FOREST PRODUCTS LABORATORY UREA-PLASTICIZED WOOD (URALLOY)

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(URALLOY)

Discovery of the wood plasticizing properties of urea, a low-cost chemical now produced synthetically, has opened a new field of research at the Forest Products Laboratory. Two of the earliest lines of experimentation followed in developing the possibilities of the new treatment are described in this mimeograph. Simple impregnation of wood with urea, followed by drying and bending with the aid of heat, comprises one branch of investigation. For the sake of convenience, the Laboratory designated the product made by this process as Uralloy A. The second line of research involves a thermosetting process and, by overcoming certain limitations of the simple urea treatment, has resulted in a markedly different product, designated Uralloy C.

It should be emphasized that in neither phase has development proceeded beyond the laboratory stage of experimentation. No extensive commercial applications have been made, and it is recommended that such applications be undertaken only after careful study of the properties of Uralloy and instructions for processing the material as set forth on the following pages. However, patents have been granted for both processes. Licenses for their free use in the United States may be granted by the Secretary of Agriculture to persons or companies who are prepared to make use of the process commercially. Patent No. 2,298,017 relates to Uralloy A and Patent No. 2,313,953 relates to Uralloy C.

UREA-IMPREGNATED THERMOPLASTIC WOOD
(Uralloy A)

Solid Wood

The original disclosure that wood becomes thermoplastic upon soaking with a solution of urea came as a result of experiments in chemical seasoning of wood at the Forest Products Laboratory. It was found that green 1-inch oak squares so soaked, and subsequently dried, became plastic and easily bendable with the hands upon application of heat. With cooling, the bent wood became rigid again, retaining its new shape.

Essentially, the simple urea treatment involves nothing more than this procedure. A technique worked out for its application on a laboratory scale can be adapted easily to other conditions, such as the home workshop or small woodworking plant.

Green wood is required for treatment. An aqueous solution of urea is formed, using equal amounts by weight of water and the chemical. The wood is placed in this solution for a length of time that varies with the species being plasticized. For oak, the soaking period may be generally stated as 10 days for each inch of thickness -- the time needed for absorption of an amount of urea equal to 25 percent of the oven-dry weight of the wood.

After this treatment, the wood should be dried to a moisture content of 8 to 12 percent. The drying time needed likewise varies with the drying temperature used, wood species, and similar considerations. In no case, however, should the temperature be higher than 140° F., and for oak it should not exceed the optimum kiln temperature of 115° F. during the initial stages of drying. Prolonged drying at temperatures higher than 140° F. will cause changes of the urea in the wood and thus destroy the plasticizing effect. The drying time for urea-soaked wood can be shorter than that of untreated wood going through the same moisture content changes; for example, if the kiln-drying period of 3-inch Sitka spruce is 30 days, this time can be reduced to 15 days with urea-impregnated wood. This accelerated drying rate in the kiln is brought about by more severe drying conditions permitted by the treatment and should largely offset the time consumed by the soaking process.

When properly dried, the wood is ready for heating and bending. A temperature range of from 212° to 220° F. is the optimum for bending operations. Thin wood can be twisted to the desired shape easily by hand. For larger pieces, mechanical aids to bending are necessary, Properly designed equipment will give much sharper bends than can be achieved with ordinary bending methods and with far less breakage to stock.[1] Best bending results will be obtained if, after drying, temperature of the wood is raised to the optimum temperature for bending by boiling in the regular urea solution for a period of 15 or 20 minutes per inch of thickness. Good bending can, however, be accomplished by heating the dry treated wood to the desired temperature in dry air. Upon cooling, the wood, as stated earlier, will retain its new shape, provided it is dried to a sufficiently low moisture content before bending. In some cases, as in thick stock, it is desirable to predry to a relatively high moisture content of 25 to 30 percent. In this event the bent products will have to be dried on the form somewhat after bending in order to preserve the desired shape.

Sawdust

Urea plasticization can also be applied to sawdust for the formation of solid sheets or panels. It is necessary, however, to use considerable pressure in the molding operation. For this, machinery is needed.

