FOREST PRODUCTS LABORATORY (Madison 5, Wis.)
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
Approved Technical Article

The Dimensional Stability of Wood

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Polyethylene glycol-1000 stabilizes wood by bulking the fibers. It also serves as a chemical seasoning agent, suppresses decay in high concentrations, and has slight effect on physical properties, gluing, or finishing.

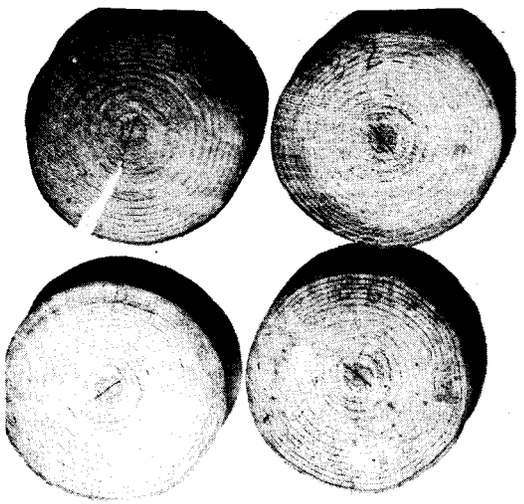

Fig. 1.--Cross sections of a southern pine log (11 inches diam., 1.25 inches thick) slowly air dried from the green condition at 90, 65, and then 30% relative humidity. Upper left: water-soaked control; upper right: 8 hours' soak in 30% aqueous solution of polyethylene glycol-1000; lower left: 16 hours' rook in the solution; lower right: 48 hours' soak in the solution.

POLYETHYLENE GLYCOL OF various molecular weights has previously been shown by the author (13)[3] to reduce greatly the shrinkage of thin cross sections of Sitka spruce. After the cross sections were completely filled with a 25 percent aqueous solution of polyethylene glycol of average molecular weight 200, the specimens were slowly air-dried and then oven-dried. They retained their green dimensions, which indicated that the polyethylene glycol had completely replaced the water in the swollen cell walls. Polyethylene glycol–1000 was only slightly less effective in replacing the water as drying progressed.

Cross sections of the wood treated with the high-molecular-weight material tended to be damp only when the equilibrium relative humidity exceeded 90 percent, while those treated with the lower-molecular-weight material tended to remain damp at appreciably lower relative humidities. For this reason, polyethylene glycol–1000 was chosen for further research.

Stabilization of Tree Cross Sections

It appeared from the previous data (13) that polyethylene glycol might serve as a chemical seasoning agent in the same manner as salt and urea (6). It was tried, therefore, in the seasoning of tree cross sections to determine if it would prevent the formation of the familiar V-shaped radial checks that open in tree cross sections.

Twelve tree cross section discs 1.25 inches thick by 10 to 11 inches in diameter where cut from two green southern pine logs. Small brass nails were driven into one face of each disc near the cambium. They were placed on two lines at right angles to each other that passed through the center of the specimens. These served as reference points for measuring the radial shrinkage.

Three discs from each log were soaked in water overnight. The diameters were measured between the nails, and the discs were then placed in the 90 percent relative humidity room. Five discs from each log were soaked in a 30 percent (by weight) solution of polyethylene glycol–1000 in water. Discs were removed after 8, 16, 48, 96, and 168 hours, soaking, placed in the 90 percent relative humidity room, and the diameters measured immediately. Four other discs from each log were placed in the 90 percent relative humidity room, a liberal coat of molten polyethlene glycol–1000 applied to both faces of each disc with a brush, and the diameters measured. Twenty-four hours later, three of the discs from each log were given a second coat of the molten polyethylene glycol. After a second period of 24 hours, two of the discs were given a third coat, and after a third 24-hour period, one of the discs from each log was given a fourth coat.

Three weeks after the first specimens were placed in the 90 percent relative humidity room, the discs from all treatments were transferred to the 65 percent relative humidity room. A day or two after the transfer, all of the untreated controls started to develop V-shaped checks, and at the end of 2 weeks they had opened up at the periphery anywhere from 0.9 to 1.5 centimeters. The ratios of width of the checks at the periphery to the radius ranged from 0.075 to 0.105. Only one of the treated specimens showed any

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[2] Maintained at Madison. Wis., in cooperation with the University of Wisconsin.
[3] Numbers in parentheses refer to the Literature Cited at the end of this report.

