FOREST PRODUCTS LABORATORY RESIN-TREATED, LAMINATED, COMPRESSED WOOD (COMPREG)

~~Information Reviewed and Reaffirmed~~

~~June 1955~~

INFORMATION REVIEWED
AND REAFFIRMED
1960

No. 1381

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

FOREST PRODUCTS LABORATORY RESIN-TREATED LAMINATED, COMPRESSED WOOD (COMPREG)

By

A. J. STAMM, Chemist
and
R. M. SEBORG, Chemist

Forest Products Laboratory,[1] Forest Service
U. S. Department of Agriculture

Compressibility

The most practical treatment thus far tested by the Forest Products Laboratory for permanently reducing the swelling and shrinking of wood consists of the formation within the cell-wall structure of a phenol-formaldehyde resin after the wood has been treated with an aqueous solution of a completely water-soluble, virtually unpolymerized phenol-formaldehyde mix. The product thus formed is called impreg, the production and properties of which are described in Forest Products Laboratory Report No. 1380, "Forest Products Laboratory Resin-treated Wood (Impreg)" (8).[2]

The treatment imparts a number of other important properties to the wood. One of these not discussed in Report No. 1380 is the wood's plasticity at polymerization temperatures, prior to the setting of the resin. Because of this plasticizing action of the resin-forming constituents, the wood can be compressed under considerably lower pressures than dry untreated wood.

---

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Underlined numbers in parentheses refer to Literature Cited at end of this report.

For example, treated spruce, cottonwood, and aspen veneer dried to a moisture content of about 6 percent under the conditions described in Report No. 1380 but not cured, will compress when subjected to a pressure of only 250 pounds per square inch at 300° F. to about half the original thickness and a specific gravity of about 1. A few preliminary tests indicate that redwood will compress to about the same degree under a pressure of only 200 pounds per square inch. The dry untreated veneers in contrast will compress only 5 to 10 percent under the same conditions. Resin-treated sweet, black and tupelo gum and yellow-poplar require somewhat higher pressures, 300 to 400 pounds per square inch, to be compressed to half the original thickness.

Under a pressure of 1,000 to 1,200 pounds per square inch most of the treated veneers compress to specific gravities between 1.3 and 1.4. In doing so, woods like spruce, cottonwood, and aspen compress to about one-third of the original thickness. The denser, harder woods naturally are reduced less in thickness. With pressures of 1,000 to 1,200 pounds per square inch the treated woods are compressed almost to the maximum extent; that is, the void volume approaches zero. This is evident from the fact that the specific gravity of wood substance is about 1.46 and that of the resin about 1.28. Dry, untreated wood will, in general, require pressures of 2,000 to 5,000 pounds per square inch to be compressed to specific gravities of 1.3 to 1.4.

The increased compressibility of veneer treated by the Forest Products Laboratory method not only simplifies the manufacture of compreg, but it also makes possible the simultaneous compression of resin-treated plies and their assembly with either untreated veneer, or resin-treated veneer in which the resin has been precured by the application of heat alone, without compression. For example, resin-treated but uncured face plies of spruce can be compressed to about half their original thickness and simultaneously assembled to a dry, untreated spruce core at 250 pounds pressure per square inch with a resultant compression of the core of only 5 to 10 percent. If the core plies were similarly treated but the resin was set within their structure by the application of heat prior to assembly with the treated faces, the core would compress hardly at all under 250 pounds per square inch pressure. If the core was of untreated poplar, it would also be practically uncompressed under this pressure. If the spruce has a dry weight-dry volume specific gravity of 0.4, the poplar of 0.5, and the resin treatment increases the specific gravity of the wood by 18 percent (30 percent increase in weight and 12 percent increase in volume), then the specific gravity of the core in the three cases will, after assembly, vary from about 0.42 to 0.52 and the specific gravity of the faces will be about 1.0. It is thus possible to cause a variation in the specific gravity of the product of about twofold between the compressed and the uncompressed plies. The product can be made with the higher specific gravity plies either on the surface or in the interior, as desired. The only restriction is that the structure be balanced to avoid warping when the treated compressed plies are combined with untreated plies. Resin-impregnated wood which has been partially compressed has been called semicompreg.

Besides the possibility of varying the specific gravity of the product in the thickness direction, it is possible to vary the specific gravity in the length direction by pressing a wedge-shaped pile of plies. Figure 1 shows one of a number of possible ways of laying up treated veneer to obtain specimens with varying specific gravity from one end to the other, together with the finished product. When pressing such unsymmetrically shaped piles of plies, the pressure is concentrated almost entirely at the heavy end. To avoid damage to the press because of the uneven loading, several specimens should be pressed at once with the heavy ends symmetrically arranged over the platen area. Specific gravities ranging from that of the uncompressed treated wood to about 1.4 can be obtained.

