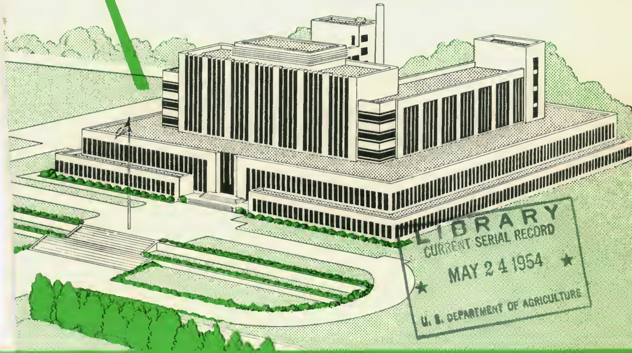
the FOREST PRODUCTS *Laboratory*



A brief account of its work and aims

FOREST SERVICE • UNITED STATES DEPARTMENT OF AGRICULTURE

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M-69986-F

Main building of the U. S. Forest Products Laboratory, completed in 1932.

A National Institution for Wood Utilization Research

THE FOREST PRODUCTS LABORATORY is a unit of the research organization of the Forest Service, U. S. Department of Agriculture. It is a scientific and technical research institution concerned wholly with the investigation of wood and wood products and their adaptation to diversified fields of use. It was the first and for several years the only institution in the world conducting general research on wood and its utilization; other Nations have since followed the lead of the United States in developing laboratories along similar lines.

Importance of wood utilization

The forest, distinct from all its other services and benefits, supplies a basic raw material—wood—that from earliest times has furnished mankind with many necessities of existence and with comforts and conveniences beyond number. Forests will return maximum values to the people of the United States only if they are fully and profitably utilized and at the same time maintained in vigorous condition for the continuous production of timber crops.

Nearly one-third of the continental United States is either in forest or suited by nature mainly or solely to the growing of forests. In a broad sense, the growing of forests appears to be the only economic use to which this enormous area, amounting to over 600 million acres, can be put. The fullest development of this use is of profound importance to the country's prosperity. Aside from providing timber, forested land affords benefits of far-reaching importance, through its favorable influence on streamflow and in preventing excessive erosion; in providing shelter and protection for homes, crops, and livestock against wind and drought; in providing forage; in supplying recreational needs; and in furnishing the environmental conditions upon which wildlife of the country depends. In addition it is desirable that a reasonable area of forested land be reserved in its virgin condition for scientific and recreational use. All these benefits, though not easily appraised, in the aggregate represent great values to the public.

Although the growing of timber on these lands for the many products demanded by modern civilization represents the more

The perpetuation of forest resources and their proper utilization are essential to the country's welfare.

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Employment and wages for thousands of workers are bound up with continued and increasing usefulness of wood in modern life.

tangible economic value or use, the mere production of an increased timber supply does not satisfy the demands of economic forestry. The utility value of wood must also be maintained and increased. From this standpoint the actual and potential value of these lands as a source of wealth and employment must be gaged in a large measure by the utility value of this principal product.

The better adaptation of wood to modern consumption requirements is a matter of direct concern to consumers, whose proper housing and standards of living are bound up with the satisfactory use of wood products; to workmen, who need the hundreds of millions of dollars in wages furnished by employment in the woods, the sawmills, the pulp mills, and broadly diversified fields of wood construction and manufacture; to farmers and other timberland owners, large and small, seeking market outlets for materials from their vast aggregate acreage of woodlands; to local communities, counties, States, and the Nation, all of which have a vital interest in stable revenues from forests, forest lands, and successful forest industries. In our national forests alone, the investment in land and timber and the responsibility for a wise utilization of the products require a comprehensive program of research designed to broaden and stabilize markets for forest products.

Purpose of Laboratory Research

Answering to these major economic needs, the research of the Forest Products Laboratory is directed toward the better and more efficient and diversified utilization of forest materials. Scientific research is the means that must be used to gain a more thorough knowledge of wood in its chemistry, growth, and structure, and to determine the technical properties of the hundreds of American wood species and their variations of quality within the stand and in the tree itself.

Research must aid in solving many difficult problems—how to utilize more efficiently the small-sized and second-growth trees that will form the bulk of our future forests; how to secure useful service from the many wood species that are now used little if at all; how to turn to economic account the large wastes that occur in the conversion of trees into commodities; how to secure greater service and economy from wood through selection of material, control and modification of its properties, improve-

M–31281–F

Improved timber harvesting and utilization methods mean increased income to farmers and other owners of small timber tracts as well as to large operators.

ment of treating processes, and the development of new and better methods of wood fabrication and conversion.

Cooperation with University

The Forest Products Laboratory was established by the Forest Service in Madison, Wis., in 1910, following acceptance of the offer of the University of Wisconsin to provide a building with necessary light, heat, and power services. This arrangement made possible the coordination and systematic development of Forest Service research activities that had previously been carried on in a number of small laboratories in various parts of the country. A cooperative relationship between the Laboratory and the University of Wisconsin was thus begun that has continued to the present, assuring collaboration in scientific matters and interchange of research facilities for staff and graduate students. The original building was occupied by the Laboratory for 20 years, and additional temporary quarters were provided by the university as increasing work required.

Present building

In 1930 the long-felt need of adequate permanent quarters for the Laboratory was recognized by Congress and construction funds were granted. A site of 10 acres, overlooking the city and Lake Mendota, was provided by the State of Wisconsin through the board of regents of the university.

America's huge volumes of logging and sawmill refuse are sources of useful products.

M–83089–F, 74979

M–26224–F
Laboratory utility building of plywood with glued laminated arches, one of the first structures of this type in the United States.

The present main building was completed in 1932. In general plan, this building is U-shaped, about 275 feet in length and overall breadth, with wings flanking a central court. In its five stories and ground floor it contains a total area of 175,000 square feet, or approximately 4 acres. The Laboratory is provided with plant facilities and experimental equipment suited to the handling, processing, testing, and investigation of wood in many forms, from the raw material of the log to lumber, plywood, pulp, paper, plastics, and other conversion products.

Accessory structures

Additional structures have been built on the Laboratory's grounds for operating or demonstrational purposes. Among these are a utility building containing some of the first glued laminated arches to be erected in America, a concrete fire-test house, a veneer and plywood plant, open and closed sheds for lumber storage, two prefabricated all-wood houses, and a wood-sugar pilot plant. Research on shipping containers and packaging is housed in several auxiliary buildings.

Personnel and research divisions

Of the personnel of the institution, about one-third is technical staff, comprising research specialists and assistants, and two-thirds is nontechnical staff, including administrative, operating, and clerical workers. The entire organization centers around and is contributory to the work of eight research divisions, whose fields of investigation are described in the following pages: Timber harvesting and conversion; silvicultural relations; chemistry, composition, and derived products of wood; timber mechanics and structural research; shipping containers and packaging; wood seasoning and moisture control; wood-treating and gluing processes; and pulp and paper. In addition, the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, conducts research in wood pathology at the Laboratory.

Timber Harvesting and Conversion

Harvesting the current timber crop presents technical problems that yesterday's virgin timber supplies did not pose. Formerly, low-quality and cull timber and waste from logging and sawmill operations were of little concern; farm woodlands and other small holdings of timber also played a minor role in the national supply. Today, however, unlimited supplies of old-growth timber are no longer available. Utilization of both low-quality timber and timber from scattered tracts is therefore important in the successful operation of forest industries and in the management of forest lands for sustained yield.

Research to develop improved methods of harvesting low-quality and scattered timber and coverting it to useful products is conducted not only in the Laboratory but also in the woods and mills, where the research men deal with the most practical aspects of the problems created by these changed conditions.

Development of log grades

A system of log grades is one of the pressing needs of the industry and of forest management. Inventory and appraisal of timber have been based heretofore more on quantity than on quality. But the large range in qualities to be dealt with as managed forests replace virgin forests requires accurate but workable quality classifications. A good system of log grades becomes even more important as integrated production of several products replaces conversion to a single product, so that processing of raw material for different products can be geared to inherent qualities and values of the individual log.

