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PLYWOOD VENEER AND LAYOUT OPERATIONS
AP-42 Section 10.3
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J. A. Leary and L. J. Mullins
Los Alamos Scientific Laboratory
University of California

PLYWOOD

Veneers 1/6 - 3/16"

Plywood is a material made by bonding layers of wood together with an adhesive. The layers are usually veneer, that is to say, no greater than 3/16 in. in thickness for hardwood plywood or 1/6 in. thickness for softwood plywood. The successive layers (plies) have their grains at a definite angle to each other, usually 90°. Usually, but not always, the number of layers is odd: The two outer layers therefore have their grain in the same direction, which is known as the grain of the plywood.

In addition to all-veneer plywood, there is a form in which veneer is attached to a lumber core, and a form in which veneer is attached to particleboard (see Wallboard).

The wood of many species of trees is used for plywood. The woods are divided into *hardwood* (from broad-leaf deciduous trees) and *softwood* (from conifers), the difference being based on botanic characteristics rather than actual hardness. The production of softwood plywood greatly exceeds that of hardwood plywood (see Tables 4–7) and is largely in the Pacific Northwest.

The following are the principal species of trees used in the manufacture of plywood:

Among the softwoods—Douglas fir, southern pine, hemlock, western red cedar, Noble fir, white fir, redwood, spruce.

Among the hardwoods—birch, maple, cherry, walnut, oak, poplar, gum, basswood, mahogany, lauan (a Philippine tree), beech, ash, hickory, elm, and a variety of foreign tropical exotic species.

Both softwood and hardwood plywood may be had in an *exterior grade* and an *interior grade.*

There are also special types such as counter front in which the grain of the face ply runs parallel to the short dimension, molded plywood, two-ply structural plywood, and two-ply decorative plywood. Two-ply, being an unbalanced construction, warps or curls badly and cannot be used for flat work. (An exception is a two-ply construction of a valuable, decorative wood and some soft hardwood such as basswood, the grains being parallel or nearly so.) However, two-ply is one of the best forms for building tubular structures since it starts to conform to a tube as soon as it is made.

A plywood panel can act as a structural sandwich (although not necessarily following strictly the definition that a sandwich has relatively thin, dense, high-strength faces on a relatively thick, weak, low-density core). So-called lumber-cored plywood comes closest to being a structural sandwich.

Properties

The principal mechanical properties of two three-ply plywoods are given in Table 1. It will be seen that plywood is anisotropic, but it is much less so than wood, which has very different properties with the grain, and across it. The number of plies has less effect than ply thickness and ply-thickness distribution. This complex variable is not subject to simple delineation (3).

Table 1. Mechanical Properties of Two Three-Ply Plywoods, Equal-Ply Construction (1,2)

Plywood	Modulus of elasticity, psi × 10^3	Tensile strength, psi	Shear strength, psi	45° Shear strength, psi
three-ply birch,				
along grain	2,260	13,210	1,840	3,425
across grain	197	7,700		
three-ply Douglas fir,				
along grain	1,530	6,180	1,150	3,160
across grain	126	3,910		

It must always be remembered that the properties of all plywood are dependent on the species of wood used. Table 1 refers to birch and to Douglas fir; for other species of wood, use can be made of the data in reference 4.

Warp. Workers in wood accept warp as a fact of life, apt to happen at any time. All lumber is capable of warping since there is no such thing as isotropic wood. However, well-made plywood will not warp. Plywood can be a balanced construction and, if alternate plies have grain directions at 90° to each other and the species and thickness are symmetrical with respect to the center of the panel, the panel must be inherently flat in the resting condition. This is not true of lumber.

The warp or absence of it which we are discussing here may be said to be the normal configuration of the panel or plank. There is another kind of warp which is a temporary distortion due to unequal moisture contents of opposite faces, or face and back. This warp persists only so long as there is a disturbance of the equilibrium and automatically corrects itself when equilibrium is re-established. This is not a true warp. A test of the presence or absence of true warp is achieved by reversing the distorting conditions. An inherently flat panel will distort symmetrically. In other

words, if the difference in moisture content between the face A and face B is such as to make face A cup ½ in. in 8 ft and the conditions are then reversed, face B will cup ½ in. in 8 ft. Lumber will also experience this type of distortion or warp if one side is made wetter than the other but it generally will not distort symmetrically.

Dimensional Stability. Because lumber is anisotropic, it is much weaker across the grain than with the grain and it expands and contracts in this direction with changes in moisture content much more than it does along the grain. Since plywood is cross-banded, the strength across the grain of one ply restrains the one above and below it with the result that plywood is much more nearly dimensionally stable than lumber. About 75% of the dimensional instability of lumber across the grain resulting from changes in moisture content is eliminated.

The *split resistance* of plywood, which is far higher than that of lumber with grain, stems from this same cross-grain construction. It can be easily tested with a hatchet.

The strength–weight ratio of wood is extremely high, and that of plywood still substantial (see Table 2). The loss in this factor is the price we pay for gains in isotropism.

Table 2. Comparison of Strength–Weight Ratios of Plywood and Metal

Material	Plies	Tensile strength, psi	Specific gravity	Strength–weight ratio psi/(g/ml)	Strength–weight ratio relative
Douglas fir plywood	3	6,180	0.48	12,800	0.65
birch plywood	3	13,210	0.67	19,600	1.00
Bessemer steel		60,000	7.79	7,730	0.39
10,000 lb test aluminum		40,500	2.81	14,400	0.73

The *stiffness* of plywood is high and it is gained without an excessive weight penalty. Remembering that stiffness varies as the cube of the thickness, the way to increased stiffness in any material is to increase thickness. Often, as in steel and even in aluminum, the thick sections necessary for high stiffness weigh so much as to be impractical. Table 3 shows that Douglas fir is 82% as stiff as aluminum on a comparable weight basis for ⅜ in.-thick panels and 76% as stiff as steel. What is more important from a practical standpoint is simply the weight of a panel. Three-quarter-inch plywood is a common commodity but one can visualize the unmanageable weight of a ¾ in.-thick panel of steel of any size.