The compressing technique employed by the Laboratory for molding urea-treated sawdust consisted of the following steps:

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[1] See "Wood Bending (Oct. 1929) with Appendix (1941) on Apparatus for Bending Boat Ribs," by T. R. C. Wilson. FPL Mimeo. R966.

1. Determine oven-dry weight of sawdust.
2. Add dry urea -- 25 percent of the oven-dry weight of the sawdust.
3. Add enough water to make the mass a paste.
4. Dry the sawdust mix to a moisture content of 2 to 3 percent.
5. Add a suitable lubricant, such as 1 to 5 percent zinc stearate, to the mix.
6. Place mix in mold.
7. Exert pressure of 1,000 to 1,500 lbs. per sq. in.
8. Raise press temperature to 356-365° F.
9. Subject to temperature-pressure 3 to 5 minutes.
10. Cool under pressure by running water through press platens.
11. When cooled to 140° F., remove product from press.

The technique used here is not necessarily the optimum for all conditions of pressing, nor the only way pressing can be done. Products manufactured at the Laboratory by following these steps were, however, of good strength properties.

Properties of the Products

Solid Wood

From limited tests it seems that lumber or dimension stock impregnated by the simple urea treatment has strength properties at room temperature about equal to those of the normal untreated wood. In color it is characteristically gray or black. It can be handled and used about as ordinary wood is used.

Sawdust

Molding of the urea-impregnated sawdust in a hot press results in considerably changed properties. The color is black or gray. The material becomes so hard that it is often difficult to nail. Sawing and machining properties are good. Veneer facings can be applied, but some work will be required to perfect suitable glues. The material is noncorrosive, so far as metal fastenings are concerned. Tests thus far made indicate that strength qualities of the treated, compressed sawdust are comparable to other common plastics.

The molded material is not as resistant to water as is ordinary untreated wood. It will withstand soaking for a comparatively few hours before losing strength through disintegration. Its water resistant properties can be greatly improved by the addition of such chemicals as furfural, carbon tetrachloride, or thiourea.

Limitations

Two important deficiencies affect the usefulness of Uralloy A, however, whether it be of solid wood or sawdust. One of them has already been mentioned with relation to compressed sawdust -- its poor water resistance. Impregnation with urea, in fact, actually increases the hygroscopicity of wood unless the soaking solution be modified with chemicals which increase water resistance. The other deficiency involves the return of the material to a plastic condition when reheated to 212° F. Softened thus, it tends to lose shape in response to any pressures or stresses it may be under.

These two deficiencies naturally place limitations upon the practical usefulness to which the simple urea treatment can be turned. Those who developed it are therefore inclined to regard it as more important from a scientific than from a commercial standpoint. The discovery that urea plasticizes wood is an interesting development in the study of basic wood properties. Wide commercial applications are not expected because of the thermoplastic nature of the complex and because urea tends to darken wood and increases its hygroscopicity. Conceivably, however, the process may have some important uses where these properties are not objectionable.

UREA-FORMALDEHYDE THERMOSETTING WOOD (Uralloy C)

The twin problems of preventing resoftening of bent urea-treated wood and improving its water resistance were in great degree solved by addition of other chemicals, notably formaldehyde, to the soaking solution. It was found that this substance, uniting chemically with urea within the wood cell walls, formed a synthetic resin which gave the wood considerable resistance to water. Swelling and shrinking were thereby materially reduced. As soon as the resin was set by heat (polymerized), the wood assumed a stiffness which could not be noticeably affected by subsequent heating, at least at 300° F. It thus became permanently thermoset. To obtain good diffusion into the wood before the resin-forming action of the formaldehyde and urea takes place, this chemical reaction must be retarded by buffers which maintain the solution in the slightly alkaline range.

A buffered urea-aldehyde solution developed at the Laboratory accomplished these results. Either of the following formulas can be used to make this solution. The ingredients should be added in the order shown with the mixture heated to not higher than 140° F. until all the urea is dissolved. The mixture should be cooled to room temperature before adding formaldehyde.

Formula A

Water...............	231	parts
Sodium hydroxide....	6	"
Borax...............	39	"
Urea................	380	"
Formaldehyde (37 percent solution)..	344	"
	1,000	

Formula B

Water...............	416	parts
Sodium hydroxide....	6	"
Borax...............	39	"
Dimethylol-urea.....	286	"
Urea................	253	"
	1,000	

All proportions in these formulas are by weight.

