

EFFECTS OF RESIN AND WAX ON THE WATER UPTAKE BEHAVIOR OF WOOD STRANDS

*Yang Zhang*¹

Post-Doctoral Research Associate

*Juwan Jin*²

Post-Doctoral Research Associate

and

Siqun Wang^{†*}

Associate Professor

Tennessee Forest Products Center

University of Tennessee

2506 Jacob Drive

Knoxville, TN 37996-4570

(Received February 2005)

ABSTRACT

Dimensional stability is an important property of wood composites. Both resin and wax are essential additives in the manufacture of composite panels such as OSB. Resin binds wood elements together while wax acts as a water repellent. The objective of this study was to investigate the effects of phenol-formaldehyde resin and emulsion wax on the water uptake behaviors of commercial southern yellow pine strands using a wicking test. During the test, the water uptake amounts of strands blended with different resin and wax levels were recorded continuously. The effects of different factors on water uptake behaviors of strands were analyzed with ANOVA. The results indicated that resin level, wax content, grain direction, and strand density had significant effects on water uptake behaviors of strands. Lower resin level and wax content led to a rapider water uptake rate during the early stage of the wicking test and a larger total amount of water absorbed at the end of test. Water uptake behavior along parallel-to-grain direction differed from that perpendicular-to-grain direction, and strands with higher density tended to have relatively lower total water uptake amount.

Keywords: Wicking test, water uptake behavior, phenol-formaldehyde resin, wax, strand.

INTRODUCTION

Dimensional stability of wood-based composites, which basically is explained in terms of water uptake, linear expansion, and thickness swelling, is of high importance, especially for a

structural material like OSB because dimensional change will eventually affect panel performance, both visually and functionally. Wood is a porous and hygroscopic material, which consists mainly of cellulose, hemicellulose, and lignin. The three main components are natural polymers that contain hydroxyls which are likely to form hydrogen bonds with water, and thus cause a high water uptake and dimension instability of wood and wood-based materials. OSB is made by processing trees into thin strands that are later bonded together under heat and pressure with an exterior resin binder; therefore,

¹ Currently, Professor, College of Wood Science & Technology, Nanjing Forestry University, Nanjing 210037, P.R. China.

² Currently, Associate Professor, College of Wood Science & Technology, Nanjing Forestry University, Nanjing 210037, P.R. China.

[†] Member of SWST.

* Corresponding Author

OSB keeps the natural tendency of wood to shrink and to swell; another factor that causes the dimensional instability of OSB is the high compressive stress applied during board manufacture. Though OSB is extensively used in the construction of residential and commercial buildings as a substitute for structural plywood in North America, the relatively poorer dimensional stability of OSB is a disadvantage that makes the product unsuitable for some applications when compared with plywood and solid wood lumber.

To decrease the natural dimensional instability of wood with changes in its moisture content, sizing agents, or dimensional stabilizers are regularly used to produce dimensionally stable wood products. As for manufacturing OSB, resin and wax are the two most common additives. Resin binds wood elements together, while wax acts as a water repellent and imparts resistance to absorption of liquid water by the final product (Maloney 1993).

A large amount of research on the influence of various factors on dimensional stability of wood and wood composites has been carried out (Kelly 1977), such as resin level (Gardner et al. 1990), mat moisture content (Hawke et al. 1993; Rowell et al. 1986), board density, other chemical treatments (Youngquist 1986), and mat structure (Lu and Lam 2001; Wang and Winistorfer 2000 and 2001). How resin and wax affect the water uptake behavior of resinated and waxed strand remains unclear. While our previous studies (Gu et al. 2005; Wang and Winistorfer 2000) dealt with the thickness swelling behavior of both commercial and lab-made OSB products, this study focuses on evaluation of water uptake behavior of commercial wood strands blended with resin and wax at different levels. Because thickness swelling and linear expansion are highly associated with the amount of water absorbed by the material itself, the water uptake behavior of OSB should have a close connection with that of strands.

Fundamental studies of the water uptake behavior of wood strands, especially of strands blended with commercial PF resin and wax in response to wetting and wicking phenomenon,

are essential to fully understand the mechanism of dimensional stability and the kinetics of wetting process, and in turn to develop strategies to improve dimensional stability of OSB.