Substantial progress has been made by the Laboratory in correlating end-product yields with log-surface characteristics for grading purposes. Log grades suited to hardwood timber in all parts of the Nation have been developed for certain products, and are being broadened to include other products. For softwood timber, similar grades are being devised. But the need for systematic log grading is a nationwide problem, and much remains to be done, not only by Laboratory representatives but through the cooperation of other forestry research agencies.

Improved logging and milling equipment

To utilize forest material formerly discarded requires lighter, more mobile equipment and faster operating methods than those used for virgin timber, in order to minimize operating and labor costs. The situation is not unlike that of the mining industry in which new methods are required in order to recover low-grade ores. Forest industries are relatively small and widely dispersed, however. There are many new techniques that cannot be worked out on a single large pilot-plant basis, but are developed by isolated operators and ingenious individuals who de-

Correlation of surface defects of a log with the amount and quality of its conversion product is the basis of log-grade development. "Unwrapping" a log on a veneer lathe discloses the relation between internal and external log defects.

M–98758–F, 98741

vise a mechanism or find a better way to carry out a particular step. A technical service provided by Laboratory investigators ferrets out these advanced techniques, analyzes their merits for more general application, and disseminates information concerning them. This type of assistance has won widespread commendation, not only from all regions of the United States but also from foreign countries.

Improved operation of small sawmills as well as improved logging methods are the aims of a major field of research in forest products. With respect to small mills, special attention is given to methods of reducing waste due to miscuts, excessive board thicknesses, and excessive saw kerf and to the fundamentals of design of saw teeth and cutting edges as they affect smoothness of surfaces, power requirements, and maintenance costs. Another aim is the development of sawing equipment that can be used as an adjunct to logging equipment to separate usable from defective parts of a log and thus help eliminate transportation costs for useless material. To improve logging methods, the furthering of the use of mobile or small stationary bark-peeling machines and

M–99206–F

Portable bark-peeling machines provide a low-cost method of handling pulpwood—a development that strikes at the core of many forest utilization problems.

chippers is an important objective, so that more sawmill and woods waste can be made suitable for use by pulp mills.

Variables of speed and saw-tooth performance are tested to improve small sawmill operations. Sawdust is not just sawdust to the expert; the form and size of the particles disclose whether the saw is underpowered, runs too fast or slow, or is overstrained.

M–78061–F, 84425

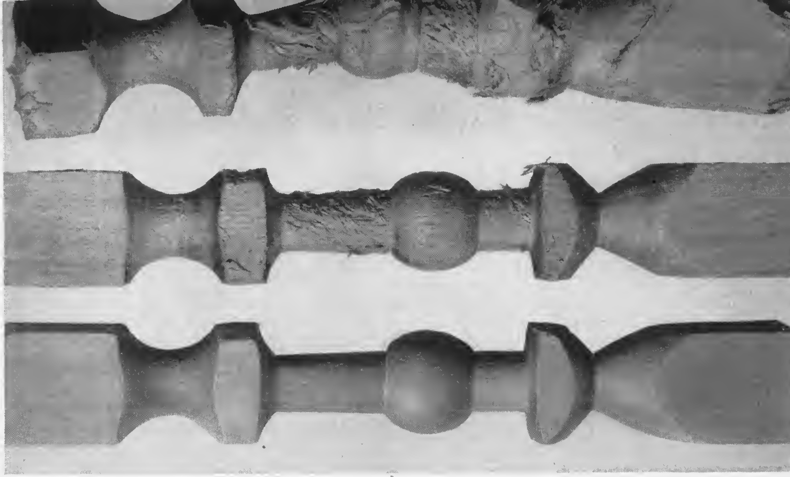
Machining wood

Some of the lesser-used wood species of the United States, as well as tropical species, present grain peculiarities that cause difficulties in planing, turning, and shaping them to a smooth surface. Establishing the machine speeds and knife angles that overcome such difficulties broadens the utilization of these species.

The introduction of new materials, such as composite or modified wood products that involve resins, densification, or numerous glue lines, presents problems in machining. The introduction of new equipment, such as carbide-tipped saws and knife cutters, presents problems as to optimum speeds and effects on power consumption. Laboratory research aims to solve these problems, so that industry can use the new materials and take full advantage of the potentialities of the new equipment for better service and lower costs.

Utilizing waste

Much of the woods and mill waste can be utilized most advantageously as sawed wood products rather than as pulp or chemical material. Exploration of the industrial uses of wood that can be met with



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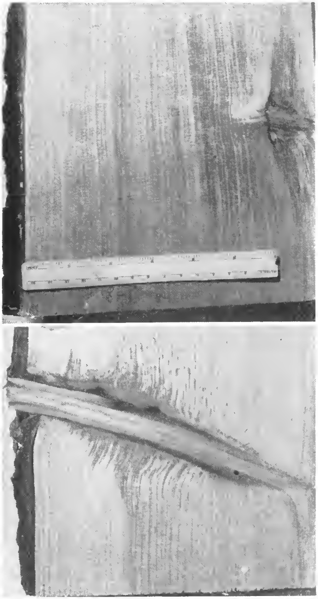
Machining tests show that some species are very exacting as to machine speeds, knife angles, and moisture content. Species with a reputation for poor behavior become useful when research determines their optimum machining conditions.

small-sized material, such as cut stock or dimension stock, rather than with standard lumber is an important research undertaking. Much headway has been made in this field, but continued research is needed for further advance. Efficient methods of producing, handling, seasoning, and marketing are essential to successful utilization of sawmill wastes for such products, hence are important subjects for research.

Silvicultural Relations

In any effort to increase the utilization value of wood, exact identification, testing, and selection of species assume essential and immediate importance. Fundamental, however, to the general program of forestry and wood use is the problem of control of wood quality at its source. Its solution must be found in the conditions of tree growth, and at this point the research of the Laboratory makes close contact with silvicultural experiments and practices in the field.



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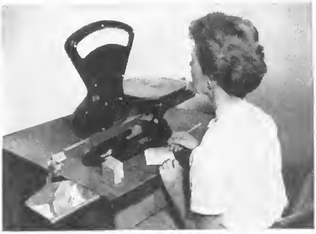
Top, a tree section showing the results of pruning 43 years ago; bottom, a similar section from an unpruned tree.

Growth and quality of wood

The wide variations in strength, hardness, shrinkage, and other properties of wood produced within a tree species as a result of growth under different conditions have prompted the Laboratory to investigate the possibilities of improving wood quality while the tree is growing. Wood grown under different natural conditions or under conditions artificially modified with respect to soil, moisture, density of stand, and associated species, is tested and compared in order to find the conditions that produce the best type of wood for given uses.



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A rapid method of determining the specific gravity of wood is used for judging wood quality and correlating density with factors of climate and soil affecting the growth of trees.

Although many years are required to grow trees of merchantable size, a change in growth conditions, such as may be effected by removal of neighboring trees, drainage, or pruning, is reflected in the character of the annual growth rings subsequently formed, thus affording a ready means of comparing wood before and after the change was made, other variables remaining constant. The resulting information can be beneficially applied to second-growth timber that is still in the formative stage. For instance, softwoods make their best development with respect to strength and other desirable properties when spaced moderately close together, whereas the quality of hardwoods is sustained or improved by opening up the stand. To aid in judging wood quality and selecting wood for special uses, as for handles of striking tools or gunstocks, simplified methods of selection have been developed.

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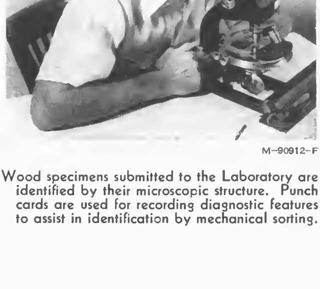
Species recommended for gunstocks are selected on the basis of similarity in specific gravity and shrinkage to black walnut.

