IN-PLANE DIMENSIONAL STABILITY OF ORIENTED STRAND PANEL: EFFECT OF PROCESSING VARIABLES[1]

Qinglin Wu

Assistant Professor
Louisiana Forest Products Laboratory
School of Forestry, Wildlife, and Fisheries
Louisiana State University Agricultural Center
Baton Rouge, LA 70803-6202

(Received April 1998)

ABSTRACT

Single-layer oriented strand panels were fabricated under a combination of three alignment levels, four densities, and two resin contents. Flake orientation, density gradient across panel thickness, linear expansion (LE), and bending properties were measured. Flake orientation was characterized with the von Mises distribution using mean flake angle and concentration parameter.

It was shown that the shape of the LE-moisture content change curve varied with alignment level and test direction. The variation was attributed to whether the LE of a panel was controlled by transverse or longitudinal wood swelling along a particular test direction. Total LE from oven-dry to water-soak condition, modulus of elasticity (MOE), and modulus of rupture (MOR) varied significantly with flake orientation distribution and density. Effects of resin content at the levels used on LE, MOE, and MOR was relatively small and was more diversified. The LE, MOE, and MOR were correlated with the concentration parameter, density, resin content, and moisture content using a power form equation. The experimental data form a database of layer properties for modeling three-layer, cross-laminated oriented strandboards (OSBs) manufactured under hot pressing.

Keywords: Flakeboard, linear expansion, modeling, stiffness, strength.

INTRODUCTION

Oriented strandboard (OSB) is a structural reconstituted panel that consists of wood strands glued with an exterior-type, waterproof resin. The physical and mechanical properties of the board are enhanced by layering and alignment of wood flakes. In the last decade, OSB has gained significant growth in the structural wood-based panel market. Oriented strandboard capacity reached about 18.4 million m^3 in 1997, with production at about 15.5 million m^3 (Spelter et al. 1997). It has become a promising substitute for structural plywood.

Oriented strandboard swells significantly when the product is exposed to high relative humidity (RH) conditions and/or in direct contact with water (Geimer 1982; Wu and Suchsland 1996, 1997). In addition to the well-recognized importance of thickness stability, in-plane swelling, known as linear expansion (LE), can be a significant factor in structural applications. This is so because the swelling can greatly affect the state of stress that exists in the material. The in-plane movements can cause high internal stresses due to the restraint offered by fastening such as nails. These stresses may be large enough to cause buckled panels, pushed-out nails, and separation of the panel from the structure (Lang and Loferski 1995; Wu and Suchsland 1996).

The in-plane dimensional change of OSB is a direct result of complex interactions among different layers across panel thickness in a three-layer, cross-laminated board (Bryan 1962; Xu and Suchsland 1997). Many processing parameters affect the dimensional change, the most important being flake orientation, shelling ratio (i.e., flake weight ratio between face layer and core layer), degree of bonding, flake geometry, density, and density

[1] This paper (No. 98-22-0139) is published with the approval of the Director of the Louisiana Agricultural Experiment Station.

Wood and Fiber Science, 31(1), 1999, pp. 28–40

TABLE 1. *Board fabrication data—single-layer uniform density oriented strand panels.*

Board type[a]	Target board density (g/cm^3)	Resin content[b] (%)	Number of replication	Number of boards made
HAL	0.55, 0.75, 0.95, 1.15	4, 6	2	16
LAL	0.55, 0.75, 0.95, 1.15	4, 6	2	16
RAL	0.55, 0.75, 0.95	4, 6	2	12

[a] HAL = High alignment level; LAL = Low alignment level; RAL = Random alignment level.
[b] Based on oven-dry flake weight.

gradient (Kelly 1977; Geimer 1982). Variation in these variables among different products has led to a large variability of LE values in commercial OSBs (Wu and Suchsland 1996). Efforts to reduce LE in these products require a quantitative understanding of the role each variable plays in controlling the in-plane movement.

The study reported here represents the first part of a comprehensive study aimed at examining dimensional stability and its effect on durability of OSB. The objective of this work was to investigate to what extent in-plane stability of oriented strand panels (single-layer) is related to processing variables, namely, flake alignment level (AL), density, and resin content (RC) at various levels of moisture content (MC). Since the in-plane movement and strength properties are closely related, data on bending modulus of elasticity (MOE) and modulus of rupture (MOR) were also presented and discussed.

