TECHNICAL SERVICES DIVISION

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Dimensional Stability of Structural-Use Panels

by

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INTRODUCTION

Plywood, waferboard, and oriented strand board (OSB) are wood-based structural-use panels that are widely used where a dimensionally stable surface is required. The dimensional stability of these wood-based panels depends upon inherent panel characteristics and the severity of the change in moisture conditions. Excessive dimensional changes due to moisture exposure may adversely affect the overall performance of structural-use panels. Therefore, dimensional stability is an important consideration when making engineered application recommendations for these structural-use panels.

Research conducted by the American Plywood Association has evaluated dimensional stability of structural-use panels in response to changing moisture conditions. The primary goal of various research studies was to develop a basis for estimating the dimensional change of wood-based panels exposed to the changing moisture conditions that exist during the service life of wood panels.

BACKGROUND

Plywood, oriented strand board and waferboard are used in structural applications in both residential and nonresidential markets. Regardless of the market, these structural panels are exposed to changing moisture conditions during the construction and in-service phases of the application. The dimensional response of the panel depends upon the change of moisture conditions and the dimensional stability characteristics of the wood-based panel.

Researchers and plant quality control programs typically evaluate dimensional characteristics of structural-use panels with standard moisture exposures such as the ASTM 50-90% relative humidity cycle (2)*, the oven-dry/vacuum-pressure-soak cycle (1) or the wet-one-side moisture cycle (1). These moisture cycles are most often used for comparing panels to acceptance criteria in product or performance standards.

The utility of standard moisture cycles in predicting dimensional stability is governed by how well the effects of specific moisture cycles relate to those in-service. The humidity moisture cycle detailed in ASTM Test Method D-1037 evaluates dimensional change from 50 to 90% relative humidity and is intended to simulate near-worst humidity variations which may occur during a panel's service life. The oven-dry/vacuum-pressure-soak moisture cycle evaluates the total possible dimensional change from oven dry to complete saturation. While the test method does not represent in-service conditions, it is an expedient test useful for characterizing relative dimensional stability. The wet-one-side moisture cycle involves two weeks of wetting of one surface with water spray to simulate rain exposure typical of exterior exposure. Unlike most moisture cycles this method does not utilize steady state equilibrium moisture conditions. Instead, the wet-one-side method simulates a harsh moisture condition which can occur in actual applications (3).

* Numbers in parenthesis refer to literature cited.

Recent studies by the American Plywood Association evaluated the linear expansion (LE) and thickness swell (TS) of structural wood panels in response to a variety of service moisture conditions. Humidity changes through the entire moisture absorption spectrum were used to evaluate dimensional changes relative to the total possible change measured by the oven-dry/vacuum-pressure-soak cycle used in the APA quality assurance program. Relative linear expansion (RLE) and relative thickness swell (RTS), both as a function of humidity exposure, were determined as a percentage of the total potential change from oven dry to soak conditions. One-sided wetting was used to evaluate dimensional changes from field wetting. The studies produced results that provide a basis for estimating the dimensional change in plywood or nonveneer panels due to typical moisture changes that exist during the service life of wood panels.

TEST METHOD

A representative selection of commercially manufactured plywood and nonveneer panels were sampled at the APA Research Center in Tacoma, Washington. Table 1 in the Appendix presents a description of panel types tested. All specimens within a panel configuration were from a single lot from a single mill. At least two replications of each panel were tested. Two 6 x 24-inch specimens were cut from each panel replication for humidity absorption; one with the 24-inch direction parallel and one with the 24-inch direction perpendicular to the long axis of the 4 x 8-ft panel. One 48 x 48-inch specimen was cut from each panel type for one-sided wetting exposure.

The length, thickness and weight of each humidity absorption specimen was evaluated at equilibrium to each of the following conditions:

1) Oven dry at 217°F
2) 14% RH at 85°F
3) 30% RH at 85°F
4) 50% RH at 70°F
5) 65% RH at 68°F
6) 90% RH at 73°F
7) VPS (Submersion under 65°F water, 27-inch mercury vacuum for 1 hour and atmospheric pressure for 2 hours)
8) Oven dry at 217°F

Practical equilibrium was achieved when the weight change was less than 0.1 percent over a 24-hour period. After this practical equilibrium was reached at one condition, the specimen dimensions were reevaluated prior to exposure at the subsequent condition. The length was measured between brass eyelets located one inch from each end of the panel specimen. Thickness was measured at the edge of each panel and also 3 inches from the edge on nonveneer panels.

The panels for one-sided wetting exposure were vertically mounted in a spray chamber and were continuously sprayed with water on one surface only. The spray wetted the entire surface and water was allowed to drain from the bottom edge. The back side was not exposed to the water spray but was exposed to the high humidity in the partially enclosed spray chamber. The moisture content was monitored over time. The thickness swell of the nonveneer panels was monitored at the edge and 3 inches from the edge.

RESULTS AND DISCUSSION

Linear expansion (LE) was calculated from the percent length increase from the oven-dry condition. Thickness swell (TS) was calculated from the percent increase from the oven-dry condition. Moisture content at each condition was calculated as a percent weight increase over the oven-dry weight. The relative LE (RLE) and relative TS (RTS) at each humidity condition were calculated as a percentage of total possible LE and TS as measured from the oven-dry to vacuum-pressure-soak cycle. Calculations used are as follows:

$$LEn = 100 * (Ln - Ld)/Ld$$
$$TSn = 100 * (Tn - Td)/Td$$
$$MCn = 100 * (Wn - Wd)/Wd$$
$$RLEn = 100 * LEn/LEo$$
$$RTSn = 100 * TSn/TSo$$

Where:

Ln, Ld = Length at condition n and oven-dry, respectively, (in.)
LEn, LEo = Linear expansion at condition n and at soaked condition, respectively, (%)
Tn, Td = Thickness at condition n and oven-dry, respectively, (in.)
TSn, TSo = Thickness swell at condition n and soaked condition, respectively, (%)
Wn, Wd = Weight at condition n and oven-dry, respectively, (g)
MCn = Moisture content at condition n, (%)
RLEn = Relative linear expansion at condition n, (%)
RTSn = Relative thickness swell at condition n, (%)

The moisture content, linear expansion and thickness swell results at each relative humidity condition are presented in Table 2 for all panel types. Thickness swell of nonveneer panels exposed to humidity is presented only for measurements taken at the edge since there was little or no difference between measurements at the edge and 3 inches from the edge.

The moisture content, thickness and edge swell after wetting exposure is presented in Table 3.

HUMIDITY EXPOSURE

When unexposed to liquid water, panel moisture content depends upon relative humidity and to a lesser extent upon temperature. The moisture absorption results of plywood and nonveneer panels exposed to humidity at 70°F are presented in Figure 1 along with results for solid wood (7).

Since isothermal conditions were not used during the entire absorption cycle, the actual data was adjusted to 70°F using the following adjustment found applicable to data generated for solid wood (7). Even the largest temperature adjustment resulted in only a minor change in moisture content. The maximum adjustment resulted in a change in MC from 4.62% to 4.69%.

$$MC = MC\ (t=70) * (1 + .001 * (70 - t))$$

Where:

MC = Moisture content at temperature t (%)

MC (t=70) = Moisture content at 70°F (%)

t = Temperature (°F)

The moisture absorption characteristics of plywood and nonveneer panels exposed to humidity differ from solid wood due to physical and chemical modifications of the wood which occur during the panel manufacturing process. Researchers have established that high temperatures and other processes used during manufacturing modify the sorption characteristics of the wood in plywood and nonveneer panels (4). Nonveneer panels experience higher processing temperatures and more extensive wood processing than plywood. Therefore, they equilibrate to lower moisture contents at identical humidities.

Linear Expansion

The linear expansion of plywood and nonveneer panels depend upon the change in moisture content and upon inherent panel properties. Panel properties are affected by manufacturing variables such as wood species, flake orientation or veneer layup, panel density, etc. Although the absolute expansion varied among the panels tested, the relative linear expansion (RLE) as a percent of total expansion from oven-dry to vacuum-pressure-soak was relatively constant between all panel types at any moisture content. The relative linear expansion depended upon panel moisture content as shown in Figure 2. Regardless of panel type or the amount of linear expansion from oven-dry to vacuum-pressure-soak, the relation between moisture content and panel expansion was relatively constant. The bulk of linear expansion occurring predominately at lower moisture contents.

The interaction of moisture on dry wood is greater than the interaction on wood at higher moisture contents (6). The linear expansion test results followed this general theory and the effect of moisture on linear expansion was greater on dry panels. At lower moisture contents, the moisture has a greater swelling effect on the wood.

The increased swelling effect of moisture on very dry panels can influence the service performance of the panel. Plywood and nonveneer panels are usually produced and distributed at moisture content levels below those of field conditions. Field conditions can include extended exposure to humidity above 80% or high moisture conditions from rain exposure during construction. Field observations have shown that most panel expansion problems are a result of the moisture increase after installation as the panel moisture content increases to ambient humidity conditions or from elevated moisture conditions from rain exposure. Panel installation at low moisture content can adversely affect service performance due to increased swelling effects of moisture at lower moisture conditions.

Some panel manufacturers use moisturizing processes after pressing to increase panel moisture content prior to shipping. Typical panel moisture contents after pressing are 5% for plywood and 2% for nonveneer panels. A moisture content increase of the panel at this point relieves an unproportionally large amount of panel expansion. Some manufacturers have reported reductions in field problems after implementation of moisturizing processes used to increase panel moisture content prior to shipping.

The sensitivity between moisture content and linear expansion in the lower moisture contents can adversely affect performance or it can improve performance. Panels installed at low moisture contents, below those typical of in-service conditions, rapidly expand through a large portion of the total range of potential expansion. Such cases may result in poor performance. However, panels which have moisture contents near those typical of service conditions are less affected by moisture changes.

Thickness Swell

The thickness swell of plywood and nonveneer panels depended upon the change in moisture content and upon production variables and inherent panel properties. Research has shown that plywood swell is slightly greater than the normal swell of the solid wood species used, the difference attributed to minor compression set that is released during wetting (8). The thickness swell of nonveneer panels depends upon a wide variety of production variables and is complicated by the compression set caused by wood densification during pressing and the increase of interparticle voids which occurs during swelling (4, 5).

Regardless of the total amount of swelling from humidity exposure between oven-dry and vacuum-pressure-soak conditions, the relative thickness swelling (RTS), as a percent of total expansion from oven-dry to soak, is related to moisture content as shown in Figure 3. Despite the panel type and the amount of swell from oven-dry to soak, the relation between moisture content and RTS is nearly linear between oven-dry and water saturated conditions.