Phenolic-resin treatment not only aids in the compression of wood, but it also tends to hold the wood in the compressed form. Normal, untreated wood, when compressed at 300° F. and below, will tend to recover from compression (springback) as moisture is absorbed. If it is water soaked, it will recover almost completely from its compression. The impregnation of wood with resin greatly reduces or almost eliminates the tendency of the wood to springback when the resin is completely cured within the wood. Springback can be largely eliminated with phenolic resins that are prepolymerized to a considerably greater degree than those that are effective in permanently reducing swelling and shrinking.

Gluing and Pressing

Bonding Glues

When resin-treated veneer is highly compressed in making parallel-laminated compreg, it is not necessary to use a bonding glue between the plies, provided the resin content exceeds 30 percent on the basis of the dry weight of the untreated wood (1). When the resin content is below 30 percent, and when the veneer is cross banded or only partially compressed, an additional bonding agent should be used to obtain optimum shearing strengths. Hot-press spreading phenolic glue seems to be most satisfactory for this purpose. Slightly less than normal spread is sufficient.

Compreg panels can be satisfactorily glued to each other or to ordinary wood only after removing the surface glaze by sanding or machining. If the panels are thick it is important to machine the surfaces very flat to avoid locally thick glue lines.

Gluing can be done satisfactorily with a number of glues. Alkaline catalyzed phenolic and resorcinol glues that set below the boiling point of water appear most satisfactory and have been most extensively used (2).

Most Favorable Moisture Content

Experience has shown that it is desirable, especially when making thick specimens of highly compressed resin-treated wood, to dry the treated plies under nonpolymerizing conditions (see Report No. 1380) to as low a moisture content as is practical, that is, about 2 percent moisture content. When hot-press glues are used, it is further desirable to re-dry the plies that have been coated with glue for about an hour at 160° to 170° F. prior to assembly of the plies. This procedure, it has been shown, practically eliminates end checking of thick pressed products, which may be very serious when the moisture content of the veneer is appreciable.

When resin-treated faces are being compressed and assembled with a dry untreated core or treated precured core in a single operation, it does not seem to be necessary to have the faces at so low a moisture content as 2 percent to avoid checking. In fact, it is undesirable to have them so dry if loss in differential compression between the faces and core is to be avoided. The moisture content of the faces at the time of assembly can, however, be too high, resulting in washboarding of the surface or face crazing when the product is taken hot from the press. The best compromise moisture content for the face plies prior to pressing has not been definitely determined for the various species. A moisture content of 4 percent, however, seems to be satisfactory for at least some species, such as cottonwood, aspen, and yellow-poplar.

Temperature and Time of Pressing

Experience has shown that the higher the temperature of pressing, the greater will be the tendency to check. This is due to embrittlement of the treating resin. The best results have been obtained by pressing at 285 to 300° F.

When heating from the press platens, the time of heating will naturally depend upon the thickness of plies between the platens. If all the heat came from the platens, the time for pressing would vary as the square of the thickness. In the case of the resin-forming mixes used, there is an appreciable amount of exothermic heat resulting from the reaction within the wood structure. As a result of this, the time required for setting the resin in thick specimens is somewhat reduced because of the fact that the internal temperature is built up more rapidly than by conduction alone. Cases have, in fact, been recorded in which the center temperature, as indicated by a thermocouple inserted at the center of thick assemblies (2-1/2 inches in the compressed condition) of resin-treated plies, rose 80° F. above the platen temperature of 310° F. and actually caused a slight charring.

In making compreg blocks six inches thick, which were heated by high frequency to temperatures above 250° F., the temperature rose sufficiently because of the exothermic reaction to cause charring at the center of the block. This is due to the fact that heat was evolved from the reaction at the center of the wood more rapidly than it could be dissipated by conduction. In making 2-1/2 inch thick compreg when the platens were held at 285° F., the exothermic reaction was sufficiently slow that the generated heat could be conducted away as rapidly as it was generated, thus avoiding the undesirable building up of heat at the center. This is further reason for avoiding temperatures appreciably above 285° F.

Because of the effect of the thickness of the pressed material upon the pressing time when heating from the platens, the pressing time is preferably expressed as the time that the center of the wood should be held at the desired temperature. This can be estimated from the curing temperature-curing time-swelling curves of figure 2 for 17 parallel laminated plies of 1/16-inch birch veneer. These had been treated with enough Bakelite Resinoid XR5995 to give a potential resin content of 30 percent of the weight of the dry untreated wood, then dried at 170° F. for 5 hours at a relative humidity of 45 percent giving a moisture content of about 6 percent, and pressed at 1,000 pounds per square inch.