MATERIALS AND METHODS

Sample preparation

Commercial strands of southern yellow pine were used in this study. The initial moisture content of the furnish was kept at 4.5%. Phenol-formaldehyde (PF) resin from Dynea with 44.5% of solid content and 145 centipoises of viscosity was applied to strands first, and then commercial emulsion wax, which was procured from Borden Chemical with 58.9% solid content and 82 centipoises, was spread to strands in a rotatory blender. For strands used to investigate the wax loading level effect, the resin level was fixed at 4.5% (oven-dry basis), and the four variable wax levels were 0.5%, 1.0%, 1.5%, and 2.05% (oven-dry basis) respectively. Three different loading levels of PF resin, being 3.4%, 4.5%, and 5.65%, were applied to determine the influence of resin strands, while the wax rate was fixed at 1.5%.

Ten resinated and waxed strands were randomly collected from each blending and then dried at a temperature of 50°C for 25 min in an oven to cure PF resin. The low temperature (50°C) was used in order to limit potential wax evaporation. These ten strands were divided into two groups based on their grain direction (perpendicular- and parallel-to-grain). All specimens were cut to a size of approximately 8.5 mm (length) by 8.5 mm (width), and were placed in a desiccator in which saturation water solution of potassium acetate was put to keep relative humidity 23% until each of these strands reached its own constant mass. Another ten strands without resin and wax applied were served as control samples and went through the same treatment. In the test room the temperature varied from 21°C to 23°C so that the moisture content of the strand specimen eventually stabilized at about 5%.

Prior to wicking test, the thickness, width, length, and weight of each specimen were taken

to calculate its actual individual density. Therefore, the water uptake behaviors of different samples could be compared in terms of the amount of water absorbed per unit volume and per unit density.

Evaluation of water uptake behavior

The evaluation of water uptake behaviors of resinated and waxed strands was carried out by a wicking test method with DCA322 instrument (DCA 322, Thermo Cahn Instruments). By performing wicking tests with this instrument, the effects of phenol-formaldehyde resin and emulsion wax on the water uptake behavior of commercial strands of southern yellow pine were determined in terms of water uptake amount at different times during the sorption process. With the DCA322 technique, the strand is supposed to be immersed and held just below the liquid surface and the weight change (the amount of water absorbed by the strand) recorded as a function of time. In this study, the immersion depth of strands into the distilled water was fixed at 1.0 mm, and strands were held in this fixed position by the electro-balance attached to the instrument (Fig. 1). The strand was held to either its grain parallel (referred as parallel-to-grain) or perpendicular (referred as perpendicular-to-grain) to immersion direction. When a strand grain is parallel to immersion direction, strand is expected to absorb water quicker. The weight change was recorded as a function of time. The total running time for each specimen was either

5 h (18,000 s) or 8 h (28,800 s), and data were collected at various time intervals. The test was performed at room temperature of 21°C to 23°C. Figure 2 illustrates a typical wicking curve recorded by computer.

Data analysis

All the data analyzed or presented in the paper were the averages of the five replicates in each group. In order to determine if factors such as resin content and wax levels have statistically significant effects on water uptake behaviors of strands, multiple comparisons of water uptake behavior among strands of different resin-loaded levels, wax-loaded levels, fiber direction, and specimen density were conducted using two-factor analysis of variance (ANOVA). To perform two-factor ANOVA method, one fixed factor in each set was the time during the sorption process; the other factor was varied among resin loading rate, wax loading level, grain direction, and strand density.

The absorbed water amounts of the samples at the end of each testing period were plotted against testing time. Considering the total testing time was 8 h, and the early stage lasted only a short period after the test began, data were plotted against a logarithmic scale of testing time to explain water uptake during the first ten minutes.

RESULTS AND DISCUSSIONS

Statistic analysis

Table 1 shows the results of the statistical analysis. The results indicated that there were



FIG. 1. Water uptake behavior of strands evaluated by a wicking test.

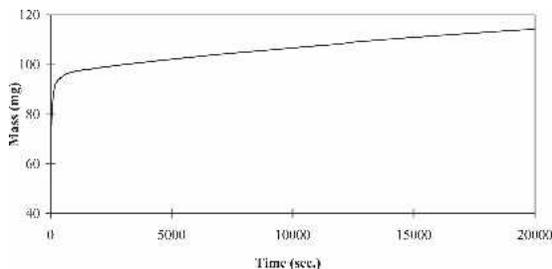


FIG. 2. Typical water uptake curves of strands for an 8-h wicking test.

TABLE 1. Statistical analysis (ANOVA, $\alpha = 0.05$) for water uptake amount of strands.

Comparison between two factors	F value	F-crit	Is the effect of the factor significant or not?
Resin level vs. Sorption time			
Parallel: Resin level	26.99	3.23	Yes
Sorption time	14.18	1.84	Yes
Perpendicular: Resin level	52.07	3.22	Yes
Sorption time	19.77	1.81	Yes
Wax level vs. sorption time			
Wax level	285.30	2.75	Yes
Sorption time	91.65	1.73	Yes
Grain direction vs. sorption time			
Grain direction	110.82	4.32	Yes
Sorption time	11.62	2.08	Yes
Strand density vs. sorption time			
Strand density	149.44	2.49	Yes
Sorption time	22.22	1.70	Yes

significant differences in water uptake behaviors between different resin/wax loaded levels, different grain directions, and densities as well, because all F values were higher than relevant F-crit values. A larger difference between F and F-crit demonstrated that the factor had a more significant effect on the water uptake behavior.

Water uptake curve

Figure 2 shows a typical water uptake curve of strands recorded by computer. From this curve, it was clear that the general shape of the water uptake curves for wood strands of yellow pine was similar to those of veneer and other natural fibers (Son and Gardner 2004; Espert and Vilaplana 2004). The figure shows a 2-stage process consisting of a rapid absorption (about 70% maximum) followed by a long slow relatively linear absorption. In other words, strands absorbed more water in a faster way at the early stage of the wicking test than they did at the second stage. To demonstrate that all strands absorbed water rather quickly at the early stage of the test, data were separated into two groups for plotting figures. The so-called first stage was fixed at 10 min from the beginning of the test, and the rest period of the test was called the second stage.

Influence of resin level on water uptake behavior of strands

The influence of resin level on water uptake behavior of strands is presented as Figs. 3 and 4. All lines in the two figures followed the same trends, i.e., samples absorbed water very rapidly during a period of time at the early stage and then the uptake rate slowed down to a certain value.

Resin binds strands together and plays an important role in providing OSB demanding properties such as mechanical strength and dimensional stability. Statistical analysis indicated that resin level had a highly significant effect on water uptake behavior of strands. A lower resin content on strands resulted in higher water uptake. As shown in Figs. 3 and 4, it was clear that the water uptake amount of strands decreased as the increase of the resin levels in the furnish. When the time of wicking test reached 18,000 s (5 h), the water uptake amount of strand decreased from 1.749 mg (water)/mm³ (volume of strand) to 1.439 mg/mm³ along perpendicular-to-grain direction and from 1.797 mg/mm³ to 1.518 mg/mm³ along parallel-to-grain direction of the strand as the resin level was increased from 0 to 5.65%. When the time of wicking test reached 28,800 s (8 h), the water absorption of the strand decreased from 1.860 mg/mm³ to 1.569 mg/mm³ along perpendicular-to-grain

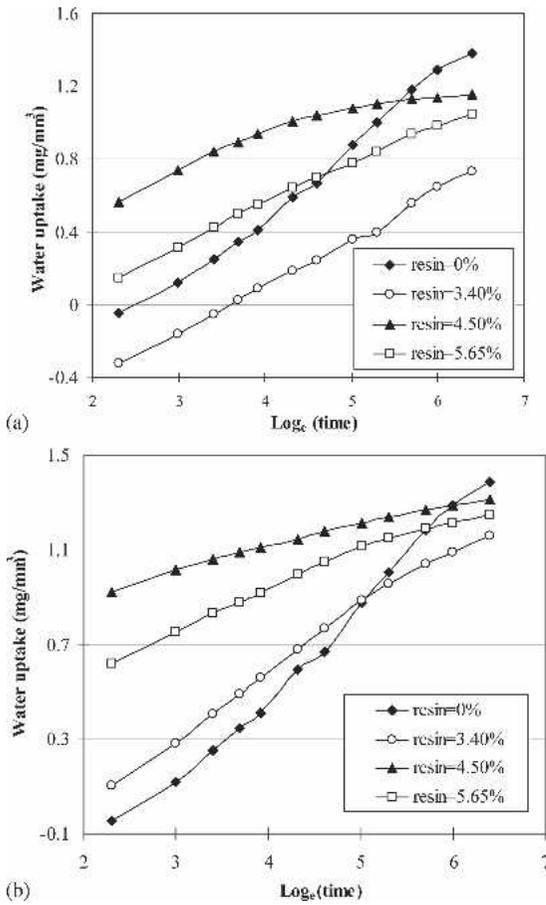


FIG. 3. Water uptake behaviors of strands loaded with different resin levels at the first stage (first 10 min) of wicking test.

direction and from 1.849 mg/mm³ to 1.636 mg/mm³ along parallel-to-grain direction of the strand as the resin loading level was increased from 0 to 5.65%.

Not only the total amount of water absorbed during the wicking test, but also the initial rate of water uptake was influenced by the resin levels. The slopes of the lines in Figs. 3 and 4 differed from each other. Generally speaking, the strands loaded with higher resin level absorbed water at a relatively slower rate at the early period of the wicking test. The control samples absorbed water in a rapid way at the early stage of the test, and reached the maximum total uptake amount at the end of the test. These facts indicated that strands blended with resin

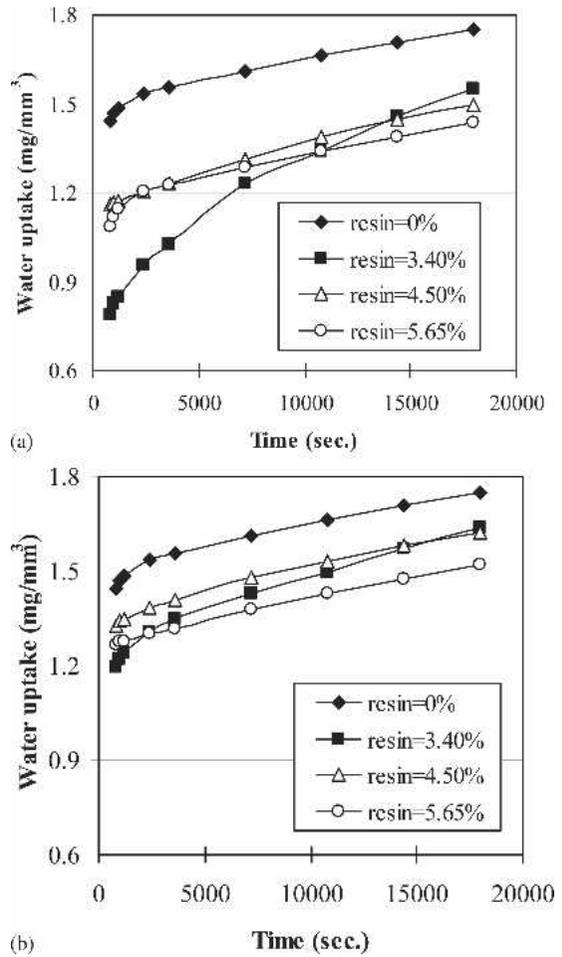


FIG. 4. Water uptake behaviors of strands loaded with different resin levels at the second stage (from 10 min to the end) of wicking test.

had better waterproof properties, especially when a relatively higher amount of resin was spread on strands. It is commonly accepted that resin could penetrate into wood cell walls, and fill lumen or some part of capillaries. This in turn would reduce the diameter of the capillaries or total void, and would result in reduced water uptake during a wicking test.

Effect of wax level on water uptake behavior of strands

The effect of wax level on water uptake behavior followed the same trend as that of resin

level. Figure 5 illustrates the water uptake behavior along perpendicular-to-grain direction of strands blended with different amounts of wax. Curves for strands of different wax loading levels clearly resembled one another except for the wax-free strand. It was apparent that higher wax content on strands led to a lower amount of water absorbed and a slower water uptake rate at the early period of the test (see the slopes of the lines). Again, the control samples absorbed water in a rapid way at the early stage of the test, and reached the maximum total uptake at the end of the test. Though the exact mechanism of wax sizing is often a controversial subject (Maloney 1993), and whether wax could penetrate into wood still remains unclear. The data presented in this study clearly show that high wax content

