WATER ADSORPTION OF PARTICLEBOARD AND FLAKEBOARD[1]

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ABSTRACT

The amount of water adsorption (WA) determines the dimensional stability of particleboard and flakeboard. Regression models showed that WA is a function of relative humidity, resin type, and board specific gravity, as well as the thickness and slenderness ratio of the wood furnish. Those factors explained 95% of all variation in WA.

Keywords: Water adsorption, particleboard, flakeboard, regression models, dimensional stability, urea- and phenol-formaldehyde resin.

INTRODUCTION

Particleboard is the generic term for a panel manufactured from lignocellulosic materials. Wood-based particleboard is made from dry wood particles that have been coated with resin, formed into a mat, and pressed under heat; flakeboard is a particleboard composed of flakes. Processing parameters—wood species, reduction of solid wood to particles or flakes, drying temperature, amount and kind of resin and wax, moisture content of the mat, compression ratio, and pressing conditions—markedly affect the properties of the finished panels.

For example, because wood particleboard and flakeboard are hygroscopic, their response to changes in relative humidity is complex. The environmental moisture affects the moisture content of the board, measurably changing linear expansion in the plane of the panel and thickness swelling perpendicular to the plane. The amounts of linear expansion and thickness swelling depend on the processing parameters, which also affect water adsorption (WA) and equilibrium moisture content at different relative humidities. In turn, WA and exposure conditions directly affect the amount of linear expansion and thickness swelling.

Again because of the processing parameters, the amount of water that particleboard adsorbs and, consequently, its equilibrium moisture content are not the

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same as those for solid wood (Halligan and Schniewind 1972; Suchsland 1972). Similarly, the "random" orientation assumed by the particles and flakes in the plane of the board during manufacture causes linear expansion to be greater than normally would be expected for solid wood in the longitudinal direction.

Thickness swelling has two components that affect dimensional change: the actual swelling of the wood and the release of compression stresses that develop during mat compaction. Because the amount of dimensional change in a board can be critical for most uses, standards for commercial products of particleboard and flakeboard specify allowable dimensional properties (U.S. Department of Commerce 1966).

Vital (1980) established the following relationships between linear expansion (LE), thickness swelling (TS), and WA. (Terms in the functions are in decreasing order of importance.) For particleboard:

$$LE = WA \times f(RT \times \Delta RH, SG, SR, TKN, SR \times \Delta RH, RT, \text{and } RT \times TKN)$$
$$TS = f(\Delta RH, RT \times \Delta RH, SG \times \Delta RH, RT \times WA, \text{and } RT)$$

And for flakeboard:

$$LE = WA \times f(\Delta RH, SAWT \times TKN, RT \times TKN, SG, TKN, TKN \times \Delta RH, SG \times \Delta RH, RT, \text{and } TKN^3)$$
$$TS = f(WA, WA \times SG, RT, WA^2, RT \times TKN, \Delta RH, \text{and } SAWT)$$

where ΔRH = change in relative humidity from either 30–65% or 65–80%, TKN = furnish thickness (0.15–0.91 mm), SG = board specific gravity (0.53–0.78) RT = resin type (urea- or phenol-formaldehyde), SAWT = flake surface area by weight (50–400 cm^2/g) and SR = slenderness ratio for particles or flakes (10–350).

Thus, its relation to linear expansion and thickness swelling makes WA an important characteristic of particleboard and flakeboard. Although processing variables are known to affect the amount of WA, this relationship has not been thoroughly established (Kelly 1977). We therefore wanted to determine how furnish geometry, resin type, and board specific gravity affect WA when the relative humidity changes from 30–65% and from 65–80%.

MATERIALS AND METHODS

The raw material was green Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], quarter-sawn into lumber with a nominal thickness of 25.4 mm and a density of 0.41 g/cm^3 (oven-dry weight/green volume). The lumber was ripped across the grain into strips 12.7, 25.4, and 50.8 mm long. Flakes of the desired thicknesses—0.15, 0.41, 0.66, or 0.91 mm—were generated with a laboratory disk-flaker. Flake width was determined by the thickness of the lumber. To generate the particles, we hammermilled flakes 25.4 mm wide and 25.4 mm long with thicknesses of 0.15, 0.41, 0.66 and 0.91 mm through a 12.7-mm screen. The green furnish, both particles and flakes, was dried at 85 C to a moisture content of approximately 3%, then sealed in plastic bags.