WATER EXPOSURE

Figure 4 presents the moisture absorption results from one-sided water exposure of all panels.

Exposure to water significantly affected panel moisture content. Moisture absorption occurred rapidly when plywood and nonveneer panels were exposed to one-sided wetting. There were differences in the initial rate of absorption between plywood and nonveneer panels, probably due to differences in capillarity and liquid permeability of the panel face. Nonveneer panel production uses higher pressures and temperatures that caused densification of the wood. The wood near the surfaces were especially densified (4). The densified surfaces and the wax additives typically used in nonveneer panels imparted short-term resistance to liquid water absorption on the panel face.

Water absorption of wood panels depends on manufacturing variables. Differences between nonveneer panel manufacturers were probably due to differences in production variables such as species, particle geometry, resin type and content, wax content and panel density. Differences between plywood types were primarily dependent upon permeability of the species. This study provided only a preliminary examination of effects of one-sided wetting and involved only a narrow range of thickness. The influence of panel thickness and other variables warrant further study.

Figure 5 presents thickness swell results of nonveneer panels exposed to one-sided wetting. As with water absorption, these results depended upon manufacturing variables. Although differences between producers were evident, there were common trends. Thickness swell measured at the edge was always greater than swell measured 3 inches in from the edge. Increased capillarity at the edge caused more rapid moisture absorption. In some cases, swell 3 inches in from the edge approached or started to converge with swell at the edge. In other cases, there was no apparent convergence after 72 hours.

CONCLUSION

The moisture sorption relations developed in this study provide a basis for estimating in service panel moisture content. When unexposed to water the panel moisture content can be estimated from the ambient humidity and temperature conditions. Exposure to rain causes a time-dependent moisture content increase in panels. Results of this study provide a means to estimate the moisture content increase after limited one-sided wetting or from humidity exposure.

This study also evaluated the relative linear expansion and relative thickness swell caused from moisture increases from humidity conditions between oven-dry and saturation. Regardless of panel types, there was a consistent relation between moisture content and relative linear expansion. A high proportion of linear expansion occured at lower panel moisture contents. The relation between moisture content and thickness swell, also consistent between the various panel types tested, was approximately linear between oven-dry and soaked conditions.

Results of this study combined with dimensional stability data collected from oven-dry to vacuum-soak conditions permit approximation of panel linear expansion or thickness swell due to changes in humidity or due to one-sided water exposure. Panel moisture content can be estimated from humidity or water exposure. The change in relative linear expansion or relative thickness swell can be estimated from relations developed from this study. When the total linear expansion or thickness swell is known from oven-dry to soak conditions, the relative dimensional change can be converted into actual dimensional change. The results of this study expand the usefulness of dimensional stability data from being strictly a quality assurance tool, to being a tool for developing design and application recommendations.

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TABLE 1. LIST OF PANELS TESTED FOR DIMENSIONAL STABILITY

Panel	Description
P-1	15/32-inch Douglas-fir plywood
P-2	1/2-inch Douglas-fir plywood
P-3	19/32-inch Douglas-fir plywood
P-4	15/32-inch southern pine plywood
P-5	19/32-inch southern pine plywood
P-6	15/32-inch southern pine plywood
N-1	3/8-inch softwood oriented waferboard
N-2	7/16-inch aspen waferboard
N-3	7/16-inch softwood OSB
N-4	7/16-inch aspen OSB
N-5	7/16-inch aspen oriented waferboard
N-6	7/16-inch softwood OSB
N-7	15/32-inch aspen OSB

TABLE 2. DIMENSIONAL STABILITY DATA OF PLYWOOD PANELS TESTED AFTER HUMIDITY EXPOSURE

RH	Property	Plywood Panels Tested (all property values are in percent) P1	P2	P3	P4	P5	P6	avg.
14	MC	1.70	1.62	1.70	1.80	1.78	1.80	1.73
	LE along	.05	.04	.05	.06	.04	.04	.05
	LE across	.06	.04	.04	.04	.06	.04	.05
	TS	.23	.20	.30	.43	.28	.25	.28
	RLE along	18.99	25.17	20.97	22.30	15.66	19.00	20.10
	RLE across	28.00	18.72	21.50	13.33	14.36	16.17	17.77
	RTS	3.11	2.77	4.88	5.44	3.15	2.92	3.67
30	MC	4.47	4.24	4.65	4.87	4.80	4.70	4.62
	LE along	.12	.10	.12	.16	.14	.13	.13
	LE across	.11	.10	.11	.13	.16	.13	.12
	TS	.97	.82	.75	.90	.94	1.00	.90
	RLE along	46.51	63.58	49.60	55.05	55.42	63.50	54.70
	RLE across	56.00	49.75	55.50	48.15	40.55	48.12	48.37
	RTS	13.11	11.36	12.20	11.39	10.59	11.70	11.67
50	MC	6.77	6.38	6.90	7.47	7.42	7.20	7.02
	LE along	.15	.11	.16	.20	.18	.16	.16
	LE across	.15	.13	.15	.18	.22	.17	.17
	TS	1.63	1.38	1.45	1.47	1.68	1.70	1.55
	RLE along	58.14	74.17	64.52	70.38	71.08	77.50	68.63
	RLE across	73.00	66.50	74.00	66.30	55.92	64.29	65.17
	RTS	22.03	19.11	23.58	18.61	18.92	19.88	20.20
65	MC	8.63	8.34	8.75	9.70	9.64	9.50	9.09
	LE along	.18	.13	.19	.23	.20	.18	.18
	LE across	.16	.16	.17	.21	.26	.20	.19
	TS	2.23	2.18	2.00	2.20	2.44	2.55	2.27
	RLE along	68.60	86.09	74.60	80.49	81.12	87.50	78.97
	RLE across	82.00	77.83	84.50	77.04	65.24	75.56	75.46
	RTS	30.14	30.19	32.52	27.85	27.48	29.82	29.50
90	MC	18.73	18.30	18.65	20.50	19.96	20.05	19.36
	LE along	.22	.14	.23	.26	.23	.18	.21
	LE across	.19	.20	.19	.25	.36	.24	.24
	TS	6.77	6.38	5.25	7.17	7.38	7.50	6.74
	RLE along	85.66	93.38	92.34	92.33	91.16	92.00	90.95
	RLE across	94.00	96.55	95.50	91.11	91.18	90.98	92.77
	RTS	91.49	88.37	85.37	90.76	83.11	87.72	87.74
SOAK	MC	30.00	30.00	30.00	30.00	30.00	30.00	30.00
	LE along	.26	.15	.25	.29	.25	.20	.23
	LE across	.20	.20	.20	.27	.40	.27	.26
	TS	7.40	7.22	6.15	7.90	8.88	8.55	7.68

