

Dimensional stability of flakeboards as affected by board specific gravity and flake alignment

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Abstract

The objective was to determine the relationship between the variables specific gravity (SG) and flake alignment and the dimensional stability properties of flakeboard. Boards manufactured without a density gradient were exposed to various levels of relative humidity and a vacuum-pressure soak (VPS) treatment. Changes in moisture content (MC), thickness swelling, and linear expansion were measured and used to develop regression equations.

Under board saturation conditions resulting from VPS, dimensional movement could be defined as a function of SG without regard to MC. The relationship between SG and MC was essential in defining dimensional stability changes at exposure conditions resulting in MC's below fiber saturation because equilibrium MC and equilibrium dimensional stability are independently time-related to SG and they vary with flake type and exposure conditions.

Derived regression equations were used to predict thickness swelling in three-layer boards with reasonable accuracy. Reliable prediction of linear expansion depends on the analysis of many board properties.

Flakeboard designed for structural applications may be constructed with several layers of flakes that vary in specific gravity (density), flake geometry, and flake alignment. Optimization of board performance is dependent on knowing the relationship between these variables and basic physical and mechanical properties. Unfortunately, most available performance data have been derived from boards of varying levels of average density which, within themselves, show a vertical density gradient. Recent publications describe the relationship between the variables of specific gravity (SG) and flake alignment and the mechanical properties of bending, tension and compression (3), and interlaminar shear, rail shear, and internal bond (4) for boards with uniform vertical density.

Analysis of the dimensional stability of flakeboards is complicated by the many variables that affect this property (6,17) and the interactions occurring among these variables (21,22). Furthermore, sound conclusions based on reviews of dimensional stability literature are made difficult by the numerous exposure conditions used (7,13). Many exposures are designed primarily to determine product durability.

The objective of this study was to outline the extent to which the variables SG and flake alignment affect the dimensional stability properties of thickness swelling (TS), linear expansion (LE), and the associated water adsorption at various levels of relative humidity (RH) and absorption following a vacuum-pressure soak (VPS) treatment. Evaluations were made of uniform-density boards made with several flake types, two species, and several degrees of flake alignment. Regression equations derived from the uniform density data were used to predict the properties of laboratory-made boards pressed in a conventional manner and having a normal density gradient.

Materials and methods

Board fabrication

Homogeneous boards, 0.5 by 24 by 28 inches (13 by 610 by 711 mm), were constructed using three types of Douglas-fir (*Pseudotsuga menziesii*) flakes (Table 1). Duplicate boards were made at each of four target density levels (30, 40, 50, and 60 pcf) (480, 641, 801, and 961 kg/m³) and at zero, 40, 60, and 80 percent (target) flake alignment (2). The experiment was expanded to include three types of northern red oak (*Quercus rubra* L.) flakes to provide data for a concurrent study (5). No replicate boards were constructed using the oak flakes; target density and alignments varied with the flake types.

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TABLE 1. — *Experimental design specifications.*

Thickness (in.)	Flake type ^a		Target board density (pcf)	Target flake alignment (%)
	Length (in.)	Machine		
0.020	3	Douglas-fir ^{b,c} Disk	30, 40, 50, 60	0, 40, 60, 80
0.020	1.5	Disk	30, 40, 50, 60	0, 35, 50, 65
0.020	0.75	Ring	30, 40, 50, 60	0, 15, 20, 30
0.010	3	Oak ^{c,d} Disk	40, 50, 60	0, 30, 50, 70
0.020	3	Disk	40, 50, 60	0, 30, 50, 70
0.045	2	Ring	30, 40, 50	0, 50

^aAll flakes were random width.

^bTwo replications per density and alignment condition, or 32 boards for each flake size.

^cOne dimensional stability specimen sample was cut from each board in both the parallel- and the perpendicular-to-alignment direction. One density gradient was sampled from each board.

^dOne board for each density and alignment condition for each flake size.

All boards except those made with the 0.045-inch (1.3-mm)-thick oak flakes contained 5 percent liquid phenolic resin and 1 percent wax. The boards made from 0.045-inch oak flakes contained 6 percent phenolic resin and 1 percent wax to conform to board specifications in the concurrent study. All mats contained 10 percent moisture (ovendry (OD) mat basis) prior to pressing.

To produce uniform-density boards, all of the mats were pressed to stops between initially cold platens. Closure time was not considered as a variable. Introduction of 180 psi (1241 kPa) steam pressure into the platens allowed the centerline temperature to reach 235°F (113°C) in 9 to 11 minutes depending on board density. The boards were heated for an additional 8 minutes and then cooled in the press until the centerline temperature was below 212°F (100°C). Sanding the 0.5-inch boards equally on both faces to a 0.4375-inch thickness removed any slight density gradient.

