New Goods From Wood

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PRACTICALLY everything was scarce the first year or two of the war, and we tried to make wood a substitute for steel, aluminum, rubber, and many other materials. Then wood became scarce, so we worked to make wood products as serviceable as possible in the uses to which they were most applicable. Our research in both periods had the same technical objective: The improvement of wood service.

From the search came an array of materials with strange names. Many of them will doubtless find their way into the production lines of the Nation's furniture, farm machinery, building, and other industries. The new products include woods specially treated to fortify them against shrinking, swelling, and the inroads of decay organisms, and other ills that raw wood is heir to; low-cost wood plastics made of the wastes ordinarily burned or otherwise disposed of by sawmills, paper mills, and similar wood-using plants; and paper and wood-pulp materials strengthened and made more durable for exposure to rain, heat, cold, and other rigorous conditions. Many of the materials are adapted to large-scale production methods.

We worked on three principal types of materials. One was the so-called "modified" woods, consisting principally of wood in the form of thin veneer sheets that were given various treatments to decrease their natural tendency to swell, and that were sometimes compressed or molded under heat and pressure to form panels or molded products. From these treatments came impreg, compreg, and staypak.

The second principal type of wood materials extensively developed during the war can be broadly called "plastic" wood-base materials, or "lignin plastics." The basic production process consists of a chemical treatment of hardwood sawdust or wood chips that removes part of the
cellulose and leaves a residue of stable cellulose and lignin. When a plasticizer like phenol-formaldehyde is added to the resulting powder or pulp, it can be molded under heat and pressure to form various boards and other articles.

The third general type includes various paper-base laminates and wood-pulp plastic materials that can be molded. Most important among these products during the war was papreg, the basic material of which is a special paper chemically treated so that it can be compressed under heat to form a multilayered sheet suitable for many uses. Thin papreg can also be molded to the faces of plywood to provide a water-resistant surface that hides plywood defects, minimizes checking, and can be painted readily. Among molded pulp materials is a long-fibered pulp preform that can be compressed to various shapes in a mold.

Impreg (from “impregnated”) is wood treated with phenolic resin-forming chemicals according to a method developed at the Forest Products Laboratory, in which the chemicals enter and bond to the cell-wall structure, and the resin is dried and cured within the structure. When resin is thus made an integral part of the wood, the tendency of the wood to swell and shrink is permanently reduced. Phenolic resin-forming systems have proved to be the most effective in stabilizing wood dimensionally. It is possible to reduce swelling and shrinking to 30 percent of normal.

The stabilizing of wood by a resin treatment differs from preservative and fire-retardant treatments in that it must be much more complete. The resin must be uniformly distributed throughout the entire cell-wall structure to be fully effective. For this reason the treating of lumber and the treating of freshly felled logs have not met with the success that some investigators have claimed. Veneer of practically any species can be adequately treated. Practically none of the woods can be properly treated in lumber thicknesses and lengths. Even if lumber could be adequately treated, the increase in cost would make the material prohibitively expensive for the majority of proposed uses.

For these reasons, development work on impreg and its commercial production have been confined to the use of resin-treated veneer. These treated plies have proved suitable as facing for solid wood or untreated plywood. The chief advantage of such resin-treated facings is that they practically eliminate face checking and greatly reduce grain raising, even when exposed outdoors without a surface finish. Even the checking of fancy crotch veneer used in furniture can be nearly eliminated.

The treatment also imparts to the panels considerable resistance against decay and attacks by termites and marine-borers. Panels consisting of two resin-treated face plies with a single untreated core ply were inserted in the ground for a year in a field in Mississippi where termite action is severe. The termites tried the faces but found them not to their liking.
Like soldiers who failed in a frontal thrust, they tried a flank attack and, finding the untreated core just what they wanted, proceeded to clean it out. Similar material that has had the edges protected with a preservative treatment and all the plies treated is frequently sound after 5 years.