Advantage is taken of this phenomenon by cladding plywood with metal. The high tensile strength of metal is thus utilized without weight penalty by gaining thickness with lightweight plywood used as a core.

Fatigue and Impact Resistance. Tests to date indicate that wood, a fibrous

Table 3. Comparison of Stiffness–Weight Ratios of Plywood and Metal

Material	Stiffness, ⅜ in. thick, psi × 10^4	Specific gravity	Stiffness–weight ratio absolute	Stiffness–weight ratio relative
Douglas-fir plywood	7.38	0.48	15.4	0.76
birch plywood	10.42	0.67	15.6	0.77
steel	158.1	7.79	20.3	1.00
aluminum	52.0	2.81	18.8	0.83

material, is less sensitive to repeated loads than are more crystalline structural materials such as metals. Endurance limits are likely to be higher in proportion to the ultimate strength values for wood than for some of the metals.

Tests in fatigue and tension parallel to the grain indicate for plywood an endurance load, for 30 million cycles of stress, of about 40% of the strength of air-dry wood.

Tests of small cantilever bending specimens of air-dried solid wood and plywood subjected to fully reversed bending stresses indicate an endurance limit, for 30 million cycles of stress, of about 30% of the modulus of rupture of the specimens. Thus, the behavior of plywood is the equivalent of the behavior of the species of which it is made, since the performance of the glued specimen is at least equal to the performance of the wood itself (4).

Impact resistance as measured in height of fall of a 50-lb hammer required to induce complete failure for yellow birch is 55 in. For Douglas fir, it is 31 in. (4). Comparable data on other materials of construction have not been run but it can be seen that these figures are high.

A significant property of wood is its *toughness* and while there is no general agreement as to the exact nature of toughness, reference 4 gives some interesting values. Toughness for yellow birch, tangentially, is 330 in.-lb; for Douglas fir it is 200 in.-lb.

There is some *plasticity* in wood and because of plywood's split resistance, bent structures can be made either by molding or gluing to contour, by heat bending, or by making special constructions.

Action in a Fire. Although wood and plywood will, of course, burn, they nevertheless have some properties that are favorable in case of a fire. Though wood is slightly plastic, it is not thermoplastic in the sense that it softens very much under heat, so that it maintains its rigidity at high temperatures such as occur in a fire. It tends to char and the char slows down the rate of destruction. Thus, plywood, if made with an adhesive not easily damaged by fire, will be consumed very slowly and will not yield and collapse until almost burnt through.

Action at Very Low Temperatures. This is somewhat unusual in that plywood does not delaminate but becomes stiffer as the temperature drops without becoming appreciably more brittle.

Weathering. The weathering of a plywood depends greatly upon species. There are woods not at all durable outdoors and plywood made from them would be no better. There are other woods which weather very slowly even without finish, so that the designer has some control over resistance to weathering.

Biological Deterioration. Deterioration often is related to weathering but deterioration may also be due to biological influences, and the susceptibility of plywood is the susceptibility of the species of the plies from which it is made, assuming the adhesive itself is resistant. For severe uses, regardless of the exposure, exterior grades should always be chosen.

Chemical Properties. The most interesting chemical property of wood which affects the use of the adhesive, its choice, and its durability is that wood is an inherent buffer. It has the capability of maintaining pH between 4.5 and 8, which is the optimum and, in this range, it shows little deterioration with age. The acid resistance of wood (pH below 4) is substantially less than the alkali resistance. Nevertheless, it is high enough for the lids for tanks to be made of plywood and for fume ducts to be often lined with plywood, since it does not rust or corrode. These are best engineered as replacement materials rather than on the basis that they should last for the life of

the equipment. The cost, when compared to that of other structural materials of adequate resistance, is low enough to permit periodic replacement.

Under alkaline exposure wood is much better, and while strong alkalies will soften and slowly deteriorate the wood, especially at elevated temperatures, the periodic replacement will be at much greater intervals. One particular advantage of the inherent buffer action is that wood exposed either to acid or alkali which is relatively dilute will give extremely long service provided the wood is never allowed to dry out so that the acid or alkali can concentrate. It is often the alternate wetting and drying that causes the principal destruction.

The salt resistance of plywood is remarkable. Exterior-grade plywood, being bonded with an alkali-catalyzed phenol–formaldehyde resin, is not attacked at all by most inorganic salts or by salt water. Concentrated salts tend to stiffen the wood by extracting moisture but, except for the oxidizing or extremely acid salts, do not harm the plywood. This lack of corrosion or rusting is a valuable property.

Manufacturing Process

The process of making plywood varies to some extent, depending on the types and size of logs available and the type of product manufactured. The largest difference exists between the operations in the Pacific Northwest (Washington, Oregon, and Northern California) as compared to those of the rest of the country. This is partly, but not entirely, a difference between softwood and hardwood operations. The Pacific Coast mills peel logs that are up to and somewhat over six feet in diameter but those six feet and over require special equipment. Most of the rest of the country, including the newer Southern Pine mills, uses logs considerably smaller in diameter. Large-diameter hardwood logs no longer exist to any practical degree. Hardwood and softwood operations differ in degree rather than in kind.

The logs are first sawed to the required length. In the Pacific Northwest, the logs are generally cut to produce panels eight or ten feet in length. To a limited extent, cuttings for hardwood are the same except that ten-foot lengths of decorative grades are sufficiently scarce to command a substantial premium. