected, the layer thickness swell was positively correlated to the layer density. All three commercial products, medium density fiberboard, oriented strandboard, and particleboard, exhibited higher thickness swell at higher density surface regions.

The FORTRAN algorithm is available from the authors.

REFERENCES

American Society for Testing and Materials. 1994. Standard test methods for evaluating properties of wood-base fiber and particle panel materials. Philadelphia, PA.

Davis, W. C. T. 1989. The effect of furnish moisture content, press closure rate, and panel density on thickness swell and the vertical density profile of a mixed hardwood flakeboard. M.S. thesis, University of Tennessee, Knoxville, TN. 118 pp.

Halligan, A. F. 1970. A review of thickness swelling in particleboard. Wood Sci. Technol. 4(4):301–312.

Hsu, W. E., W. Schwald, J. Schwald, and J. A. Shields. 1988. Chemical and physical changes required for producing dimensionally stable wood-based composites. Part 1: Steam pretreatment. Wood Sci. Technol. 22(3): 281–289.

Kelly, M. W. 1977. Critical literature review of relationships between processing parameters and physical properties of particleboard. Gen. Tech. Rep. FPL-20. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Strickler, M. D. 1959. Effect of press cycle and moisture content on properties of Douglas-fir flakeboard. Forest Prod. J. 9(7):203–205.

Suchsland, O. 1962. The density distribution in flakeboard. Q. Bull., Mich. Agric. Exp. Sta., Michigan State University, E. Lansing, MI. 45(11):104–121.

Suo, S. 1991. Computer simulation modeling of structural particleboard properties. Ph.D. thesis, University of Minnesota, St. Paul, MN. 158 pp.

Wang, P., J. Shi, W. Xu, and J. Guo. 1988. Reducing board density and improving dimensional stability of particleboard. Unpublished Project Progress Report. The Chinese Academy of Forestry, Beijing, China.

Winistorfer, P. M., W. C. Davis, and W. W. Moschler. 1986. A direct scanning densitometer to measure density profiles in wood composite panel products. Forest Prod. J. 36(11/12):82–86.

Winistorfer, P. M., D. L. McFarland, and R. C. Slover. 1992. Performance of ten wax formulations in OSB manufacture. Pages 236–250 *in* T. M. Maloney, ed. Proceedings of the 26th International Particleboard/Composite Materials Symposium. Washington State University, Pullman, WA.

Winistorfer, P. M., T. M. Young, and E. Walker. 1995. Modeling and comparing vertical density profiles. Wood Fiber Sci. (in press).

Youngquist, J. A., R. M. Rowell, and A. Krzysik. 1986. Mechanical and dimensional stability of acetylated aspen flakeboard. Holz Roh- Werkst. 44:453–457.