Structure and properties

The variations in weight, strength, and shrinkage of wood are related to the differences in amounts and kind of its fibers and their structure. Certain growth conditions cause formations of abnormal types of fibers that make the wood extremely erratic in weight and strength. Such fibers cause heavy shrinkage along the grain and thereby serious warping and are responsible for rough surfaces on lumber and veneer. But normal fibers of most tree species also vary widely in their size, shape, and internal structure, and sometimes to the extent that the desirable characteristics of wood are lost. It is the purpose of one part of anatomical research to determine how the basic features in the structure of wood affect its properties and behavior in use, so that kinds of wood having suitable properties can be selected for such important uses as lumber, veneer, and pulp.

Identification

Wood as lumber, removed from association with living trees and their external characteristics of bark, foliage, flowers, and fruits, may be identified by a knowledge of kinds and arrangements of structural features, some of which can be seen only under the microscope. With this knowledge, the families, genera, and many individual species of wood are identified as readily by cell and pore arrangement as by the botanical characteristics of trees. A specialized service in wood identification, provided by the Laboratory, is widely used by the general public. About 3,000 samples, approximately one-third of which are foreign species, are identified each year.



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Wood specimens submitted to the Laboratory are identified by their microscopic structure. Punch cards are used for recording diagnostic features to assist in identification by mechanical sorting.

Frequently important questions of use and even lawsuits hinge on the result of an examination of a few chips or shavings, sawdust, or wood flour. In criminal cases the careful identification of pieces of wood may furnish valuable evidence; an outstanding example was the Laboratory's discovery of the source of the wood from which the ladder used in the Lindbergh kidnaping was made.

In development at the present time is an identification key to the woods of the world that will be used with business-machine equipment to facilitate this work.

Foreign woods

The Laboratory has a wood collection that includes samples of wood from all parts of the world. Data are also being collected concerning the properties and characteristics of commercial species being brought into this country to supplement native species that are in short supply. Leaflets including these data are published to permit comparison of the properties of the foreign woods with those of native woods.

Chemistry, Composition, and Derived Products of Wood and Wood Waste

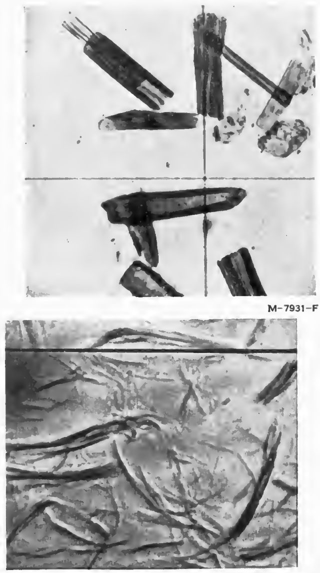
The fundamental nature of wood as a substance must ultimately determine its possibilities as well as its limitations in use. The chemical composition of wood, the arrangement of the constituent parts in the wood fibers, and the variations of such characteristics according to species and growth conditions are therefore explored by the Laboratory for the aid and insight they can afford in all fields of wood research—in silvicultural control of wood and its properties, in its selection, seasoning and handling, its impregnation with preservatives, its use in construction, and its conversion into pulp and chemically derived products of all types.

Microstructure

All wood is composed of hollow elongated fibers or cells that are its main visible construction units. But Laboratory research has helped reveal that the structure of wood can be subdivided further. The walls of the wood fibers are made up of concentric layers of spirally arranged fibrils and the fibrils in turn are made up of still smaller elongated units. Other subdivisions of wood continue on down the size scale until the individual molecules of cellulose are reached. Cementing all these structural units together is a noncarbohydrate material called lignin. Extractives and infiltrating substances, such as resins, gums, or tannins, are present throughout the gross structure to a greater or less extent.

Cellulose

Cellulose, the most abundant constituent, comprises about 70 percent of wood. Wood cellulose, used mainly in paper production, is similar in properties to cotton. In purified form it is the basis of rayon, lacquers, cellophane, gunpowder, and a variety of nitrate and acetate plastics. The cellulose from wood may be subdivided into alpha cellulose, the main basis of the useful products obtained from cellulose, and hemicelluloses. On complete acid hydrolysis of alpha cellulose, essentially the simple sugar glucose is obtained. The hemicelluloses, which represent between 30 and 40 percent of the total carbohydrate content of the wood, are formed mainly from pentose and hexose sugars and uronic acids. Further research is needed before the hemicelluloses can be completely and profitably utilized.



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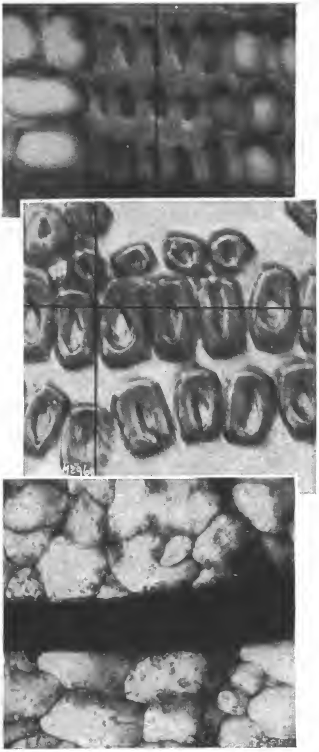
Top, "Sleeve" structure of wood fiber revealed by endwise slippage of the concentric layers of fibrils; bottom, wood fibers resolved into their component fibrils.



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Top, Cross section of wood, magnified; center, cellulose fibers of wood, with lignin removed; bottom, lignin structure of wood, cellulose removed.

Lignin

Next to cellulose the greatest bulk constituent of wood is lignin, the material that surrounds the cellulose fibers and forms a continuous matrix or honeycomb throughout the wood. Its complex chemical structure has delayed development of suitable uses for lignin, and, as a consequence, it is usually considered waste in pulping processes and discarded or used as fuel. Research at the Laboratory and elsewhere, however, is revealing the structure of lignin and should result in a means of unlocking the complex lignin molecule to produce a wide variety of important chemicals.

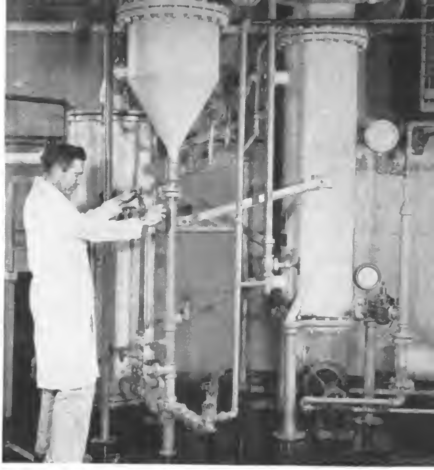
Lignin and lignin derivatives are finding uses as road binders, oil-well drilling mud, soil stabilizers, bases for plastics, extenders for resins, emulsifying agents, surface-active agents, air-entraining agents for concrete, boiler-scale inhibitors, and tanning agents. They are also sources or potential sources for many organic chemicals, such as vanillin, a substitute for vanilla flavoring, and pyrogallol, an important photographic chemical. An increasing knowledge of lignin—such as is gained through special treatments and methods that show the changes occurring in lignin under various conditions and sharper differentiation of the characteristics of hardwood and softwood lignins—and the development of new processing methods indicate that there are even greater possibilities for lignin utilization.

Conversion products

Vast increases in forest market values await the greater development of useful products from wood waste. The best opportunity for utilization of wood waste, if it is unsuitable for high-grade pulps, is in the manufacture of synthetic board materials. A huge supply of waste is available, however, that is unsuitable for both pulping and board manufacture. For this material, chemical utilization procedures, such as extraction, carbonization, or hydrolysis, may become economically attractive. The production of naval stores by extraction of stumpwood is a good example of a profitable scavenging operation.

Research at the Laboratory to improve the production of charcoal by carbonization of wood aims at revitalizing the oldest of the chemical wood-processing industries. The production of charcoal from wood waste is a comparatively simple operation, does not require careful selection of wood, and provides a product with a widely distributed market.