In each case it took from 10 to 15 minutes to attain the desired temperature at the center and about 5 minutes to cool the panels to 200° F. at the center subsequent to curing. The cooling was necessary to prevent immediate springback of panels pressed under incomplete curing conditions. It further gives improved surfaces on all panels. The curves of figure 2 show, from the large swelling and springback occurring upon immersion in water, that the resin was not cured in any of the panels at 235° F. At 260° F. the resin is partially cured only under the longest curing time of 45 minutes. At 285° F. it is completely cured in about 20 minutes and at 300° F. in about 10 minutes.

With the use of electrostatic heating equipment, the time required to bring the wood to the polymerization temperature should be markedly reduced. No data are as yet available on curing times by this method.

It has been found desirable to apply heat when possible before exerting pressures great enough to compress the wood, as less stresses and rupture of the structure seem to result under these conditions due to plasticization of the wood. This procedure, however, cannot be followed in making thick, compressed material heated only by the platens. In such a case it is necessary to apply compressing pressures before the center of the wood is plastic, to avoid setting the resin in the outer plies before they are compressed. This difficulty can be largely avoided by preheating the plies or by using high frequency heating.

Thick material should be cooled in the press until the center of the wood is down to about 200 to 220° F. before releasing the pressure, especially when the moisture content of the wood is appreciably above 2 percent. This procedure is necessary to avoid the formation of steam blisters, crazing of the surface, and washboarding of the surface in woods with contrasty grain. Surface crazing can, however, be avoided with most of the species tested by using very dry treated veneer. It is advisable that the cooling step be omitted only when making relatively thin panels, using quite dry treated veneer of uniform textured woods, such as cottonwood, aspen, and yellow-poplar or when the pressed surface is to be machined from thick blocks of compreg made at moisture contents below 2 percent.

Properties

Moisture Absorption and Swelling

Compreg is far more resistant to moisture absorption from the liquid phase than the corresponding uncompressed resin-treated wood. This is due to the relative lack of mechanical voids and capillary structure in the compressed material. The final equilibrium adsorption of water from the vapor phase, however, is practically unaffected by compression, although the rate of adsorption is considerably less for the compressed material. Similarly, the rate of swelling of compreg is considerably less than that for impreg, but the former will swell to a greater degree, due to the fact that the amount of fiber substance per unit dimension is increased.

Phenolic resins which have a low molecular weight (i. e., are water soluble and only slightly prepolymerized) are the most readily absorbed by the cell walls of the wood fibers and are, therefore, the most effective in reducing dimensional changes. The degree of dimensional stabilization increases directly with an increase in resin content up to a resin content of about 30 percent (8). These resins also impart a greater degree of brittleness to the wood which increases with an increase in resin content.

The alcohol-soluble type of phenolic resins (only partly or not soluble in water) have been prepolymerized to a greater degree and have a high molecular weight (i. e., larger molecules) than the less polymerized water-soluble resins and, therefore, are not as effective in reducing dimensional changes because they show less tendency to diffuse into the cell walls. This type of resin, however, imparts less brittleness to wood than does the water-soluble type.

For applications of compreg requiring a high degree of resistance to moisture and in which the toughness property is of minor importance, such as in cutlery handles, it is recommended that water-soluble phenolic resin be used as the wood impregnant. If the toughness property of the compreg is of prime importance and the dimensional changes are of little significance, such as in picker sticks and shuttles, the treatment of wood with alcohol-soluble resins is recommended. Both types of phenolic resins are commercially available and the two types of compreg are now being manufactured.

Army Air Forces specification No. 15065 of June 10, 1942 for compreg allowed a maximum water adsorption, after 24 hours' water immersion, of 6 percent by a specimen 3 inches by 1 inch by 3/8 inch (1 inch in the fiber direction). Specification No. 15065-A, March 15, 1944, allowed but 2.5 percent water adsorption. Compreg made from resin-treated veneer according to the Forest Products Laboratory procedure (Rept. No. 1380) will adsorb less than 1 percent moisture under these conditions.

A few tests indicate that compreg serves as even a better moisture barrier than the uncompressed resin-treated wood (Rept. No. 1380). The moisture transfusion through a panel under a relative humidity gradient is, for most purposes, negligible.

Surface Finish

Compreg has a lustrous varnish-like finish when it is compressed between highly polished platens. The degree of luster diminishes with a decrease in the polish of the mold, a decrease in the compression of the wood, and an increase in the amount of precuring of the plies prior to pressing. Cut surfaces of the compressed material in which the resin within the cell-wall structure was cured at the time of pressing can be sanded and buffed to give fully as lustrous a finish as can be obtained with the platens. The wood is finished throughout the structure. Sanding and buffing to give a smooth surface merely bring out the finish. Articles manufactured from resin-treated, compressed wood can thus be restored to their original finish when scratched or marred by merely sanding and buffing.

Compreg made according to the Forest Products Laboratory method between polished metal platens has a high surface hardness and finish as shown by tests made with a Sword surface hardness tester, which measures a combination of smoothness and hardness. The instrument, which is calibrated to give an empirical reading of 100 for plate glass, gives values ranging from 65 to 90 for different resin-treated, compressed wood specimens with different resin contents made under different degrees of compression. Ordinary smooth spruce gave a value of 6. The latter with a good varnish finish gave a value of 18.

Only a few tests have thus far been made on painting compreg with a yellow lacquer and a yellow enamel used by the Army for painting insignia on metal airplanes. One coat was sprayed on half of the surface of panels with resin-treated, compressed faces of spruce and on untreated, uncompressed spruce controls. The one coat gave a smooth finish on the treated panels, but on the controls showed an obvious need for building up the finish. Southern exposure out-of-door weathering tests after three years showed no deleterious weathering of the film in any case. Some face checking of the untreated controls occurred through the paint film, starting largely at the exposed unpainted parts of the panels. As far as the tests go, it appears that this type of lacquer or enamel will stand up satisfactorily on resin-treated, compressed wood.

Strength Properties

The strength properties (3, 4, 5, 6) of compreg are, in general, appreciably greater than those of normal untreated wood. The specific strength properties (strength per unit specific gravity), are, however, in all cases but the compressive strength and hardness, less for compreg than for normal wood. The increased strength is primarily due to the compression of the wood. The resin seems to be effective only in increasing the compressive-strength properties and the shear. It further causes an appreciable decrease in the toughness.

The hardness of wood is increased to a slight degree by the resin and to a high degree by the compression of the wood. Wood, such as spruce, with a specific gravity of 0.45 after resin treatment and compression to a specific gravity of 1.3, is increased 15 fold in hardness. Birch, with a specific gravity of 0.6, is increased tenfold in hardness when resin treated and compressed to the same degree (10).

Table 1 gives the strength values obtained on a panel consisting of 16 parallel laminations of 1/16-inch rotary cut spruce veneer containing about 35 percent of resin on the basis of the weight of the dry untreated wood that had been compressed to 0.35 of the original thickness and an average specific gravity of 1.32. No glue was used between the plies. The data show that laminated, resin-treated, compressed wood has very high strength properties. Because of the limited number of tests, these values can be considered only as approximate.

Inasmuch as the data on properties are related to test methods, a brief description of the tests is pertinent. Because of the small size of the samples, and their thinness, the standard test methods are not applicable without some modification.

Tension parallel to grain. --The specimen was approximately 14 inches long with an end cross section 1 inch by approximately 0.35 inch (the thickness of the panel) and a central cross section 3/8 by 3/16 inch. The center 2-1/2 inches of the length of the specimen was of constant cross section and the transition from the central cross section to the end cross section was effected with a curve of 30-inch radius. A constant rate of motion of the movable head of the testing machine of 0.025 inch per minute was used, and strain measurements over a 1-inch gage length were taken during the early portion of the test. This specimen is substandard, in that the tension test recently developed calls for a specimen 26-1/2 inches long to provide a more favorable filler radius.

Compression parallel to grain. --A specimen of 1-3/8 inches long (4 times least dimension) by 1 inch wide by approximately 0.35 inch (the thickness of the panel) was used. A constant rate of movement of the movable head of the testing machine of 0.004 inch per minute was used, and strain measurements over a 1/2-inch gage length were taken during the early portion of the test.

Static bending. --The specimen used was 2 inches wide and sufficiently long to provide a ratio of span to depth of 14. Center loading was used, with a rate of descent of the movable head of 0.018 inch per minute.

Shear parallel to grain. --The specimen used was 2-1/2 inches long by 2 inches wide by the thickness of the panel, with a notch 1/2 by 3/4 inch in one corner. The rate of descent of the movable head was 0.015 inch per minute. The specimen was an adaptation of the Forest Products Laboratory standard shear test specimen, differing from the standard only in that the thickness or width was approximately 0.35 inch instead of 2 inches.

The Johnson shear tests (11) were made on specimens 1 inch wide and 1/2 inch deep cut from another specimen 1 inch thick.

In conjunction with curing tests on resin-treated, parallel-laminated, compressed birch bonded with phenolic film and made under the conditions given on page 4, measurements were made of the modulus of rupture and the modulus of elasticity in static bending, and the shear parallel to the grain and across the plies, by the Forest Products Laboratory method. For these tests, 45 different specimens cured under different conditions were used. The average, the maximum, and the minimum values for the modulus of rupture were 40,300, 47,000, and 36,500 pounds per square inch. The corresponding modulus of elasticity values were 3.64, 3.92, and 3.25 million pounds per square inch, and the comparable maximum shearing strength values were 4,000, 4,500, and 3,700 pounds per square inch.

