HYGROSCOPIC PROPERTIES AND SHRINKAGE OF SOUTHERN YELLOW PINE PLYWOOD[1]

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ABSTRACT

Five constructions of southern yellow pine plywood, unidirectionally laminated veneer, and loblolly pine solid wood were used for investigation of hygroscopic properties at several RH conditions. EMC values of the southern yellow pine plywood between 20% RH and 90% RH were approximately 1% lower than corresponding values of loblolly pine solid wood. Most plywood panels shrank less along the face grain than across. From water-soaked condition to about 4.5% MC, thickness shrinkages of plywood varied from 7% to 9% while length shrinkages were always less than 1% except for ½-inch, 4-ply plywood. The ratio of number of glue lines to plywood thickness influenced thickness and volume shrinkage. Plywood with a higher ratio had a tendency to shrink less. FSP values were determined by two intersection point methods—one with volumetric shrinkage, the other with MOE. The respective approximate FSP values were 28.7% and 27.3% MC for plywood, and 31.0% and 27.5% for solid wood.

Keywords: Southern yellow pine, *Pinus spp.*, *Pinus taeda*, plywood, laminated veneer, moisture relations, equilibrium moisture content, fiber saturation point, shrinkage, modulus of elasticity.

Southern yellow pines provide the raw material for approximately 30% of the softwood plywood manufactured in the U.S.A. Plywood, like solid wood, is a hygroscopic material and readily absorbs or releases water, depending on moisture content, in relation to surrounding humidity and temperature. Physical and mechanical properties of plywood are affected by moisture below fiber saturation point (FSP).

Choong (1969) and Yao (1972) determined FSP of southern yellow pine solid wood by the intersection point method of volumetric shrinkage. They found average FSP values to range from 26 to 32% moisture content (MC).

Plywood is anisotropic in both shrinkage and strength characteristics. Generally, plywood shrinks most in thickness and least in the direction parallel-to-face-grain (length). Shrinkage of plywood varies with ply arrangement, ply thickness, number of plies, as well as with species and density. For practical purposes, thickness shrinkage of plywood made from rotary-cut veneers is equivalent to radial shrinkage of solid wood (U.S. For. Prod. Lab. 1955).

Specific objectives of this study were:

(1) to determine and compare the dimensional changes of several constructions of southern pine plywood with changes in moisture content below FSP;

(2) to establish the relationship between equilibrium moisture content (EMC) and relative humidity (RH) for southern pine plywood;

(3) to establish the relationship between volumetric shrinkage and moisture content for southern pine plywood;

(4) to determine the FSP of southern pine plywood by the intersection point method of volumetric shrinkage and by the method based on the relationship between moisture content and elastic properties; and

(5) to compare hygroscopic properties of southern pine plywood and loblolly pine (*Pinus taeda* L.) solid wood.

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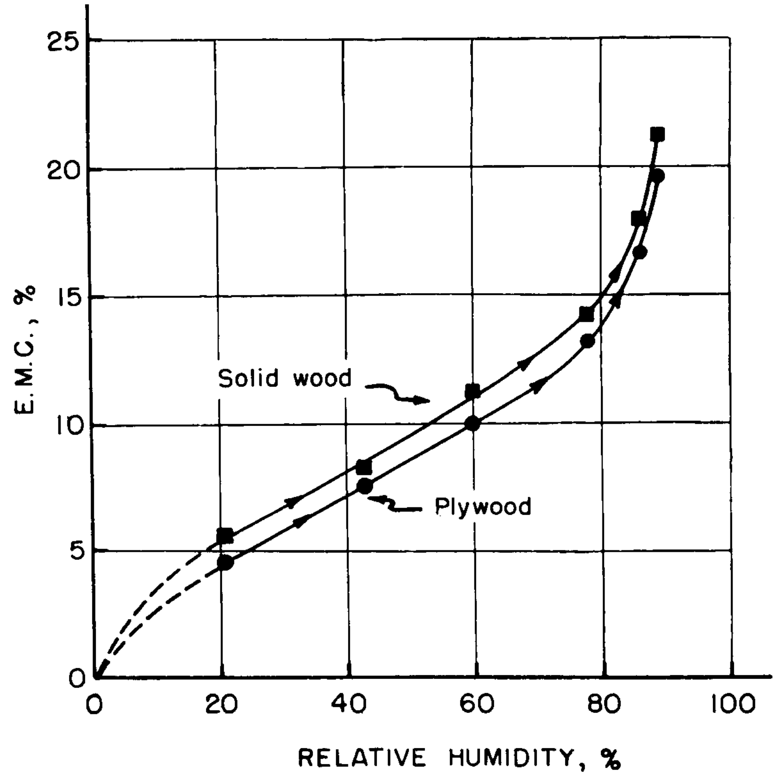