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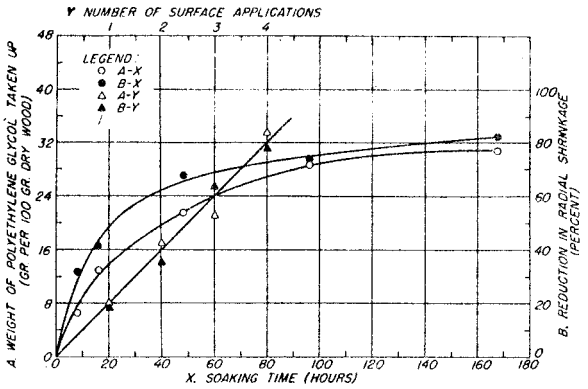

Fig. 2.—Weightof polyethylene glycol-1000 (A) taken up by green southern pine tree cross sections from a 30% aqueous solution and from surface applications of the molten chemical, together with the accompanying reduction in shrinkage (B), plotted against the soaking time (X) and !he number of surface applications applied a day apart at 90% relative humidity (Y).

significant checks, namely, one of those that had a single coat of molten polyethylene glycol. The ratio of the check width to the radius of this single specimen was 0.034.

After 2 weeks in the 65 percent room, all specimens were transferred to the 30 percent relative humidity room. After two more weeks, the checks of the controls had opened up still further. The ratios of width of check to the radius of the discs ranged from 0.142 to 0.192. The check in the disc that had received one surface coat of molten polyethylene glycol had by then opened up to a width-to-radius ratio of 0.124. During this last period, the other specimen that had received one coat of molten polyethylene glycol developed a very slight check with a width-to-radius ratio of 0.016. The two discs that had been soaked in polyethylene glycol for 8 hours developed slight internal radial checks that did not extend to the periphery. All of the other specimens were free from checks.

The polyethylene glycol content of the discs was determined by cutting a small wedge-shaped specimen from the discs, cutting it up into thin shavings, oven-drying and weighing the shavings, impregnating them with water by the vacuum desiccator technique, and boiling them in a large volume of fresh water once a day for several days. They were allowed to stand in the water for the periods between heating. The extracted shavings were then oven-dried and weighed. The polyethylene glycol content was calculated from the loss in weight after a correction was made for the extractive loss of the controls.

The polyethylene glycol content of the various discs together with the radial shrinkage to 30 percent relative humidity, the reduction in shrinkage due to the bulking, and the average check widths divided by the discs radius are given in Table 1. Fig. 1 is a photograph of an untreated and three treated southern pine discs. Fig. 2 gives both the weight of polyethylene glycol–1000 taken up by the tree cross sections, and the reduction in radial shrinkage plotted against the time of soaking and against the number of surface coatings.

The data show that a polyethylene glycol content of 13 percent or more caused a reduction in radial shrinkage of 32 percent or more, and prevented the V-shaped checks from forming. The relationships plotted against the time of soaking are parabolic, and those plotted against the number of surface coatings are linear, as would be expected. An overnight., or longer, soak in a 30 percent solution of polyethylene glycol-1000 or two surface coats a day apart, it appears, will prevent the V-checks in green sapwood discs of southern pine 1 to 1.25 inches thick. As the thickness of the discs increases, the soaking time will have to be increased—probablyin proportion to the square of the thickness.

Heartwood will require more soaking time or more coats than will sapwood. Two tree discs of ponderosa pine 1.5 inches thick by 18 inches in diameter were coated with two applications of molten polytheylene glycol a day apart. Fig. 3 shows the dried control (left) and the dried coated disc (right). The two coats were adequate to stabilize the outer sapwood but not the heartwood, as seen by the two narrow honeycomb checks in the heartwood. If the disc had been held under nondrying conditions for a longer time to allow deeper diffusion of the coatings into the heartwood, or if more coats had been applied to the center heartwood than to the outer sapwood, the honeycomb checks might have been prevented.

WHAT THIS RESEARCH MEANS

A method for simultaneously seasoning wood and giving it dimensional stability is described. It is already in use to avoid the face checking of decorative objects that are roughly precarved from green wood. The roughly precarved wood is soaked overnight in a 30 percent solution of polyethylene glycol-1000. It can then be air dried without checking, and can be finally carved to the finished dimensions. It is felt that this procedure could be equally well adapted for making curved furniture parts, lamp stands and other decorative objects, and possibly gun stocks. This report shows that the treatment has only a minor effect upon the strength properties of wood, and does not seriously affect gluing or finishing.

Rate of Diffusion of Polyethylene Clycol-1000 into Water-Saturated Wood

The previous investigations showed that polyethylene glycols in concentrated aqueous solutions swell wood more than does water alone (13). This makes it possible to determine the diffusion coefficientof polyethylene glycol into water-saturated wood simply by following the rate of swelling in the tangential direction, the direction in which practically all swelling beyond the swelling in water occurs (9).

