DIMENSIONAL STABILIZATION OF WOOD WITH CHEMICALS

By Ben S. Bryant

In recent months there have been several news releases calling attention to a new process for chemically modifying wood that involves the use of radiation techniques to produce a "wood-plastic alloy" which has been called "Novawood". If you have followed these news releases with any interest you will note some progress in the development of this product from the University research stage through a market study, a design phase and now a contract for the building of a plant in Georgia with a daily production capacity announced at 2000 pounds.

When sufficient publicity has been given to such a development it is regarded by some in the forest products industry as a sign of potential change in the nature of wood processing which will enable us to avoid one of wood's disadvantages, namely of the aspects of wood science and technolody, as well as economics, which make it possible to evaluate intelligently such proposed new systems for solving man's ancient problems with wood.

Those of you who are engaged in the business of drying lumber are well aware of the dimensional instability of wood and can appreciate why men have been challenged by the thought that wood would be more useful if we could only make it dimensionally stable. In the tangential direction, let me remind you, wood shrinks from the green condition to the oven dry condition from about 5 to 10% of its green dimension and on the radial surfaces, from about 2 to 6%. Generally speaking, the higher the density of the wood the greater the shrinkage in both radial and tangential directions. It is interesting to a wood technologist, however, that the ratio of tangential-to-radial shrinkage differs markedly between species and is generally greatest among the soft-woods rather than the hardwoods.

We can account for some of these variations within and between species on the basis of the anatomical structure of wood as well as the presence of extractive chemicals which serve as the natural bulking agents within the cell wall wherein lies the hygroscopic nature of wood itself. By chemically modifying the cell walls of wood we can reduce this water absorbing tendency. Yet it is interesting to note that no matter how hard men have tried to stabilize wood dimensionally, they have only succeeded in removing as much as 80% of wood's inherent tendency to swell and shrink. There has never been such a thing as a completely dimensionally stabilized wood material.

In reviewing the various methods of stabilizing wood Stamm has listed five approaches.[1] These

1. Stamm, A.J. 1959. "The effect of polyethylene glycol on the dimensional stabilization of wood". For. Prod. Jour. 9(10):375-

may be listed as follows:

1. Mechanical stabilization through cross laminating: (The manufacture of plywood is an example.) Here advantage is taken of the fact that in the longitudinal direction (along the grain) wood has dimensional stability. If this were not true wood could not be used with such versatility for structural purposes, and the moldings surrounding doors would open up at the corners, even if there were a slight amount of shrinkage in long lengths of molding.

2. Applying water-resistant surfaces to wood, both externally and internally: External coating is best illustrated by painting or finishing of wood and internal coating by treating wood with a low-viscosity, penetrating, solvent-borne water-repellent usually in the form of dissolved wax. When incorporated with pentachlorophenol or other suitable preservatives, internal coating liquids are recognized as water-repellent preservatives of which several brand names are familiar.

3. Reducing the hygroscopicity of cellulosic material by treatment of the wood with chemicals: Chemicals must enter the cell walls of wood. This may be done in the form of a vapor treatment or by liquid penetration. Perhaps the best example of such reduction in cell wall hygroscopicity is acetylated wood, which has been treated in lumber dimension sizes by vapor treatment, presumably on a commercial basis.[2] A recent attempt has been made to reduce the hygroscopicity of the cellulosic material by grafting polymers onto the cellulose by the use of gamma radiation.[3] However, this has not been done on commercial-sized speciments, nor is it likely to replace more economical methods of stabilizing wood.