A series of boards made in the regular hot-pressing fashion, with a normal density gradient, were designated as control panels. Each of the three Douglas-fir flake types was used to make duplicate 0.5-inch-thick single-layer boards of both a random and aligned flake configuration. Four types of three-layer control boards were also constructed using 1.5-inch (38-mm)-long Douglas-fir flakes in the faces and 0.75-inch (19-mm)-long Douglas-fir flakes in the core. Board types were distinguished by the combinations of flake dispersment (random or aligned) used to fabricate the layers. Layered boards were constructed using a face:core:face ratio of 15:70:15. All of the control boards were made at 40 pcf density OD basis with 5 percent liquid phenolic resin. Mat moisture was 10 percent, closure time was 1 minute, and total press time was 10 minutes at 350°F (117°C) platen temperature.

Tests and measurements

Density gradients were measured on all boards by removing 0.030-inch (0.762 mm)-thick layers with a thickness planer. Deviation of the gradient was generally within 5 percent of the average except in the 60 pcf boards which had slightly higher density variations within the board.

Flake alignment was measured both directly and indirectly. The direct method measured the angles 200 individual flakes made with the cardinal alignment

direction on the surface of each board. The average of these measured angles without regard to sign was defined as θ and

$$\% \text{ alignment} = \frac{45 - \theta}{45} (100) \quad [1]$$

defining a random board as having zero percent alignment.

A second, indirect method used to determine flake alignment measured the velocity of a wave produced by an ultrasonic timer through 3- by 9-inch sections of matched sets of bending specimens that had been cut with the long dimension both parallel to and perpendicular to the direction of alignment. Measurements were taken both parallel to and perpendicular to the direction of alignment on each specimen. Because sonic velocity data had proved to have a high correlation in developing regression equations describing bending properties (3), they were used throughout the course of statistical data analysis as a measurement of alignment.

The ratio of the average velocity in the aligned direction to that in the cross-aligned direction was denoted as the sonic velocity ratio (SVR) (4) and

$$\% \text{ alignment} = 75.8 (\ln \text{SVR}). \quad [2]$$

Dimensional stability samples measured 2.5 by 13 inches (63.4 by 329.4 mm). One of two specimens was cut with the long dimension parallel to the panel's long dimension (in the case of an aligned board, parallel to the alignment direction). The other sample was cut with its long dimension at 90° to the long dimension of the panel. Grommets 10 inches (254 mm) apart on the surface of the boards provided reference points for LE measurements (9).

Each sample was progressively subjected to the following conditions:

OD—215°F(101°C) for 24 hours
 30 percent RH, room temperature—77days
 50 percent RH, room temperature—41days
 90 percent RH, room temperature—32days
 VPS—1/2 hour under water at 25 in. Hg
 vacuum followed by 22 hours under water
 at 60 psi
 OD—215°F(101°C) for 24 hours.

TABLE 2. — Coefficients for equation relating moisture content to specific gravity, $MC = \mu + \alpha(SG)$.

Condition	Coefficients and parameters	Flake size and type					
		Douglas-fir		Oak			
		0.020×3 Disk	0.020×1.5 Disk	0.020×0.75 Ring	0.010×3 Disk	0.020×3 Disk	0.045×2 Ring
30% RH	μ	6.52	4.38	4.11	7.25	7.63	3.01
	α	-3.46	-1.02	-0.83	-3.89	-4.63	1.03
	R^2	62	30	40	75	76	65
50% RH	μ	9.73	7.15	6.99	10.00	10.60	5.53
	α	-4.50	-1.56	-1.25	-4.72	-5.5	0.95
	R^2	62	40	45	69	71	42
90% RH	μ	21.9	20.1	19.6	30.0	27.1	19.7
	α	-12.1	-10.7	-9.3	-18.6	-15.0	-2.1
	R^2	75	75	58	91	91	10
VPS ^b	μ	197	213	201	172	167	203
	α	-131	-143	-139	-119	-119	-145
	R^2	81	95	91	97	98	98

^a R^2 —Coefficient of determination.^bVPS—Vacuum-pressure soak treatment.

Sample length, thickness, and weight were determined following each exposure condition. The times shown for sample retention at the various RH conditions are not necessarily the minimum times to reach equilibrium. Sampling measurements showed less than 0.05 percent change in MC in 24 hours prior to the specimens being removed for testing.

Results and discussion

Moisture content

Below fiber saturation.—With few exceptions, moisture content (MC) (expressed as a percentage of the original OD weight) decreased as board SG increased at all levels of exposure. Regression equations relating MC and SG were calculated by individual flake type (Table 2). Regression equations describing the relationship between MC and SG for all of the different flake type data taken as a group are shown in Figure 1.