Laboratory chemists have found methods for converting cellulose into sugars that may be concentrated into molasses for feeding animals, fermented to produce grain alcohol, glycerine, and other valuable chemicals, or used for the growth of yeast. Chemically, the conversion of wood cellulose to simple sugars is extremely simple, but cellulose is unique among all other carbohydrates in its resistance to acid hydrolysis. Work is now in progress at the Laboratory on the fundamental chemistry involved in this reaction, with the aim of increasing both the speed of the reaction and the amount of sugars produced.



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In pilot-plant-scale equipment, such as this evaporator, wood sugar solutions from the Laboratory's wood-hydrolysis plant can be converted to molasses, alcohol, and other products.

Modified woods

The treatment of wood to impart decay resistance and to give it resistance to burning are both old and well-established industries. Treating wood primarily to modify other properties, such as giving it dimensional stability against changing moisture conditions, is still in its infancy, although some forms of modified wood have been in production for a number of years. Dimensional stabilization has been accomplished in a number of different ways, but impregnation with synthetic resins has been the most promising approach from a commercial standpoint. Further research is under way at the Laboratory with the aim of broadening the choice of stabilizing agents and decreasing processing costs.

Shuttles and picker sticks for the weaving industry, aircraft components, knife handles, musical instruments, insulating fastenings, mallets, and flooring are a few examples of high-strength, moisture-resistant articles produced from resin-impregnated, compressed wood.

M-90901-F

Timber Mechanics and Structural Research

Each year more than 22 billion board-feet of lumber—better than 65 percent of our national sawed-timber production—is used in buildings and other structures where its load-carrying capacity and shock-resisting ability are of primary importance. Whatever the type of load or condition of service—a long-continued load, as in a warehouse floor; a severe load of short duration, as in an aircraft member; a load repeated thousands of times, as in a railroad bridge timber; or a load of short or long duration while exposed to elevated temperatures or frigid conditions—the foundation for proper and efficient use of wood is accurate knowledge of its mechanical properties and the factors that affect them. The days when this valuable natural resource was overabundant and wasteful practices and rough approximations in design were common, are past; we must practice conservation and use wood as an engineering material.

Strength tests

To supply data on the strength of wood it was first necessary for the Laboratory to develop testing procedures and methods of analysis and then to proceed with an extensive testing program.

The results from thousands of tests have determined the basic strength properties of 175 of the principal tree species of the United States. As supplies of preferred species and old-growth timber become depleted, the properties of secondary species and second-growth material must be evaluated to include them properly in our timber economy. Foreign species are also evaluated to enable manufacturers to select those with desirable characteristics and thus augment our supplies of native timber.

Determination of mechanical properties through tests leads to proper and efficient engineering use of wood and wood-base materials.

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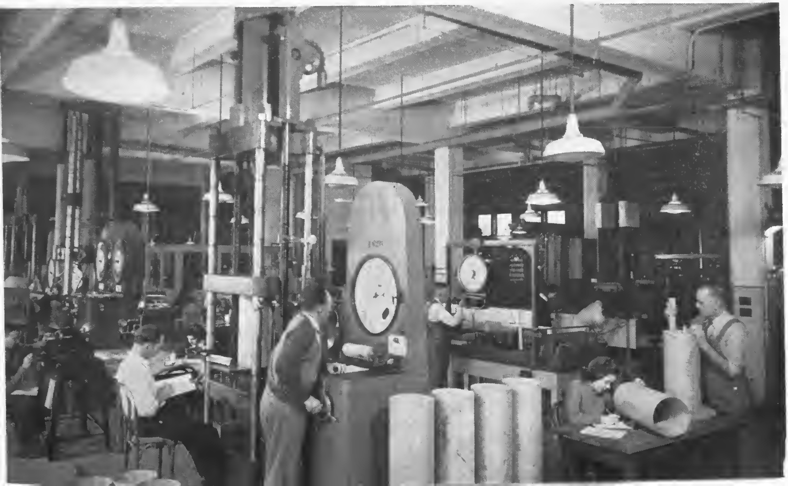

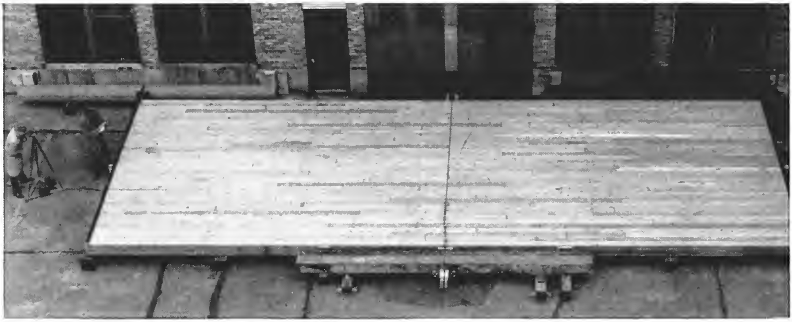

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Information obtained in tests of this large-scale panel permits barns, schools, and other buildings having large floor areas to be designed with greater resistance to wind and earthquakes.

These data provide a fundamental basis for structural design, for selection of species for particular uses, and for finding serviceable substitutes for scarcer and higher-priced woods. They are also the basis of design criteria for plywood and laminated construction as well as the primary requisite for proper use of fastenings. The Laboratory's methods of evaluating strength properties have been adopted as standard throughout the United States and are being correlated with those of foreign countries to permit comparison of data. They are under constant scrutiny with a view to taking advantage of new developments in instrumentation that will improve the accuracy of the data or reduce the testing cost.

In addition to conducting basic strength studies, the Laboratory continually investigates the performance of wood under diverse conditions of load and exposure, such as instantaneous or long-continued loadings, fatigue conditions where the load is repeated thousands of times, or extremes of temperature and humidity that correspond to use in tropic or arctic regions.

Structural investigations

On the foundation of reliable strength values for the principal species, Laboratory research is able to deal effectively with the problems of wood structures in which the form, size, and condition of members must be taken into account. Tests of full-size structural members have demonstrated in quantitative fashion the influence of common growth characteristics, such as knots and checks, on strength. On the basis of these test results, structural designers have been given more efficient working-stress values, building codes have been modified to take advantage of wood's favorable strength properties, and fundamental grading methods have been devised by which timbers can be rationally and economically selected for the intended use and condition of loading.

The principles used in establishing stress grades of structural timbers are being adapted to the dimension grades to extend their field of use. Research is under way on the design of shear-resistant diaphragms that will be capable of carrying the shock loads of earthquakes and high wind loads and thus insure safer public buildings and reduction in wind damage to barns.

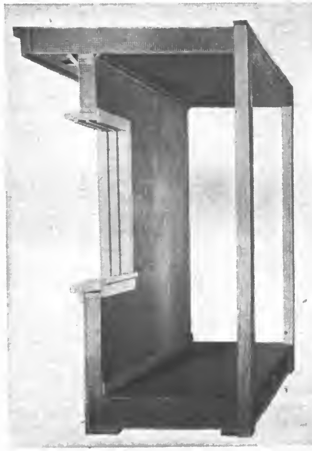
Joints and fastenings

Since the joints of a structure are usually its weakest parts, Laboratory investigations are pointed toward improved fastenings and joint design in an effort to develop greater joint strength and rigidity in construction. Basic data have been determined on the holding power of nails and screws, driven at various angles to the grain, in wood and plywood. Test work has been done on nails with modified or treated shanks designed to increase holding power, and corrosion-resistant nails intended for special purposes or to reduce maintenance costs in dwellings. Improved nailed joints have been designed for homes and barns to provide more rigid structures and reduce losses from wind damage. The best techniques of house nailing have been published to provide builders and home owners with information that will insure better construction and decreased maintenance costs.

Design criteria for modern plate and ring connectors, which act as keys or dowels in wood framing, have been developed to provide for sound engineering use of these fasteners in the construction of long-span bridges and roof trusses, towers, oil-field equipment, and public buildings.