A cross section of Sitka spruce with a thickness in the fiber direction of 0.165 inch was saturated by immersing it in water under a vacuum for 1 hour, followed by soaking overnight under atmospheric pressure. The water-saturated specimen was immersed in molten polyethylene glycol–1000 at 60° C., and the increase in tangential dimension was measured periodically. Fig. 4 is a plot of the tangential swelling beyond that in water plotted against the square root of time. The relationship is linear up to two-thirds of the final swelling. This would be expected for true diffusion when the concentration gradient is parabolic (12, 15). The diffusion coefficient, D, was calculated from the data by means of the Boltzmann modification of Fick's general diffusion equation (12, 15).

$$D = \frac{\pi a^2 E_a^2}{16t} \qquad (1)$$

where a is the thickness of the specimen and E, is the amount of solute that diffuses into the specimen in time t expressed as a fraction of the final equilibrium amount. The author has previously shown (5) that the fractional swelling, E_s, can be substituted for the fractional take-up of solute,

Table 1.—EFFECT OF POLYETHYLENE GLYCOL TREATMENTS UPON CHECKING AND SHRINKING OF SOUTHERN PINE TREE CROSS SECTIONS 1.25 INCHES THICK

Treatment	Chemical content	Average radial shrinkage[1]	Reduction in shrinkage	Average ratio of check widths to radii[1]
	Percent	Percent	Percent	
None	0	2.2[2]	0	0.158[2]
Hours of soaking[3]				
8	6.7	1.5	32	none
16	12.9	1.3	41	none
48	21.7	.7	68	none
96	28.9	.6	73	none
168	30.9	.4	82	none
Number of surface coats[4]				
1	7.7	2.0	18	0.070
2	16.9	1.4	36	none
3	20.9	.8	64	none
4	33.5	.5	78	none

[1] Dried to 30 percent relative humidity.
[2] Average for six discs; other values are the average for two discs.
[3] Soaked in 30 percent solution of polyethylene glycol-1000.
[4] Coated with molten polyethylene glycol-1000.

Table 9.—DIFFUSION OF POLYETHYLENE GLYCOL-1000 INTO 1/16-INCH-THICK EDGE-GRAIN SITKA SPRUCE VENEER UNDER DIFFERENT MOISTURE CONTENT CONDITIONS

Before polyethylene glycol application		After polyethylene glycol application		
Moisture content	Swelling from oven-dry condition	Amount applied as surface coatings	Swelling 5 weeks after application	Moisture plus chemical absorbed
Percent	Percent	Percent	Percent	Percent
At equilibrium with 30 percent relative humidity				
4.4	0.64	0	0.64	4.4
4.4	.65	18.7	.65	4.4
4.4	.63	21.1	.63	4.4
At equilibrium with 65 percent relative humidity				
9.6	1.46	0	1.46	9.6
9.6	1.47	26.6	1.67	11.0
9.5	1.46	24.2	1.64	10.7
At equilibrium with 80 percent relative humidity				
13.3	1.91	0	1.91	13.3
13.5	1.99	23.9	2.34	15.9
13.3	1.99	22.8	2.36	15.8
At equilibrium with 90 percent relative humidity				
17.9	2.58	0	2.58	17.9
17.7	2.59	25.5	3.01	20.6
17.8	2.56	19.9	2.96	20.6

E_a, at $E_a = 0.667$, since they are equivalent. *D* was then calculated from the thickness *a* and time corresponding to $E_s = 0.667$. This gave a value of $D = 0.32 \times 10^{-5}$ cm.²/sec.

The diffusion coefficient of solutes into water-saturated wood in the fiber direction, D_1, has previously been shown to be related to the bulk diffusion coefficient, D_o, as follows (11):

$$D_1 = D_o (1 - d/d_o) \quad (2)$$

where *d* is the specific gravity (dry-weight green-volume) of the swollen wood and do is the specific gravity of wood substance determined in water. The experimental values of 0.365 for d and of 1.52 for d_o (8) when substitute in equation (2) give $D_o = 0.42 \times 10^{-5}$ cm²/sec. No data are available for the bulk diffusion constant of polyethylene glycols. If Graham's law, which states that the diffusion coefficients are inversely proportional to the square root of the molecular weight, is assumed to hold, and if the diffusion coefficient increases 1.4 times for each raise of 10° C., which is the case of glycerine, mannitol, and sucrose, then the theoretical diffusion coefficient would be 0.48×10^{-5} cm.²/sec.