Differences in MC between specimens of varying SG were very small at the 30 and 50 percent RH exposure levels. The average MC at 30 percent RH of the samples of all flake types treated as a group was 3.6 percent. Coefficient of variation on this pooled set of data was only 16 percent. At 50 percent RH exposure, MC averaged 6.0 percent, and the coefficient of variation for this set of data was 12.4 percent. The effect of SG on water adsorption became more pronounced at 90 percent RH and coefficient of determination (R^2) values indicated that MC and SG were highly correlated at this exposure.

Other researchers (8,12,20,21) have also indicated that equilibrium MC is reduced as board SG increases. This has been attributed to adhesive bonding and/or a reduction of available hygroscopic bonding sites. It is possible, of course, that the criterion of a 0.05 percent or less change of MC in 24 hours, which occurred in 32 days in this study, does not adequately define a true MC equilibrium state at 90 percent RH levels. The change of MC beyond this time point, however, has been shown to be relatively small (11,14). A criterion of less than 1.5 percent change in MC over a period of 30 days may be

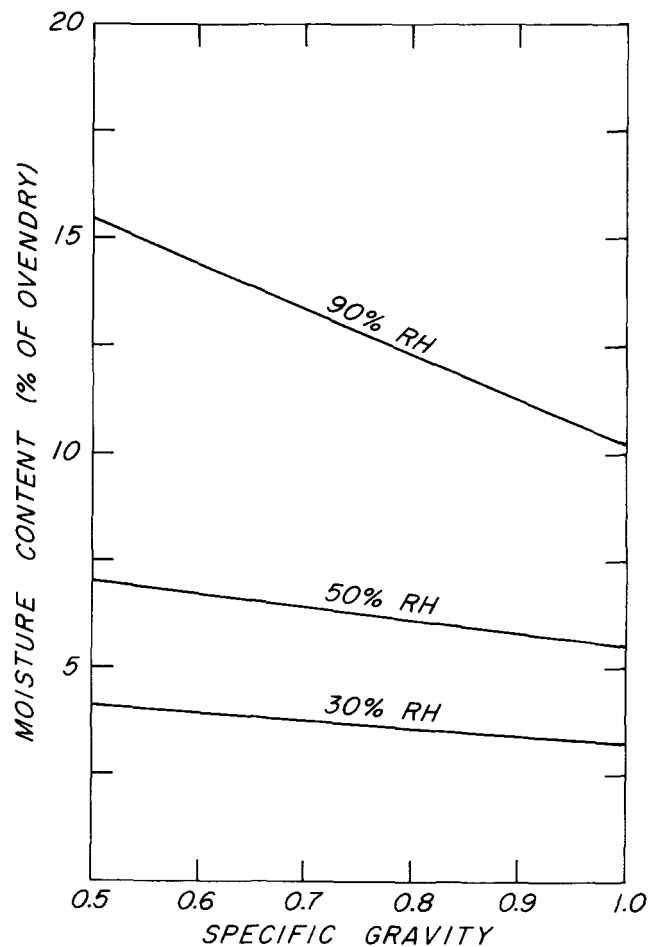


Figure 1. — Relationship between equilibrium moisture content and specific gravity at three relative humidity test conditions.

TABLE 3. — Coefficients for equations relating thickness swelling to moisture content and specific gravity,
 $TS = \mu + \lambda(MC) + \alpha(SG)$.