MATERIALS AND METHODS

Board fabrication

Forty-four oriented strand panels were manufactured (Table 1) in the USDA Forest Products Laboratory, Madison, Wisconsin. In brief, a number of aspen (*Populus grandidentata*) logs with an average diameter of 45 cm were obtained at a local Wisconsin sawmill. The logs were band-sawn into 13-mm-thick boards, which were ripped to eliminate bark, and crosscut into 152-mm-long blocks. These blocks were oriented with the grain direction parallel to the knives of a disc flaker and cut into flakes measuring 0.645 mm thick × 13 mm wide × 76 mm long. The flakes were then dried to about 5% MC and screened. The boards were pressed to a thickness of 12.7 mm in a cold press and were then heated under pressure until the core temperature passed 104°C. This was done to eliminate vertical density gradient inside the boards (Geimer 1982). All boards were made with liquid phenol-formaldehyde adhesive (solid content = 53%) and 0.5% wax. Table 1 lists RC level and number of board replication used in manufacturing the test panels. Immediately after pressing, the boards were weighed and measured for thickness. They were then placed in a plywood box for thermal equalization. The panel size was 609.6 × 711.2 × 12.7 mm.

Specimen preparation and testing procedure

Flake alignment distribution.—A strip of 50.8 mm was trimmed from the four sides of each panel to reduce the edge effects on test specimens. A clear plastic sheet, marked with a 50.8- × 50.8-mm dot grid, was placed on the top surface of each board. One flake from each grid square was randomly selected, and a line representing the flake was drawn on the plastic film parallel to the long dimension of the flake. The plastic film was then placed on a drafting table, and a protractor was used to measure orientation of each line. Flake angles measured varied from −90° to 90° with 0° set along the major alignment direction. A total of 143 flakes were measured for each panel.

Density gradient.—Three 50.8- × 50.8- × 12.7-mm specimens were cut from each panel, totaling 132 specimens for 44 panels. Density profile in the specimen thickness direction was determined on a Quintek Density Profile Model QDP-01X. This equipment is an X-ray-based precision instrument for making density profile measurements in wood composites. The profiler uses an X-ray tube operating in a range of 40 kV to produce a photon beam for density determination.

Linear expansion.—Two samples, 25.4 × 304.8 × 12.7 mm, were cut along each of the two principal directions from each board, to-

taling 88 samples for each direction. This gave four replications for each combination of density, flake alignment level, and resin content. They were numbered according to board type, test direction (parallel or perpendicular), and replication number. Two holes (1.1 mm in diameter) 254 mm apart were drilled along the long dimension of each specimen, and a small rivet (1.0 mm in diameter), dipped in epoxy glue, was plugged into each of the two holes. After the glue set, one reference cross was carefully cut on the tip of each rivet using a sharp razor blade. The cross facilitated LE measurements with an optical comparator.

All specimens were initially dried in a convection oven at 60°C to reach a constant weight. Measurements including specimen weight, length, width, thickness, and reference dimension between the two rivets of each specimen were made at this initial dry state. The specimens were successively conditioned to reach equilibrium at each of the five RH levels: 35%, 55%, 75%, 85%, and 95%. They were then subjected to a 48 h water-soak (WS) treatment. Finally, all specimens were oven-dried for 24 h at 105°C. The measurements were repeated at each specified RH level, WS, and oven-dry (OD) condition.

Bending test.—Static bending specimens, 76.2 × 355.6 × 12.7 mm, were cut along two principal directions of each panel according to ASTM D1037-96 (ASTM 1996). One parallel and one perpendicular specimen from each panel were prepared, totaling 44 specimens for each direction. This gave two replications for each combination of density, alignment level, and RC. The specimens were conditioned to equilibrium at 45% RH and 25°C. Their weight and size (i.e. length, width, and thickness) were measured before testing. Bending tests were made on a Model 4260 INSTRON machine with a computer-controlled data acquisition system. After breaking, a 50.8- × 76.2-mm section was cut from each end of each sample for further testing in a separate study. The rest of the specimen was weighed and oven-dried to determine its MC on the OD basis.

Data analysis

Flake alignment distribution.—The underlying flake orientation distribution for the test panels is assumed to be the von Mises probability distribution (Harris and Johnson 1982). To obtain the concentration parameter, alignment percent defined by Geimer (1982) and mean flake angle among the number of flakes measured were calculated for each panel. The look-up table published by Shaler (1991) with the alignment percent and mean angle as input was used to obtain the concentration parameter.

Linear expansion, MOE, and MOR.—Linear expansion was calculated as

$$LE = \left[\frac{L_I - L_O}{L_O}\right] \times 100\% \qquad (1)$$

where, LE is expressed in % (mm/mm), L_I is the reference dimension at a given RH level (mm), and L_O is the reference dimension at the reference RH level (mm). Linear expansion data were presented in two formats: LE as a function of MC from dry to equilibrium conditions at 35%, 55%, 75%, 85%, and 95% RH; and total LE value from OD to WS condition. Bending MOE and MOR were calculated by the testing program after each test.