We manufactured a total of ninety-six homogeneous boards under constant conditions (Table 1) according to a completely randomized, single-replication factorial design. A laboratory-type, rotary drum blender was used to apply either

TABLE 1. *Processing conditions for particleboard and flakeboard.*

Factor	Constant condition
Board size	1.5 × 46 × 46 cm
Resin solids content	5%, oven-dry basis
Wax	0.5% wax, oven-dry basis
Mat moisture content	7.0 ± 0.5%
Press	Temperature, 170 C; cycle, 11 min for phenol- and 8 min for urea-formaldehyde; closing time, 60 sec; decompression time, 30 sec

phenol-formaldehyde (PF) or urea-formaldehyde (UF) resin to the furnish. Wax, resin, and water were applied sequentially with an air spray-gun. The mats were hand-felted and loaded in a single-opening hot press and pressed to specific gravities of 0.53, 0.66, or 0.78, corresponding to compression ratios (board density: wood density) of 1.30:1, 1.60:1, or 1.90:1. PF-bonded boards were stacked hot overnight, and UF-bonded boards were cooled immediately. All boards were conditioned at 32 C and 30% relative humidity.

Before testing, all boards were sanded until about 13 mm thick. Three subsamples 304 mm long and 76 mm wide were taken from each board and sequentially exposed to each of three regimes—relative humidities of 30, 65, and 80% coupled with temperatures of 32, 21, and 32 C, respectively—until the boards were equilibrated (about 2 months at each regime). Water adsorption was determined by measuring the incremental change in weight to the nearest 0.1 g for each change in regime. Thus, the first adsorption cycle of the study involved starting with green wood, drying and hot pressing as a board to about 2–3% moisture content, then measuring WA after exposing the board to successively higher relative humidities.

We used multiple regression analyses to correlate the WA increment with furnish geometry, board specific gravity, and resin type. Using a step-wise procedure (Neter and Wasserman 1976), we selected the best set of variables for each equation. The regression equations were used to predict the change in WA of the UF- and PF-bonded boards at the low and high relative humidities.

RESULTS AND DISCUSSION

Although WA is strongly related to linear expansion and thickness swelling of particleboard and flakeboard, the relationships between WA and the latter two variables are nonlinear (Vital 1980). In fact, several interactions occur between WA and other variables affecting linear expansion or thickness swelling. The relationships between WA and these dimensional characteristics of the board are further complicated because variables affecting them also affect WA.

Listed below are the multiple regression equations relating furnish geometry, board specific gravity, and resin type to WA increments resulting from increases in relative humidity from 30–65% and from 65–80%. All terms in the equations were significant at the 1% level. For particleboard:

$$\begin{aligned}\ln(\mathrm{WA}) = {} & 1.3146 + 0.4499 \times \Delta\mathrm{RH} + 0.0552 \times \mathrm{RT} \\ & -0.1714 \times \mathrm{SG} - 2.52 \times 10^{-3} \times \mathrm{SR}\end{aligned} \tag{1}$$

with Sy.x = 0.0154 and $R^2 = 0.957$.