Condition ^a	Coefficients and parameters	Flake size and type					
		Douglas-fir			Oak		
		0.020×3 Disk	0.020×1.5 Disk	0.020×0.75 Ring	0.010×3 Disk	0.020×3 Disk	0.045×2 Ring
30% RH	μ	-1.60	-0.170	0.401	7.81	1.01	1.61
	(ρ) ^b	(0.0019)	(0.7403)	(0.5484)	(0.0040)	(0.2890)	(0.1849)
	λ	0.49	0.43	0.14	-0.96	-0.03	-0.27
	(ρ)	(0.0001)	(0.0001)	(0.3809)	(0.0072)	(0.8242)	(0.4850)
	α	0.38	-0.38	0.28	-3.90	-0.52	0.74
	(ρ)	(0.3422)	(0.0417)	(0.1954)	(0.0131)	(0.4057)	(0.1475)
	R^2	49	44	3	30	13	27
	MSE ^c	0.1390	0.0515	0.0630	0.2044	0.0333	0.0170
50% RH	μ	-3.12	-1.79	-0.36	7.95	-0.90	-0.60
	(ρ)	(0.0006)	(0.0327)	(0.6934)	(0.0017)	(0.9568)	(0.8043)
	λ	0.69	0.74	0.40	-0.64	0.19	0.49
	(ρ)	(0.0001)	(0.0001)	(0.0030)	(0.0067)	(0.2218)	(0.2758)
	α	1.21	0.19	0.82	-2.67	0.56	0.27
	(ρ)	(0.0157)	(0.5009)	(0.0012)	(0.0374)	(0.5711)	(0.6722)
	R^2	64	51	17	30	16	30
	MSE	0.2188	0.1017	0.0767	0.1740	0.1039	0.0495
90% RH	μ	-16.7	-8.60	-10.1	9.34	-6.30	-10.0
	(ρ)	(0.0001)	(0.0002)	(0.0001)	(0.3383)	(0.3477)	(0.3606)
	λ	1.42	1.24	1.21	0.18	0.65	0.83
	(ρ)	(0.0001)	(0.0001)	(0.0001)	(0.5657)	(0.0155)	(0.1411)
	α	8.58	3.01	5.17	-5.85	4.17	16.9
	(ρ)	(0.0004)	(0.0254)	(0.0001)	(0.3491)	(0.2773)	(0.0005)
	R^2	69	86	78	55	72	75
	MSE	3.0224	0.9116	1.3305	1.3390	0.4767	2.1233
Combined 30-50-90 % RH	μ	-4.3	-2.4	-3.5	-3.79	-4.14	—
	(ρ)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	—
	λ	0.85	0.92	0.90	0.61	0.59	—
	(ρ)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	—
	α	1.74	0.02	1.55	2.46	2.75	—
	(ρ)	(0.0002)	(0.9549)	(0.0001)	(0.0001)	(0.0001)	—
VPS ^d	μ	-9.8	-10.6	-3.2	-20.5	-4.6	10.7
	α	52	57.4	47.3	49.4	24.0	21.3
	R^2	74	90	91	84	83	58
Spring- back	μ	-22.9	-19.2	-16.4	-30	-28.2	-11.5
	α	52.7	51.8	48.6	46.9	42.1	29.2
	R^2	85	84	95	89	61	90

^a(MC) is not considered as an independent variable in VPS and springback equations.

^b ρ =Level of significance for coefficient.

^cMSE=Mean square error.

^dVPS=Vacuum-pressure soak treatment.

better suited to define MC equilibrium at the 90 percent RH level.

Saturation.—When exposed to a vacuum-pressure soak (VPS) treatment, flakeboards become saturated and TS is maximum. Under these conditions, the total amount of water absorbed is dependent on the ratio of void volume to solid wood and decreases as board SG increases. Using Tiemann's equation (19), the maximum theoretical moisture a saturated sample contains is:

$$M = \frac{d-D}{dD} 100 \quad [3]$$

where M = maximum moisture, percent of OD weight
d = SG of wood substance modified for 5 percent resin and 1 percent wax (approximately 1.55)

D = SG of the swollen specimen based on wet volume and OD weight.

Maximum theoretical MC calculated using Equation [3] and regression curves defining TS in terms of OD SG

(Table 3) is approximately 20 percent greater than MC values calculated using the regression equations defined in Table 2. The discrepancy may be due to the testing technique used (1), which allows some of the water to be drained off prior to weighing.

Thickness swelling

Below fiber saturation.—Prediction of thickness swelling (TS) for flakeboards exposed to RH conditions with equilibrium MC below the fiber saturation point is dependent on knowing both SG and MC. This is because equilibrium MC and equilibrium TS are independently time dependent on SG, flake type, and exposure conditions. Specifications defining procedures used to obtain equilibrium MC do not necessarily define the equilibrium TS point. Liiri (14) has shown that, after reaching equilibrium MC at 95 percent RH in 30 to 40 days, boards with SG $\approx$ 0.7 increase an additional 3.5 percent in thickness during the next 100-day period.

Coefficients for regression equations defining TS in terms of SG and MC at the various exposure levels are

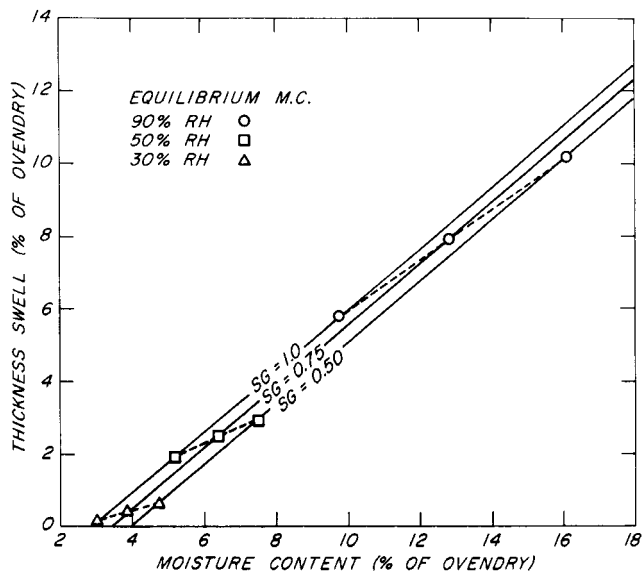


Figure 2. — Thickness swelling of flakeboard at three equilibrium moisture content levels. Regression curves describe boards made from 0.020- by random by 3-inch Douglas-fir disk flakes.