TABLE 3. DIMENSIONAL STABILITY DATA OF WAFERBOARD AND OSB PANELS TESTED AFTER HUMIDITY EXPOSURE

Waferboard and OSB Panels Tested
(all property values are in percent)

RH	Property	N1	N2	N3	N4	N5	N6	N7	avg.
14	MC	1.20	1.20	1.20	1.30	.80	1.10	1.10	1.10
	LE along	.02	.03	.03	.02	.01	.03	.02	.02
	LE across	.03	.05	.04	.04	.01	.03	.01	.03
	TS	.50	.50	.10	.20	.20	.30	.10	.27
	RLE along	8.33	11.54	12.50	10.53	5.00	10.71	9.52	9.73
	RLE across	8.11	13.89	8.00	9.30	2.78	4.76	3.70	7.22
	RTS	1.27	1.36	.59	1.02	.57	1.26	.34	.91
30	MC	2.20	2.20	2.20	2.20	1.60	2.10	1.80	2.04
	LE along	.07	.07	.07	.05	.03	.05	.05	.06
	LE across	.07	.11	.11	.11	.06	.11	.05	.09
	TS	1.10	.60	.20	.80	1.00	.80	.10	.66
	RLE along	29.17	26.92	29.17	26.32	15.00	17.86	23.81	24.03
	RLE across	18.92	30.56	22.00	25.58	16.67	17.46	18.52	21.39
	RTS	2.78	1.63	1.18	4.06	2.83	3.35	.34	2.31
50	MC	5.50	5.60	5.60	5.70	4.50	5.10	4.60	5.23
	LE along	.13	.15	.16	.12	.09	.14	.10	.13
	LE across	.19	.22	.29	.28	.16	.29	.13	.22
	TS	4.40	3.20	1.70	2.50	3.70	2.90	2.80	3.03
	RLE along	54.17	57.69	66.67	63.16	45.00	50.00	47.62	54.90
	RLE across	51.35	61.11	58.00	65.12	44.44	46.03	48.15	53.46
	RTS	11.14	8.72	10.06	12.69	10.48	12.13	9.52	10.68
65	MC	7.30	7.20	6.90	7.20	6.20	6.60	6.50	6.84
	LE along	.16	.17	.19	.14	.12	.17	.12	.15
	LE across	.25	.28	.35	.34	.25	.38	.18	.29
	TS	5.90	4.60	2.60	3.20	5.30	3.80	3.70	4.16
	RLE along	66.67	65.38	79.17	73.68	60.00	60.71	57.14	66.11
	RLE across	67.57	77.78	70.00	79.07	66.67	60.32	66.67	69.72
	RTS	14.94	12.53	15.38	16.24	15.01	15.90	12.59	14.66
90	MC	18.40	17.50	15.80	18.60	17.20	17.10	15.70	17.19
	LE along	.23	.23	.23	.18	.18	.25	.18	.21
	LE across	.30	.32	.42	.38	.31	.52	.22	.35
	TS	28.10	24.90	11.40	14.80	24.60	16.80	18.00	19.80
	RLE along	95.83	88.46	95.83	94.74	90.00	89.29	85.17	91.41
	RLE across	81.08	88.89	84.00	88.37	86.11	82.54	81.48	84.64
	RTS	71.14	67.85	67.46	75.13	69.69	70.29	61.22	68.97
SOAK	MC	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
	LE along	.24	.26	.24	.19	.20	.28	.21	.23
	LE across	.37	.36	.50	.43	.36	.63	.27	.42
	TS	39.50	36.70	16.90	19.70	35.30	23.90	29.40	28.77

TABLE 4. PLYWOOD, WAFERBOARD AND OSB DATA AFTER EXPOSURE TO ONE-SIDED WETTING.