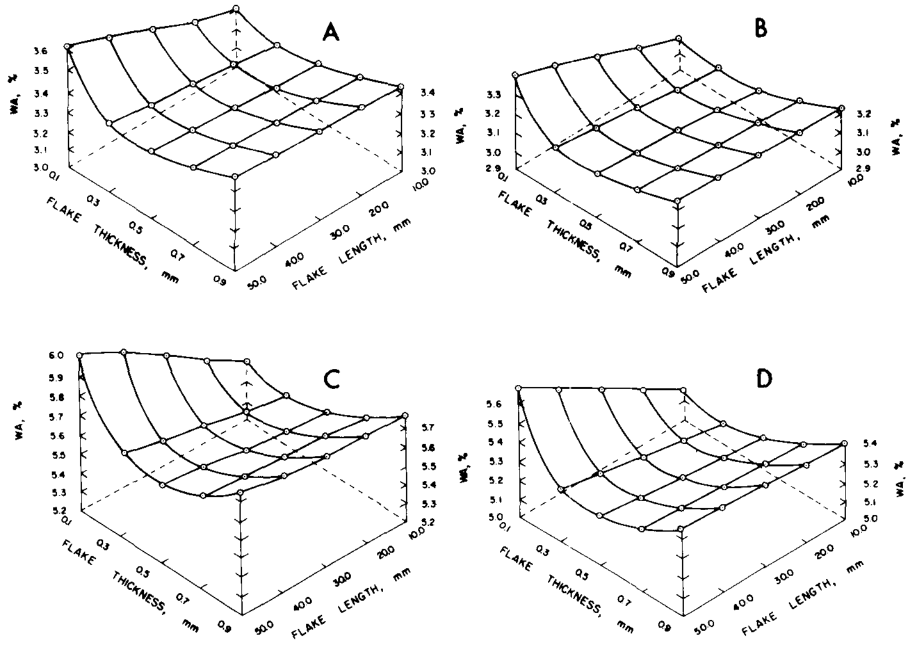

FIG. 1. Predicted effect of flake length and thickness on the water adsorption (WA) of flakeboard (specific gravity = 0.70) when relative humidity changes (A) from 30–65% in a PF-bonded board, (B) from 30–65% in a UF-bonded board, (C) from 65–80% in a PF-bonded board, and (D) from 65–80% in a UF-bonded board.

And for flakeboard:

$$\begin{aligned} \ln(\mathrm{WA}) = {} & 1.3854 + 0.2621 \times \Delta\mathrm{RH} + 0.0648 \times \mathrm{RT} \\ & - 0.5032 \times \mathrm{SG} + 2.40 \times 10^{-4} \times \mathrm{SR} \\ & + 0.0483 \times \mathrm{TKN}^2 + 0.3654 \times \mathrm{SG} \times \Delta\mathrm{RH} \qquad (2) \\ \text{with } \mathrm{Sy.x} = {} & 0.0196 \text{ and } R^2 = 0.949 \end{aligned}$$

where ln(WA) = natural logarithm of the increment in water adsorption (WA = %), ΔRH = 0 for a relative humidity change from 30–65% and 1 for a change from 65–80%, RT = resin type (assumes UF = 1 and PF = 2), SR = slenderness ratio (furnish length/thickness), and TKN = furnish thickness.

Regression analyses explained about 95% of all variation we observed in WA. As expected, a change in relative humidity was the most important variable affecting WA increment. Relative humidity alone explained 93 and 91% of all WA variation for particleboard and flakeboard, respectively. Normalizing the data indicated that the increase in WA per 1% increase in relative humidity was larger at higher relative humidities. Other experimental variables caused a smaller but statistically significant variation in the WA increment.

Once we had accounted for changes in relative humidity in the model, the next most important variable affecting WA in flakeboard was board specific gravity. This variable and relative humidity interacted to affect WA. An increase in board specific gravity generally decreased WA, but such increases had less effect at

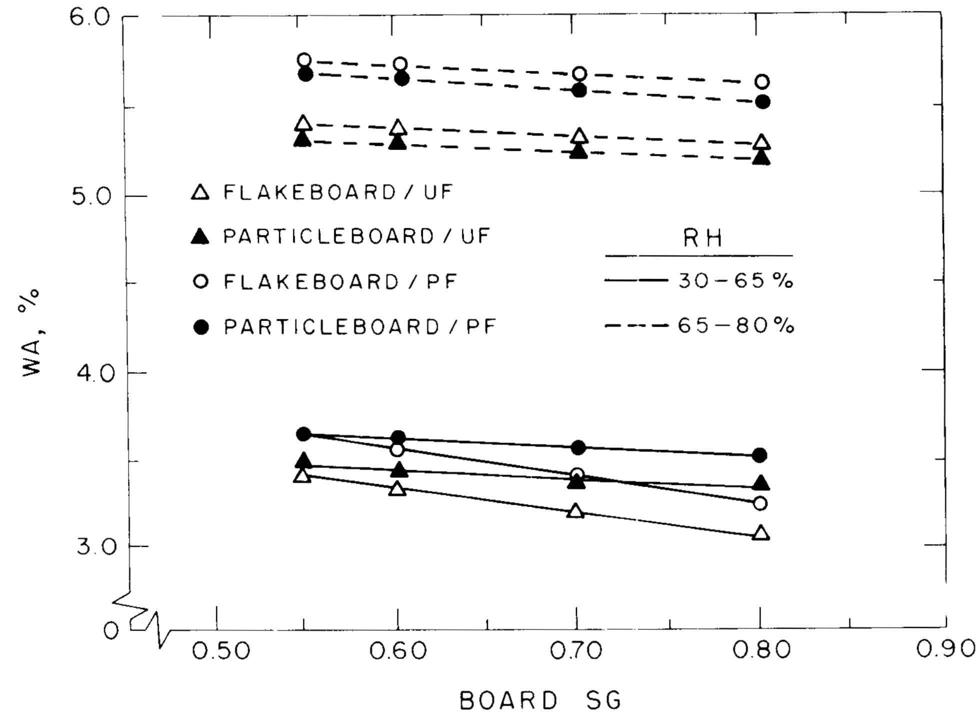

FIG. 2. Predicted effect of board specific gravity (SG) and changes in relative humidity (RH) on the water adsorption (WA) of flakeboard made with 0.30- × 50-mm flakes and particleboard made with particles 0.40 mm thick.

high relative humidity. Apparently, specific gravity had little effect on WA once the board had adsorbed enough water to release the larger stresses from the compression set in the denser boards. Lehmann (1974) and Vital et al. (1974) also found that the rate of water adsorption decreased as board specific gravity increased.

Flakeboard made with phenolic resin generally adsorbed more water when relative humidity changed than did flakeboard made with urea resin. Schneider (1973) found that the difference in WA as a result of resin type increased as the relative humidity increased. However, we found no significant interaction between resin type and relative humidity. This tendency of phenolic-bonded boards to adsorb more water is associated with their high caustic content (Wittmann 1973).

Water adsorption in flakeboard was also affected by flake geometry, as indicated in the regression model by thickness squared (TKN^2) and slenderness ratio (SR). The effect of flake or particle geometry on WA was probably related to the change in the surface area covered by the resin and its bulking effect, as well as by the change in the amount of end-grain surface as flake length and thickness changed. Geometry may also affect WA indirectly by causing a mechanical restraint in the board from stresses induced by crushing and density variations. Increases in specific gravity would also cause mechanical restraint in the board.

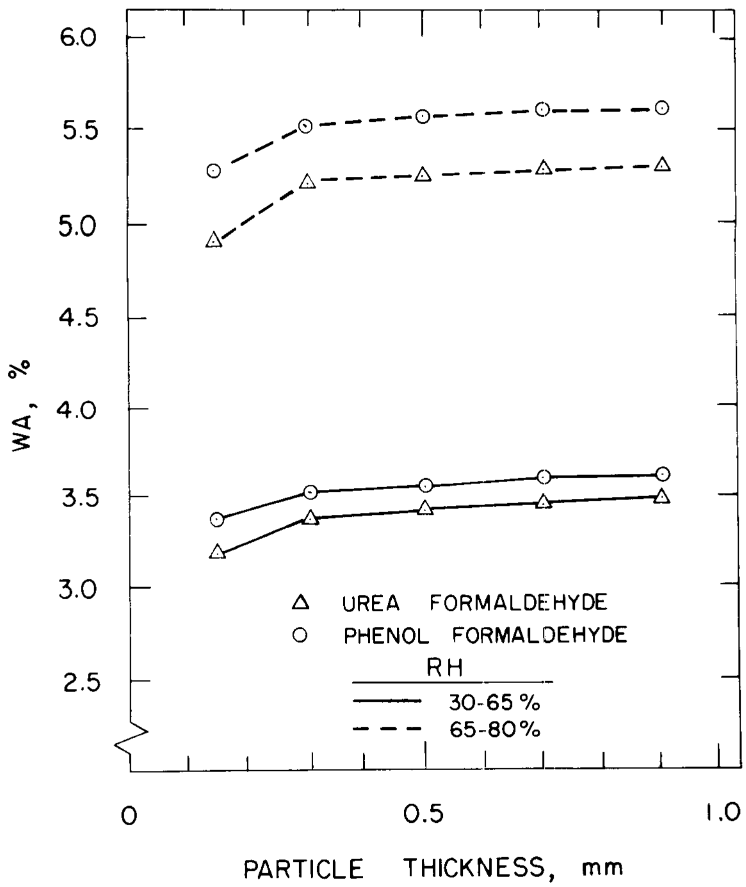

FIG. 3. Predicted effect of particle thickness and changes in relative humidity (RH) on the water adsorption (WA) of particleboard with a specific gravity of 0.70.

Adsorption curves were similar for furnish, board, and solid wood, indicating that the effect of geometry was due to the mechanical restraint or resin distribution or both.