For dilute solutions, the calculated coefficient does not vary greatly from the experimental value obtained with concentrated solutions. Tre data indicate that polyethylene glycol-1000 will just reach the center of a specimen 0.70 inch in the fiber direction in 24 hours. From measurements of the relative rates of diffusion of salts into wood in the three structural directions (2, 11), it can be predicted that it would take about 10 to 15 days for the polyethylene glycol-I000 to reach the middle of long green boards 0.70 inch thick in either of the transverse directions. Soaking times for long boards would thus have to be quite long to allow for adequate transverse take-up of chemical.

The diffusion coefficient for the polyethylene glycol into the green cross sections of southern pine from the 30 percent solution was also calculated from the data of Fig. 2. A value of 0.5×10^{-5} cm.²/sec. was obtained. This slightly larger value can be accounted for on the basis that some capillary absorption took place, since the wood, although green, was not completely saturated with water.

Diffusion into Wood at Different Moisture Contents

A means of dimensionally stabilizing wood in service has long been sought. Therefore, it seemed worth while to determine how well a surface application of polyethylene glycol penetrates the cell-wall 'structure of wood at different moisture contents. Twelve specimens of edge-grain Sitka spruce veneer 1/16 inch thick by 5 inches in the radial direction and 3 inches longitudinally were oven-dried, weighed, and their radial dimension measured. Three specimens were placed in each of the following relative humidity rooms: 30, 65, 80, and 90 percent; they were allowed to come to equilibrium moisture content, after which the weight increase and radial swelling were determined. A coat of molten polyethylene glycol was applied to both faces of two sheets out of each set of three sheets of the veneer. After the sheets remained in the same relative humidity room for five more weeks, the radial dimension of the veneer was again measured. No change occurred for the controls or the coated specimens in the 30 percent relative humidity room.

The coated specimens in the higher relative humidity rooms all showed additional swelling that increased with an increase in the relative humidity. The data are given in Table 2. They show that polyethylene glycol must have diffused into the cell walls, and that the amount that entered exceeded the amount of water displaced. At 90 percent relative humidity an amount of polyethylene glycol equivalent to at least 2.8 percent of the weight of the wood must have diffused into the cell-wall structure. Even at this high rela-

Fig. 3.—Cross sections of ponderosa pine log (18 inches diam., 1.5 inches thick) slowly air dried at 90, 65, and then 30% relative humidity. Left: water-soaked control; right: 2 surface applications of polyethylene glycol-1000 a day apart at 90% relative humidity.

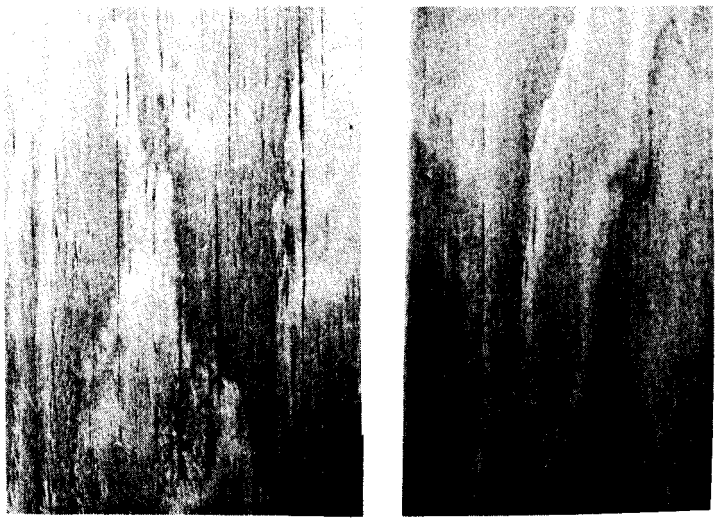

Fig. 5. –Surfaces of 2 Douglas-fir plywood panels that had alternately been exposed to 4 cycles of 90% relative humidity for 2 weeks followed by 30% relative humidity for 2 weeks. left: panel with untreated faces; right: panel the facer of which were impregnated with 30% of polyethlene glycol-1000 prior to bonding to on unimpregnated core.

tive humidity, the amount of bulking afforded by polyethylene glycol that diffuses into the cell wall is very small compared to that caused by diffusion into the cell walls of green wood. Even in humid climates, the application of polyethylene glycol to such things as layed floors would not be very effective in swelling them tight.

Reduction in Face Checking of Plywood

Eight sheets of dry 1/8-inch-thick, rotary-cut Douglas-fir veneer of four types, namely, 1) tangential grain containing considerable compression wood, 2) tangential grain, slow growth, 3) partly edge grain slow growth, and 4) tangential grain, fast growth, were each cut into four end-matched, 1-foot-square specimens. One specimen from each sheet was impregnated with 10, 20, and 30 percent solutions of polyethylene glycol–1000 and with water to obtain about a 100 percent weight increase. The impregnation was done in a treating cylinder at 200 psi for several hours.