Shear values are highly dependent upon the method. Values taken from different sources hence should not be compared unless the method and the size of the specimens are identical. For example, the standard Forest Products Laboratory shear-test method for testing the joints of glue blocks gave about double the values on compreg that were obtained by the Laboratory's shear-test method for normal wood when shearing in the plane of the plies.

The shear strength of compreg parallel to the grain is considerably greater in the direction in which the surface of failure is parallel to the direction of compression than it is when the surface of failure is at right angles to the direction of compression, even when the bond between the plies is sufficiently strong to give 100 percent wood failure. It has been shown from tests on solid blocks of wood compressed in either the radial or tangential structural directions of the wood that the structural direction of the wood plays only a minor part in the difference. The difference seems to be due primarily to variations in the structure in the direction of compression and at right angles to the direction caused by the compression. The average shear strength parallel to the grain and in the direction in which the compression was applied for 24 plies of laminated, resin-treated, compressed sweetgum specimens that were bonded with phenolic film was, as determined by the Forest Products Laboratory method, 3,200 pounds per square inch. The corresponding value for the shear at right angles to the direction of compression was 1,200 pounds per square inch. Similar averages for six specimens of cottonwood were 2,600 pounds per square inch in the direction of compression and 1,500 pounds at right angles to the direction of compression. Only the shear strength, in the direction in which the plane of rupture is parallel to the direction of compression, is appreciably increased over that for the normal wood.

The shear strength in the plane of the plies is highly dependent upon the nature of the bonding material, especially when the dense, stronger woods like birch that cannot be greatly compressed are used. In the case of parallel laminated highly compressible woods like spruce, 100 percent wood failure is obtained when the treating resin exuding from the plies serves entirely as the bonding medium. In the case of sweetgum and birch, glue failure sometimes occurs, indicating that the bond may not be as strong as the wood. When phenolic film is used as the bonding medium for resin-treated, parallel-laminated sweetgum, 100 percent wood failure is obtained in the shear tests. In the case of birch the failure is largely glue failure, indicating that the wood is stronger than the paper lamina containing the resin glue. When hot-press phenolic glues of the spreading type are used, 100 percent wood failure is obtained even with birch. For example, birch compreg that was bonded with phenolic film gave shear strength values in the plane of the plies in a series of 45 tests of only 900 to 1,600 pounds per square inch. In all cases glue failure predominated. When a hot-press phenolic spreading glue was used, 10 specimens gave shear strengths averaging 2,000 pounds per square inch, and complete wood failure resulted.

The modulus of rupture in bending and the modulus of elasticity are practically unaffected by curing conditions above a minimum threshold value (7). The toughness, however, is greatly affected by the condition of cure, over-cure causing a decrease in toughness (6).

More extensive strength data for birch compreg are given in ANC-18a bulletin, "Design of Wood Aircraft Structures," obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., for 75 cents cash or money order.

Fabrication and Molding

It is more difficult to cut and machine compreg than normal wood, but less difficult than metals. Special hardened saws and tools should be used; lower tool speeds than for normal wood are desirable.

Because compreg is more difficult to machine than treated uncompressed and uncured wood, the Forest Products Laboratory developed a method for molding precarved blanks rather than carving the final compreg blanks. The process was used during the war for molding "club" motor test propellers and aerial masts. Resin-treated veneer is glued up into blanks with a phenolic glue, such as Resinous Products PR14, or Bakelite cold-setting resin XC3931 with less than normal amount of catalyst XK2997, under conditions such that the bonding glue sets only partially and the treating resin is unaffected (temperatures below the boiling point of water). The blanks are then carved to the desired width and shape but with a thickness 1-1/2 to 2-1/2 times that of the finished product. The carved blanks are then heated and compressed in a split mold to the final desired specific gravity. A slight flash that can be readily machined off normally occurs at the parting line.

A more generally applicable means of molding compreg after precompression without the use of a press has recently been developed (9). This method, known as expansion molding, consists of precompressing dry but uncured resin-treated wood at about 200° to 240° F. At this temperature the wood is plasticized by the resin-forming chemicals but the resin does not cure in the short period involved. If the pressure is released while the wood is hot, it springs back immediately. If cooled under pressure, however, the wood retains its compression for months when kept dry. This uncured material is cut to templates and laid up to fit and fill a mold. The mold is then locked in the closed position and heated. The tendency for the wood to expand and release the pent-up stresses exerts back pressure as high as 750 p. s. i. against the mold.