4. Dimensional stabilization through the use of chemicals to cross-link the cellulose itself: Formaldehyde in vapor form has been used to directly connect together the water bonding groups of cellulose, thus rendering them ineffective. The process has not been successful, however because of the deleterious effect on the wood of the acid catalyst that is used to make the reaction effective.[4]

5. Treatment with chemicals to add bulk to the cell wall: This may be called the bulking approach. The object here is to cause a certain chemical to diffuse into the swollen cell walls of wood and occupy the spaces which were occupied by water in the green wood. As the wood is dried the water, being of relatively high vapor pressure, is removed from the cell wall leaving the higher-molecular-weight treating chemical behind and the wood in a semi-swollen condition. Ordinary table salt, first dissolved in water, will be effective as the bulking agent for wood as will sugar. The bulking agent which has proven to be most effective over the years is low-molecular-weight phenolic resin. It can be cured into a very hard wood-resin system after the water has been removed by drying.

   If the dried, treated wood is compressed as it is heated, the resin will go through a melt stage, permitting the highly-plasticized wood fibers to be flattened under compression without physical damage. When the resin is cured the wood is left in a compressed, highly-

---

2. Goldstein, J.S. and others. 1961. "Acetylation of wood in lumber thickness." For. Prod. Jour. 11(8): 363.

3. Kenaga, D.L., Fennessey, J.P. et al. and Stannett, V.T. 1962. "Radiation grafting of vinyl monomers to wood." For. Prod. Jour. 12(4) 161-168.

4. Stamm, A.J. 1959. "The effect of polyethylene glycol on the dimensional stabilization of wood." For. Prod. Jour. 9(10):375-?

densified state. This product is known as Compreg. It was perfected at the Forest Products Laboratory in Madison, Wisconsin, during World War II and was used for airplane propellers and the base of radar masts, due to its hardness and high electrical resistance properties. Currently one sees Compreg being used as cutlery handles and its limited industrial application, due to its high cost, include its use in tool and die sets.[5]

A recent addition to the phenolic resins as effective bulking agents for wood for the purpose of dimensional stabilization is polyethylene glycol. This waxy liquid has been found to be effective in giving suitable dimensional stability to high-valued items such as gun stocks and imported carvings. For example, it is being used to protect the Viking ship which was brought up from the bottom of the sea off of Sweden and is being preserved as a museum piece.[6] In his recent review on the stabilization of wood Stamm points out that only phenolic resin, polyethylene glycol and acetylation have been proven sucessful as commercial treatments.[5]

6. Cell Filling: An approach to dimensional stabilization which is inefficient, but nonetheless, somewhat effective, might be called the cell filling approach. Here liquid is impregnated into wood until it occupies the cavity in the center of each of the cells.

If the liquid is converted to a solid without appreciable shrinkage, it may inhibit the cell wall from swelling as well as slow down the movement of moisture into wood, particularly in the liquid form. Metals with very low melting points have been used for this purpose as well as to improve some of wood's mechanical properties. More recently plastics which are liquid in the monomeric form (unpolymerized molecules), such as styrne, have been used to impregnate wood. When energy in the form of gamma radiation is available from a cobalt 60 source, for example, it can be used to convert the liquid into a solid directly without the use of external heat and catalysts. Unless rather elaborate steps are made to move such plastic materials into the cell wall through the mechanism of diffusion -- by using solvents such as acetone which are compatible with both water and the plastic monomer -- such modifications of wood must be classed as wood filling treatments, because the liquid monomer, by itself, cannot penetrate the cell walls of dry wood due to their incompatibility with water.

Where wood has been modified chemically by the use of cell filling techniques, some benefit to certain mechanical properties of the wood may be expected. If the cell cavities have been completely filled with the liquid which has been converted to a solid, obviously the wood plastic system is more resistant to deformation by forces applied across its grain, as in compression perpendicular to the grain and hardness. However, any dimensional stability derives from the blocking effect resulting from the cavities of the cells having been filled with solid resin. This also serves to retard the movement of moisture into the wood, but it does not prevent the cell walls from swelling ultimately upon exposure to higher humidities. Since most of the mechanical properties of wood are related to the chemistry of its cell walls, and the cell walls have not been altered, there will be no deleterious effects to the mechanical properties of wood treated by cell filling techniques.