Figure 1 shows the surface responses for flakeboard (specific gravity = 0.70) as predicted by the equations we derived in the multiple regression analyses. The effect of changes in flake length and thickness on boards of other specific gravities can be estimated with these equations; the specific gravity for each resin type and change in relative humidity should remain constant while flake length and thickness are increased slightly. Because board specific gravity and flake geometry do not interact, other specific gravities will induce shapes similar to those in Fig. 1. Figure 2 shows the predicted effect on WA when board specific gravity of a flakeboard made with 0.30- × 50-mm flakes is changed.

The smallest increment in WA for each change in relative humidity and resin type (Fig. 1) should occur with short 10-mm flakes between 0.30 and 0.50 mm thick. At this thickness, lengthening the flake slightly increased WA. Flakes thicker than 0.50 mm or thinner than 0.30 mm also increased WA slightly. As flake length increased, WA became more sensitive to changes in flake thickness.

As with flakeboard, the WA increment in particleboard was also higher in boards made with phenolic resin than in those made with urea resin. For particleboard, however, WA was more sensitive to changes in particle geometry than to changes in board specific gravity. Boards made with particles having a larger slenderness ratio (thinner particles) adsorbed less water than did those with a smaller ratio.

Figure 3 predicts how changes in particle thickness will affect WA of UF- or PF-bonded particleboard when specific gravity equals 0.70. Water adsorption is most sensitive to changes in particle thickness between 0.15 and 0.30 mm. The smallest increment in WA should occur with thin particles. The effect of particle thickness at other specific gravities can be calculated by the same technique discussed for flakeboard.

For particleboard, increasing specific gravity decreased WA (Fig. 2). The effect was linear for both changes in relative humidity but was smaller than for flakeboard, as in other published reports.

CONCLUSIONS

1. For particleboard and flakeboard, the incremental change in WA is mainly a function of the exposure condition (% relative humidity).
2. In particleboard, once the change in relative humidity has been accounted for, the factors affecting WA in decreasing order of importance are resin type, particle slenderness ratio, and board specific gravity.
3. In flakeboard, once the change in relative humidity has been accounted for, the factors affecting WA in decreasing order of importance are board specific gravity, resin type, the interaction of board specific gravity with change in relative humidity, flake thickness, and flake slenderness ratio.
4. WA decreases as board specific gravity increases, but this decrease is smaller at higher relative humidities.
5. Because of the high caustic content of phenolic resin, boards bonded with it adsorb more water than those made with urea-based resins.
6. For particleboard of both resin types, the smallest increment in WA should occur with high-density boards made with thin particles (0.15 mm).
7. For flakeboard of both resin types, the smallest increment in WA should occur with high-density boards made with short flakes (10.0 mm) between 0.30 and 0.50 mm thick.

REFERENCES

HALLIGAN, A. F., AND A. P. SCHNIEWIND. 1972. Effect of moisture on physical and creep properties of particleboard. For. Prod. J. 22(4):41–48.

KELLY, M. W. 1977. Critical literature review of relationships between processing parameters and physical properties of particleboard. USDA For. Serv. Gen. Tech. Rep. FPL-10. For. Prod. Lab., Madison, WI.

LEHMANN, W. F. 1974. Properties of structural particleboard. For. Prod. J. 24(1):19–26.

NETER, J., AND W. WASSERMAN. 1976. Applied linear statistical models. Richard D. Irwin, Inc., Homewood, IL.

SCHNEIDER, A. 1973. On the sorption-behavior of phenolic-bonded and urea-bonded particleboard. Holz Roh-Werkst. 31(11):425–429.

SUCHSLAND, O. 1972. Linear hygroscopic expansion of selected commercial particleboards. For. Prod. J. 22(11):28–32.

U.S. DEPARTMENT OF COMMERCE. 1966. Mat-formed wood particleboard. A recorded voluntary standard of the trade. 2nd ed. Commercial Standard CS-236-66. U.S. Gov. Print. Off., Washington, DC.

VITAL, B. R. 1980. Dimensional stability and water adsorption of flakeboard and particleboard as related to furnish geometry, board specific gravity, and resin type. Ph.D. Thesis, Oregon State University, Corvallis, OR.

VITAL, B. R., W. F. LEHMANN, AND R. S. BOONE. 1974. How species and board densities affect properties of exotic hardwood particleboards. For. Prod. J. 24(12):37–45.

WITTMANN, O. 1973. Alkali in phenolic resin bonded particleboard. Holz Roh-Werkst. 31(11):419–425.