FIG. 1. Adsorption curves for southern yellow pine plywood and loblolly pine solid wood. Each point is the average of 120 observations for plywood, 12 observations for solid wood.

MATERIALS

All plywood panels used in this study were fabricated in a plywood mill from rotary-cut veneers of southern yellow pine. All veneers were selected to exclude visible defects and were bonded with a commercial extended phenolic resin at a spread rate of 90 lb/MDGL (1,000 square feet of

TABLE 1. *Experimental plywood constructions and their manufacturing conditions*[a]

Thickness (in.)	Number of plies	Construction (in.)	Hot press time (min.)
3/8	3	(1/8) + (1/8) + (1/8)	2.75
1/2	3	(1/6) + (1/6) + (1/6)	3.5
1/2	4	(1/8) + (1/8) + (1/8) + (1/8)	4
5/8	5	(1/8) + (1/8) + (1/8) + (1/8) + (1/8)	5.5
3/4	5	(1/6) + (1/8) + (1/6) + (1/8) + (1/6)	7
1/2[b]	4	(1/8) + (1/8) + (1/8) + (1/8)	4

[a] Hot press temperature was 310° F and pressure was 200 psi for all plywood constructions.

[b] Unidirectionally laminated veneer.

TABLE 2. *Percentage shrinkage of southern pine plywood*[a]

CONSTRUCTION	DIRECTION OF SHRINKAGE	PERCENT SHRINKAGE AT INDICATED MOISTURE CONTENT[a]					
3/8" 3-ply plywood	MC(%) =	4.70	7.65	10.64	13.93	16.05	19.91
	Thickness	8.30	7.55	6.52	5.03	3.90	2.41
	Width	1.54	1.39	1.19	0.97	0.86	0.61
	Length	0.93	0.77	0.69	0.63	0.58	0.47
	Volume	10.55	9.53	8.27	6.54	5.28	3.46
1/2" 3-ply plywood	MC(%) =	4.37	7.37	10.04	13.22	17.32	18.60
	Thickness	9.08	8.26	7.55	6.10	4.15	3.09
	Width	1.39	1.22	1.11	1.05	0.89	0.75
	Length	0.95	0.80	0.73	0.65	0.48	0.41
	Volume	11.20	10.10	9.24	7.69	5.46	4.21
1/2" 4-ply plywood	MC(%) =	4.83	7.77	10.51	13.55	18.01	20.81
	Thickness	7.85	7.23	6.26	4.90	2.99	1.74
	Width	0.41	0.31	0.23	0.19	0.08	0.05
	Length	1.81	1.66	1.56	1.35	0.97	0.70
	Volume	9.89	9.05	7.93	6.36	4.01	2.48
5/8" 5-ply plywood	MC(%) =	4.54	7.49	10.19	13.92	16.66	21.31
	Thickness	7.38	6.69	5.82	4.48	2.90	1.30
	Width	0.93	0.79	0.68	0.59	0.43	0.15
	Length	0.97	0.83	0.77	0.65	0.52	0.46
	Volume	9.13	8.20	7.18	5.66	3.82	1.90
3/4" 5-ply plywood	MC(%) =	5.00	8.23	10.95	14.79	17.65	21.14
	Thickness	8.12	7.32	6.38	5.05	3.68	2.34
	Width	1.12	1.00	0.90	0.71	0.63	0.47
	Length	0.63	0.45	0.40	0.30	0.18	0.14
	Volume	9.72	8.66	7.59	6.01	4.46	2.94
1/2" 4-ply unidirectionally laminated veneer	MC(%) =	4.68	7.52	9.56	13.23	15.47	21.12
	Thickness	6.94	6.36	5.63	4.26	3.47	1.57
	Width	5.23	4.83	4.15	3.06	2.40	1.00
	Length	0.25	0.13	0.11	0.09	0.07	0.03
	Volume	12.03	11.00	9.65	7.27	5.85	2.58