The resin treatment cuts down the passage of water vapor through the panels to a marked extent and greatly increases the electrical resistance and the resistance to most chemicals, except strong alkalies. Resin treatment has a negligible effect upon fire resistance. Fire-resistant salts, however, when incorporated in the wood with the treating resin, are fixed in the structure and give the wood good fire-retardant properties.

Only a few of the strength properties of wood are significantly increased by a resin treatment. Toughness is lowered, but hardness and compressive strength are increased.

Impreg was manufactured during the war only for military use. The most interesting use was for facing laminated redwood aircraft carrier decking to obtain a wear- and splinter-resistant decking equivalent to teak but lighter than Douglas fir. Service tests on one carrier indicated wearing qualities far superior to Douglas fir. Another wartime application of impreg was as housing for electrical control equipment, in which its superior electrical properties proved especially advantageous. Impreg shows the greatest promise as resin-treated faces for ordinary plywood. Such panels might be used as siding for houses, trailers, and boxcars, flooring, and paneling. It remains to be proved, however, that the improved properties warrant the increased cost of the treatment.

**Compreg**

Compreg is the name given to a stable form of phenolic resin-treated compressed wood. Its dimensional stability and its resistance to wood-destroying organisms, chemicals, and flow of electricity are practically the same as that of impreg. Most of the strength properties are increased about in proportion to the compression. It is tougher than impreg but not quite so tough as the original wood.

Because of the plasticizing action of the resin-forming chemicals on wood at temperatures used in hot pressing, the treated wood can be appreciably compressed under a pressure that scarcely compresses untreated wood at all. Because of this plasticizing action of the resin-forming chemicals on wood, it is possible to make a combination of resin-treated compressed faces on an untreated and uncompressed core in a single assembly and compression operation.

When compreg is compressed to about one-third to one-half the thickness of normal wood, it assumes a glossy finish. A marred surface can be sanded and buffed to virtually its original glossy finish without the use of applied coatings. This is a feature of compreg that would make it
desirable to use in furniture and flooring. Panels with a yellow-poplar compreg face, a yellow-poplar impreg back, and a Douglas-fir plywood core have been made for a flooring service test at our laboratory.

Compreg, largely in the form of thick, highly compressed panels, was manufactured by several companies for war use, chiefly in the manufacture of airplane propellers. Compreg has also been used to some extent for various connector and bearing plates, aerial antenna masts, and tooling jigs. Solid compreg shows promise for use in fan blades, pulley and gear wheels, bearings, and tooling jigs; shuttles, bobbins, and picker sticks for textile looms; high-strength electrical insulators; handles, such as for knives; and various decorative novelties.

Compreg has better strength properties than fabric-reinforced plastics, and it should be appreciably cheaper because veneer is cheaper than fabric, and about half as much resin is used in making compreg as is used in the fabric-reinforced plastics. Compreg may thus replace these plastics in a number of uses.

Impreg and compreg are made with synthetic resins of the phenolic (related to carbolic acid) type. A somewhat similar product can be made with chemicals that, under conditions comparable to those used in manufacturing impreg, form resins of the urea type within the wood. Treatment of wood with these urea-resin chemicals was pioneered by the Forest Products Laboratory, but research was suspended during the war because the phenolic resins appeared more promising. Commercial development of urea treatments was undertaken elsewhere, however, with great fanfare. The laboratory later resumed research with these chemicals to determine whether the properties of wood so treated are as markedly improved as the publicity about the commercial products set forth. This newer research has demonstrated that, on the whole, wood treated with phenolic resins has superior properties to that treated with urea at comparable cost of production.