Housing

Well-constructed, economical, and comfortable homes are a constant need, and the more efficient use of wood and wood-base materials for this purpose is a major research target of the Laboratory. An intensive study of housing has resulted in the development of the principles of stressed-skin construction, using plywood-covered



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Experimental assembly used to study the performance of sandwich panels for house construction.

Connector-joined timbers are used in the construction of this modern three-hinged arch bridge.

M–31316–F

panels, which have been the basis of prefabricated house construction. More recently, sandwich panel construction—high-strength facing materials bonded to a lightweight core material—has been investigated for dwelling use and details of fabrication and erection have been worked out.

New sheathing materials are investigated, and the strength and rigidity of wall, floor, and roof panels are evaluated to provide data for establishing performance standards. To provide for better dwellings and to enable the home owner to understand and recognize good construction practices, manuals on prefabricated and conventional house construction have been prepared.

Plywood and sandwich construction

The strength properties of wood vary with its grain direction. If this variation is undesirable, it may be overcome by the use of plywood in which the strength properties parallel to the length and width of the plywood sheet tend to be equalized. Plywood also offers greater resistance to checking and splitting and less dimensional change with changes in moisture content than normal wood. Its effective use, however, requires knowledge of its performance with different ply thicknesses and orientations, combinations of species, and types of loading. Design criteria for plywood obtained through test and analysis at the Laboratory have enabled designers to utilize this material fully in the construction of highly stressed structural elements in the construction and transportation fields.

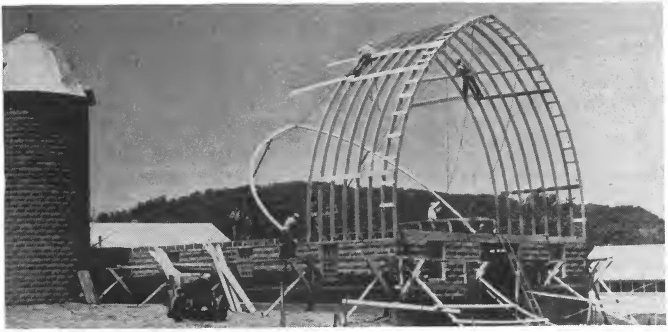
The same techniques and principles used to analyze plywood performance are used for sandwich construction. This new material combines light weight with high strength and rigidity through the use of lightweight core materials, such as balsa, paper, fabrics, or metal, bonded to facings of plywood, veneer, treated paper, or metal. This construction found earliest use in the aircraft industry, but Laboratory research is uncovering new uses in housing, trailer construction, and transportation.

Glued laminated construction

With the changing character of the Nation's timber stand, utilization of low-grade and short-length pieces has become of

M-25188-F, 86844

Strength tests of glued laminated construction provide basic data for the use of laminated arches, rafters, and beams in many types of buildings.



M-86846-F

Use of curved rafters made of glued laminated wood results in an improved type of barn.

greater importance. Laminated wood construction permits better utilization of available wood by using high-quality wood in exterior laminations and lower-grade material where the stresses are less severe. It also offers countless advantages for saving by designing members of uniform strength and basing designs on the use of seasoned wood.

Through the use of glued laminated construction, large-size structural members may be fabricated—long, thick beams; arches of great span and excellent architectural appearance for industrial buildings, hangars, and churches; and boat framing members of desired size and curvature. Principles that apply to fabrication of these large members may be used also in the fabrication of curved rafters that result in improved barns and other farm structures. Not only are its advantages in structural applications recognized, but with material shortages of perferred species, laminated construction is finding new uses in furniture, bowling pins, and baseball bats.

Laboratory research has indicated that some available adhesives will insure the integrity of laminated products under the most severe conditions of exposure. Investigations of the properties of glued laminated wood have resulted in the preparation of a bulletin that presents the basic principles involved in the use of this type of construction.

Shipping Containers and Packaging

The work of the Laboratory in improving the strength and serviceability of wooden boxes and crates has resulted in a more efficient utilization of billions of board feet of lumber, and has led to savings to the consuming public in freight handling charges, commodity losses, and damage to goods, amounting to millions of dollars a year.

It is frequently possible to redesign a container so as to reduce the amount of material required, to save shipping weight and warehouse space, and at the same time to make it stronger and safer. The principal American wood species have been classified for boxmaking, and box designs have been standardized and specifications prepared for the proper number, size, and spacing of nails. Through the cooperation of railway companies, boxmakers, and shippers, the Laboratory's findings and recommendations are widely used.

Fiberboard containers

In addition to making investigations of the design of nailed-wood, plywood-panel, and composite containers, and the improvement of commercial as well as Government specifications, the Laboratory has made a study of the broad field of fiberboard containers, which account for about half of the consumption of wood pulp made into paper and paperboard. Correlation of the strength of the component papers with the performance of the finished fiberboard boxes has now brought to this important class of containers the engineering principles and methods that have so largely improved the service of wood containers.

Interior packing

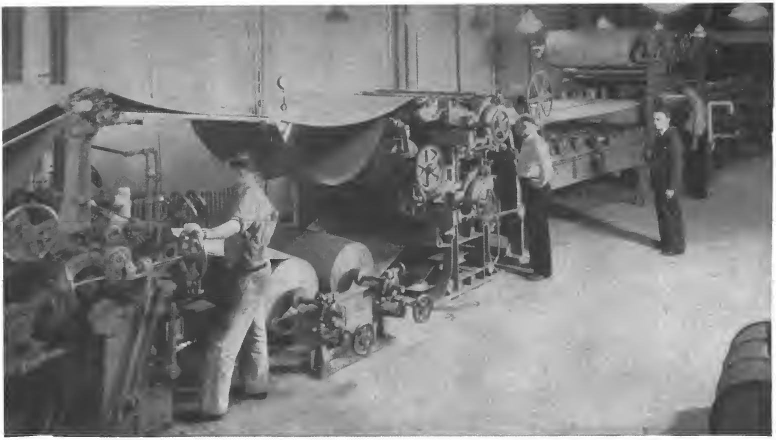
Experience during recent emergencies has shown that the container alone cannot protect against extreme changes in temperature and humidity encountered in storage and shipment. Work has been extended to include interior packing in which wood or corrugated fiberboard is utilized for blocking and bracing, cellulosic products for cushioning of delicate or fragile parts, and special papers for barriers to retain corrosion-preventive compounds or prevent the entrance of water.

Container testing

Container investigations are carried on with the aid of special equipment, including dummy loading materials and testing machinery that subjects packages to repeated shocks and vibrations similar to those they would receive in transit. Tests have been developed to subject completed packs to temperatures ranging from −65° F. to +160° F. and humidity conditions ranging from low relative humidity to simulated rainfall.

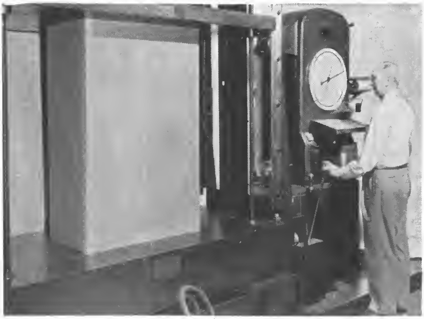
Revolving drum for testing boxes and crates.

M–22077 F



M-26068-F

Equipment for corrugating and gluing fiber container board.



M-90916-F

Compression test of a fiberboard box. Based on Laboratory research, the strength of finished boxes now can be predicted from the strength of paperboard sheets used in fabricating the boxboard.

Military packaging

During military operations, shipping space is at a premium and efficient packaging is therefore of first order. A major part of container and packaging research at the Laboratory is the improvement of packaging for the armed forces. During World War II, for example, improved packaging methods made it possible for four ships to carry the guns, explosives, and other supplies that formerly required five. In more recent work on military packaging, the emphasis has been on reduction of the weight of the container for air shipment, without sacrificing protection. Air cargo does not require the heavy protection needed for cargo in the holds of ships or in railroad cars. Many manuals, specifications, packing instructions, and other publications have been prepared. Through its packaging courses, the Laboratory has trained thousands of military men and civilians in the best ways of packaging equipment.

