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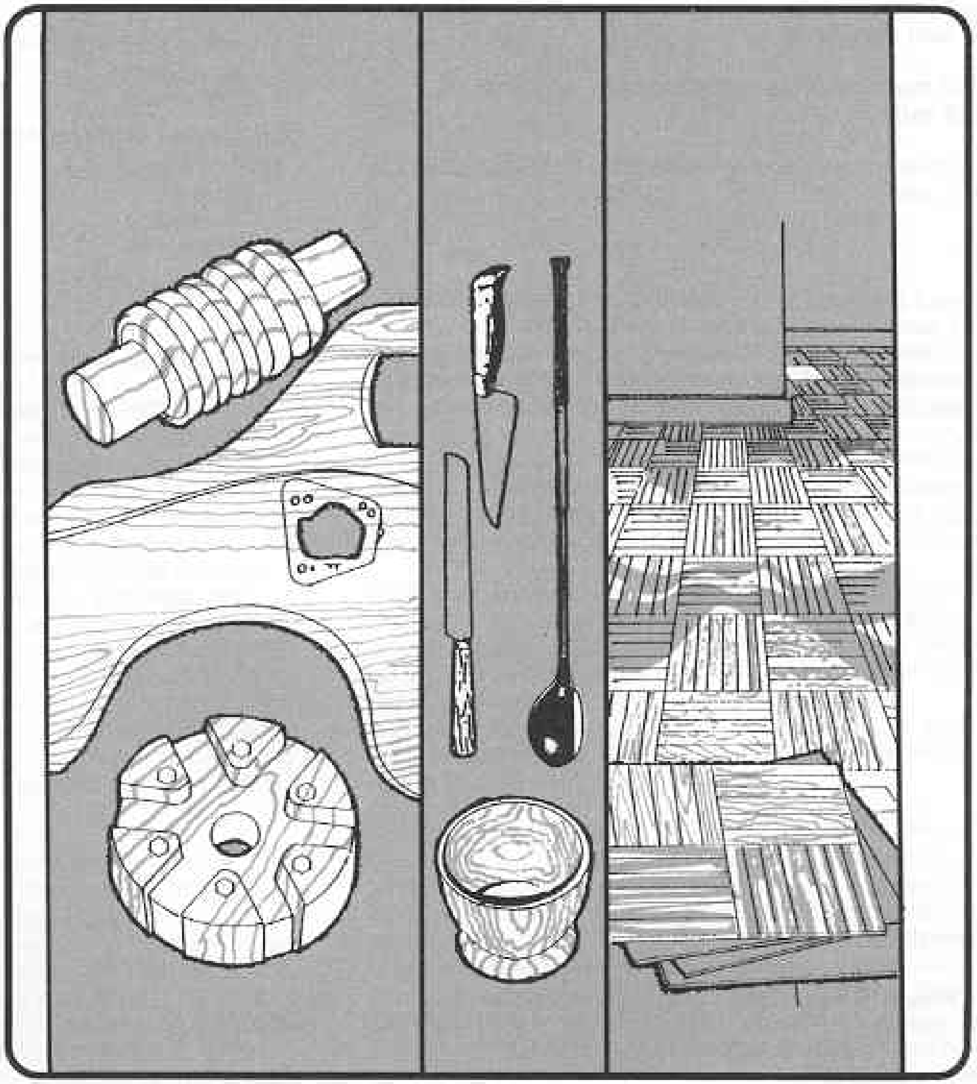
Treatments that Enhance Physical Properties of Wood



Abstract

This paper was prepared for anyone who wants to know more about enhancing wood's physical properties, from the amateur wood carver to the president of a forest products company.

The authors describe chemical and physical treatments of wood that enhance the strength, stiffness, water repellency, and stability of wood. Five types of treatments are described:

1. water-soluble polymers or synthetic resins that become insoluble after curing,
2. organic chemicals or cross-linking agents that bond cell wall polymers,
3. liquid monomers that polymerize in the lumen of wood cells,
4. compression of wood while heating or curing with resin, and
5. heat

Treatment methods and properties and applications of treated woods are described in the text and summarized in a table. Though some of the chemical reactions described are complex, the language used to describe them is not. Several terms are defined in a glossary.

Keywords: Modified wood, Impreg, Compreg, PEG, Staypak, Staybwood, methyl methacrylate, epoxy resin, mechanical properties, dimensional stablilty.

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Caution

Some of the chemicals referred to in this paper are volatile, toxic, and/or flammable. Follow the handling instructions recommended by the manufacturer.

Treatments that Enhance Physical Properties of Wood[1]

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Introduction

Wood is one of the few natural products that man has used throughout history without having to modify its properties. In recent years, however, several treatments have been developed to modify wood for special applications. For example, Impreg, the commercial term for wood treated with water-soluble polymers, is often used for electrical control equipment because of its electrical resistance. This report describes five treatments that alter the physical properties of wood and thus affect its strength, stability, stiffness, and water repellency: (1) water-soluble polymers or synthetic resins (polyethylene glycol (PEG), Impreg); (2) organic chemicals or cross-linking agents that bond cell wall polymers; (3) liquid monomers that polymerize in the lumen of wood cells (methyl methacrylate, epoxy resin); (4) compression of wood while heating or curing with resin (Staypak, Compreg); (5) heat (Staybwood).