---

5. Stamm, A.J. 1962. "Stabilization of wood, a review of current methods." For. Prod. Jour. 12(4): 158-160.

6. Mitchell, H.L. and Fobes, E.W. 1962. "Protect imported carvings with P.E.G." For. Prod. Jour. 12(10): 476-477.

Many people do not appreciate the fact that when wood is treated chemically to stabilize it the treatment has an effect -- sometimes an adverse effect -- on the mechanical behavior of wood. Thus when wood is treated with phenolic resin, as in the manufacture of Compreg or Impreg, the cell walls are rendered so hard and brittle that they cannot adjust to stress in the same manner as the untreated wood. Therefore, they possess little or no shock resistance, and dimensionally stabilized wood with phenolic resins cannot be used under impact loading conditions for this reason. Certain properties, however, are improved. Most conspicuous of these is compression parallel to the grain, compression perpendicular to the grain and hardness. Among the properties which are slightly weakened as a result of the treatment is the tensile strength parallel to the grain.

Polyethylene glycol as a bulking agent does not have a deleterious effect on the mechanical behavior of wood in the same way as phenolic resin treatment, however. Since the polyethylene glycol is in a liquid state, after the removal of water it is established in the cell wall as a waxy material which therefore cannot have a profound effect on the compression properties of the wood, nor its tensile strength nor stiffness. On the other hand, neither is the wood rendered as hard and consequently must be used for a different range of use requirements than the Compreg and Impreg products.

Since all of the techniques for chemically modifying wood involve first impregnating it with liquids -- or vapors, it is well to consider the nature of the movement of the liquids into wood. Those who are in the business of wood preservation are quite familiar with the problem of variability between and within wood species when it comes to their relative ease of permeability to liquids. On the other hand, those who work in the laboratory in the area of chemically modifying wood are able to ignore some of these differences by concentrating their experiments on easily-treated species of wood or on species whose dimensions along the grain may be in the order of 1/4 of an inch, thus eliminating permeability problems.

There are other ways around the permeability problem in the laboratory. The author demonstrated a technique for rapidly impregnating Ponderosa pine boards with phenolic resin, but there were severe limitations to the species, treatment of the lumber and orientation of the grain which made the process of academic interest only. The species had to be Ponderosa pine. The sapwood portion of the tree only could be used. The lumber had to be either kiln dried or solvent seasoned, and the treatment would only be effective if the liquid were applied under high pressure to the flat grain face of the board.[7] The reasons for these limitations can be ascribed to the anatomical structure of Ponderosa pine and the pathways to liquid flow in softwood species.

Dr. Harvey D. Erickson, of the College of Forestry of the University of Washington, has worked in the field of wood permeability for many years. In recent studies with styrene (currently of interest as a cell filling chemical that can be cured in place by gamma radiation techniques) he showed that the penetration of softwood to liquids along its grain is extremely variable. His work emphasizes the impossibility of completely filling with liquids the cavities of the fibers -- or cells -- to a significant depth, especially if the material is of a non-polar liquid, such as styrene.[8] This work further emphasizes the danger of generalizing about wood treating processes on the basis of laboratory work with short sections of easily-penetrated species.

In the commercial preparation of resin-impregnated, compressed wood (Compreg), the problem of liquid permeability is largely overcome by the use of diffused porous, open-pored species of some

---

7. Bryant, B. S. 1948. "A Study of the impregnation of ponderosa pine with synthetic resin." Master's thesis, University of Washington, Seattle.

8. Erickson, H. D. and Balatinecz, J. J. 1964. "Liquid paths into wood using polymerication techniques - Douglas-fir and styrene." For. Prod. Jour. 14(7):293-299.

abundance, such as yellow birch, in the veneer form. By using veneer almost every pore is likely to intersect the surface of the wood at an angle, thus providing a network for resin to diffuse into the wood by means of the coarse capillary structure of the pores -- or vessels -- and the slower side-wise diffusion from the pores to the surrounding fibers, of which the most remote fiber is only a few fiber diameters away from the nearest pore.