The chief advantage of urea resins is that they are freer from color and taste than are the phenolic resins. On the other hand, under the most favorable conditions they are only about one-half as effective as phenolic resins in curbing the tendency of wood to shrink and swell with changes in its moisture content. Possible economies resulting from the relative cheapness of urea are in large part nullified by the fact that much more urea resin than phenolic resin is needed to attain even a moderate amount of stability in the dimensions of wood. It is no easier to treat wood with urea than with phenolic resins; assertions that urea can be used to treat dry wood in lumber sizes have not been substantiated by laboratory tests. Such properties as compressive strength and abrasion resistance are no better in wood treated with urea resins than in that treated with the phenolics. Decay, termite, and marine-borer resistance of urea-treated wood appears somewhat inferior to that obtained with phenolic resins.
These findings have led to the conclusion that, while urea treatment may be suitable for a few special applications, its usefulness in its present stage of development appears limited.

**Staypak and Staybwood**

Resin-treated wood in both the uncompressed and compressed forms is more brittle than the original wood. To meet the demand for a tougher compressed product than compreg, a compressed wood containing no resin was developed at our laboratory. It will not lose its compression under swelling conditions as will ordinary compressed wood. The material, named staypak, is made by modifying the compressing conditions so as to cause the lignin-cementing material between the cellulose fibers to flow sufficiently to eliminate the internal stresses.

Staypak is not so water-resistant as compreg, but it is twice as tough and has higher tensile and flexural properties. The natural finish of staypak is almost as good as that of compreg. Under weathering conditions, however, it is definitely inferior to compreg.

For outdoor use staypak should have a good synthetic-resin varnish or paint finish. Staypak can be used in the same way as compreg where extremely high water resistance is not needed. It shows promise for use in propellers, tool handles, forming dies, and connector plates where high impact strength is required.

The cheapest and simplest method of imparting dimensional stability to wood thus far found is to heat the wood under conditions that just avoid charring. This can be done with a minimum loss in strength properties by our method of heating the wood under molten metal for a few minutes. The wood becomes dark brown in color and loses about one-half of its original toughness, and a moderate amount of other strength properties. Equilibrium swelling and shrinking can be reduced to 60 percent of normal and an appreciable decay resistance is imparted to the wood by this treatment. Staybwood may find some use in places where dimensional stability and moderate decay resistance are more important than strength.

**Lignin Plastics**

Lignin, which in a sense is nature's cementing material between the cellulose fibers, can be freed from the cellulose by a mild acid hydrolysis and subsequently used as a semiplastic to bond the structure together again.

Besides breaking the cellulose-lignin bond, the mild hydrolysis converts the hemicelluloses to sugars while the stable cellulose remains with the lignin to serve as a plastic reinforcing material. The removed sugars can be either fermented or used for the growing of yeast. The residue is dried
and then ground to a powder. Although this hydrolyzed residue does have some plastic properties, it does not make a good plastic when used alone, because of the extremely high temperature necessary to cause the lignin to flow even moderately and the relatively low water resistance of the product. For this reason it is used preferably in conjunction with other plastics, such as phenol-formaldehyde, which improve both the flow and the water resistance.

Under these conditions, a plastic quite similar in appearance, water resistance, and electrical properties to common black phenol-formaldehyde plastics can be made by using 75 percent of hydrolyzed wood and 25 percent of phenolic resin. This mixture is in contrast with the mixture of 50 percent of wood flour and 50 percent of phenolic resin used in making the phenol-formaldehyde molded products. The strength properties—notably toughness—of the lignin plastic are slightly lower than those of the normal phenol-formaldehyde molded products. Mold flow is also inferior, but the acid resistance of the ligning product is better.

A commercially developed modification of the acid-hydrolysis process, in which the wood is hydrolyzed with an alkaline medium that becomes slightly acid at the end of the cook, gives a similar molding powder with strength properties superior to those of the acid-hydrolyzed product. This material, when used with only 25 percent of phenolic resin, still lacks the rapid and more extensive flow of the ordinary phenol-formaldehyde molding powders. Although the addition of more resin improves the flow, it reduces the price advantage. It is this lack of flow that has held back the commercial use of hydrolyzed-wood plastics. In large objects with limited need for flow, hydrolyzed-wood plastics may be used to advantage, however, because of their lower cost.