given for each flake type in Table 3. While the relationship between TS and MC has been shown to be curvilinear over the range of OD to saturation (8), it may be roughly approximated by a straight line for MC's less than 16 percent associated with exposures less than or equal to 90 percent RH. Regression equations derived from the combined 30, 50, and 90 percent RH data (Table 3) are used to show the effect of MC on TS on a 0.020- by random by 3-inch flake type board for several levels of SG (Fig. 2). Equilibrium MC's derived from equations in Table 2 are shown. At any one level of MC, TS was greatest in the boards with the highest SG. However, at any one level of environmental exposure, TS was less in the high-SG boards.

The coefficient of determination (R^2), mean square error (MSE), and coefficient p values (level of significance of individual coefficients) have been determined for equations at all RH levels (Table 3). The low p values indicate that the variables of MC and SG are significant at low levels. Poorer significance (higher p values) of both variables may be due to the high correlation (multicollinearity) that exists between MC and SG. As an example, in the case of the 0.045-inch-thick oak flakeboard at 90 percent RH, MC is highly significant if used as the sole variable to define TS. Increased variability of the data with increasing MC is shown by the progressively larger MSE values from low- to high-RH exposure levels. Mean square errors for the combined data equations are an average of the MSE's for the individual RH exposures and do not adequately define the increasing variability.

Likewise, R^2 values are not given for the combined set of data. The low MC levels resulting from exposure to 30 and 50 percent RH are relatively distant from the MC's obtained at 90 percent RH. Combination of these

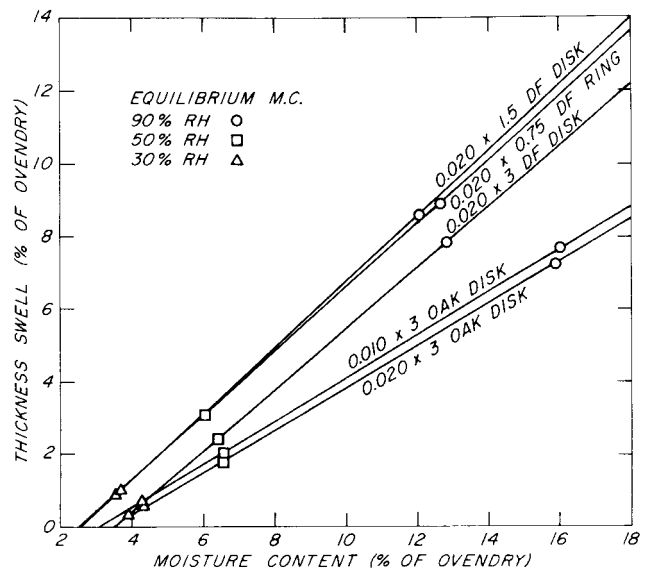


Figure 3. - Thickness swelling of five flakeboard types (DF=Douglas-fir) at three equilibrium moisture content levels as determined from regression equations. Target specific gravity was 0.75.

groups results in a situation similar to regressing a straight line between two points, producing R^2 values that are artificially inflated.

An analysis of covariance showed that in most cases the data describing the effect of MC and SG on TS were significantly different for each flake type. Notable is the difference between the oak and Douglas-fir disk-cut flakes. Boards made from the oak disk-cut flakes adsorb more water but swell less than do those made from Douglas-fir (Fig. 3). The thick (0.045 in.) oak ring-cut flakes showed both high moisture adsorption and high TS at 90 percent RH. Regression curves describing TS for the grouped data for that flake were not computed because the average MC at 90 percent RH was above 16 percent.

Saturation.—Between exposures of 90 and 100 percent RH, equilibrium MC and TS changed considerably and at different rates. Fiber saturation MC will vary with flake type and SG but has been shown to be between 20 and 30 percent (15,16). Considerable unrecoverable TS occurs during exposure to these high MC conditions.

A fully saturated board shows maximum TS. Under these conditions, TS can be approximated with good reliability using SG as a single predictor. Thickness swelling increased with an increase in board SG (Table 3, VPS). The volume of void space relative to that of solid wood, as mentioned previously, becomes less as board SG increases. Consequently, during a VPS treatment, total water absorbed (expressed as a percentage of OD weight) becomes less as board SG increases (Fig. 4).