Exposure Time	Property	Panel (all property values are in percent) N1	N2	N4	N5	N6
0 hr.	MC	2.7	4.0	5.7	3.5	4.6
3 hr.	MC	4.8	7.4	8.6	7.4	21.6
	TS edge	8.9	7.4	5.5	8.1	21.8
	TS interior	3.2	3.8	3.4	4.7	6.4
7.5 hr.	MC	6.1	7.8	10.9	7.1	34.6
	TS edge	9.6	7.2	6.5	8.4	24.6
	TS interior	3.5	2.5	2.8	5.3	14.6
24 hr.	MC	8.7	10.2	16.4	16.1	58.5
	TS edge	15.9	14.2	11.2	13.9	27.4
	TS interior	5.8	5.1	4.5	9.5	24.9
48 hr.	MC	11.5	12.6	20.8	23.4	70.6
	TS edge	21.5	17.9	16.0	35.1	29.2
	TS interior	7.7	4.5	7.1	13.6	29.4
72 hr.	MC	13.6	13.7	25.4	28.7	76.5
	TS edge	20.1	21.8	16.9	38.1	29.8
	TS interior	12.2	5.2	9.6	17.1	30.6

Exposure Time	Property	Panel P1	P2	P4	P6
0 hr.	MC	7.8	6.2	8.2	6.7
1 hr.	MC	12.9	10.3	24.4	23.6
2.3 hr.	MC	15.8	14.4	26.5	28.4
4.8 hr.	MC	18.8	14.4	30.8	32.1
6 hr.	MC	21.0	16.4	32.9	35.2
10.5 hr.	MC	24.9	18.5	34.0	39.7
23 hr.	MC	32.8	25.8	43.2	38.8
47 hr.	MC	41.6	30.3	51.9	61.9

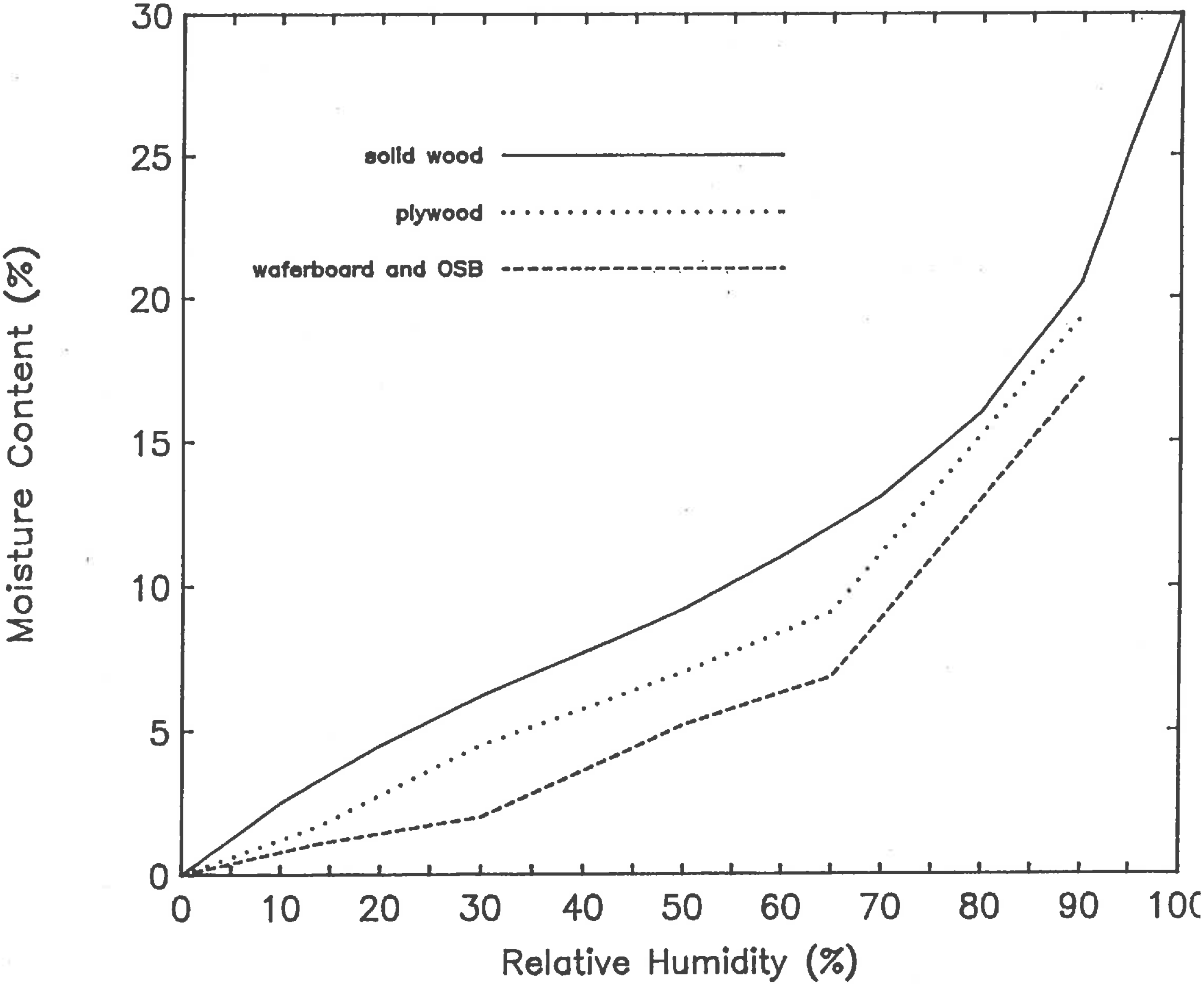

Figure 1. Panel Moisture Content as a Function of Relative Humidity.