[a] Each value is an average for 12 specimens. Shrinkage at each equilibrium condition was expressed as percentage of dimension at soaked condition.

double glueline). Arrangement of plies and manufacturing conditions of panels are listed in Table 1. Specimens of 4-ply, ½-inch, unidirectionally laminated veneer and air-dry loblolly pine solid wood strips with the same thickness were included for comparison with plywood.

Flexural specimens of plywood and laminated veneer were prepared according to ASTM standards D 3043-72, method A (ASTM 1974). One set (12 specimens) was cut with face grain parallel-to-span, the other set with face grain perpendicular-to-span. Twelve solid wood specimens were cut ½-inch thick, 2 inches wide, and 14 inches long. All specimens were used for both measuring dimensional changes and determining the modulus of elasticity (MOE).

PROCEDURE

Specimens of each construction of southern pine plywood, unidirectionally laminated veneer, and loblolly pine wood were conditioned in a controlled temperature-humidity chamber. To attain the preassigned sequence of moisture content of approximately 4, 7, 10, 13, 16, and 19%, specimens were conditioned at the following sequence of relative humidities of 21, 43, 60, 78, 86, and 89%. The control chamber was maintained at a dry bulb temperature of 80 F except for the first condition, where temperature was 94 F. This exception was necessary because it was impossible to obtain the 21% RH at 80 F in this control chamber.

When specimens reached equilibrium weights at the first condition (21% RH, 94

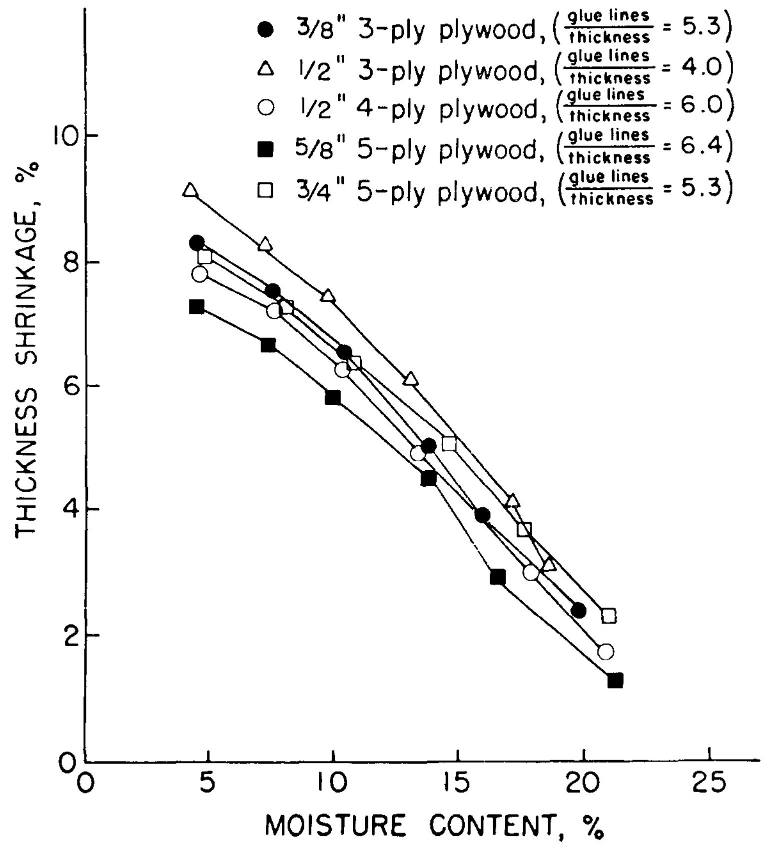

FIG. 2. Relation between moisture content and thickness shrinkage of southern pine plywood. Each point is the average of 12 observations.