The Forest Products Laboratory receives many requests for information on wood that has been modified by one or more of the five treatments listed above. This report presents an overview of the properties and applications of wood modified by these methods. Sources for more detailed information about modified woods are given at the end of each treatment. General references about wood properties, wood chemistry, and dimensional stability are listed at the end of the report. The glossary contains definitions of many less familiar terms. Table 1 summarizes the Properties of wood as they are modified by these five methods.

Water-Soluble Polymers and Synthetic: Resins

Impregnating wood with water-soluble chemicals, such as PEG, or with synthetic resins that become water insoluble after curing (Impreg) results in dimensional stability by keeping the wood in a partially or completely swollen state. Treating wood with resins also improves its strength and water repellency.

Polyethylene Glycol (PEG)

PEG, also known as carbowax, is a white, wax-like chemical that resembles paraffin. PEG 1000 has an average molecular weight of 1,000 (a molecule small enough to penetrate the cell wall), melts at 104 °F (40 °C), dissolves readily in warm water, is noncorrosive, odorless, and colorless, and has a very high fire point (580 °F, 305 °C). in this paper, PEG refers to PEG 1000.

PEG is usually used with green wood (Fig. 1). Pressure is not needed because the treatment is based on diffusion. PEG is dissolved in water at a concentration of 30 or 50 percent by weight. The treating solution is usually mixed and used in a plastic container (plastic trash container or a wooden box lined with a thick-walled polyethylene bag or sheet) that is large enough so that the entire wood piece can be completely submerged in treating the solution. The solution can be used many times; however, after each application. more solid PEG is added to the treating tank to bring the concentration back to 30 percent (specific gravity 1.05 at 60 °F, 15 °C) or 50 percent (specific gravity 1.09 at 60 °F, 15 °C). Treating times are adjusted to achieve uniform uptakes of 25 to 30 percent of the treating solution. based on dry weight of wood.

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[1] The original article by A. J. Stamm, "Modified Woods," first appeared in the 1948 edition of Modern Plastics Encyclopedia. The present report is a revision of Report No. 2192 (1962).

Figure 1–Cross section of walnut treated with polyethylene glycol (PEG). PEG-treated wood resists cracking and retains its bark. (M 87 0065)

PEG treatment is usually done at temperatures ranging from 70 °F (21 °C) to 140 °F (60 °C). Diffusion of PEG into wood can be greatly accelerated by increasing the temperature as well as the concentration of the treating solution. The time necessary for the desired chemical uptake (25 to 30 pct) depends on the thickness and density of the wood and may require weeks. Some experimentation is usually required to work out the best treating schedule for wood of a given species, size, and thickness.

After treating with PEG, the wood is stickered (stacked using spacers between boards) and dried under cover in a well-ventilated, preferably heated room. Time needed for air drying will vary with wood thickness, temperature, and relative humidity. Bark firmly attached prior to treatment will remain attached after drying.

PEG is not "fixed" or cured in the wood and remains water soluble. If the treated wood comes In contact with liquid water, PEG will start to leach out.

Almost any common adhesive can be used on wood treated with PEG. Good results are obtained with polyvinyl, resorcinol, epoxy, or urea-resin type glues. The surfaces should be clean and smooth before applying the adhesive; for best results, wipe them with methyl alcohol before applying the adhesive.

PEG-treated wood becomes sticky at relative humidity above approximately 60 percent because glycol attracts moisture. Consequently, certain metals in contact with the treated wood may corrode. PEG-treated wood is usually finished to seal in the glycol. Two coats of a polyurethane varnish give the best results. PEG-treated wood can also be finished with a natural "Danish-oil"-type penetrating oil, which is particularly suitable for treated bark. Paint can be applied over these finishes following the instructions of the paint manufacturer.

The primary application of PEG, for treating cross sections of trees to make plaques, tabletops, etc., Prevents the cracking that is nearly inevitable in untreated cross sections. PEG is also used for treating green wood sections for bowls and other turnings as well as carvings and rifle stocks. Another use of this chemical is to reduce the checking (cracking) of green wood during drying. For this application, PEG is used as a seasoning agent, and a high degree of penetration is not required. PEG has been used to reduce checking during drying of small wood blanks or turnings. Finally, PEG is commonly used to treat archeological water-logged wood. During the drying process, partially decomposed wooden artifacts usually crack, fragment, and, in extreme cases, turn to dust. When artifacts are treated with PEG, PEG readily diffuses into the deteriorated, water-soaked fine structure, supporting and keeping it intact during drying. Treatment of badly deteriorated artifacts may initially require PEG solutions that are low in concentration and molecular weight to prevent further damage to the wood.

Impreg

Treatment of wood with a thermosetting, fiber-penetrating resin and cure of wood without compression results in a product known as Impreg. The most successful thermosetting agents that have been commercially applied are highly water-soluble, phenol-formaldehyde resin-forming systems, with initially low molecular weights. No thermoplastic resins have been found that effectively stabilize the dimensions of wood.

Water-soluble phenol-formaldehyde resin penetrates the cell wall, like PEG, and keeps the wood in a swollen state. Unlike PEG, the resin is further polymerized or cured by heat to form a water-insoluble resin bulked in the cell wall. The wood (preferably green veneer to facilitate resin pickup) is soaked in the aqueous resin-forming solution or, if air dry, is impregnated with the solution under pressure until the resin content equals 25 to 35 percent weight gain based on the dry weight of wood. Some commercial water-soluble phenol-formaldehyde resin solutions are concentrated and need to be diluted. Wood is treated at temperatures between 70 to 100 °F (21 to 38 °C) to facilitate penetration.

Treatment with resin is usually limited to veneers that are no more than one-third inch thick because treating time increases rapidly with increases in thickness. Any species can be used for the veneer except the resinous pines. Uniform distribution of the resin in thicker specimens has been effectively accomplished only in sapwood of readily penetrated species. Thicker wood may be subject to checking and honeycombing when drying. AS an alternative to using thick wood, layers of treated and cured veneer (parallel or crosslaminated) can be used to create wood of a desired thickness.

Figure 2–Roof master die model made from mahogany Impreg. impreg is workable and has dimensional Stability. (M 96073 F)

Following resin impregnation, the wood is dried at 175 to 200 °F (80 to 93 °C) for approximately 30 minutes, which results in a moisture content of about 10 percent. A low temperature (below the boiling point of water) is initially used to prevent the solution and the dissolved resin from being forced to the surface of the wood by the steam pressure that develops at high temperatures. The resin in the dried, treated veneer is then cured by heating at a high temperature. This is a timetemperature reaction; at 310 °F (155 °C) the curing time is approximately 30 minutes. For kiln drying, the treated veneer is stickered to allow adequate circulation between the plies. The time required to dry and cure the resin depends on the maximum temperature that can be maintained in the kiln and may vary from a few days to a week or more.

The dried and cured product of resin treatment—impreg—can be finished with most paints and varnishes. The color resulting from the cured phenol-formaldehyde treatment is usually reddish brown, an acceptable color for most applications.

Almost any adhesive can be used with Impreg. Adhesives with a high percentage of solvent must be allowed to evaporate somewhat since the treatment reduces the tendency of wood to adsorb the solvent.

Impreg has several improved properties compared to unmodified wood and plywood. Swelling in liquid water is reduced to 25 to 35 percent that of untreated wood when 30 to 35 percent of resin (on the basis of the oven-dry weight of the untreated wood) is formed within the cell wail structure. The reduction in swelling and shrinkage Is accompanied by a marked reduction in grain raising and surface checking. Impreg shows improved compression strength properties. Though modulus of rupture and elasticity are unaffected, impact bending strength is reduced. Impreg shows considerable resistance to decay, termite, and marine-borer attack, presumably because the treated cell wails cannot take up sufficient moisture to support biological attack. it also has high resistance to acid and can thus be used to store batteries. Although Impreg has no greater resistance to fire than untreated wood, it can be heated to much higher temperatures without an appreciable change in properties.

The dimensional stability and heat resistance of Impreg make it suitable for pattern and die models (Fig. 2). Despite the tendency of resins to dull cutting tools, Impreg is readily used because it machines with less splitting than untreated wood. impreg has also been used for electrical control equipment because its electrical resistance is higher than that of untreated wood.

References

Polyethylene glycol (PEG)

Mitchell, H. L. 1972. How PEG helps the hobbyist who works with wood. Madison. WI: U.S. Department of Agriculture, Forest Service; Forest Products Laboratory. 20 p.

Spielman, P. 1960. Working green wood with PEG. New York: Sterling Press. 120 p.

Impreg

Stamm, A. J.; Seborg, R. M. 1962. Resin treated wood—impreg. Rep. No. 1360. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Organic Chemicals or Cross-linking Agents that Bond to Cell Walls

The cell-wall polymers of wood itself can be permanently bonded by adding an organic chemical to the hydroxyl groups or by adding a cross-linking agent. These treatments increase stability but can reduce strength and stiffness.

Bonded Bulking Chemicals

Many reactive chemicals have been used experimentally to chemically modify wood. The chemicals that produce the best results can react with wood hydroxyl groups under neutral or mildly alkaline conditions at temperatures below 250 °F (120 °C). The chemical system should be simple and must be capable of swelling the wood structure to facilitate penetration. The complete molecule needs to react quickly with wood components (so that no byproducts are formed) to yield stable chemical bonds. Anhydrides, epoxides, isocyanates, acid chlorides, carboxylic acids, lactones, alkyl chlorides, and nitriles have been used for wood modification. Acetylation of wood with acetic anhydride has undergone the most study

Acetylation of wood reactions is usually carried out on dry wood (less than 5 pct moisture) in a pressure cylinder at 230 to 250 °F (110 to 120 °C), using a catalyst to speed up the reaction. At chemical weight gains of approximately 15 percent (based on original dry weight), the acetylated wood is equal in volume to its original green volume. Acetylation reduces the hygroscopicity of wood; at chemical weight gains of 15 to 20 percent, swelling is less than 20 to 25 percent that of untreated wood. The bonded chemical bulking results in dimensional stability.