Unfortunately, none of the molding compositions shows promise of utilizing very large quantities of wood waste. For example, if all the present phenol-formaldehyde molded products were to be replaced by the hydrolyzed-wood plastics, three moderate-sized lumber mills could furnish all the raw material needed in the country. As board materials show promise of larger volume consumption, we have focussed considerable attention upon such materials.

The hydrolyzed-wood molding powders are not suitable for making board materials with adequate strength properties, notably toughness. The strength properties can be greatly improved by having the cellulose reinforcing material in longer-fibered form. This can be accomplished by using hardwood chips in place of sawdust and abrading the washed hydrolyzed chips while still wet to a pulp rather than grinding them to a powder. This pulp can be made into paper on a paper machine. After 10 to 15 percent of phenolic resin has been added, the sheets can be pressed at high temperatures and a pressure of about 2,000 pounds to the square inch into a high-density board with good strength properties and
water resistance. The board cannot be nailed but can be drilled. This fact, together with its high density and molding cost, makes it unsuitable for general housing applications. It appears suitable for electrical paneling and for such purposes as shower-bath walls.

Pulp boards have been made in the laboratory from the hydrolyzed chip fiber by forming thick pulp mats that are pressed wet under a pressure of 100 pounds to the square inch or less without the addition of any phenolic resin. The boards have properties comparable to those of untempered commercial hardboards. They can be nailed. They can be made from softwoods as well as hardwoods, but the strength properties and water resistance of the softwood product are somewhat inferior to those of the hardwood product.

Although these and other similar hardboards show promise for use as a sheathing material for houses and in other ways that wood is used, they are far from being synthetic lumber. Their use in housing should nevertheless expand.

Cooperative research with a paper mill has demonstrated the possibility of using soda-pulp lignin in laminated plastics. Soda-pulp lignin is the simplest to isolate and has the best plastic properties of the various forms of lignin waste. It can be incorporated with the pulp in the beater to form a laminating sheet which requires no auxiliary resin to produce a dense plastic material with good properties. This is potentially one of the cheapest plastic laminates now known and should find considerable use. We have learned that soda-pulp lignin can be used to dilute phenolic resin and the solution can be applied to paper or fabric. It can replace 50 percent of the phenolic resin ordinarily used without significantly affecting the properties of the resulting laminate.

**Papreg**

Paper laminates treated with phenolic resins have been made for a number of years. They have been used chiefly for electrical insulating panels and for other nonstructural uses that do not require exceptional mechanical properties. The manufacturers, in developing these materials, have approached the problem primarily from the resin standpoint. We felt, therefore, that further development of paper-base laminates, from the standpoint of finding the most suitable paper for the purpose, was a promising field of research. This proved to be the case. Within 6 months after the research was started, a paper-base laminate was developed that possessed several properties having more than double the mechanical values of those of the former laminates. For example, before the war the tensile strength of materials of this type rarely exceeded 14,000 pounds per square inch. Parallel-laminated papreg is now being made with tensile-strength values from 35,000 to 50,000 pounds to the square inch.
Papreg is stronger than fabric-base plastics, and can be molded at considerably lower pressures—75 pounds to the square inch—in contrast to 1,000 to 2,000 pounds to the square inch. It is not equal to the cloth laminate in toughness, however.

Several commercial concerns make papreg. It was extensively used in airplane parts and accessories, such as gunner's seats, gunner's turrets, ammunition boxes, and the surface of a type of cargo aircraft flooring. It was tried to a limited extent for the skin surface of structural airplane parts, such as wing tips. The chief objection to it in this use is that it is more brittle than aluminum and requires special rather than conventional fittings. By modifying the fittings, we were able to fabricate a papreg fin for a trainer airplane that met laboratory tests as well as did the counterpart aluminum fin.