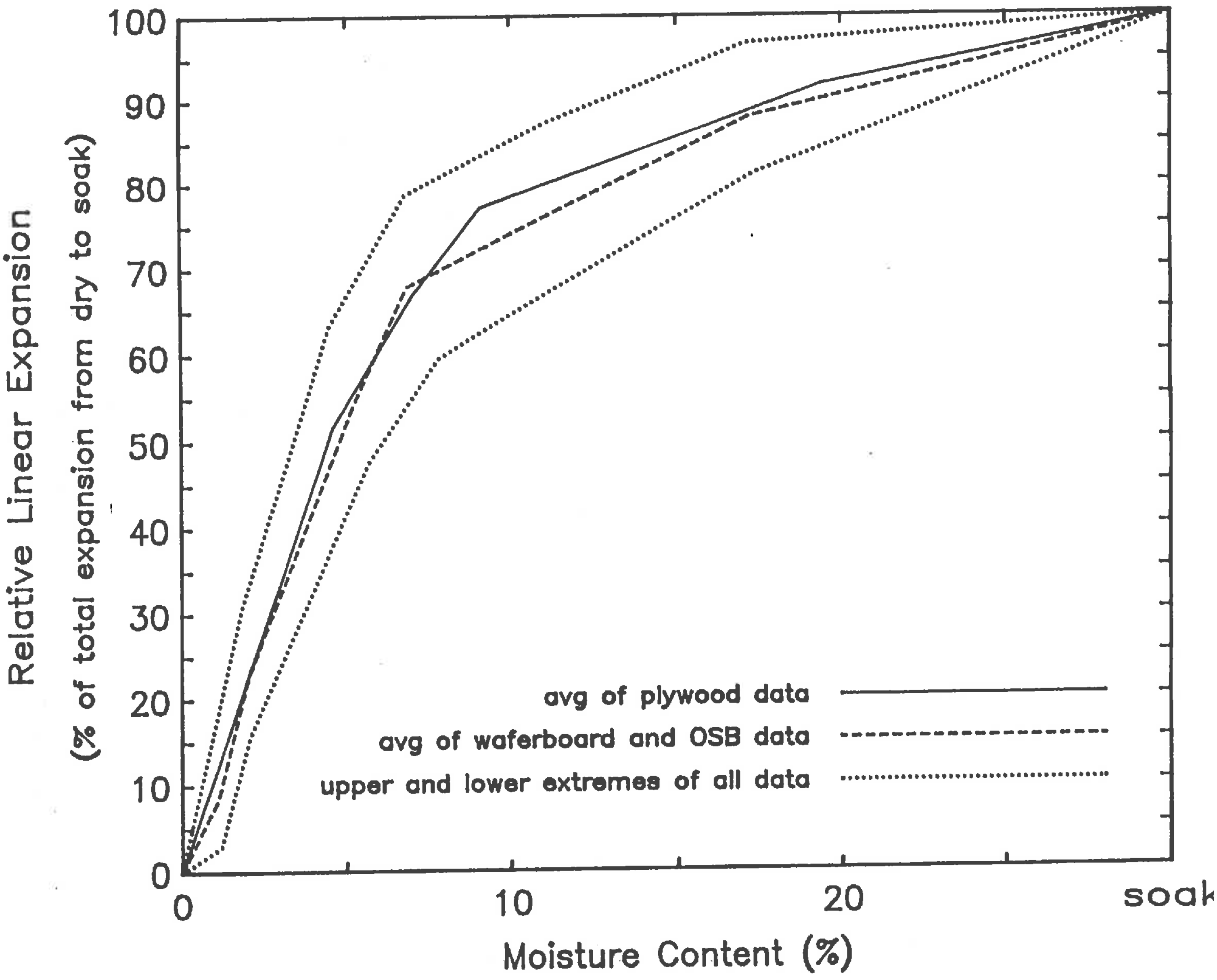

Figure 2. Relative Linear Expansion as a Function of Panel Moisture Content.