The average polyethylene glycol contents attained were 10.8, 20.2, and 32.2 percent, respectively. In all cases the compression wood specimens took up only about 75 percent as much solution as the others. The test pieces were air-dried to 30 percent relative humidity and then glued up as faces and backs to 3/16-inch untreated Douglas-fir veneer cores to form three-ply plywood. A hot-setting phenolic resin glue was used. The glue was spread with a hand roller on the core sheets to give a single glue line of 35 pounds per 1000 square foot. The pressing was for 10 minutes at 285° F. under a pressure of 175 psi. Good glue bonds were obtained in all cases.

The 16 plywood panels were cycled four times between 90 and 30 percent relative humidity. No checks appeared in the panels treated to the two highest degrees. Three of the four panels that contained only 10.8 percent of polyethylene glycol had a few hairline checks. All of the four controls showed medium to bad checking. Fig. 5 shows a control panel (left) and a panel with faces that contain 30 percent of polyethylene glycol–1000 (right). The polyethylene glycol treatment was quite effective in minimizing face checking of the Douglas–fir plywood.

In practice it appears more advantageous to soak green veneer in a concentrated solution of polyethylene glycol in water or in the molten polyethylene glycol at 60° to 90° C. rather than to impregnate dry veneer. A few preliminary measurements indicate that the required soaking time for 1/10-inch-thick veneer in molten polyethylene glycol–1000 at 60° C. would be between 4 and 8 hours, depending on the moisture content of the veneer (60 to 40 percent). The green veneer could also be impregnated by passing it between compression rolls beneath the surface of the hot treating solution. As the veneer recovers from the compression, it will suck in the solution (10).

Strength Tests

Tests were made to determine the effect of polyethylene glycol treatment upon the toughness, abrasion resistance, modulus of rupture, and modulus of elasticity of wood. The first two tests were made primarily because they are very sensitive to treatments that cause embrittlement of wood, such as resin treatment (4) and heat stabilization and formaldehyde cross-linking (14, 16). In the two latter cases the values may be reduced to one-twentieth of the values for untreated wood (14).

The toughness tests were made with the small Forest Products Laboratory toughness tester (19) on 1/4- by 1/16 inch strips of edge-grain Sitka spruce veneer 3 inches long in the fiber direction. Five end-grain matched specimens, 3 inches in the fiber direction by 5 inches radially were cut from each of four strips of 1/16-inch-thick veneer. One specimen from each of the strips was impregnated by the vacuum desiccator technique with each of the following concentrations of polyethylene glycol–1000 dissolved in water; 0, 10, 20, 30, and 40 percent. The specimens were air-dried at 65 percent relative humidity followed by 30 percent relative humidity, and were then oven-dried, weighed, and the radial dimension measured. They were then reconditioned to 65 percent relative humid-

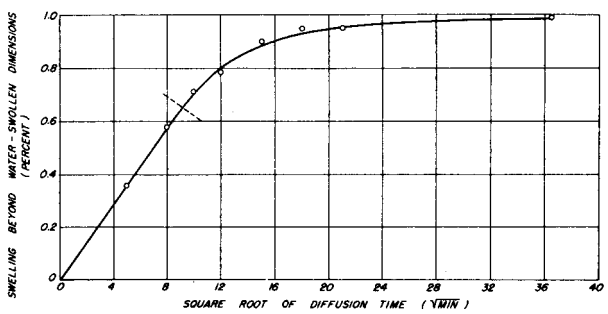

Fig. 4. - Rate of swelling of a water-saturated cross section of Sitka spruce (0.165 inch thick) beyond the water-swollen condition in the tangential direction when immersed in molten polyethylene glycol-1000 at 60°C. Cross line at two-thirds of the final swelling.

Table 3 —EFFECT OF IMPREGNATING 1/16 INCH THICK EDGE GRAIN SITKA SPRUCE VENEER WITH POLYETHLENE GLYCOL-1000 UPON THE DIMENSIONAL STABILITY AND ON THE TOUGHNESS

Chemical content[1]	Reduction in swelling[1, 2]	Relative toughness[3]
Percent	Percent	
0.0	0	1.00
11.1	44	.99
20.6	68	1.04
35.3	78	1.02
44.6	80	1.08

[1]Average for four specimens 5 inches radially by 3 inches longitudinally.
[2]From oven-dry to equilibrium with 65 percent relative humidity.
[3]Average for 10 specimens 0.25 inch radially by 3 inches longitudinally cut from each of the four original specimens.