The rate of change in LE (from OD to WS), MOE, and MOR per percent change in flake alignment level was calculated as:

$$\text{Property change rate} = \left[\frac{100(P_1 - P_2)/P_1}{(AL_1 - AL_2)}\right] \qquad (2)$$

where P_1 and P_2 represent LE (%), MOE (GPa), or MOR (MPa) values at the alignment levels 1 and 2 (AL_1 and AL_2, %). Finally, LE as a function of MC, total LE from OD to WS condition, MOE, and MOR were expressed as a function of processing variables using SAS (SAS Institute 1996) as:

$$P = aRC^bSG^cK^dMC^e \qquad (3)$$

where

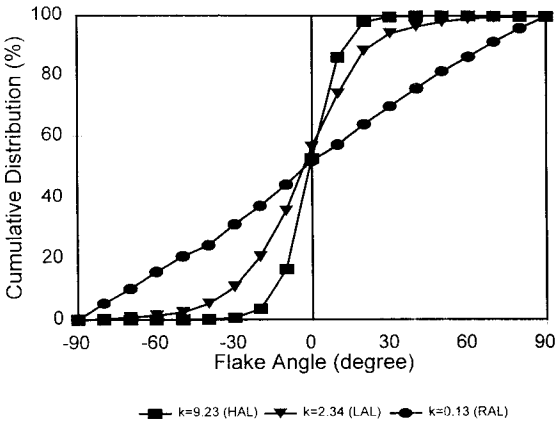

Fig. 1. Measured flake orientation distributions for the test panels at high, low and random alignment levels (HAL, LAL, and RAL).

P = property: LE (%) or MOE (GPa) or MOR (MPa);

RC = resin content (%);

K = concentration paramenter for the von Mises distribution;

SG = specific gravity;

MC = moisture content (%);

a, b, c, d, and e = regression constants.

In fitting Eq. (3), natural logarithm transformation of both dependent variables (LE, MOE, or MOR) and independent variables (RC, SG, K, and MC) was first performed. A multilinear regression analysis based on a backward selection procedure was then made with the transformed variables. The backward selection procedure removed insignificant terms at the 0.1000 level from the model.

RESULTS AND DISCUSSION

Flake alignment distribution

Figure 1 shows measured flake orientation for boards at the three alignment levels. The mean angle for all panels was within ±5°. An assumption of a 0° mean angle was thus made to look up the concentration parameter (Shaler 1991).

The concentration parameter, K, averaged 9.23, 2.34, and 0.13 for the boards with high, low, and random alignment levels, respectively (Table 2). The corresponding alignment percent (Geimer 1982) was 82.3%, 61.3%, and 5.2%. There was a large drop in K value between 82.3% and 61.3% alignment levels. This was due to the nature of the von Mises distribution itself (Harris and Johnson 1982). As the alignment level further increases, K increases sharply and becomes infinite at the 100% alignment level. Also shown, random boards were not completely random (i.e., K was not equal to zero), according to the measured flake orientation distribution.

As the value of K decreases, flake orientation changes from a perfectly aligned distribution toward a completely random distribution. This quantity can thus be used to correlate both physical and mechanical properties of the panel with flake orientation distribution. The fact that the cumulative distribution curves for flake alignment follow a common mathematical rule is of special significance in comparing analytical expressions of OSBs properties with experimental results.

Density gradient

Figure 2 shows measured density distribution across board thickness for boards at various density levels. As shown, vertical density gradient was effectively eliminated by using a cold press at closing. Subsequent heating after press closure did not cause a significant density gradient inside the panel. Absence of density variation across board thickness allows the study of effects of board density alone on both physical and mechanical properties. From this, layer properties as a function of density can be established to simulate individual layers in three-layer boards with vertical density gradient.

Relationship between LE and MC change

The shape of LE-MC change curve depends on alignment level and test direction (Fig. 3). For the high alignment boards shown (K = 11.5), LE in the perpendicular direction fol-