Springback

Springback is defined for this study as the TS remaining in a board exposed to a VPS treatment and

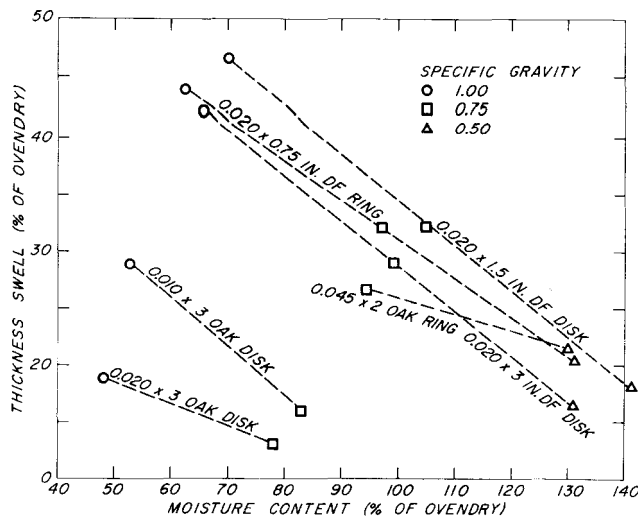


Figure 4. — Relationship of specific gravity to thickness swell of five flakeboard types (DF=Douglas-fir) exposed to a vacuum-pressure soak treatment.

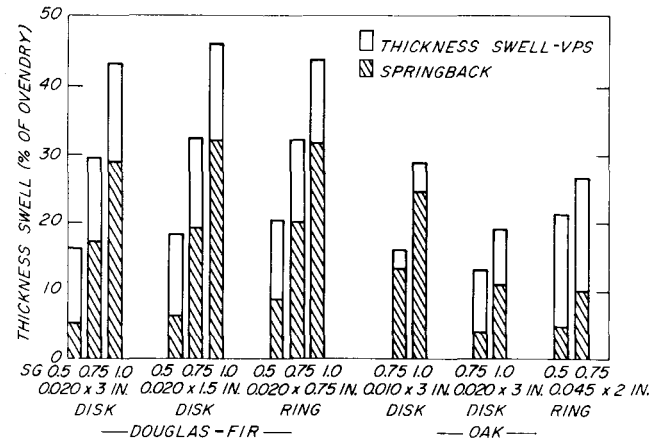


Figure 5. — Thickness swell and springback following a vacuum-pressure soak treatment.

TABLE 4. — Exponents for equations relating linear expansion to flake alignment^a and either moisture content or specific gravity, $LE = e^{SVR^{\beta}MC^{\lambda}SG^{\alpha}}$.

Condition	Exponents ^b and parameters	Flake size and type					
		Douglas-fir				Oak	
		0.020×3 Disk	0.020×1.5 Disk	0.020×0.75 Ring	0.010×3 Disk	0.020×3 Disk	0.045×2 Ring
30% RH	μ	-3.47	-3.23	-1.71	-3.73	-3.40	-4.10
	β	-0.86	-0.84	-0.44	-1.06	-1.11	-1.00
	λ	1.12	0.90	-0.14	1.32	1.23	1.82
	R^2	80	75	12	78	80	93
50% RH	μ	-3.53	-2.05	-0.68	-3.11	-2.84	-4.96
	β	-1.04	-0.93	-0.74	-1.16	-1.33	-1.09
	λ	-1.07	0.19	-0.43	0.95	0.86	1.99
	R^2	84	79	47	86	92	95
90% RH	μ	-1.66	-1.74	-1.42	-2.50	-1.60	-1.40
	β	-1.40	-1.33	-1.07	-1.81	-1.76	-1.69
	λ	0.18	0.11	0.15	0.59	0.35	0.27
	R^2	89	87	58	94	93	94
Combined 30-50-90 % RH	μ	-2.88	-2.69	-2.62	-2.94	-2.90	—
	β	-1.13	-1.03	-0.83	-1.36	-1.41	—
	λ	0.68	0.51	0.62	0.78	0.84	—
	R^2	90	88	87	93	80	45
VPS ^c	μ	-0.75	-1.01	-0.42	-0.66	-0.46	-1.07
	β	-1.57	-1.53	-1.31	-2.07	-1.75	-1.23
	α	0.44	0.49	0.68	0.33	-0.33	0.41
	R^2	90	88	87	93	80	45

^aFlake alignment is described in terms of sonic velocity ratio (SVR) where percent alignment = $75.8 (\ln SVR)$.

^bSG is not an independent variable in relative humidity (RH) equations; MC is not an independent variable in VPS equations.

^cVPS = Vacuum-pressure soak treatment.

reconditioned to an OD state. This unrecoverable, or plastic, deformation is the partial release of deformation of the wood (compression set) which occurred during the hot-pressing process. The release of compression set accounts for nearly all of the difference in TS caused by changes in SG for boards exposed to a VPS

condition (Table 3; Fig. 5). Springback averaged 30 percent of the VPS thickness swelling in a 0.5 SG board and increased to 60 percent at 1.0.