Acetylation is effective in both heartwood and sapwood of many hardwood and softwood species. it makes the wood very resistant to attack by fungi, termites, and marine organisms, and causes very little color change; the color is more stable to sunlight. Acetylation also improves the acoustical properties of wood (Fig. 3). Sound quality is maintained even at high relative humidity. Acetylated wood can be adhered and finished like untreated wood, and mechanical properties are almost the same as those of untreated wood

The greatest single application of bonded chemical bulking of the cell wall is in reconstituted products such as fiberboard, flakeboard, or particleboard, in which standard operating procedures call for dry wood materials and small particle size (for ease of chemical penetration and recovery).

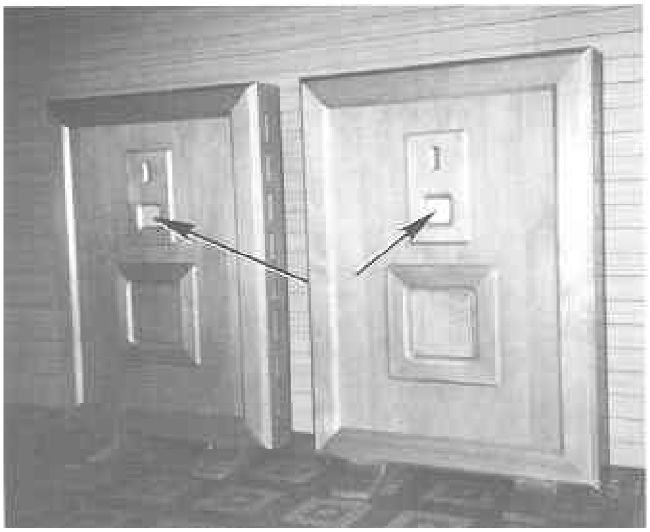

Figure 3–Stereo speakers made with acetylated sounding boards (arrows). Acetylation improves the acoustical properties of wood. Sound quality is maintained even at high relative humidity. Photograph by Misato Norimoto, Wood Research Institute, Kyoto University, Uji, Japan. (MC87 9006)

Cross-linking Chemicals

If Structural units of the wood cell wall are chemically bound together (cross-linked), the bonds restrain the units from swelling when moisture is present. One of the most widely studied chemical systems for cross-linking is the reaction between wood cell-wail hydroxyls and formaldehyde. Cross-linking can take place between hydroxyl groups on the same or different cellulose, hemicellulose, and lignin polymers. The reaction is usually catalyzed with strong acids

At very low cross-linked chemical weight gains (3 to 4 pct), swelling in liquid water is reduced about 50 percent. At weight gains of 8 to 10 percent, swelling is reduced by about 90 percent.

Formaldehyde cross-linked wood is resistant to attack by fungi at weight gains as low as 5 percent. However, formaldehyde cross-linking greatly reduces strength and stiffness. The loss in toughness is directly proportional to the gain in dimensional stability; i.e., a 60 percent decrease in toughness is associated with an increase of 60 percent dimensional stability. Crushing and bending strengths are reduced about 20 percent, and impact bending strength is reduced as much as 50 percent. Abrasion resistance is also greatly reduced. Most of the loss in wood strength properties is probably a result of the hydrolysis of structural cellulose units by the strong acid catalyst.

Although formaldehyde cross-linking has been used experimentally to increase the wet strength of paper, there are no commercial applications at present.

Reference

Rowell, R. M. 1984. Penetration and reactivity of cell wall components. in: Rowell, R. M., ed. Chemistry of solid wood. Advances In Chemistry Series 207, Chap. 4. Washington, DC: American Chemical Society: 175–210.

Liquid Monomers that Polymerize in the Lumens

In the chemical modifications described so far, most of the chemical resides in cell walls; the lumens (the spaces enclosed by the cell walls) are essentially empty. If wood is vacuum impregnated with certain liquid monomers that do not cause swelling and that are later polymerized by gamma radiation or a catalyst (heat and/or chemical), the resulting polymer resides almost exclusively In the lumens.

Two different lumen-fill systems are commercially available: methyl methacrylate (Fig. 4) and epoxy-resin. Both of these treatments increase strength and stiffness. Very little dimensional stability results from (Poly) methyl methacrylation or epoxy resin treatment.