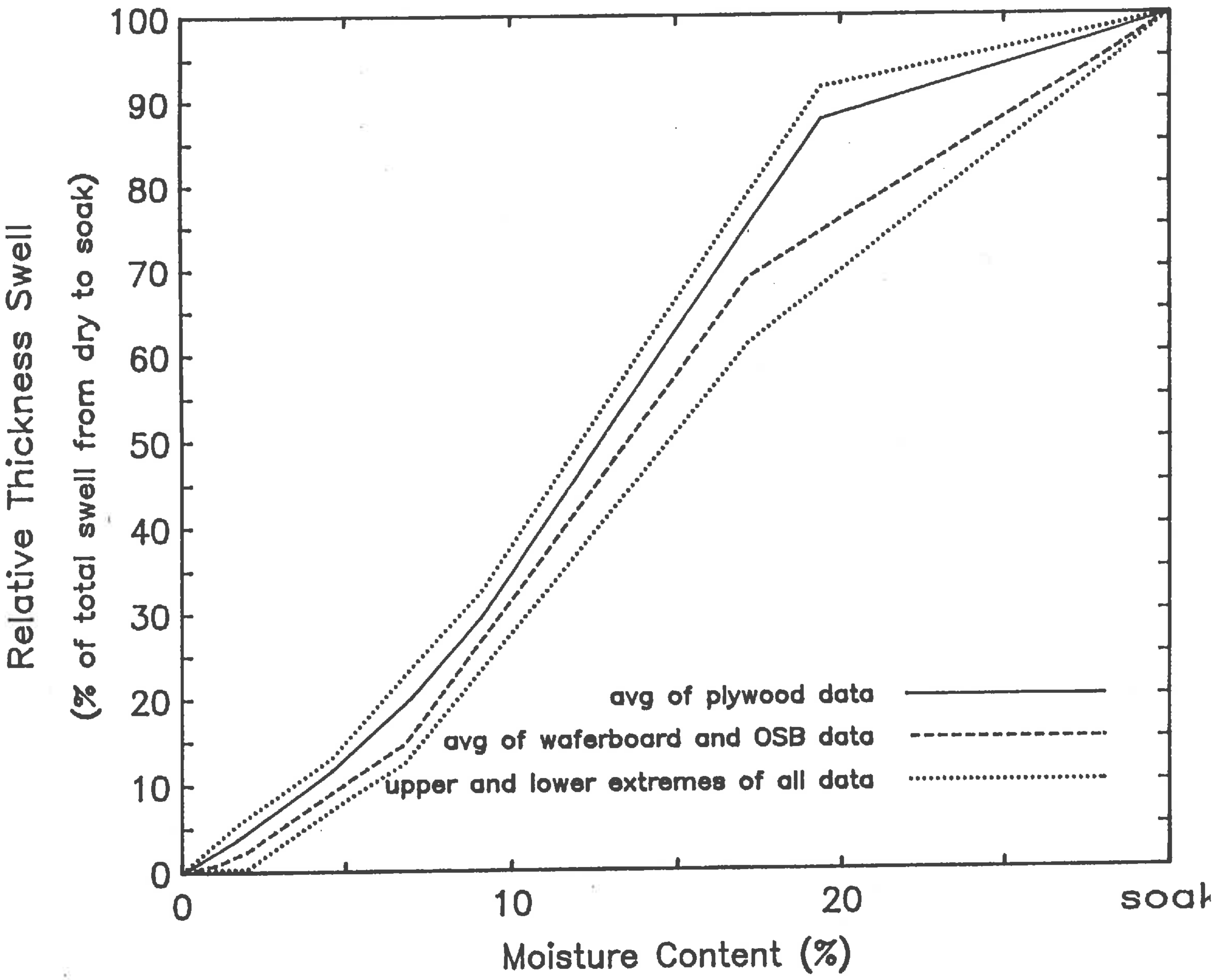

Figure 3. Relative Thickness Swell as a Function of Panel Moisture Content.