F), they were tested nondestructively in bending according to ASTM standards D 3043-72, method A (ASTM 1974). Solid wood was tested in bending with 12-inch span. Dimensions were measured at the middle section of each specimen and weights were recorded. Afterward, all specimens were reconditioned to reach equilibrium weights at the next higher RH condition and retested. Finally, all specimens were soaked in water for 48 hours and retested in the soaked condition.

Equilibrium moisture content at each condition was expressed as percentage of oven-dry weight. Shrinkage at each equilibrium condition was expressed as percentage of dimension at the water-soaked condition.

RESULTS AND DISCUSSION

The relationship between RH and EMC of both southern pine plywood and loblolly pine solid wood had a sigmoid form as shown in Fig. 1. The curve for plywood was based on average values of five different constructions. Average densities were 0.60 g/cm^3 for plywood and 0.54 g/cm^3 for solid wood. Because of included resin, high temperature, and densification of veneers during fabrication, plywood had somewhat lower EMC values than solid wood at the same RH condition.

Shrinkage in three linear directions (length, width, and thickness) and in volume of plywood and unidirectionally laminated veneer is presented in Table 2. Shrinkage along the face grain (length)

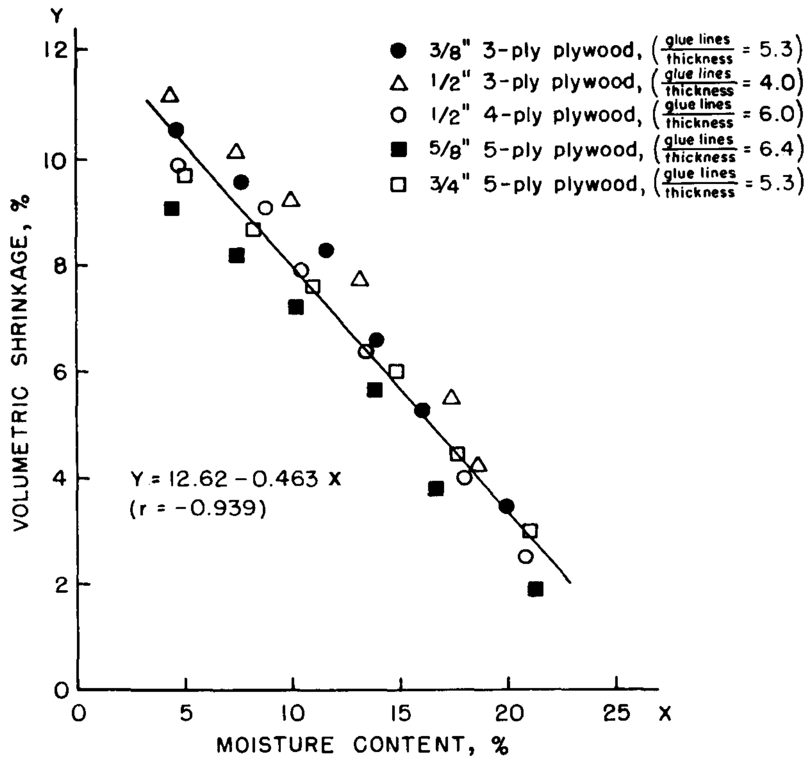

FIG. 3. Relationship between moisture content and volumetric shrinkage of southern pine plywood. Each point is the average of 12 observations.

was generally less than shrinkage perpendicular-to-face grain (width) in most constructions of plywood. Exceptions were the ½-inch, 4-ply plywood, where the difference was reversed, and the ⅝-inch, 5-ply plywood, which exhibited a nearly equal shrinkage in length and width. The unidirectionally laminated veneer, as expected, was especially stable along the face grain, but shrank more in width than any plywood construction.