Wood Seasoning and Moisture Control

Wood in nature is a material combined with one-third to three times its weight of water; a freshly cut log 16 feet long and 18 inches in diameter may have a liquid content of more than 100 gallons.

For most uses of wood it is imperative that the greater part of this water be removed, a requirement that gives rise to the complex problems of seasoning. When wood dries, it shrinks. The amount of shrinkage is different in different directions in the piece. Uncontrolled drying causes more or less severe damage by checking, splitting, and warping. Unsuccessful seasoning accounts for the fact that many wood species are not used and for pronounced losses of material in other species, and it is often a source of difficulties and dissatisfaction with wood in service. Scientific research shows that these drawbacks can be largely overcome through adequate control of seasoning operations.

Air drying

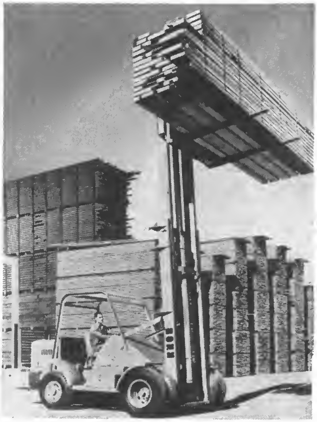
Air drying green wood in a yard, when the wood is piled in such ways as to obtain reasonable safeguards, remains the most economical method for seasoning many hardwoods and the bulk of lower grades of softwoods. Long series of tests have shown the common sources of loss and damage in drying wood and the means of bringing the losses and damage under control. Important factors determined are proper yard layout; proper spacing of lumber; adequate support to prevent warping, both in standard piles and in piles made up of packages; and measures to prevent stain and decay, including elevated pile foundations, proper yard drainage, and control of vegetation. Mechanized handling equipment and package handling of lumber have caused major changes in air-drying practices; the effects of these changes on drying rates and safe storage of lumber need to be evaluated.

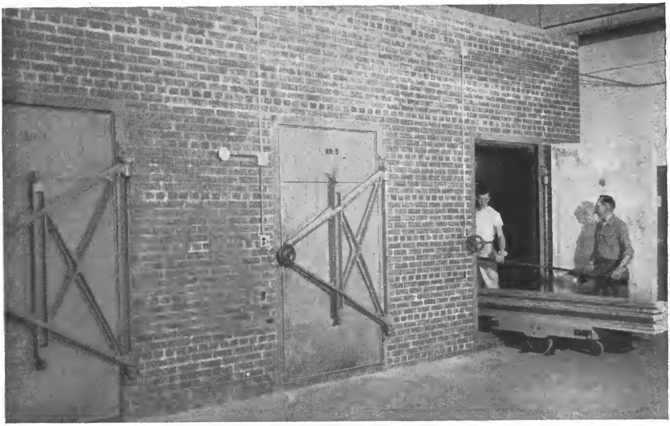
Kiln drying

The development of the lumber dry kiln arose from the need of speeding up and otherwise improving the seasoning process. Generally, however, its use has been attended with serious problems and variable results, because of the lack of precise technique. The Laboratory's kiln-drying investigations are centered on underlying physical principles, and the development of apparatus and methods by which the drying may be performed efficiently. A number of completely equipped experimental dry kilns provided with accurate temperature, humidity, and air circulation controls are in constant use to test every desired variation of conditions in the drying of sample lots of lumber.

Modern ways of handling and piling lumber have caused major changes in air-drying practices.

M–90356–F





M-91287-F

Lumber is seasoned experimentally in the Laboratory's dry kilns.

Practical methods have been developed for drying the principal commercial hardwoods and softwoods, many of which were previously considered impossible to kiln dry from the green condition. The engineering design of dry kilns has been radically improved. More than 5,000 commercial kilns embodying principles developed at the Laboratory are in operation, and new installations of these types by far outnumber all other types.

It is estimated that improvements in kiln drying resulting from the Laboratory's research are already saving American wood users more than $10,000,000 annually, and even larger savings are possible as the findings are more widely applied. Further investigations are under way with a view to discovering ways in which many difficult species and special sizes of wood may be kiln dried. Work has progressed on a broad program of research to correlate the more severe conditions of drying with their effects on wood quality, and in this way safely reduce the drying time of all species.

A necessary supplement to research on seasoning of wood is research on the improvement of methods of lumber storage and handling. All the care expended in the original drying may be wasted because of reabsorption of moisture by the stock while in transit or awaiting sale. Studies of this problem have pointed the way to better protection of lumber at all stages, from the mill yard to the finished structure. Special attention has been given to control of moisture content of lumber in closed sheds.

Moisture control

By whatever means it is accomplished, the seasoning process has one main purpose—to fit wood for the moisture conditions it will meet in service. Research is contributing to this end in many ways. Instruments for the quick determination of the moisture content of wood have been developed and are now manufactured and sold commercially. By extensive field tests the principal wood-moisture climates of the United States have been charted as a guide to seasoning for different regions. Definite moisture tolerances are thus determined for lumber according to localities and uses and are finding an increasing place in commercial specifications.

Moisture condensation control is necessary in houses and other buildings to prevent certain problems that can arise from the tighter construction of today's buildings. Reduction of air infiltration into a house results in a higher indoor relative humidity. During cold weather moisture vapor from inside the house, if not controlled, passes into the walls or attic and condenses and collects as frost or ice. In subsequent warm weather when the ice melts, water soaks into roof members and sets up conditions favorable for decay or drips on the ceiling below and wets, stains, and loosens plaster. Moisture collecting in the walls is also a common cause of paint failures. Through extensive research, methods of construction that include vapor barriers and attic ventilation have been developed that are effective and inexpensive in preventing cold-weather condensation.

M-36966-F, 36962

A vapor barrier on the warm side of insulated walls prevents frost from collecting on the sheathing or on the sheathing paper. Top, An insulated panel protected by a vapor barrier; bottom, an unprotected insulated panel. (Samples of sheathing are reversed.)

Wood bending

Wood bending is of special importance in such industries as furniture, boats and ships, agricultural implements, tool handles, and sporting goods. Of various methods commonly used to produce curved wood parts, wood bending is perhaps the cheapest, least wasteful of material, and most efficient from the standpoint of the strength of the finished part. Investigations at the Laboratory have revealed methods and procedures for preventing serious losses, due to breakage, by proper attention to such factors as selection of stock, drying and plasticizing the wood to prepare it for bending, design and operation of bending machines, and drying and fixing the bent part to the desired shape.

M-66379-F

Producing a boat frame in the Laboratory's bending machine.

Wood-Treating and Gluing Processes

Surface or impregnation treatments of wood to protect it or to increase its service value in other ways have been practiced, with varying success, from the earliest times. With the increasing volume and diversity of wood uses in the modern era, the aid of research in examining, improving, and developing all kinds of treating processes has become increasingly important.

Protection against decay

Decay is by far the greatest destroyer of wood in service. Practical methods of preventing it mean large money savings to wood users, more lasting and satisfactory wood structures and utilities, and the curbing of a heavy drain on forest resources. The effectiveness of standard and promising preservatives in protecting wood against decay, insects, and other destructive organisms is determined in experimental treatments and field tests of great numbers of treated specimens, including railway ties, piling, poles, posts, building timbers, and stakes. Research in impregnation processes is leading the way to better treating methods for the wide variety of woods in use and is of additional benefit in extending preservative treatment to wood species not before successfully treated.

M–23214–F

The effectiveness of wood preservatives is determined by impregnation treatments.

Simple processes for the preservative treatment of fence posts and lumber have been devised and are being further developed for use with various woods. Investigations have also included the treatment of laminated wood and plywood with preservatives.

For wood products that are exposed intermittently to rain or moisture, treatment with water-repellent preservatives serves to reduce swelling and shrinking and the hazard of decay. The Laboratory has developed apparatus for measuring the effectiveness of water repellents and is continuing its investigation of their usefulness in improving the service of wood in buildings.