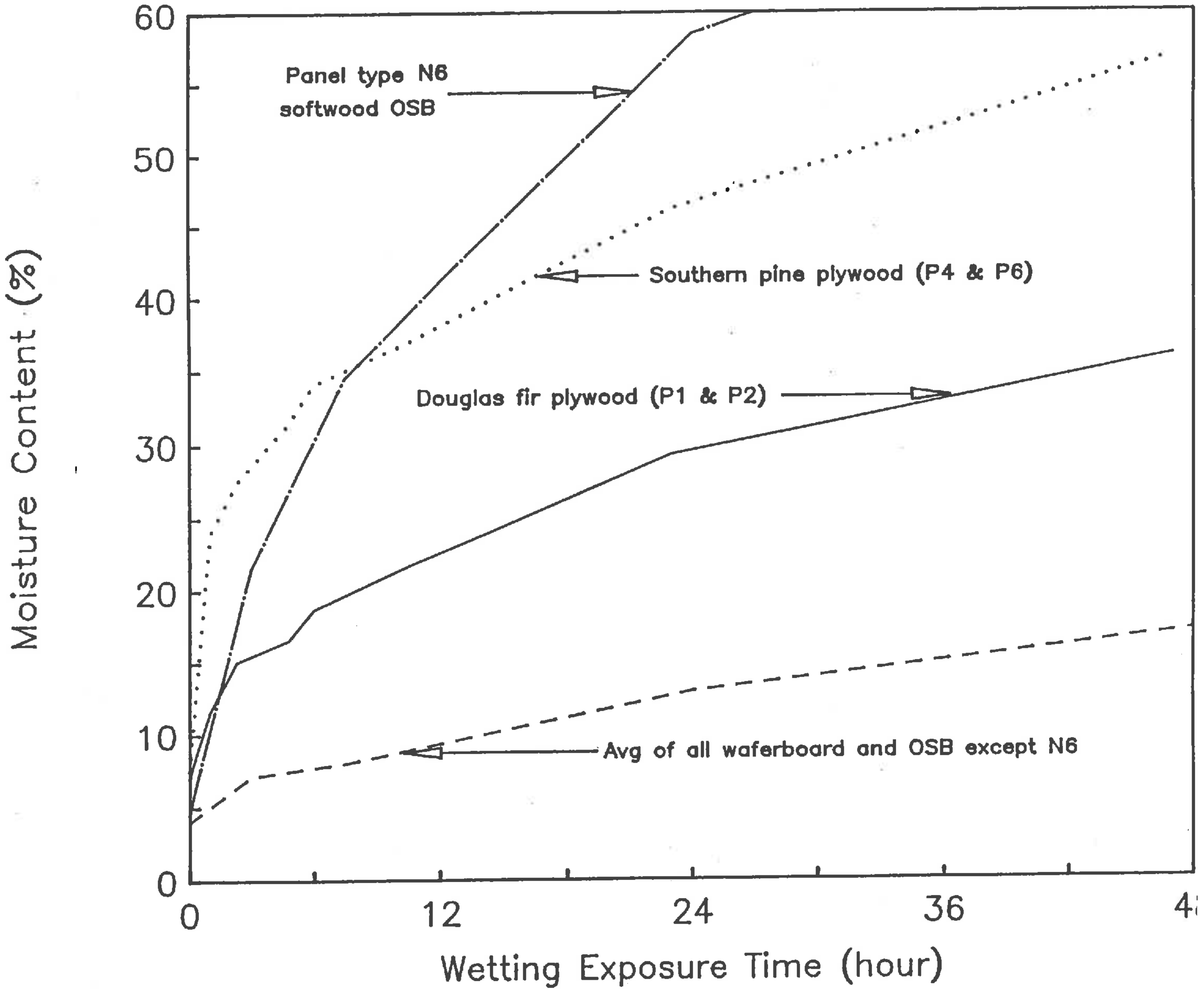

Figure 4. Panel Moisture Content as a Function of One-Sided Wetting Exposure Time.

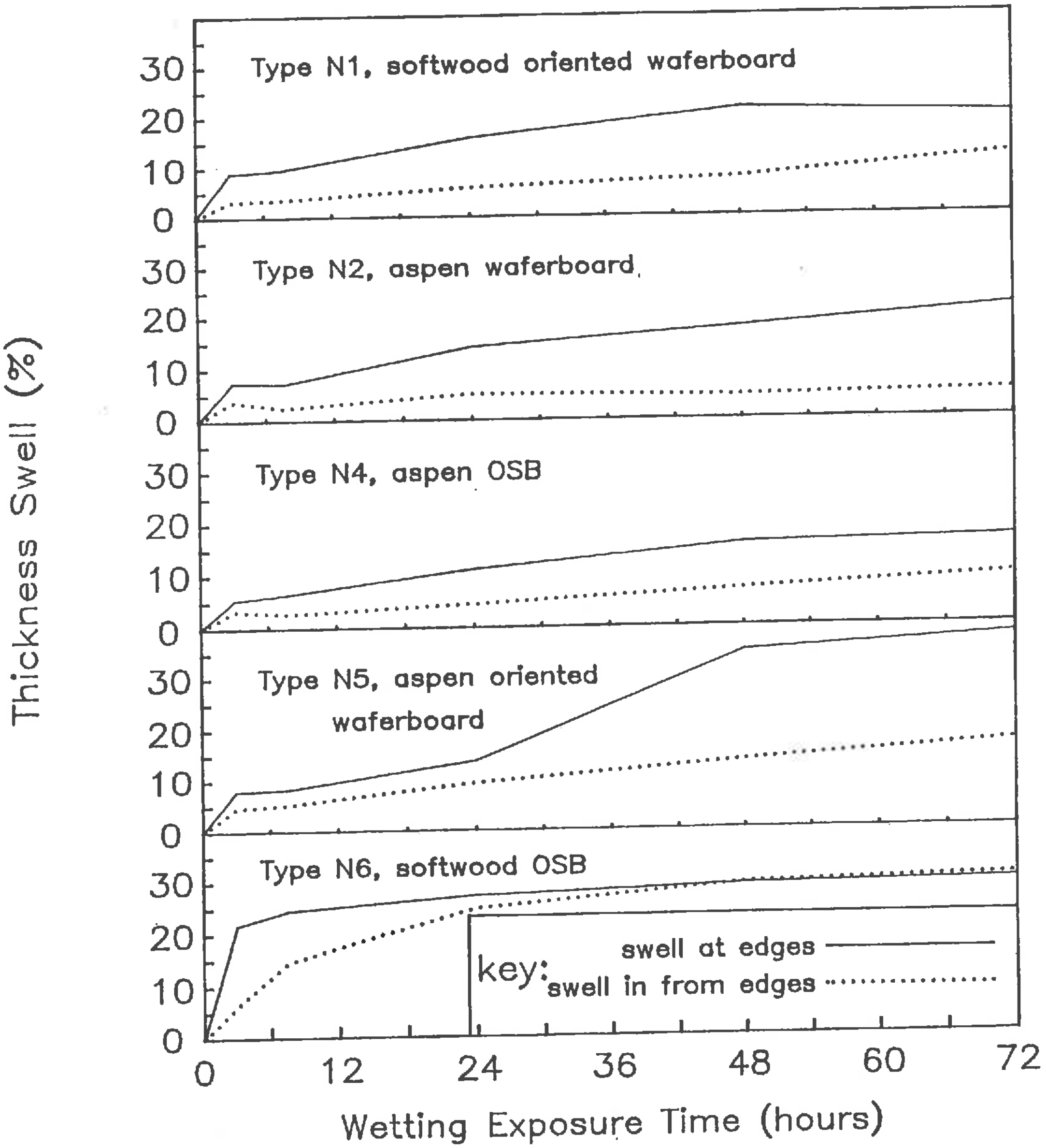

Figure 5. Thickness Swell of Nonveneer Panels as a Function of One-Sided Wetting Exposure Time.