Thickness shrinkage for all constructions of plywood is shown in Fig. 2. An investigation was made to relate shrinkage to the ratio of number of glue lines to plywood thickness. Duncan's multiple range test was used to determine the significance of differences among all plywood constructions. Thickness shrinkage of ½-inch, 3-ply plywood (with a ratio of number of glue lines to thickness equal to 4.0) was significantly higher than any other plywood construction at 5% level. On the other hand, ⅝-inch, 5-ply plywood (with a ratio of number of glue lines to thickness equal to 6.4) shrank significantly less in thickness than any other plywood construction. Therefore, plywood with a higher ratio had a tendency to shrink less in thickness.

Relationship between volumetric shrinkage and moisture content of plywood is shown in Fig. 3. The ratio of glue lines to plywood thickness also influenced volumetric shrinkage; the higher this ratio, the lower the shrinkage. This suggests that glue lines have restrained volumetric shrinkage. The combined linear regression between volumetric shrinkage and moisture content of all plywood constructions was calculated based on the 30 points shown in Fig. 3.

Determination of FSP was made by two independent intersection point methods (Wilson 1932; Wangaard 1957; Stamm

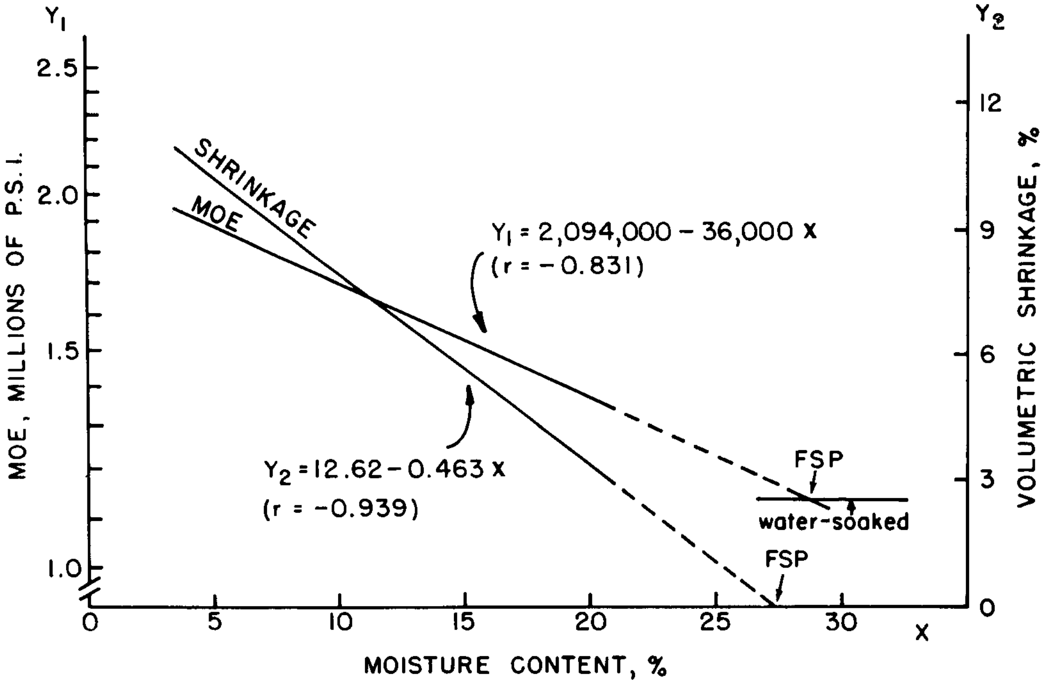

FIG. 4. Determination of FSP value of southern pine plywood by two intersection point methods using logarithm of MOE (Y_1 axis) and volumetric shrinkage (Y_2 axis).