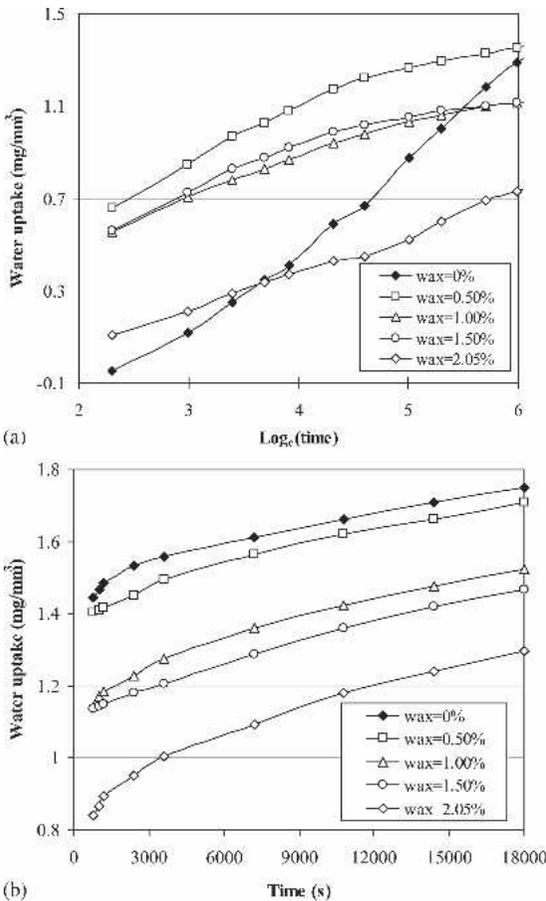


FIG. 5. Water uptake behaviors along perpendicular-to-grain direction of strands loaded with different wax levels.

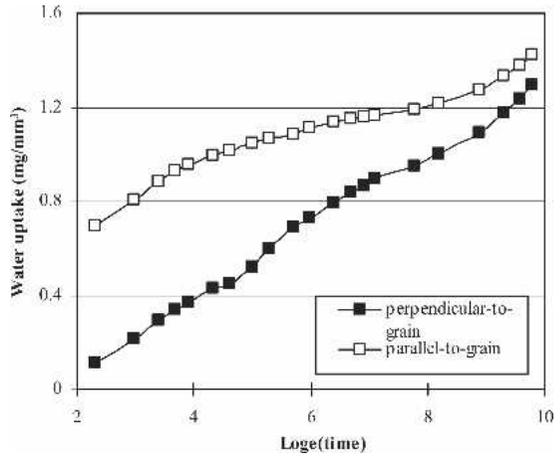


FIG. 6. The effect of grain direction on water uptake behavior of strands.

does reduce the total water uptake amount and decrease the rate of water uptake during 8-h wicking test.

Water uptake behaviors along two directions

Figure 6 shows that water uptake behaviors of strands were different in two directions in terms of water uptake rate and amount. Water was absorbed more quickly and more abundantly along the parallel-to-grain direction than that along the perpendicular-to-grain direction. However, the water uptake difference between the two directions became smaller as the test time elapsed. This could be attributed to the natural structure of the wood cell. It was reported that water was absorbed rapidly into the transverse surface of unextracted and water-extracted wood, followed by radial, and then tangential surface; and uptake of water in the transverse section is usually a thousandfold greater than in the tangential surface because of open cell cross-sections (Maldas and Kamdem 1999). In the wicking test, the perpendicular-to-grain direction of the strand was similar to radial or tangential, and the along parallel-to-grain direction was similar to transverse section.

Water uptake behaviors of strands with different density

Wood is a material with high variation in terms of structure and properties because of the

existence of sapwood, heartwood, earlywood, and latewood etc. Even being cut from the same tree, the density variation exists among strands. Figure 7 shows that the absorbed water amount decreased in the wicking test as the strand density increased. This indicated that it was more difficult for water to penetrate into strands with higher density, which could be explained by different void levels contained in strands with different density. Therefore, if strands from high density and low density wood species are mixed together to make a panel, unexpected dimensional instability problems may be encountered due to the different water uptake-related behaviors of strands with different density. In order to produce stable OSB products, it is recommended that wood species with similar density be mixed if more than one species is adopted.

CONCLUSIONS

To provide fundamental knowledge to better understand and improve OSB dimensional stability, the evaluation of water uptake behavior of resinated and waxed commercial strands was carried out by a wicking test. The following conclusions were reached:

1. Water uptake behaviors of yellow pine strands significantly changed with resin/wax loaded levels, grain directions, and densities.
2. With increased resin content and wax level, water uptake rate of the strands was low during the early stage of the test, and the total water uptake amount was small at the end of test.
3. Water was absorbed faster and more along parallel-to-grain direction than along the perpendicular-to-grain direction.
4. Different water uptake behaviors existed between high-density strands and low-density strands. Low-density strands absorbed more water than high density ones.

