THE ANTI-SHRINK TREATMENT OF WOOD WITH SYNTHETIC RESIN-FORMING MATERIALS AND ITS APPLICATION IN MAKING SUPERIOR PLYWOOD

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THE ANTI-SHRINK TREATMENT OF WOOD WITH SYNTHETIC RESIN-FORMING MATERIALS

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To the general user, one of the greatest drawbacks to wood in service has been its tendency to shrink or swell as its moisture environment changes. Although surface coatings of high effectiveness are known through experience and scientific study, the protection which they give is dependent entirely upon the permanence of the coating envelope. Cutting, nailing, or abrasion break the envelope and permit the wood to respond to normal humidity changes. It thus has seemed highly desirable to find a type of impregnation treatment that would reduce the inherent tendency of the wood itself to gain and lose moisture.

Depositing ordinary waxes and resins in the capillary structure of the wood and even in the cell walls was found to give only temporary protection. The rate of shrinking and swelling was appreciably reduced, but at best the final shrinking and swelling resulting from prolonged exposure to dry and damp air was not affected. Although materials of this class are highly water resistant, their bond for the wood seems to be insufficient to prevent water from working its way along the junction of the treating material and the wood. Several commercial water-repellent agents are of this type. They are effective in shedding water, but have little value for indoor use where the atmosphere is either dry or moist for long seasonal intervals.

It was apparent from the foregoing findings that the treating material must definitely bond to the wood. Unfortunately, all wood-bonding materials also have an affinity for water. It thus became necessary to use soluble materials which bond to wood and then convert them to water-insoluble materials in the wood structure after they have been bonded. This has been done effectively in the new process of forming synthetic resins within the wood structure. A large number of different resin-forming materials have been tried. Of these, phenol-formaldehyde resin intermediates that are soluble in water have been found to give the best and most permanent reduction in swelling and shrinking. The superiority of this combination over others seems to be due to the fact that these chemicals have small molecules that can readily penetrate the structure and that they bond better to the wood. Their large affinity for the wood is demonstrated by the fact that they cause the wood to swell beyond the normal green dimensions to a greater extent than other resin-forming chemical combinations prior to forming the resin.

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Properties of Plywood

The anti-shrink treatment of plywood might logically be questioned as plywood is so constructed, with its alternate odd number of plies at right angles to each other, that it mechanically minimizes external dimension changes under varying moisture-content conditions. The change in width of a piece of plywood on swelling or shrinking is only about one-tenth of the change of the separate plies in the across-the-fiber direction. This does not mean that swelling and shrinking have been mechanically prevented, but that the direction in which swelling and shrinking takes place has been restricted. A piece of plywood takes up the same percentage of moisture under a definite relative humidity as the plies from which it is made. This moisture adds to the volume of the cell walls. The fibers must swell the normal amount, irrespective of the restraining force within the force range involved. Since the dimension changes in the plane of the plywood are restrained, the changes must occur either in the thickness direction of the plywood or into the fiber cavities. For the latter to occur the fibers must be distorted or even ruptured.

Within the last few years synthetic-resin glues have been developed that produce joints equal or greater in strength than the wood even under high moisture-content conditions. The glue line of plywood assembled with these hot-press phenol-formaldehyde or urea-formaldehyde glues will withstand rather severe weathering conditions. The wood itself, however, is subjected to such severe stresses, due to alternate swelling and shrinking of the fibers, that it will eventually fail. As the outer surface of the outer plies is not restrained like the inner surfaces, differential stresses will be set up across these plies and eventually will result in face checking. Because of these stresses, plywood is much more subject to surface checking than is a solid board of the same size.

Application of Treatment to Plywood

It was hence hoped that applying the anti-shrink treatment to veneer from which the plywood is made would not only minimize checking under weathering conditions, but also add other desirable properties. This will be shown to be the case.

The veneer can be treated by either the cylinder treating method in which the solution flows into the coarse capillary structure of the wood by capillarity, aided by an applied vacuum or pressure, or by the diffusion method in which green wood is merely soaked in the solution and the dissolved material diffuses into the water within the wood structure. It is of importance to compare these two methods in order to determine which would be the preferable method to use in the treatment of veneer. A series of tests was hence made on air-dry 1/16-inch Douglas fir veneer sheets 14 inches square. The sheets were placed on edge in a galvanized iron tank...
Veneer was also treated by the simple soaking method. Sheets of veneer with moisture contents of 100 percent and 6 percent on the basis of the dry weight of the wood were used in order to compare green and seasoned wood. Both were placed in a 50 percent by volume solution of the resin-forming intermediate which was continuously stirred. Veneer specimens were removed, stacked, dried, and cured the same as in the case of the cylinder-treated material. The amount of synthetic resin remaining in the veneer after the curing is plotted in Figure 1 against the time in solution. The green wood attains the higher resin content much more rapidly. It will be shown later that the resin content of the wood on the basis of the dry weight of the untreated wood (the basis on which all the resin contents will be expressed) should be between 25 and 30 percent to gain the most efficient improvement in properties. This would require 8 to 15 hours soaking for the green wood and 30 to 60 hours for the dry wood. It is thus obvious that if the simple diffusion treating method is to be used, it should be applied to the green veneer just after it comes from the cutter knives. When thicker veneer is treated, the time for the cylinder treatment will not be materially increased, whereas the diffusion time will be increased as the square of the thickness. In the case of the treatment of 1/8-inch veneer and thicker, the cylinder method might be the most economical, but for veneer thinner than 1/16-inch the diffusion method would, undoubtedly, be preferable.

The anti-shrink efficiency (the reduction in the shrinkage caused by the treatment divided by the shrinkage of the control) of Douglas fir veneer containing different amounts of synthetic resin (Fig. 1) is plotted in Figure 2 against the resin content. It increases with increasing resin content of the wood up to a resin content of 30 to 40 percent, above which additional resin has but little effect. In the lower concentration range the synthetic resin is undoubtedly formed almost entirely within the cell walls. At concentrations above 30 to 40 percent the cell walls are saturated with synthetic resin and the excess resin is deposited in the coarse capillary structure where it can show very little anti-shrink effect. There is thus no object in forming more than 30 to 40 percent of synthetic resin within the wood.

Assembly of the Treated Veneer

The treated and cured veneer has been successfully assembled with the following glues: animal, vegetable (starch), soybean, casein, and phenol-formaldehyde and urea-formaldehyde hot-press resin glues. For the longer assembly periods (15 minutes) all of these glues gave joints of practically equal strength to those obtained with untreated veneer. When the assembly period was only a few minutes, the joints were definitely inferior to those obtained with untreated wood. This appears to be due to the fact that the treatment has reduced the tendency for the wood to absorb the glue solvent, so that the longer assembly periods are necessary to get the desired absorption. Wet strength tests gave results comparable to those for untreated veneer, the animal and starch glues losing practically all
Preliminary tests on panels faced with treated fancy crotch veneer indicate that the treatment greatly reduces face checking of this check-susceptible material. If the treatment is made on the green veneer just after cutting, the large losses in stock veneer due to checking and splitting prior to use should also be appreciably minimized. The treatment should thus be of considerable value to furniture manufacturers.

Dyeing the Veneer

Wood siding on houses is painted for two reasons, namely, to reduce the weathering degrade of the wood, and to give pleasing aesthetic effects. As the weathering degrade is reduced to a minimum by the synthetic-resin treatment, it seemed highly possible that pleasing aesthetic effects could be obtained by dyeing, which would not involve the high cost of paint upkeep.

Tests were hence made on incorporating inexpensive water-soluble dyes with the resin-forming intermediate and fixing them with the resin. Black, red, orange, and yellow Calco condensation dyes were used. The last two dyes dyed the wood much more uniformly than did the first two. The dyeing of 1/16-inch veneers of tupelo, black gum, yellow poplar, sugar maple, aspen, Douglas fir, and yellow birch decreased in uniformity in the order given. The birch showed a definite tendency to filter out the dye on treatment, whereas the gums and poplar dyed the veneer completely throughout the thickness of the plies. The dyes, of course, are like stains in that the grain of the wood is visible. The contrast between the light and dark portions is, however, considerably less pronounced than is obtained with ordinary stains. Leaching tests made after polymerization of the dyes indicated that an insignificant amount of dye was removed after continuous soaking in water for over a month. Weathering tests indicate that there is some fading of the dyes, most of which takes place in the first few weeks. Dyes more permanent to light exposure might, of course, be found than those tested. Sufficient evidence has been obtained, however, to indicate the possibilities of making a permanently dyed plywood.