Applications

Solid compreg was used chiefly during the war for trainer-plane adjustable-pitch propellers, motor-test propellers, antenna masts, spar and connector plates, refrigerator blocks for ships, and tooling jigs. The flight propellers were carved from glued-up blocks of compreg made up from compreg panels 1-1/4 inches thick. Compreg, because of its high compressive strength, was found to make excellent spar and connector plates. For this purpose the cross-banded product has been usually used. Its combined load-bearing and thermal-insulating properties were taken advantage of in using it for supporting blocks for refrigerators. Compreg was found extremely useful for aluminum drawing and forming dies, drilling jigs, and jigs for holding parts in place while welding, because of its excellent strength properties, dimensional stability, low thermal conductivity, and ease of fabrication.

Compreg is being used to a considerable extent for knife handles and for picker sticks in looms. It also shows promise for use in silent gears, pulleys, water-lubricated bearings, fan blades, shuttles, instrument bases and cases, electrical insulators, tool handles, and various novelties. Compreg has better strength properties than fabric-reinforced plastics, and it should be significantly cheaper because veneer is cheaper than fabric on a weight basis and because half as much resin is used per unit weight of compreg as for fabric laminates. Compreg may thus replace fabric laminates in a number of uses.

Compreg and semicompreg show promise for future use as facing materials for ordinary plywood. These facing materials may find external use in house, trailer, and box-car panels and in boat siding, and internal use in panels, furniture, and flooring. A test floor has been laid at the Forest Products Laboratory consisting of 10-inch square tongue-and-groove panels, composed of three-ply yellow-poplar semicompreg faces compressed from a 3/16- to a 1/8-inch thickness, a single 1/16-inch thick back ply of impreg to balance the construction from a swelling standpoint, and a 1/2-inch thick five-ply Douglas-fir core, with all plies glued with phenol glues. The floor has a very attractive greenish-tan natural finish. It is in excellent shape after 8 years' service. Such a floor would be more expensive than the normal strip oak floor. It is, however, hoped that it will require less service to keep in good condition. The original finish can be restored by sanding with fine sandpaper, and then buffing.

Cost

The cost of resin-treated, compressed wood will be primarily dependent upon the cost of the treating resin, the veneer, and the treating process (8). The cost per unit volume will be increased primarily because both the wood and the resin are made to occupy a smaller volume under compression. The cost of compressing and assembling in the form of flat panels will be but slightly more than the cost of assembly of the resin-treated, uncompressed material. The cost of production of resin-treated, compressed wood per pound will vary from about 40 cents to 50 cents, depending upon the species of wood used, the thickness of the panels, and the efficiency of manufacture.

Availability

Compreg is manufactured by the following companies:

Formica Insulation Co., Cincinnati, Ohio
Parkwood Corp., Wakefield, Mass.

Literature Cited

(1) BURR, H. K. and STAMM, A. J.
1945. COMPARISON OF COMMERCIAL WATER-SOLUBLE PHENOL-FORMALDEHYDE RESINOIDS FOR WOOD IMPREGNATION. Forest Products Laboratory Rept. No. 1384. 12 pp., illus.

(2) EICKNER, H. W. and BRUCE, H. D.
1946. GLUING OF THIN COMPREG. Forest Products Laboratory Rept. No. 1346. 10 pp.

(3) ERICKSON, E. C. O.
1952. MECHANICAL PROPERTIES OF LAMINATED MODIFIED WOOD. Forest Products Laboratory Rept. No. R1639. 16 pp.

(4) ERICKSON, E. C. O. and FAULKES, W. F., Jr.
1949. BASIC PROPERTIES OF YELLOW BIRCH LAMINATES MODIFIED WITH PHENOL AND UREA RESINS. Forest Products Laboratory Rept. No. R1741, 14 pp.

(5) FINDLEY, W. H., WORLEY, W. J., and KOCALIEFF, C. D.
1946. EFFECT OF MOLDING PRESSURE AND RESIN ON RESULTS OF SHORT-TIME TESTS AND FATIGUE TESTS OF COMPREG. Trans. Am. Soc. Mech. Eng. pp. 317-325.

(6) MILLETT, M. A., SEBORG, R. M., and STAMM, A. J.
1943. INFLUENCE OF MANUFACTURING VARIABLES ON THE IMPACT RESISTANCE OF RESIN-TREATED WOOD. Forest Products Laboratory Rept. No. 1386, 7 pp., illus.

(7) SEBORG, R. M. and STAMM, A. J.
1945. EFFECT OF RESIN TREATMENT AND COMPRESSION UPON THE PROPERTIES OF WOOD. Forest Products Laboratory Rept. No. 1383, 6 pp., illus.