Large numbers of inquiries are received annually regarding the relative value of wood-treating chemicals and methods. Impartial information developed by research is bringing substantial savings to thousands of wood users.

Fireproofing tests

The combustion of wood can be materially retarded, and the danger of spread of fire in wood structures can be greatly decreased by the addition of chemicals. The Laboratory's research in fireproofing extends over a wide range of chemical treatments and types of fire-resistive construction. Methods of testing are developed and improved, and proprietary fire-retardants are tested. Treated wood specimens are tested in specially designed combustion apparatus. Full-size house parts are subjected to flame tests in a separate building equipped with a panel furnace having 67 large gas burners. Although highly effective fireproofing treatments are now available, they are too expensive for general construction purposes. One objective of research is to reduce costs and to bring the benefits of fire-retardant wood within reach of the average home builder.

Painting and moistureproofing

The Laboratory has made, and continues to make, definite contributions to methods of obtaining more lasting and satisfactory service from paints and other coatings on wood. Exposure tests of painted panels in many locations have demonstrated the relative paint-holding power of the principal commercial species of wood, the advantage of aluminum house-paint primer over conventional paint primers on woods of contrasting springwood and summerwood bands, and the optimum thickness for coatings of house paints (0.004 to 0.005 inch).

A comprehensive investigation of house-paint maintenance, conducted over a period of 15 years, showed that too much as well as too little paint can lead to serious troubles. Too frequent repainting leads within 15 years, and with some paints much sooner, to conspicuous cracking and scaling of a kind rarely seen during the life of first paint jobs on new wood. A repaint schedule of two coats at 6-year intervals proved best for reducing the amount of such cracking and scaling. If more frequent repainting is considered necessary, it should be limited to a one-coat job at 4-year intervals.

The Laboratory supplements its paint research by examining paint failures on houses and maintaining an extensive file of case histories of the painting of such houses.

The work with paints indicates that there is a distinct need for more fundamental knowledge of the chemistry and physics of deterioration of house paint, and the Laboratory has now embarked on such a study.

M-92094-F

The modified Schlyter test measures the effectiveness of fire-retardant coatings.

Protective efficiency of paints on wood is investigated by exposure of test panels.

M-29826-F

Gluing

Gluing is a process as old as the woodworking art. Early glues for wood were of natural origin and generally lacked resistance to moisture and other severe exposure conditions. The development of synthetic-resin glues has resulted in more durable glue lines capable of withstanding outdoor exposures and the use of glued wood products in boats, aircraft, prefabricated housing, and laminated structural timbers for service in all parts of the world has expanded substantially.

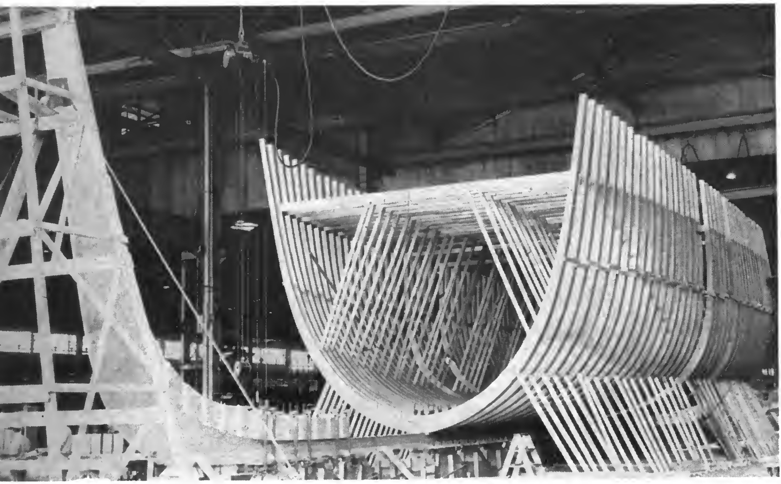
Problems involved in utilizing both the new resin glues and glues of natural origin effectively and with confidence have been largely resolved by continuous Laboratory research. As a result, commercial woods can now be glued to make joints that are stronger than the wood itself. Many tests involving long exposures to laboratory and service conditions have established the relative permanence of glue joints made with the various types of woodworking glues. The woodworking industry may now select with confidence the type of glue and the gluing process to be used for any purpose. This insures better products and more economical service for wood users and less waste of wood.

Recently, new types of glues have been introduced for gluing metals and plastics to wood. The establishment by Laboratory investigations of many of the limitations of these glues has opened the way to their wider use in fabricating composite wood products, and thus an expanded utilization of wood in conjunction with other materials.

Problems of great importance that still need investigation are the factors that affect adhesion and the nature of adhesion itself. Additional research is also needed to improve the fundamental nature of various glues and to make glues cheaper, easier to use, and more generally adaptable.

Laminated keel-stem and frames of a Navy minesweeper glued with moistureproof resin glues. Laboratory research has solved many of the problems of using these new glues effectively.

M-91328-F



Veneer and plywood

Plywood is a sheet panel material made by gluing together thicknesses of veneer or of veneer and lumber with the grain of successive layers usually at right angles. During recent years plywood has gained general acceptance as a desirable material for construction and fabrication, and its commercial production has increased greatly.

Current problems facing veneer and plywood producers are a growing shortage of suitable raw material and the need for manufacturing refinements to reduce waste and to improve the quality of the product. The Laboratory is investigating these problems by fabricating and testing plywood of species and types of logs not commercially used today, by observing the performance of plywood under various exposure conditions, and by developing and testing overlay materials that provide improved surface properties and cover defects in the wood.

Test material is made under closely controlled conditions in the veneer and plywood laboratory for use in various other research programs, such as strength testing, housing research, aircraft design studies, container research, and fire testing.

M-86641-F

Plywood research begins with the cutting of veneer from the log.

Wood Diseases

The infection of wood by staining or decay-causing fungi is investigated as a part of Forest Service research in tree and wood diseases. Fungus species and their growth conditions are investigated in order to develop more effective control during manufacture and use.

Wood-destroying fungi

The effects of wood-destroying fungi upon the structure and service life of wood are examined, and temperature and moisture conditions favorable and unfavorable to fungus growth are determined. The causes of decay in buildings and wood products are investigated. Rules of construction for the avoidance of decay have been developed, with consequent large savings to thousands of home owners.

Effectiveness of preservatives

Wood-preservative chemicals are evaluated by means of accelerated tests with typical wood-destroying and staining fungi grown in pure cultures. The results of studies of the adaptation of various chemicals for mechanical or hand-dipping treatments of freshly sawed lumber have been given wide commercial application in the prevention of sap stain during air drying.

Control of deterioration in storage

Heavy losses to users occur as a result of the storage of wood under improper conditions of drainage, ventilation, and exposure. Studies and recommendations are made, in cooperation with other divisions of the Laboratory, for improving storage of general lumber stocks at sawmills and retail yards and for the better storage of logs, pulpwood and pulp, box lumber, veneers, staves, vehicle parts, and other wood products.

M–91992–F

Inoculating a specimen for tests of the resistance of preservative-treated wood to a decay fungus.

Pulp and Paper

The purpose of the Laboratory's pulp and paper investigations is to increase the possibilities of more economical production, higher yield, and better pulp quality from our native woods, including those now little used or unused.

Each American now consumes more than 400 pounds of paper a year. Some 35,000,000 cords of wood[1] are needed yearly to make this tonnage of paper. This huge demand emphasizes the need for a broad domestic supply of fiber. Supplies of the preferred long-fibered species of wood, such as eastern spruce, fir, and hemlock, are waning, and for some time major changes in the source of raw materials have been taking place.

Utilization of hardwoods

Because the fiber industries seem to be a natural outlet for little-used species, low-grade wood, and wood waste, the Laboratory was among the first to investigate the possibilities of these materials for pulp and thus to contribute to the overall objectives of waste reduction and more complete utilization of our forests. For example, the Laboratory issued about 15 reports dealing with its research on the pulping of west coast Douglas-fir wood some years before this species began to be pulped in quantity.