In the manufacture of Compreg, of course, there is another advantage which stems from the fact that the resin used to impregnate the veneers also serves as an adhesive to glue the adjacent veneers together when the thick laminate is pressed in a steam-heated hot press under high pressure. It is important to note, therefore, that any proposed process for chemically modifying wood in the form of lumber dimensions is subject to all the limitations of liquid permeability faced by the wood preservation industry. This industry is able to cope with lack of complete penetration of heavy cross sections by machining the pieces to be treated before the impregnation process and obtain protection with the impregnated shell. Machining after impregnation not only wastes the preservative, but it ruins the protection against attack by fungus or insects. Although the product is largely manufactured before treatment the market for preservatively treated wood is large enough to justify such customized preprocessing.

You who are in the very competitive business of manufacturing kiln dried lumber are very much aware of the practical implications of economic thinking. Like most businesses your activity involves providing the customer a product which does the job as good or better as your competitors at a comparable price. Applying the same economic principles to the field of chemically modified wood, the customer must be willing to pay an additional price for chemically-modified wood in order to overcome some of wood's disadvantages. Obviously this depends on whether or not he can overcome the disadvantages of wood through design or through selection of an alternative product at a lower cost. This alternative could lead him away from the use of wood entirely, to the use of aluminum, steel or even plastic. Those of you in the pine molding and millwork business have seen the effect of this principle of alternatives in your own business.

Perhaps you have never thought of yourselves as dimensional stabilizers of wood, but, that is exactly what you are. Remember that no treatment can completely stabilize wood dimensionally and certainly the drying of lumber does not pretend to. But to the extent that you provide the customer with lumber which is very close to the average moisture content which the lumber will acquire during the course of a yearly cycle of changes, you have overcome most of the disadvantages associated with the dimensional instability of wood. Fortunately most of the lumber you dry is in relatively narrow widths, and therefore the actual change , during the yearly variations in moisture content, will be very small in terms of fractions of an inch. The actual change is so small that it can be ignored for many purposes or it can be allowed for by the nailing technique used to fasten the lumber in place.

Fortunately for us in the softwood region in the United States, the percentage change with moisture content is not very great, especially in the lower density species where it is minimum. Thus we can overcome the disadvantages of dimensional change in wood by utilizing low density species as well as edge grain lumber, which shrinks and swells less than flat grain lumber in the width direction.

Another way in which we "design around" the disadvantages of wood's dimensional instability is to use narrow widths when we apply lumber as flooring, for example. When narrow widths of lumber are used a free edge for shrinkage to occur is created every few inches, so that, in the event of severe shrinkage, numerous narrow cracks develop and the shrinkage does not accumulate in any one place as it would if the lumber were edge glued into great widths. The principle of creating free edges to relieve stresses is also utilized to overcome the dimensional instability of wood in providing stress relief in thick lumber panels such as may be used for patterns.

As mentioned earlier the most common treatment for minimizing the rate of movement of moisture into and out of wood is to paint it. Together with kiln drying and the use of narrow boards this approch has overcome most effectively and economically many of the disadvantages of wood for the mass markets which account for the bulk of the sales of lumber products.

Any proposed new treatment for chemically modifying wood for the purpose of enhancing its mechanical properties must face the economic fact that we have only begun to take advantage of the structural potential of lumber products. Lumber is so cheap we still can afford to waste it, apparently, because when we use it for semi-structural purposes we use it most inefficiently. Therefore we can conclude that before a customer is willing to pay more for a stronger lumber product, he will take advantage of the existing technology which will permit him to use less wood to do the same structural job through the use of engineered wood products or structurally graded lumber. Before mass markets are created for dimensionally stabilized wood through chemical modification, the user of wood products will have exhausted his alternatives for minimizing the movement of wood due to moisture content changes at prices approximately similar to what he is paying now.

As dimensional stabilizers of wood it is encouraging to attend a gathering of this sort and witness the concern you have for applying modern technology for the purpose of providing the customer with a more effectively stabilized product at the same price.