(8) STAMM, A. J. and SEBORG, R. M.
1943. FOREST PRODUCTS LABORATORY RESIN-TREATED WOOD (IMPREG). Forest Products Laboratory Rept. No. 1380, 9 pp.

(9) STAMM, A. J. and TURNER, H. D.
1945. METHOD OF MOLDING. U. S. Patent No. 2,391,789.

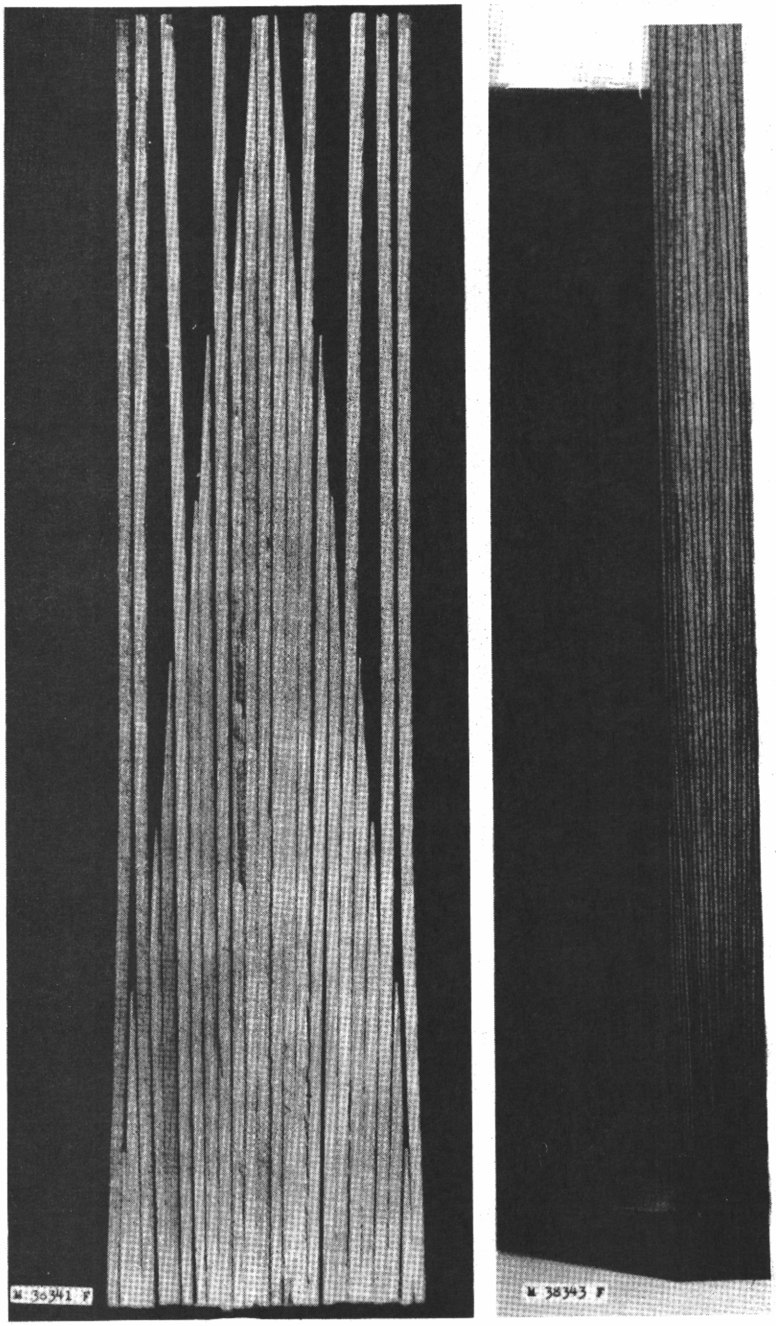
(10) WEATHERWAX, R. C., ERICKSON, E. C. O. and STAMM, A. J.
1948. A MEANS OF DETERMINING THE HARDNESS OF WOOD AND MODIFIED WOODS OVER A BROAD SPECIFIC GRAVITY RANGE. ASTM Bull. 153, Aug. (TP176)(1948).

(11) WITHEY, M. O. and ASTON, J.
1930. JOHNSON'S MATERIALS OF CONSTRUCTION. 7th ed., p. 61. John Wiley and Sons.

Table 1. --Strength values for resin-treated, parallel-laminated spruce compressed to a specific gravity of 1.32

	Number of tests	FPL compreg	German specifications[1]
		P. s. i.	P. s. i.
Tension parallel to the grain:			
Maximum tensile strength.......	7	42,500	28,500
Modulus of elasticity...........	1	4,700,000	----
Compression parallel to grain:			
Maximum crushing strength.....	8	23,400	18,500
Modulus of elasticity...........	8	5,000,000	----
Static bending:			
Modulus of rupture.............	4	43,400	35,500
Modulus of elasticity...........	4	4,400,000	2,700,000
Shearing parallel to the grain --			
Maximum shearing strength perpendicular to plies:			
Modified FPL method.........	4	3,000	
Johnson single shear method ..	1	5,000	
Johnson double shear method ..	1	6,000	

[1]Strength values taken from the German specifications for artificial resin-treated compressed wood (Kunststoffe 30:58-62, 1940) are given here for comparison.