To secure best results, the solution formula must be modified and adjusted to suit various species. Thus the above formulas, which have a pH of about 10, are admirably adapted to plasticizing oak, a highly acid wood. For other woods it may be desirable to adjust the pH nearer to 8. This may be done by omitting the sodium hydroxide in the formulas, or by adding 10 parts of glacial acetic acid, or by other suitable means. When the solution is used to resinify wood in applications which do not involve bending, the proportion of formaldehyde can be increased so as to obtain greater water resistance and increased strength properties.

The soaking period necessary to get complete diffusion of the chemicals within the wood is about the same as that for the simple urea solution. From this point on the steps necessary in the entire bending and molding process are different from those suitable for Uralloy A. After the treated wood is removed from the urea-formaldehyde solution, it is not dried, but is promptly heated and bent in the wet condition. If the heating and bending are not done promptly, resin will begin to form, and the plasticity of the wood will decrease. When this happens, reheating will be of no avail in resoftening the wood. Heating is done by boiling the treated wood in a 50 percent solution of urea in water at a temperature of 212 to 220° F. for a period of 15 to 20 minutes per inch of thickness. The wood is then bent to the desired shape. Under such conditions, the bending properties appear to be as good as those of Uralloy A. The wood is then dried while held to the bent form in an oven, kiln, or by simple exposure to air, after which it is heated to about 300° F. in order to fully polymerize the resin. Prolonged exposure to temperatures of 150° F. or above also will set the resin sufficiently for most purposes.

When the thermosetting process is used to resinify wood for applications which do not involve bending, such as for modification of hardness or moisture resistance, the heating in urea and the bending are omitted.

Properties of the Product

As experimentation with the materials produced by the process has been limited, all the properties of the new substances have been by no means established. In general, however, the tests made thus far indicate that the strength qualities are not materially affected by temperatures up to the boiling point of water. Uralloy C is stiffer than normal wood, that is, it does not bend as much under the same load. It is considerably harder. However, it can be readily worked with ordinary woodworking tools. It takes a high polish when buffed. Unlike urea treatment, the urea-aldehyde treatment tends to bleach rather than to darken the wood.

The formation of a water-resistant urea-formaldehyde resin in the fine swelling structure of the wood cell walls destroys some of the natural hygroscopic properties of the wood. The treatment thus imparts true water resistance. The rate of moisture movement through the wood and the ultimate amount of shrinking and swelling in response to moisture changes are considerably decreased compared with those of normal wood.

GENERAL

The mechanics of successfully bending wood treated by either method depends largely upon good technique in handling properly designed apparatus, as mentioned earlier. As yet, research has not been carried far enough to establish the shortest radius upon which wood of a given thickness may be bent. Stock 1-1/2 inches thick has been bent through 180 degrees on an inside radius of 5 inches, and 1/4 inch stock was similarly bent on a radius of 3/4 inch. While this degree (3/4 inch) of upset is not necessarily the maximum obtainable, it will be noted that the ratio of the length of the inside radius to the thickness of the stock is about 3:1 in both instances. It can be assumed, however, that thicker wood requires a proportionately longer radius.

It has not yet been possible to establish whether the treatment adds to the resistance of wood to destructive insect and decay attack.

Research has been carried out on only a limited number of wood species. It appears, however, that the hardwoods respond better than do softwoods to the plasticizing action of both processes, Of the hardwoods, oak and sweetgum give better results than the other species tried. Resinification of the wood by the urea-aldehyde solution probably can be accomplished with all hardwoods and softwoods, although this has not been verified by research.

Urea, the synthetic chemical which is the basis for this plasticizing treatment, is manufactured commercially by combining liquid carbon dioxide and liquid ammonia under pressure. It is commonly sold in crystalline form at $80 to $90 a ton. It is not sold by the manufacturers in quantities less than 100 pounds, but smaller quantities can be obtained from chemical and drug supply houses at a considerably higher price.

It should be pointed out to those interested in undertaking commercial applications of either process that existing limitations upon domestic sales of critical chemicals and pressure machinery, molds, dies, etc., caused by the war must be taken into consideration.