Today, one of the most promising and abundant sources of additional raw material for pulp and paper is the hardwoods, which not many years ago were considered unsuitable for paper manufacture because of their short fibers. Slightly more than half of the second-growth timber throughout the United States is hardwood. In addition to the millions of cords of this material that might be removed in thinnings for pulpwood, many areas have hardwood species that might well be cleared off to make way for more useful hardwoods or softwoods.

The Laboratory has accomplished much toward increasing the utilization of hardwoods. In the middle 1920's it developed the so-called semichemical pulping process, in which wood chips are given a mild chemical treatment to loosen the fibers, followed by mechanical processing in some form of refining mill to separate the fibers entirely. This process returns high yields of pulp—in the neighborhood of 70 percent of the wood as against 50 percent for straight chemical pulping—not only from standard pulping species but from hardwoods and other less-used species as well.

The semichemical process is now firmly established alongside the older groundwood, soda, sulfate, and sulfite methods, its use is growing steadily, and many of its potentialities for diversification and expansion are yet to be realized. Currently about 800,000 tons of semichemical pulp are produced annually, practically all from hardwoods. Principal development of the semichemical pulping process to date has taken place in the production of corrugating board for containers, a high-tonnage product. On the basis of both commercial and experimental papers already produced

Wood is reduced to pulping size by use of a mechanical chipper.

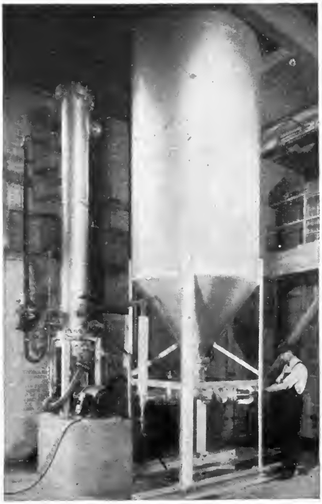
M–58855–F

[1] Includes nearly 3,000,000 cords of imported pulpwood and the wood equivalent of 2,400,000 tons of imported pulp and of 5,600,000 tons of imported paper and paperboard.

by the process, semichemical pulp, used alone or in mixture with other pulps, may soon be used for linerboards, newsprint, wallboards and roofing felts, coating papers, book papers, glassine, and bond papers.

Several years ago the Forest Products Laboratory announced the cold soda process, a new pulping method that promises even higher yields from hardwoods than the semichemical method. This process consists essentially in treating wood chips at room temperature and atmospheric pressure with caustic soda and then fiberizing the softened chips in a disk mill. As much as 90 percent of the wood is used, compared to about 50 percent under the older chemical processes. The process seems especially suited to production of hardwood pulps for corrugating boards.

Pulp of high chemical purity, or "dissolving pulp," is the raw material for rayon, cellophane, photographic film, plastics, smokeless powder, and many other less widely known wood products. The production of purified pulp has received considerable study at the Laboratory, with a view to improving the quality of the purified cellulose and to broadening the base of wood species from which the pulp can be made. The hardwoods, such as aspen, maple, gum, and birch, are among the promising woods for making purified pulp.



M–26174–F

Pulping experiments over a wide range of chemical concentrations and pressures are made possible by use of a digester lined with chrome-nickel.

On the way to the paper machine, the pulp, after bleaching, is further refined in the beater.

M–99207–F

Because of the very large tonnage of newsprint consumed by the United States and the fact that most newsprint is imported, the prospect of increasing domestic production has commanded special interest. Many years ago the Laboratory gave special attention to the production of newsprint from Southern woods, particularly pines, and the principles it recommended are those now used by the Southern newsprint industry. More recently the Laboratory has considered carefully the potentialities of hardwoods for use in newsprint and has conducted many experiments that show how paper of good newsprint quality can be made from them.

One of the largest consumers of fiber for paper is the shipping container industry.

The Laboratory's pulp and paper research, together with research on containers, has contributed much to the improvement of container boards and to the use of hardwoods and other little-used species in pulps for container stock. Fundamental studies of materials used in boxes showed that hardwood pulps give special properties to container board, which in turn stimulated the use of hardwoods for the purpose.

Another natural outlet for little-used wood, such as the hardwoods that can be reduced to fibrous form, is for hardboards and building boards. Decreasing supplies of good-quality lumber and logs for plywood and the distinct trend towards sheet materials in building have stimulated investigations of these products.

M-26040-F
The tensile test—one of many tests used in evaluating paper quality.

Improvement of pulp and paper manufacture

The more efficient utilization of woods of all species used for pulp requires progressive improvement of pulping processes. Studies of pulping processes of all types are carried on at the Laboratory constantly, and are showing the way to substantial increases in yields and improvement in pulp quality.

The utility of a given wood species for paper production is not determined by its pulping behavior alone, however, but by the possibilities of adapting the pulp to the varied requirements of papermaking. Therefore, in addition to work on pulping, Laboratory research is also intimately concerned with all the other manipulations involved in producing a final paper product—bleaching, beating, refining, papermachine operations, and finally the testing of the finished product and the salvaging of waste fiber and chemicals.

The Laboratory is equipped to evaluate promising processes on a pilot-plant basis, starting with wood and ending with the paper or paper product. Because the ultimate success of a pulp often depends on the behavior of the material in process, such

M-90788-F
An experimental Fourdrinier machine, with press and drier rolls and calender, transforms the pulp into finished paper. Operating elements are under precise control.

pilot-plant trials offer a convincing demonstration of the inherent advantages or problems involved.

New pulp and paper products

Further studies on woods and processes inevitably bring to light new products that broaden the usefulness of wood. An indication of the demand for more fibrous raw material for new pulp and paper products that may develop in the future is the use of paper in sanitary products, plastics, electrical products, frozen-food wrappings, milk bottles, and protective bags, already well established.

Papreg, a high-strength laminated paper plastic, was developed during World War II and found use as a substitute for metal in molded aircraft parts. This material has a tensile strength about three times as great as that of earlier paper plastics. It has potentialities as a highly durable flooring material and an experimental floor of papreg on a plywood base has been laid in the lobby of the Laboratory.

The advent of synthetic resins made it possible to produce papers for permanent structural use. The Laboratory pioneered such developments as a sandwich building panel with a paper honeycomb core. This panel proved to have good resistance to moisture and decay organisms, and research has also established manufacturing and structural requirements for this product. To evaluate the suitability of sandwich material for house panels, a test structure was built on the Laboratory premises some years ago and is available for inspection. Sandwich panels are coming into use in doors, partitions, furniture, and demountable buildings. Their use in houses seems only a question of time.

A related development in which pulp and paper desearch played an important part is the use of paper or plastic overlays on wood and plywood. One of the more promising objectives of this work from the Laboratory standpoint is the use of "masking-type" overlays of low resin content on the surface of veneer or plywood to yield panels with a uniformly textured and durable surface for painting. It is hoped that these papers can upgrade veneers and increase the area of usable veneer that can be obtained from a given log. These overlay papers are also being evaluated as overlays for house siding made from lower-grade wood.

The lobby floor of the Forest Products Laboratory is made of papreg, a high-strength laminated paper plastic developed through pulp and paper research.

M-92090-F

M-92089-F

Vigorous climatic conditions test the durability of this experimental unit made of sandwich panels.

How To Use the Laboratory

All the information that the Forest Products Laboratory has gained through years of research is available to the public. Every year thousands of inquiries are answered by letter and problems are discussed with those who come to the Laboratory seeking help on wood-utilization questions.

Where the problem presented is of such scope and difficulty as to warrant a cooperative research project, the work will be undertaken if consistent with the Laboratory's public objectives, under an advance agreement as to methods to be followed and the payment of costs. The Laboratory's guiding purpose in such studies is to secure facts that will promote the best use of wood. A pamphlet explaining this cooperative service more fully is obtainable on request.

Laboratory publications are available covering the main findings of its research work, and mailing lists are maintained for the distribution of current information in different fields of wood use. General visitors are conducted through the Laboratory at regular hours.

Inquiries should be addressed to the Director, Forest Products Laboratory, Madison, Wis.

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