In this study, flake alignment had very little influence on the TS property. No definite trends or improvement in correlation could be obtained when

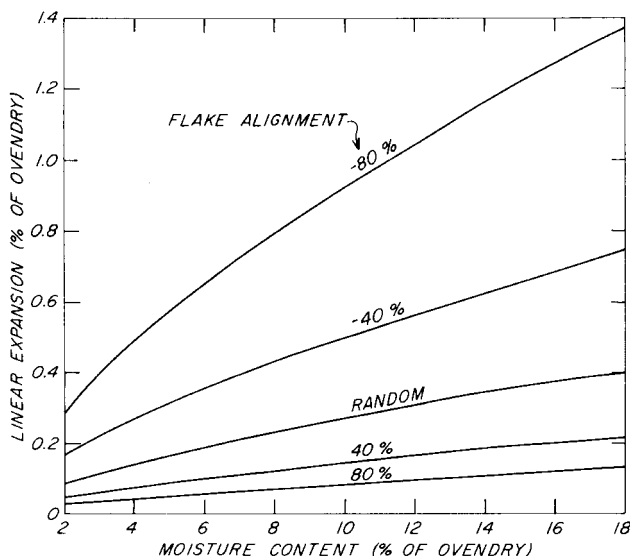


Figure 6. — Variation in linear expansion with moisture content and flake alignment. Regression curves describe boards made from 0.020- by random by 3-inch Douglas-fir disk-cut flakes.

alignment was incorporated into the multiple regression analysis.

Linear expansion

Linear expansion (LE) varied exponentially with flake alignment (2). The equation format found to best describe the data was similar to that used earlier to predict bending, tensile, and interlaminar shear properties (3).

$$LE = e^{\mu}(SVR)^{\beta}(MC)^{\alpha}(SG)^{\nu} \quad [4]$$

where LE = linear expansion, percent of OD dimension
SVR = sonic velocity ratio

Exponents for regression equations relating LE to flake alignment and MC are given for the various RH levels in Table 4. Because of the strong effect of both alignment and MC, incorporation of the SG variable did not appreciably improve the equations. The relationship between LE, MC, and flake alignment for the combined 30, 50, and 90 percent RH data of the 3-inch Douglas-fir flakeboard is shown in Figure 6. The rate of change of LE with any MC change decreased at the higher MC's. This may be a result of the same time-related MC and TS equilibrium phenomena referred to earlier.

As with TS, LE of flakeboard exposed to VPS conditions is not dependent on total moisture absorption. Regression relationships describing the effect of flake alignment on LE at VPS exposures, however, were improved with incorporation of the SG variable (Table 4). The equations are used to show how LE of flakeboard made from 0.020-inch by random by 3-inch Douglas-fir disk-cut flakes changed with board SG and flake alignment (Fig. 7). The same relationship was derived in a previous study (2) for various types of flakeboards all

having a normal density gradient and average board SG of 0.640.

Consistent relationships describing the effect of SG and flake alignment on LE following reconditioning to an OD state were not obtained.

Prediction

The developed regression equations for the various exposure conditions (Tables 2, 3, and 4) were used in conjunction with density gradient data to predict MC, TS, and LE of the control boards. Prediction values were calculated as a summation of the values for each layer weighted for layer thickness. Prediction accuracy based on measured values is given in Table 5. Linear expansion data for the 50 percent RH control boards were incorrectly recorded and are not reported here.

Moisture content was predicted with reasonable accuracy. Thickness swelling predictions shown in Table 5 were calculated using these predicted MC values. When actual measured MC values were used in place of calculated MC values, TS predictions improved. Use of the combined 30-50-90 percent RH equations resulted in lower predicted TS values for the 30 percent RH condition, higher values for the 50 percent RH condition, and approximately the same values for the 90