Table 4 —EFFECT OF IMPREGNATION 1/16 INCH-THICK ROTARY-CUT YELLOW BIRCH VENEER WITH POLYETHLENE GLYCOL-1000 UPON THE RELATIVE ABRASION RESISTANCE

Chemical content	Specific gravity[1]	Relative abrasion resistance[2]	Ratio, relative abrasion resistance to specific gravity
Percent			
0.0	0.62	1.0	1.61
9.8	.60	1.04	1.73
21.3	.56	.93	1.66
33.8	.53	.82	1.55

[1]Based on unimpregnated dry weight and impregnated volume.
[2]Each value is the average for 4 specimens at 5 arbitrarily chosen fixed points for 100 revolutions of the disc.

ity, weighed, and measured. Each of the specimens was cut into ten 1/4-inch-wide strips for the toughness tests.

Table 3 gives the polyethylene glycol content of the specimens, the reduction in swelling from the oven-dry to equilibrium with 65 percent relative humidity caused by the treatment, and the average toughness of 40 specimens relative to that of the unimpregnated control. The data show that the treatment has virtually no effect upon the toughness of the material up to treating levels of 45 percent, with a resulting dimensional stabilization of 80 percent.

The abrasion-resistance tests were made with the Navy abrader (3, 18) on rotary-cut birch veneer specimens 2.75 inches long by 2 inches wide glued to supporting blocks. Fresh aluminum oxide grit No. 80 continuously flowed onto the grinding plate. The data are given in Table 4. At the higher polyethylene glycol contents, the abrasion resistance decreases by an amount approximately proportional to the specific gravity (unimpregnated weight/impregnated volume), which is reduced due to the bulking of the fibers.

A flat-grain board of Sitka spruce 0.5 inch thick was cut into 12 side-matched strips 0.5 inch wide by 26 inches long. Each of these was in turn cut into two 13-inch-long, end-matched specimens. Sets of four side-matched specimens were impregnated with each of the following concentrations of polyethylene glycol–1000 in water: 10, 20, and 30 percent. All 12 of the end-matched specimens were similarly impregnated with water to serve as controls. The sticks were air-dried and conditioned to 65 percent relative humidity. Static bending tests were made on each stick in the tangential direction. The data expressed as values relative to those for the end-matched controls are given in Table 5. The various strength properties decrease slightly or moderately with increasing polyethylene glycol content. In each case, the ratios for the highest chemical content ace either higher or about equal to the corresponding ratios for the properties of green wood relative to wood at 12 percent moisture content. In no cases is the loss in strength due to impregnation with polyethylene glycol significantly greater than would be expected from the extent of bulking of the fibers, which is indicated by the decrease in the ratio of the specific gravities.

Decay Resistance

A flat-sawn Sitka spruce board 5 inches wide by 0.5 inch thick was cut into a series of specimens 0.5 inch in the fiber direction for decay-resistance tests. The specimens were impregnated by the vacuum desiccator technique with 0, 5, 10, 20, and 40 percent solutions of polyethylene glycol–1000 dissolved in water- resulting in polyethylene glycol contents of the wood ranged from 8.6 to 63.7 percent. The specimens were air-dried to equilibrium with 30 percent relative humidity and then subjected to the standard block culture test (1) for 3 months after inocluation with *Lenzites trabea* 517. Because washing to remove the fungus and decay products also extracted polyethylene glycol from the specimens, the weight-loss technique for determining the amount of decay could not be used. The extent of decay was thus judged qualitatively by the ease of penetration of a knife blade into the structure. All specimens that contained at least 17.6 percent of polyethylene glycol were perfectly sound. Specimens that contained only 8.6 percent of polyethylene showed some evidence of decay, while the controls were badly decayed. Culture tests showed that polyethylene glycol–1000 is nontoxic. The practical elimination of decay occurred when the reduction in swelling was 50 percent and more. Under these conditions only half of the normal amount of water can enter the fiber. This evidently is insufficient to support decay.

Gluing Tests

A number of the potential applications of the polyethylene-glycol-treated wood will depend upon its gluability. To determine this factor, two sheets of rotary-cut yellow birch veneer 1/16. inch thick were each cut into 4 strips 5 inches wide in the tangential direction and parallel to a split edge in order to get the grain as straight as possible. The strips were cut into twelve 3-inch lengths, which gave a total of 96 3-inch by 5-inch pieces of veneer. The experiment involved 3 levels of treatment and an untreated control, 6 different glues, and 2 specimen replications, each of which consisted of 2 specimens glued together to form lap joints. Pieces cut from one sheet were in all cases glued to the corresponding treated piece from the other sheet. The four levels of treatment for bonding with each glue were the longitudinally adjacent pieces from the same strip. Replications were either from the same strip or from adjacent strips. In this way, the best matching occurred between the different levels of treatment, the variable of chief concern in this study.