Methyl Methacrylate

Methyl methacrylate is a colorless liquid that boils at 212 °F (100 °C). Before treating wood with methyl methacrylate, the wood is placed in a vacuum chamber to remove air from the wood structure. While the wood is Still under vacuum, enough methyl methacrylate (along with a cross-linking agent and catalyst) is introduced into the chamber to cover the wood. The vacuum is then released, and the wood is allowed to soak up the chemical. Soaking time depends on the structure of the wood being treated.

After impregnation is complete, the woodmonomer composite is removed (sometimes wrapped in aluminum foil) and placed in an explosion-proof oven or a cobalt-60 source for curing. A free radical catalyst (usually 2,2´-azobisisobutyronitrile (Vazo)) is used in the heating process. Heating time varies with the temperature of the oven, but can be as low as 140 °F (60 °C).

The resulting wood-plastic composite can have as high as 160 percent weight gain of polymethyl methacrylate, The polymer is almost completely located in the lumen; only minor amounts are in the cell wail. Consequently, polymethyl-methacrylated wood is very water repellent, but its dimensional stability is only about 10 percent. The specific gravity of the composite is approximately 1.

Methyl-methacrylated wood is best glued with adhesives developed for plastics. It can be buffed to a high polish without varnishing; if scratched, the surface can be redone because the polymer is located throughout the thickness of the wood. The color of methyl-methacrylated wood can be altered by adding a dye to the monomer treating solution. Paint can be applied over the treated wood following the paint manufacturer's instructions for painting plastics.

The mechanical properties of polymethyl-methacrylated wood are greatly improved compared to the properties of untreated wood. Tensile (both parallel and perpendicular to the grain), impact bending and compression strengths, modulus of rupture, and hardness are Improved by 100 to 200 percent.

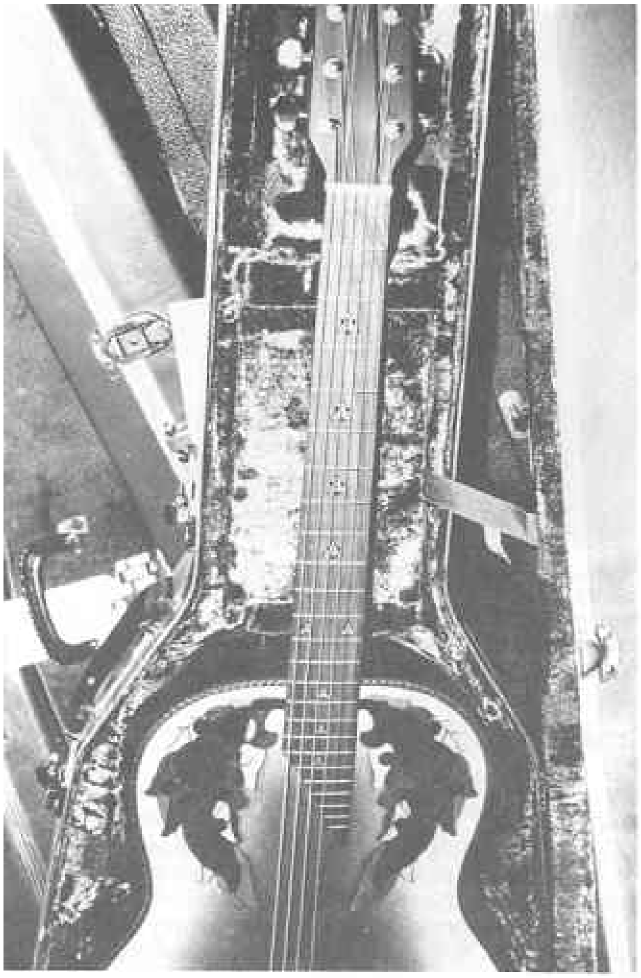

Figure 4–Guitar fret board made of black walnut impregnated with methyl methacrylate. Hard maple inlays were also treated with methyl methacrylate. Methyl methacrylate Increases the hardness of wood and decreases the rate at which moisture is absorbed by the wood. Photograph by John Meyer, College of Environmental Science and Forestry, State University of New York, Syracuse, NY. (MC87 9005)

At present, the main commercial use of this modified wood is in parquet flooring. Other applications include archery bows, billiard cues, golf clubs, musical instruments, office equipment, knife handles, and novelty items (Fig. 4). Methyl-methacrylated wood is sold under several trade names—Acrylic wood, Perma-Grain, and methyl methacrylated-wood plastic composite.

In Europe, Japan, Taiwan, and New Zealand, extensive research has been carried out using styrene as the monomer alone or in combination with methyl methacrylate for impregnation. The resultant products are known as Lignomer in Poland and as Aploid in Japan.

Epoxy Resin

In methyl methacrylation, wood is treated with monomers that are polymerized after saturation. In the case of epoxy resin treatment, the resin is already partially polymerized and is cured or hardened within the lumen structure. The epoxy resin is a clear solution with a consistency at 70 °F (21 °C) that is slightly thicker than varnish. Just before the wood is treated with the epoxy resin, the resin is mixed with a hardener to set the resin. The pot life of the resin and hardener mixture varies from a few minutes to a few hours, depending on the hardener and temperature. Epoxy resin treatment is usually used on veneers because the epoxy resin molecule is too large and viscous to penetrate deeply into the wood structure. Veneers are soaked or vacuum treated with the resin-hardener solution, drained, and allowed to cure. The epoxy resin cures to a solid state in 5 to 6 hours at room temperature. Higher temperatures accelerate the cure.

Veneers can be adhered together after treating but before curing, and dyes can be added to the epoxy-hardener solution. Paint can also be applied following the paint manufacturer's instructions for painting plastics.

The epoxy resin acts as a moisture barrier by encapsulating the wood in resin, and the rate at which the wood sorbs moisture is greatly retarded. However, this treatment does not increase dimensional stability because little, if any, of the resin enters the cell wall.

Epoxy resin treatment greatly increases wood's mechanical properties (especially hardness) compared to untreated wood, making the treated wood suitable for wooden boat hulls and the outer ply of plywood. Epoxy resin treatment has also been used to strengthen softened or decayed wood. Saturation and curing of the resin in decayed wood can partially restore lost strength and stiffness.

References

Methyl methacrylate

Meyer, J. A. Wood-polymer materials. 1984. In: Rowell, R. M., ed. Chemistry of solid wood. Advances in Chemistry Series 207, Chap. 6. Washington, DC: American Chemical Society: 257-290.

Epoxy resin

Gougeon, M. 1979. The Gougeon Brothers on boat construction. Wood and West System Materials Midland, MI: Pendell Printing Inc. 316 p.

Compression of Wood While Heating or Curing with Resin

Compression of wood while heating (Staypak) or while curing with resins (Compreg) greatly improves stability, strength, and stiffness.

Staypak

Staypak is produced by compressing wood under conditions that cause sufficient flow of lignin (the cementing material between the cellulose fibers) to relieve the internal stresses resulting from compression. This process greatly reduces the tendency of the wood to swell when wet.

Before compression, thin veneers are conditioned to 30 to 65 percent relative humidity. A pressure of 1,400 to 1,600 lb/in^2 is applied to the wood at a temperature of 340 to 350 °F (170 to 177 °C). Compression time varies with the thickness of the veneer. For making Staypak, the wood is usually compressed to a specific gravity of at least 1.3.

Staypak can be made from several wood species, with the exception of species high in resins. Solid wood should be flat-grain stock free from knots. Because of its higher specific gravity, latewood (summerwood) will not compress to the same extent as earlywood (springwood). Knots are to be avoided since they are difficult to compress.

Staypak can be glued and finished like untreated wood. The conditions under which the wood is compressed cause appreciable darkening of the wood.

Staypak absorbs water at a slower rate than uncompressed wood and is more dimensionally stable, but its resistance to biological attack is not increased. Strength properties of Staypak are much higher than those of untreated wood. Strength increases almost proportionally to the amount of compression. Tensile strength both parallel and perpendicular to the grain, modulus of rupture, and elasticity in bending are increased; the greatest Increase is In impact bending strength.

Suitable applications for Staypak are tool handles, mallet heads, and various tooling jigs and dies. Materials similar to Staypak (Lignostone and Lignofol) are produced in Germany. Jicwood and Jablo are two types of compressed plywood manufactured in England.

Compreg

Compreg is resin-treated wood that is compressed while the resin is curing in the wood structure. Although several resins have been tried, none has been more successful than water-soluble phenol-formaldehyde resin (see section on impreg). Compreg is usually made from layers of treated veneers that are compressed to the desired specific gravity and thickness. Wood for Compreg can also be pressed and cured in a mold.

When Compreg is made from veneers, each veneer is treated with water-soluble phenol formaldehyde to a level of 25 to 30 percent resin, based on the ovendry weight of wood. The veneers are dried at a temperature of 175 °F (30 °C) or less so that the resin does not cure during drying. The resin is cured later during the heating and densification (compression) process. (In contrast, treated veneers used to make impreg are cured in the final, high-temperature drying process.) When the Compreg panels of treated veneers are made more than 3 mm thick, their wood moisture content should be less than 2 percent to avoid subsequent checking of the product. Veneer material can have a slightly higher moisture content without subsequent checking.

Treated veneers are made into high-density parallel-laminated panels without applying bonding resin between the plies because sufficient resin is exuded from the plies under compression to give a good bond. The pressure required for compressing the panels depends upon the resin and its volatile contents, the degree of precure of the resin, and the distribution of the resin throughout the structure as well as on the species of wood. Veneer of most species can be used to make Compreg at a specific gravity of 1.3 to 1.4 (at 25 to 30 pct resin content) by applying pressures of 1,000 to 1,200 ib/in^2 at a temperature of 300 °F (150 °C), when the volatile content (percent of solution that will evaporate) of the resin is between 2 and 4 percent, Panels that are compressed to specific gravities above 1.35 are more subject to checking than those compressed at lower specific gravity. Hence, specific gravities greater than 1.4 should be avoided.

Experience has shown that the higher the temperature during pressing, the greater the tendency of the panels to check. The best results have been obtained by pressing at 285 to 300 °F (140 to 150 °C). The temperature in the center of the wood should be held at 300 °F (150 °C) for 30 to 40 min to obtain complete cure of most of the resins. Compreg panels that are more than 3 mm thick should be cured at a lower temperature to avoid an exothermic resin-curing reaction that could raise the temperature at the center of the panel to more than 300 °F (150 °C).

Figure 5–Compreg gears. Compreg is tough, hard, and machinable. (M 87 0064)

Compreg panels can be adhered to each other or to ordinary wood after removing the surface residue by sanding or machining. Several adhesives are satisfactory. Alkaline-catalyzed phenolic and resorcinol glues that set below the boiling point of water are most satisfactory and have been used most extensively. Machining is usually done with metalworking tools because normal woodworking tools are quickly dulled

A high degree of polish can be obtained on any cut Compreg surface by sanding with fine sandpaper and then buffing. The natural finish is highly resistant to such organic solvents as alcohol and acetone.

The Compreg wood structure is so densified by resin and compression that the rate and extent of water absorption are greatly reduced. Small blocks (1/2 in thick or less) of Compreg (specific gravity 1.35) will swell only 4 to 7 percent in thickness when immersed in water at room temperature. Large blocks (2 in thick or more) do not reach a swelling equilibrium in water even after 1 year.

Compreg is very resistant to decay, termites, and marine borers. It has increased electrical and acid resistance compared to untreated wood and is more resistant to fire because of its greater density. Flame retardancy can be Increased even more by adding fire-retardant chemicals to the resin treating solution.

The strength properties of Compreg, except for impact bending strength, increase in proportion to the increase in specific gravity. Abrasion resistance and hardness are significantly higher than that of untreated wood.

Compreg has been used to form dies, drilling and welding jigs, nuts and bolts, aircraft parts, gears, pulleys, water-lubricated bearings, fan blades, shuttles, bobbins and picker sticks for looms, instrument bases and cases, electrical insulators, musical instruments, and novelty items (Fig. 5). Compreg is also widely used for handles of knives and other utensils, and it is used as the outer ply on plywood where abrasion resistance is needed. The German equivalent of Compreg is known as Kunstharzschichtholz.

References

Staypak

Seborg, R. M.; Millett, M. A.; Stamm, A. J. 1945. Heat-stabilized compressed wood–Staypak Mechanical Engineering. 67(1): 25–31.

Compreg

Stamm, A. J.; Seborg, R. M. 1951. Resin-treated laminated, compressed wood–Compreg. Rep. No. 1381. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Heat (Staybwood)

Heating wood in a vacuum at high temperatures causes lignin to flow and hemicellulose decomposition, which produces water-insoluble polymers. This treatment increases stability but decreases strength. One such treatment results in a product known as Staybwood.

Staybwood is made by heating wood at temperatures between 200 and 600 °F (93 and 160 °C) in a bath of molten metal (50 pct tin, 30 pct lead, and 20 pct cadmium) with a melting point of about 302 °F (150 °C). This alloy does not stick to the wood surface. Sand circulated with dry nitrogen has also been used to heat veneers with similar results. Heating times range from a few minutes at high temperatures to a few hours at lower temperatures. Dimensional stability of Staybwood increases as both heating time and treating temperatures are increased, whereas strength decreases. Under conditions thayt reduce swelling and shrinking by 40 percent, toughness is reduced to less than half that of untreated wood. Abrasion resistance is also reduced. Hygroscopicity of Staybwood is greatly reduced and resistance to decay increased.

Because strength properties are lost in the manufacturing process, Staybwood has not been used commercially.

Reference

Stamm, A. J.; Burr, H. K.; Kline, A. A. 1960. Heat stabilized wood–Staybwood. Rep. No. 1621. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Summary

The five general types of wood treatments described in this paper enhance the strength, stiffness, water repellency, and stability of wood. However, modified woods of all types comprise only a very small percentage of commercially used wood. The high cost of most modification procedures limits the production of modified wood to special end uses. Researchers worldwide continue the search to improve existing modification methods and to develop new ones.

General References

The following publications provide information about wood properties and wood chemistry.

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Rowell, R. M.; Banks, W. B. 1985. Water repellency and dimensional stability of wood. Gen. Tech. Rep. FPL-50. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Wood Chemistry

Rowell, R. M. ed. 1984. The chemistry of solid wood. Advances in Chemistry Series 207. Washington DC American Chemical Society.