TABLE 2. *Summary of LE data from oven-dry to water soak condition.*

Board Type[a]	Alignment level		Parallel		Perpendicular		LE ratio[e]
	Percent[b]	κ[c]	Density[d] (g/cm³)	LE (%)	Density (g/cm³)	LE (%)	
	4% Resin content						
HAL	84.6	11.52	0.51 (0.02)	0.20 (0.04)	0.58 (0.03)	2.12 (1.05)	10.60
	82.5	9.69	0.76 (0.02)	0.13 (0.05)	0.75 (0.02)	3.30 (0.40)	25.38
	82.1	9.04	0.96 (0.02)	0.15 (0.04)	0.98 (0.03)	3.17 (0.74)	21.13
	81.8	8.66	1.18 (0.03)	0.12 (0.08)	1.21 (0.04)	3.23 (1.23)	26.92
LAL	61.2	2.33	0.59 (0.02)	0.22 (0.08)	0.61 (0.01)	0.83 (0.10)	3.77
	63.1	2.49	0.75 (0.04)	0.22 (0.04)	0.79 (0.02)	0.87 (0.11)	3.95
	60.8	2.29	0.97 (0.02)	0.20 (0.06)	0.89 (0.04)	0.98 (0.18)	4.90
	62.3	2.42	1.13 (0.02)	0.16 (0.02)	1.18 (0.02)	1.28 (0.48)	8.00
RAL	5.86	0.15	0.52 (0.03)	0.39 (0.03)	0.59 (0.03)	0.30 (0.13)	0.77
	8.35	0.21	0.71 (0.01)	0.31 (0.11)	0.79 (0.02)	0.28 (0.07)	0.90
	6.21	0.15	0.90 (0.01)	0.35 (0.09)	0.93 (0.03)	0.41 (0.07)	1.17
	6% Resin content						
HAL	82.8	9.69	0.54 (0.02)	0.21 (0.04)	0.54 (0.01)	2.88 (0.74)	13.72
	82.6	9.73	0.76 (0.04)	0.16 (0.05)	0.84 (0.01)	3.07 (0.56)	19.19
	81.6	8.49	0.97 (0.06)	0.12 (0.06)	0.99 (0.02)	2.96 (0.55)	24.67
	80.2	7.05	1.19 (0.04)	0.11 (0.12)	1.16 (0.02)	3.33 (0.93)	30.27
LAL	59.5	2.18	0.61 (0.02)	0.21 (0.07)	0.60 (0.02)	0.87 (0.19)	4.14
	61.7	2.36	0.78 (0.01)	0.23 (0.04)	0.76 (0.03)	0.89 (0.08)	3.87
	60.9	2.29	0.96 (0.02)	0.20 (0.05)	1.00 (0.03)	1.13 (0.41)	5.65
	60.8	2.33	1.11 (0.08)	0.17 (0.08)	1.09 (0.06)	1.15 (0.36)	6.76
RAL	3.97	0.10	0.53 (0.02)	0.42 (0.03)	0.56 (0.01)	0.44 (0.14)	1.05
	5.25	0.13	0.70 (0.03)	0.37 (0.06)	0.73 (0.02)	0.32 (0.11)	0.86
	1.49	0.04	0.95 (0.05)	0.36 (0.05)	0.91 (0.03)	0.35 (0.13)	0.97

[a] HAL = High alignment level; LAL = Low alignment level; RAL = Random alignment level.
[b] Alignment percent follows the definition by Geimer 1982.
[c] κ = Concentration parameter of the flake orientation distribution.
[d] Density—based on the oven-dry weight and volume at about 2% MC.
[e] LE ratio = LE in the perpendicular direction divided by LE in the parallel direction.

lowed a nearly linear relationship with MC change (Fig. 3a). This relationship agrees with well-established linear MC-shrinkage or swelling relationships in the transverse directions for solid wood. The swelling coefficient, % swelling/%MC change, of the high aligned boards averaged 0.12 in the perpendicular direction. This value compares well with the published radial shrinkage or swelling coefficient of 0.11 for aspen based on a total radial shrinkage or swelling of 3.4% and a fiber saturation point of 30% (USDA Forest Service 1987). Linear expansion in the parallel direction followed a curvilinear relationship with MC change (Fig. 3b). Over a given MC change, LE change in the parallel direction was larger at lower MC levels. Thus the swelling rate decreased as MC levels increased such that the LE-MC curve gradually approached an asymptote parallel to the MC axis. The small magnitude of LE in the parallel direction and its curvilinear relationship with MC change reflected the true longitudinal wood swelling (Sadoh and Christensen 1964).

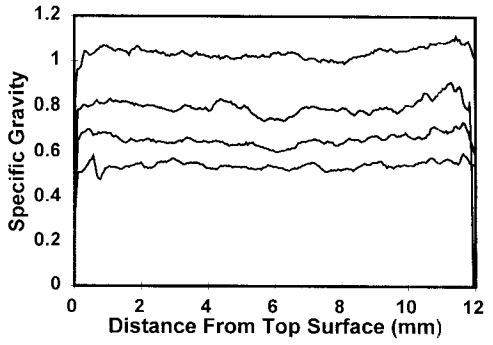

Fig. 2. Measured density profiles across board thickness for the test panels at various density levels.