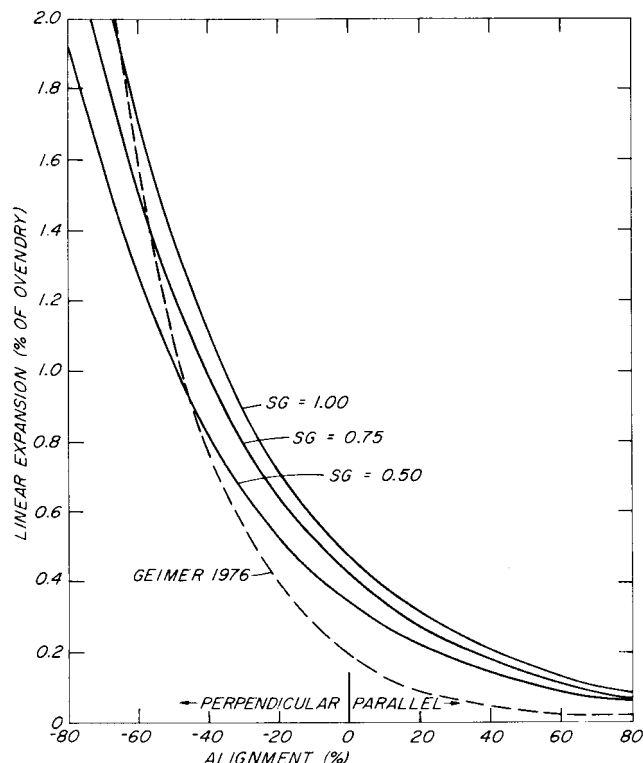


Figure 7. — The effect of flake alignment and specific gravity on linear expansion in a saturated board for a 0.020- by random by 3-inch Douglas-fir disk-cut flake type. Dotted line describes data from previous report (2). Average board specific gravity = 0.640.

TABLE 5. — Control board prediction values as percent of measured values.

Exposure	Test direction	Flake size and type						
		Homogeneous boards ^a			Three-layer boards ^b			
		3-in. disk	1.5-in. disk	0.75-in. ring	Random/random	Aligned/random	Aligned/aligned	Aligned/cross-aligned
Moisture content								
30% RH		98	92	86	83	84	86	85
50% RH		103	98	94	89	91	88	91
90% RH		86	101	108	108	105	105	104
VPS ^c		126	121	106	110	118	111	111
Thickness swell								
30% RH		70	100	84	88	95	93	84
50% RH		82	96	84	83	84	79	81
90% RH		68	105	117	118	112	109	105
VPS		120	120	111	115	118	117	120
Linear expansion								
30% RH	Random	127	108	85	120	—	—	—
	Parallel	102	87	118	—	123	92	114
	Perpendicular	126	62	85	—	83	91	105
90% RH	Random	174	160	115	136	—	—	—
	Parallel	113	180	127	—	185	161	202
	Perpendicular	98	67	112	—	109	121	121
VPS	Random	173	160	108	144	—	—	—
	Parallel	92	166	117	—	209	175	220
	Perpendicular	127	77	105	—	102	124	128

^aHomogeneous boards were made in both random and aligned configurations. Thickness swell (TS) values were determined for each homogeneous board type as an average of both random and aligned boards.

^bThree-layer boards were made using 1.5-in. Douglas-fir disk flakes in the faces and 0.75-in. Douglas-fir flakes in the core. Alignments are indicated for face and core, respectively. Alignment averaged 70% for the face flakes and 15% for the core flakes.

^cVPS = Vacuum-pressure soak treatment.

percent RH conditions, compared to the values in Table 5. The differences result from the use of a straight-line regression to approximate a curvilinear relation.

Linear expansion predictions are all quite variable. Prediction of this property is quite complex and has been related to modulus of elasticity of the wood as measured in both the parallel- and perpendicular-to-grain direction (10) and to the stress at proportional limit in lateral compression (18). No attempt was made in this study to proceed with an analysis beyond the direct type of comparisons given above.

Conclusions

Regression equations defining linear expansion (LE) and thickness swell (TS), at several controlled environmental conditions in terms of specific gravity (SG) and flake alignment, were developed for various flake types using data from boards made with a uniform density through the thickness plane.

At exposure conditions resulting in moisture contents below fiber saturation, it was necessary to establish the relationship between board SG and MC to predict dimensional stability properties because equilibrium MC and equilibrium dimensional stability are independently time-related to SG and they vary with flake type and exposure conditions. At any one level of MC, TS became greater as board SG increased. Equilibrium MC, however, as defined by the criteria used in this study, decreased at all exposure conditions as board SG increased. Consequently, the TS measured

at the time equilibrium MC was reached was less in the high-SG boards.

Dimensional movement resulting from a vacuum-pressure soak treatment is maximum and can be defined as a function of board SG without considering MC. Total water absorbed is dependent on the ratio of void volume to solid wood and is greater in low-SG boards. The increase in TS that occurred in saturated boards when board SG was increased is attributed mainly to the release of compression set and was greater in high-density boards.

Flake alignment had little effect on TS but was the major variable controlling LE. In exposure conditions of 90 percent RH or less, board SG affects LE mainly through its effect on equilibrium MC. Inclusion of the SG variable in regression equations defining LE in a saturated condition, however, increases the reliability of prediction.

Using the developed equations, TS and MC of hot-pressed boards with a normal density gradient were predicted with reasonable accuracy. Linear expansion predictions were quite variable. Linear expansion is a function of many board mechanical properties and must be analyzed in greater depth.

The regression equations defined herein are peculiar to the manufacturing techniques and testing variables used in this study. Any changes in these conditions, especially the criteria for defining equilibrium MC and equilibrium dimensional stability, may alter the derived equations.

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