ACKNOWLEDGMENTS

This work was supported by the USDA Wood Utilization Research Grant, Research Initiative Competitive Grants Program (Grant No. 2001-02109) and the Tennessee Agricultural Experiment Station, Project #83. The authors would also like to thank Huber Engineered Wood, LLC for providing experimental materials.

REFERENCES

- ESPERT, A., AND F. S. VILAPLANA. 2004. Comparison of water absorption in natural cellulosic fibres from wood and one-year crops in polypropylene composites and its influence on their mechanical properties. *Composites: Part A* 35:1267–1276.
- GARDNER, D. J., S. K. WAAGE, AND T. J. ELDER. 1990. Bonding flakeboard with filled and extended phenol-formaldehyde resin. *Forest Prod. J.* 40(7/8):31–36.
- GU, H., S. WANG, T. NEIMSUWAN, AND S. G. WANG. 2005. Comparison study of commercial OSB flooring products in thickness swell and mechanical performance. *Forest Prod. J.* 55(12):239–245.
- HAWKE, R. N., B. C. H. SUN, AND M. R. GALE. 1993. Effect of fiber mat moisture content on physical properties of

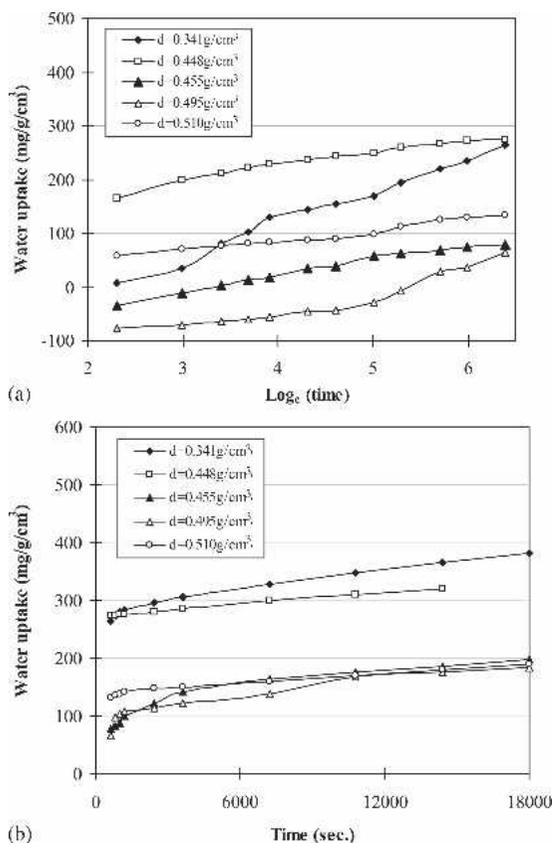


FIG. 7. The effect of density on water uptake behavior of strands.

- polysocyanate-bonded hardboard. *Forest Prod. J.* 43(1): 15–20.
- KELLY, M. W. 1977. Critical literature review of relationships between processing parameters and physical properties of particleboard. USDA Forest Serv. Gen. Tech. Rep. FPL-10. Forest Prod. Lab., Madison, WI, 65 pp.
- LU, C., AND F. LAM. 2001. Relationship between thickness swelling and mat structures in robot-formed flakeboard mats. *Holz Roh- Werkst.* 59:201–210.
- MALDAS, D. C., AND D. P. KAMDEM. 1999. Wettability of extracted southern pine. *Forest Prod. J.* 49(11/12):91–93.
- MALONEY, H. M. 1993. *Modern particleboard and dry-process fiberboard manufacturing.* Miller Freeman Inc. San Francisco, CA.
- ROWELL, M. R., A. M. TILLMAN, AND L. ZHENGIAN. 1986. Dimensional stabilization of flakeboard by chemical modification. *Wood Sci. Technol.* 20:83–95.
- SON, J., AND D. J. GARDNER. 2004. Dimensional stability measurements of thin wood veneers using Wilhelmy plate technique. *Wood Fiber Sci.* 36(1):98–106.
- WANG, S., AND P. M. WINSTORFER. 2000. The effect of species and species distribution on the layer characteristics of OSB. *Forest Prod. J.* 50(4):37–44.
- , AND ———. 2001. Flake compression behavior in a resinless mat as related to dimensional stability. *Wood Sci. Technol.* 35:379–393.
- YOUNGQUIST, J. A. 1986. Dimensional stability of acetylated aspen flakeboard. *Wood Fiber Sci.* 18(1):90–98.