Papreg is not so readily molded to complex shapes as are fabric laminates, but can be made to take considerable double curvature. Normally it has a tan to amber color, but can be made from pigmented paper in a number of the darker colors. When the surface sheets are treated with a melamine rather than a phenolic resin, pastel surface colors are obtainable. Papreg shows considerable promise for use in a number of products.

**Plastic Paper-Faced Plywood**

During the war, plywood was faced with plastic paper laminates to increase its water resistance, hide plywood defects, minimize grain raising, and to produce a readily paintable surface. The paper surface can be molded directly to plywood under pressures as low as 75 pounds to the square inch without compressing the plywood. When it is desired only to hide plywood defects and avoid grain raising, high-strength grades of paper need not be used.

A considerable amount of paper-faced Douglas-fir plywood was made during the war for military use in storage lockers, table tops, and similar objects. New uses indicated for plastic paper-faced plywood are walls, floors, partitions, cabinets, showers, ramps, bins, sheathing, and concrete forms for buildings; boxcar, passenger car, and truck-trailer lining and siding; hulls, bulkhead, and cabins for small boats; airplane cabin linings; refrigerators; and boxes, trunks, and containers in general.

**Low-Density Core Materials and Pulp Preforms**

Wartime airplane construction needs produced a growing demand for a light core material to be used between plywood or metal faces to obtain skin surfaces less subject to flexing and buckling, without significantly increasing the weight of the airplane. A material was sought that was as light or lighter than balsa wood but more uniform in properties, readily
available, and obtainable in larger sheets. These requirements were met with a light insulating type of board treated with phenolic resin to impart stability to the core. This and related cellular materials may find postwar use in prefabricated house construction, soundproof partitioning for boats, railroad passenger cars, doors, and other uses where lightweight and high rigidity are necessary or desirable.

Wartime research showed that plastics with a high percentage of long-fibered filler possess general strength and impact properties far superior to those obtainable with ordinary molding powders. In many cases, moreover, the double curvatures needed are too great to permit molding preformed flat laminates to the desired shape. For such purposes, the Forest Products Laboratory devised a means of molding special ordnance items by the pulp preform method, which consists of forming a mat of resin-treated pulp in a suction box with screen surfaces having approximately the contour of the final item. After they are dried, these preforms are compressed in a conventional mold. For some articles uncontoured preforms can be used and flowed to shape in the mold.

Shaped preforms would appear to be especially suitable for large contoured objects where exceptional toughness is required. Refrigerator cabinets, theater seats, desk drawers, cafeteria trays, furniture, and motor-car and aircraft parts have been suggested. It might be used also for smaller objects such as ashtrays, hand wheels, instrument cases, and other purposes for which the usual molding-powder plastic is too brittle.

THE AUTHORS

Alfred J. Stamm has been a member of the Forest Products Laboratory staff since 1925 and chief of its Division of Derived Products since 1945. He has been largely responsible for the development of impreg, compreg, and staypak. A native of Los Angeles, Dr. Stamm is a graduate of California Institute of Technology and the University of Wisconsin. His research in the physical chemistry of wood won for him a Rockefeller Foundation fellowship, which enabled him to spend a year at the University of Upsala in Sweden. While there he represented the United States at the International Forestry Convention in Stockholm. Dr. Stamm has also investigated the electrical properties of wood, various aspects of the way moisture is held within wood, and the molecular properties of wood constituents.

G. H. Chidester has spent the past 20 years at the Forest Products Laboratory doing research in pulp and paper manufacture. Since 1942, he has been chief of the Laboratory's Division of Pulp and Paper. He has specialized in the sulfite and semichemical processes of pulping woods, seeking to reduce costs and waste and to adapt the processes to a wider assortment of tree species, especially hardwoods little used for pulping. During the war he directed the laboratory's research in the field of paper plastic materials. A native of Hastings, Mich., Mr. Chidester is a chemical engineering graduate of the University of Michigan and worked for 5 years in pulp mills and on the staff of a paper-trade magazine before joining the laboratory staff.