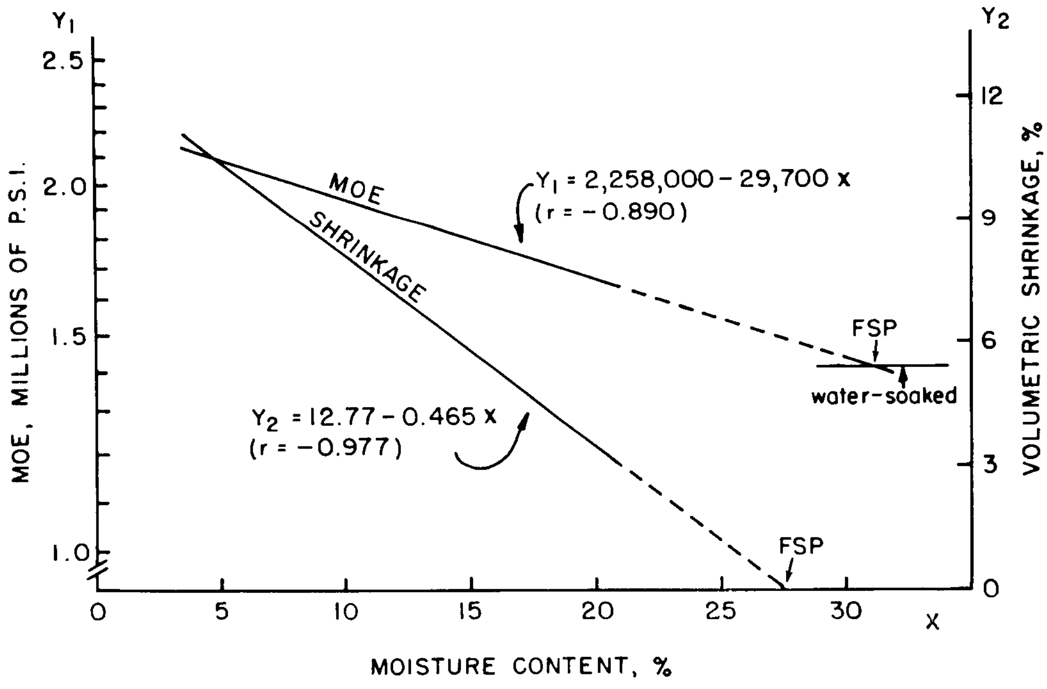

FIG. 5. Determination of FSP value of loblolly pine solid wood by two intersection point methods using logarithm of MOE (Y_1 axis) and volumetric shrinkage (Y_2 axis).

1971); one using volumetric shrinkage, the other MOE (with face grain parallel-to-span). FSP values of plywood determined by these two methods are shown in Fig. 4. The regression line for MOE was calculated in the same way as that for shrinkage. FSP values of plywood, determined by semi-logarithmic plotting of MOE vs MC and volumetric shrinkage vs MC, were 28.7% and 27.3% MC, respectively. FSP values of loblolly pine solid wood were 31.0% and 27.5% MC as shown in Fig. 5. As expected, solid wood values slightly exceeded plywood values.

SUMMARY AND CONCLUSIONS

Relationship between RH and EMC in adsorption was established for southern yellow pine plywood and for loblolly pine solid wood. EMC values of plywood between 20% RH and 90% RH were approximately 1% lower than corresponding values of loblolly pine solid wood. Shrinkage in thickness of plywood from the water-soaked condition to about 4.5% MC averaged from 7% to 9%. Most plywood panels shrank less along the face grain than across. Maximum shrinkage along the face grain of plywood, from water-soaked condition to about 4.5% MC, was found always to be less than 1%. The ⅝-inch, 5-ply plywood construction showed minimum differential shrinkage between the two surface directions.

The ratio of number of glue lines to the thickness of plywood influenced percentage shrinkages in thickness and volume. A high ratio caused low shrinkage, which indicates a restraining influence of glue lines.

Average FSP values of southern pine plywood, determined by two intersection point methods, were 28.7% and 27.3% MC. FSP values of loblolly pine solid wood determined by the same two methods were 31.0% and 27.5% MC. These FSP values for solid wood agree closely with published values (Choong 1969; Yao 1972).

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