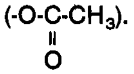
Table 1–Summary 01 properties of woods modified by five different treatments

Properly	Water-soluble polymers and synthetic resins		Compression		Heat	Organic chemicals or cross-linking agents		Liquid monomers	
	Polyethylene glycol (PEG)	Impreg	Staypak	Compreg	Staybwood	Bulking	Cross-linking	Methyl methacrylate	Epoxy resin
Specific gravity	Slightly increased	15 to 20 pct greater than normal wood	1.2 to 1.4	1.0 to 1.4	Unchanged	Slightly increased	Unchanged	increased	Increased
Permeability to water vapor	Hygroscopic	Better than normal	Better than normal	Greatly improved	Better than normal	Unchanged	Unchanged	Greatly improved	Greatly improved
Liquid water repellency	Hygroscopic	Better than normal	Better than normal	Greatly improved	Better than normal	Better than normal	Better than normal	Greatly improved	Greatly improved
Dimensional stability	80 pct	60 to 70 pct	Slightly improved	80 to 85 pct	40 pct	65 to 75 pct	80 to 90 pct	10 pct	Slightly improved
Decay resistance	Better than normal	Better than normal	Unchanged	Much batter than normal	Better than normal	Much better than normal	Better than normal	Somewhat increased	Somewhat increased
Heat resistance	No data	Greatly increased	No data	Greatly increased	No data	No data	No data	Increased	No data
Fire resistance	No data	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	No data
Chemical resistance	No data	Better than normal	Slightly better than normal	Much better than normal	Better than normal	No data	No data	Much better than normal	Much better than normal
Compression strength	Slightly increased	Increased	Increased	Greatly increased	Reduced	Slightly reduced	Slightly reduced	Greatly increased	Greatly increased
Hardness	Unchanged	Increased	Increased	10 to 20 times greater	Reduced	Slightly reduced	Slightly reduced	Greatly increased	Greatly increased
Abrasion resistance	Slightly reduced	Reduced	Increased	Increased	Greatly reduced	Slightly reduced	Greatly reduced	Greatly increased	Greatly increased
Machinability	Unchanged	Better than normal but dulls tools	Metalworking tools required	Metalworking tools required	Unchanged	Unchanged	Unchanged	Metalworking tools preferred	Metalworking tools preferred
Glueability	Special glues required	Unchanged	Unchanged	Same as normal after sanding	Unchanged	Unchanged	Unchanged	Special glues required	Epoxy used as adhesive
Finishability	Requires poly. urethane, oil, or 2 parts polymer	Unchanged	Unchanged	Plastic-like surface (can be polished without finish)	Unchanged	Unchanged	Unchanged	Plastic-like Surface(no finish required)	Piastic-like surface (no finish required)
Color change	Little change	Reddish brown	Little change	Reddish brown	Darkened	Little change	Little change	Little change	Little change

Glossary

Abrasion resistance. Resistance to wearing.

Acetylation. A chemical reaction between a hydroxyl group and a reactive chemical resulting in an acetate group



$(-O-\underset{\underset{O}{\|}}{C}-CH_3)$.

Cellulose. The principal carbohydrate chemical constituent of the cell walls of wood, forming 40 to 50 percent of the whole. It is used for a variety of purposes: paper, cellophane, celluloid, clothing, explosives, glass substitutes, lacquer, etc.

Compression strength. Strength of wood as a support column.

Cross-linking agent. A chemical which causes two polymers to link up with each other.

Cross-linked chemical weight gains. Weight Increase due to cross-linking reaction.

Dimensional stability. The ability of a material to maintain its original dimensions under variations in moisture.

Elasticity in bending. That property of wood that allows it to regain its original condition after distortion.

Hardness. The ability to resist cutting, scratching, denting, pressure, or wear.

Hemicellulose. A carbohydrate polymer that constitutes part of the wood cell wall.

Hydroxyl groups. A chemical functional group in the cell wall that contains oxygen and hydrogen (-OH).

Hygroscopicity. The property of absorbing moisture from the atmosphere.

Impact bending strength. Ability to resist impact bending loads (i.e. baseball bats and hammer handles have high impact bending strengths).

Lignin. A phenolic-like polymer in the cell wall that acts as an adhesive.

Mechanical properties. The strength and stiffness properties of a materlal that provide resistance to imposed loads.

Modulus of elasticity. A measurement of stiffness. Factors affecting the MOE include size, span, load, and the species being tested.

Modulus of rupture. A measurement of bending strength.

Moisture content. The weight of the water in wood expressed as the percentage of the weight of the ovendry wood.

Monomers. A single reactive chemical unit.

Organic chemicals. Reactive materials containing carbon.

Ovendry weight. The weight of bone-dry wood at 212 °F (100 °C).

Polymers. Large-molecular-weight chemicals made up of many single chemical units (monomers).

Polymerized. To combine small molecules chemically into larger or especially very large molecules.

Relative humidity. The ratio of the amount of water in the air to the highest amount possible at a given temperature.

Specific gravity. The weight of a substance relative to that of an equal volume of water.

Strength properties. The measure of a material's resistance to failure (i.e. breaking).

Tensile strength. Measure of the resistance of wood to forces acting either parallel or perpendicular to the grain that tend to split a member.

Toughness. A measure of impact bending strength.

Water repellency. The ability of a material to slow down the rate at which moisture is sorbed.

Water resistance. The ability of a material to reduce the amount of moisture sorbed.

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