Moisture Transfusion Through Treated Plywood

Measurements were made to compare the rate at which water vapor passed through the treated plywood in contrast to the untreated plywood under a relative humidity gradient. Pieces of plywood 1-foot square were sealed on top of metal trays containing water so that 100 square inches of surface were exposed. These were placed in a 30 percent relative humidity room. Moisture passed through the plywood under a relative humidity gradient of 100 to 30 percent. After a steady-state moisture gradient was set up through the specimen, loss of moisture occurred at a uniform rate. The loss in weight of the tray and plywood after this condition had been reached per 15 days is given in Table 2 for untreated plywood and plywood with different proportions of the total thickness treated.
Mechanical Properties of Treated Wood

Tests were made of the hardness, compressive strength, modulus of rupture, modulus of elasticity in bending, and the toughness of treated and untreated sugar maple sapwood and sugar pine heartwood blocks. The former contained 23 percent resin and the latter 43 percent resin on the basis of the dry weight of the wood. The hardness of the maple and the pine was increased by 42 percent and 84 percent, respectively. The compressive strengths of the two woods perpendicular to the grain was increased about 50 percent, and parallel to the grain they were increased about 20 percent. The other properties were practically unaffected. It appears that only compressive strength properties are affected by the treatment.

Decay Resistance of Treated Wood

Decay-resistance tests were made on small specimens of Douglas fir heartwood containing 32 and 49 percent of synthetic resin. These specimens, together with matched controls, were incubated in contact with cultures of the wood-destroying fungus, Trametes serialis, for 3 months. The controls lost, on the average, 40 percent of their dry weight and the treated specimens lost between 3 and 5 percent. The former could easily be crumbled with the fingers, whereas the latter were mechanically sound. The large reduction in the decay is apparently due to the fact that the treated wood could not take up enough water to support decay rather than due to any inherent toxic effect on the residual part of the phenol-formaldehyde. This conclusion is based on the fact that fungus grew on the surface of the treated blocks, whereas it would have shunned the blocks had they been toxic.

Further tests were made with a more decay-susceptible wood, sugar pine, and another decay fungus, Lenzites trabea. To further insure a favorable moisture content for development of the fungus in the wood, the specimens were immersed in water and the air removed by alternate application of a vacuum and pressure. In this way the moisture content of the treated specimens was made to exceed 100 percent. The specimens were incubated for 3 months. The average loss in weight of 3 controls was 42 percent of their dry weight. The average loss of weight of 4 specimens containing 15 percent resin was 5.3 percent and of 7 specimens containing 30 percent resin was 1.2 percent. Again the controls could be crumbled with the fingers and the treated specimens were mechanically sound. Even with a supply of free water throughout the coarse capillary structure of the treated specimens an insufficient amount of water entered the cell walls to support normal decay.
Other Properties

Tests have been started on the paint-holding power of the treated plywood. These will have to be reported later as sufficient time has not elapsed for noticeable deterioration of the paint films.

Conclusions and Costs

Making plywood from veneer treated with a phenol-formaldehyde resin-forming intermediate has been shown to improve many of the properties: (1) reduce swelling and shrinking and, consequently, the face checking under weather conditions; (2) make possible the fixing of inexpensive water-soluble dyes in the structure; (3) reduce moisture transfusion through the plywood; (4) increase decay resistance; (5) increase acid resistance; (6) increase the hardness and the compressive-strength properties; (7) slightly improve the fire resistance; and (8) lose but slightly in thermal insulating properties. This array of improved properties can be obtained at only a nominal increase in cost. On the basis of the undiluted resin-forming intermediate costing 25¢ per pound, the chemicals required per square foot of 1/16-inch veneer of average specific gravity, in order to give an adequate improvement in properties, would cost 1¢. If the treatment were to cost 1/2¢ per square foot, the additional manufacturing cost of 3-ply plywood with two 1/16-inch treated faces and an untreated core would be about 3¢ per square foot. This would be an increase of about 50 percent over present retail cost of 1/4-inch Douglas fir resin-bonded plywood (3 1/12-inch plies). The cost of incorporating water-soluble dyes with the treating intermediate should not exceed 1/4¢ to 1/2¢ per square foot. If the dyed wood were considered an acceptable substitute for painted wood for house siding, the treated dyed plywood would cost less than the untreated plywood plus paint. There thus appears to be economic possibilities for the use of this treatment.

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Figure 2.—Anti-shrink efficiency of 1/16-inch Douglas fir veneer containing different amounts of synthetic resin.