The pieces of veneer were impregnated with 0, 5, 10, and 20 percent aqueous solutions of polyethylene glycol–1000 to give chemical contents ranging from 8 to 33 percent. The treated pieces were then dried to equilibrium at 30 percent relative humidity.

Paired specimens of the treated and conditioned veneer were glued together with the end grain of each overlapping the other by 1 inch, thus giving a 5-inch by 5-inch specimen. The 6 glues —casein, polyvinly emulsion, cold-setting urea resin, cold-setting resorcinol resin, hot-setting phenolic resin, and a hot animal glue—were all applied in accordance with recommended procedures (7, 17).

The glued specimens were conditioned at 30 percent relative humidity for 10 days, and then each was cut into 4 test specimens 1 inch wide. The strength of the glued joint was determined by measuring the tensile load required to break the specimen and estimating the percentage of wood failure. The data are given in Table 6. The casein, cold-setting urea and hot-setting phenolic glues all gave consistently high tensile strength and high percentages of wood failure. The poly-

Table 5. - RATIO OF THE PHYSICAL AND STRENGTH PROPERTIES[1] OF SITKA SPRUCE STICKS (0.5 BY 5 BY 13 INCHES) IMPREGNATED WITH POLYETHLENE GLYCOL-1000 TO THE VALUES FOR END-MATCHED UNIMPREGNATED CONTROLS (THIRD-POINT TANGENTIAL LOADING)

Chemical content	Specific gravity[2]	Modulus of elasticity	Fiber stress at proportional limit	Modulus of rupture	Work to proportional limit	Work to maximum load
Percent						
15.3	0.94	0.99	0.74	0.87	0.55	1.18
30.5	.94	.90	.57	.67	.38	.70
45.5	.94	.85	.46	.62	.27	.81
Ratio of green wood to wood at 12 percent moisture content[3]						
	.92	.78	.49	.56	.33	.67

[1]Averages of four values.
[2]Based on dry unimpregnated weight and impregnated volume.
[3]U.S.D.A. Agriculture Handbook No. 72 (1955).

vinyl emulsion, cold-setting resorcinol, an 8 hot animal glues gave somewhat decreasing tensile strengths and decreasing or irratic percentages of wood failure with increasing polyethylene glycol contents.

Confirmatory tests were made on a duplicate set of samples. In the second series, both the polyvinyl emulsion and the resorcinol glues still showed a tendency to decrease in tensile strength with an increase in polyethylene glycol content, but they did give higher wood failures. The hot animal glue gave good tensile values that did not decrease with increasing polyethylene glycol content, and more consistently high wood failure values. The lowest tensile strength value obtained in the second series was 450 psi with a wood failure of 12 percent for the cold-setting resorcinol resin and the highest polyethylene glycol content. The data thus indicated that quite good glue joints can be obtained for wood containing as much as 33 percent of polyethylene glycol. Casein, cold-setting urea, and hot-setting phenolic resin gave the best results.

The marked suitability of hot-setting phenolic resin for gluing the treated veneer was noted above in the discussion of the face-checking tests. The cycling of the glued-up panels between 90 and 30 percent relative humidity set up a very severe stress at the glue line. None of the panels showed any sign of deliminating under this rigorous treatment.

Finishing Tests

Standard ponderosa pine paint-test panels 2⅝ inches wide by ¼ inch thick were each cut into two equal 5.5-inch lengths. One half of each of the end-matched specimens was impregnated with polyethylene glycol solution and the other half with water by the vacuum desiccator technique. Three concentrations were used, namely, 10, 20, and 40 percent; these gave polyethylene glycol contents of 10 to 13 percent, 18 to 24 percent, and 36 to 50 percent on the basis of the dry weight of the wood. This variability was due to the nonuniformity of the wood. The specimens were all dried at 65 percent and then 30 percent relative humidity.

Seven different finishes were applied to the specimens. These were a floor sealer, shellac, phenolic resin spar varnish, alkyd resin clear varnish, a clear lacquer, natural exterior finish (Forest Products Laboratory No. 497), and an exterior white paint. Two coats of each finish were applied to three specimens that contained the three different amounts of polyethylene glycol and their corresponding controls.