Z M 39045 F

Fig. 1. Means of laying up veneer to obtain product with varying specific gravity from one end to the other.

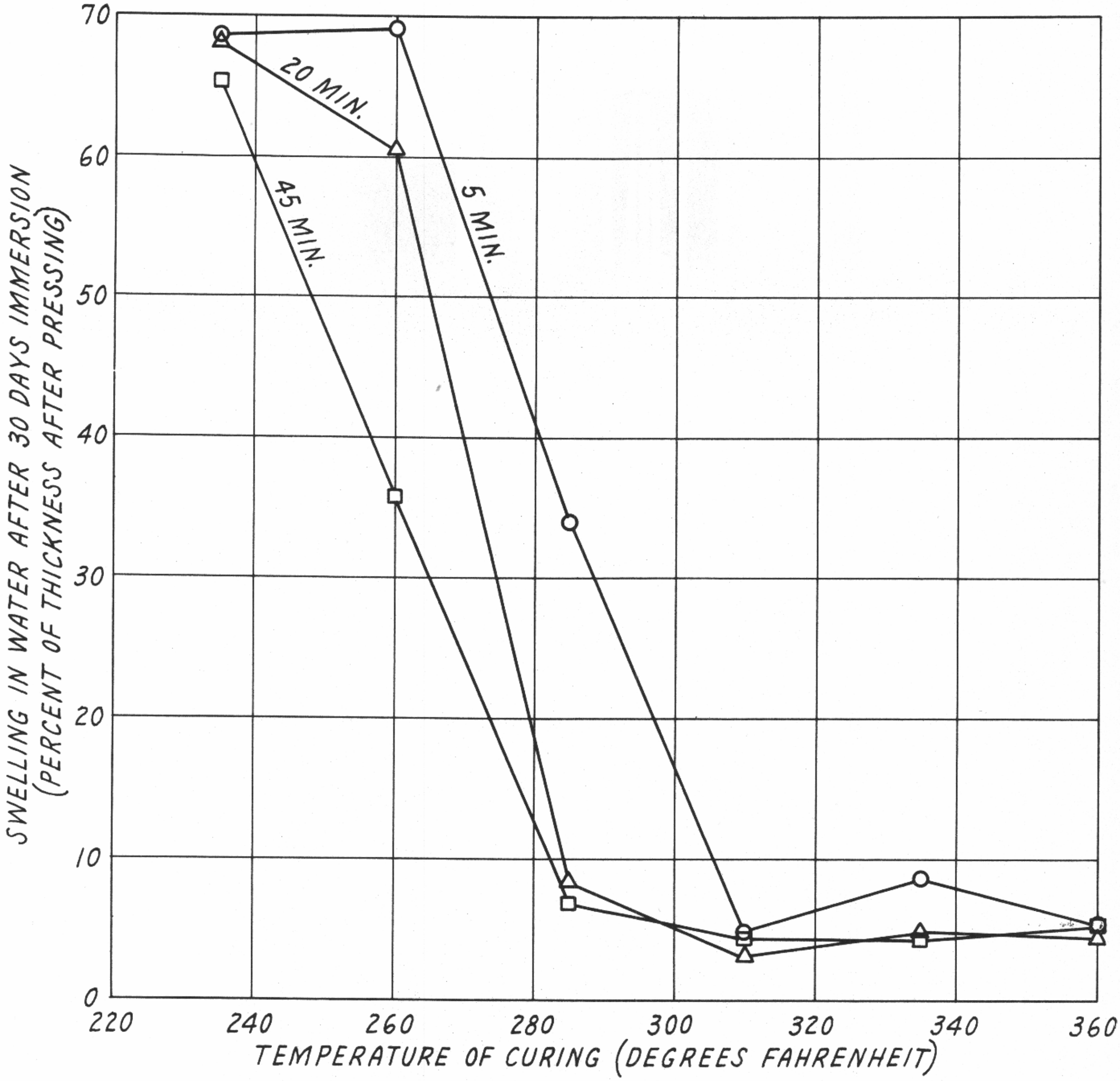


Fig. 2. Relation of the temperature at three periods of cure to the combined swelling and recovery from compression of laminated, resin-treated, compressed birch in the direction of compression when immersed in water. Times are in terms of the period that the center of the wood is held at the designated temperature.

ZM-39675-F