The panels were inspected 24 hours after application of the first coat. In all cases the specimens that contained polyethylene glycol were much more tacky than the controls which indicates that drying was retarded by the chemical. The panels were hence allowed to dry for a few more days before application of the second coat. Three days after the second coat was applied, all of the specimens treated with polyethylene glycol were somewhat tacky, especially the ones containing the largest amount.

Two months later the panels were carefully examined. All of the impregnated panels with clear finishes were lighter in color than the unimpregnated controls. This was especially noticeable with the varnishes. The panels that contained the two lower levels of polyethylene glycol were dry to the touch like the unimpregnated controls. The specimens containing the largest amount of polyethylene glycol that were coated with floor sealer and shellac were also dry. All of the others had a slight tendency to bond to one's finger when pressed firmly on the surface.

The slow drying of the finishes can be partly attributed to the fact that the finishes were applied during the humid summer months. Three coats of a polyurethane varnish and three coats of outside white paint were applied to redwood specimens for leaching tests described later. The finishes were applied at 30 percent relative humidity. Three days after the final coats, the varnish was dry on the polyethylene-glycol-impregnated specimens, but the outside white paint was still slightly tacky. Excepts for the retarded rate of drying, it appears that polyethylene-glycol-impregnated wood can be satisfactorily finished.

Leaching Tests

It is well known that all wood finishes are somewhat permeable to water (5). There was a question, however, whether they would be permeable to polyethylene glycol with a molecular weight of 1000. Experiments were made to determine if varnish or paint finishes acted as semipermeable membranes and tended to retain polyethylene glycol within the wood under leaching conditions, and also to determine if the osmotic action tended to blister or loosen the films from the wood.

A 0.75-inch-thick, edge-grain redwood board 3.75 inches wide was cut into 3-inch-long specimens in the fiber direction. All corners and edges were rounded by sanding. Eight specimens were impregnated with a 30 percent solution of polyethylene glycol-1000 to give an average chemical content of 39 percent. These specimens together with an untreated control were conditioned to 30 percent relative humidity. Three of the impregnated specimens were given three coats of a polyuroethane varnish and three were given three coats of a commercial white house paint. When the finishes were dry, the specimens were weighed and measured. These six specimens together with the two impregnated but uncoated specimens and the unimpregnated uncoated specimen were immersed in running water for two weeks. The weight increase of the unimpregnated nonsurface-coated specimen was 57 percent. The impregnated but non-surface-coated specimens increased on the aver-

Table 6. - EFFECT OF POLYETHLENE GLYCOL-1000 ON THE GLUING OF YELLOW BIRCH VENEER

Glue	Tensile strength of glue joint for chemical content of [1,2]				Wood failure at glue joint for chemical content of [2]			
	0 percent	8 percent	15 percent	33 percent	0 percent	8 percent	15 percent	33 percent
	Psi	Psi	Psi	Psi	Percent	Percent	Percent	Percent
Casein	712	726	722	778	57	64	93	78
Polyvinyl	875	804	622	470	52	27	29	15
Cold-setting urea	600	590	590	583	64	89	92	97
Cold-setting resorcinol	672	552	360	352	30	42	0	0
Hot-setting phenolic	590	575	573	606	75	74	82	88
Hot animal	675	676	795	533	8	0	47	3

[1]Specimens 1 inch wide by 1 inch overlap.
[2]Each value is the average of 8 determinations.

age 53 percent in weight. The average increase in weight of the varnished specimens was only 2.6 percent, and of the paint-coated specimens, 3.8 percent. This small weight increase merely raised the average moisture content of the specimens from 7 percent to 10 to 11 percent. Under these conditions, polyethylene glycol was not leached out to any measurable degree.

The specimens were oven-dried, weighed, and measured. The impregnated specimens that were not surface-coated had lost a little over half of their polyethylene glycol during leaching. The paint-coated specimens blistered during the drying, but the varnish-coated specimens did not. It thus appears that, in spite of the fact that polyethylene glycol can be readily leached from wood, a good surface coating retains practically all of it in the wood.

Conclusions

Polyethylene glycol-1000 is shown to be a good seasoning and dimension-stabilizing agent for wood. Although an amount of chemical equivalent to about 30 percent of the dry weight of the wood is required to give high degrees of dimensional stabilization, less is needed to cut down face checking that results from seasoning and occurs due to humidity changes in service.

Although the chemical can be leached from wood, surface coatings do an excellent job of keeping them in the wood.

The toughness of wood is not reduced by the treatment as is the case for most other dimension-stabilizing agents. Static-bending and abrasion-resistence properties are reduced only to the extent that would be expected from the bulking of the fibers.

The treated wood has good decay resistance and can be readily glued and finished, but the rate of drying of finishes is greatly retarded.

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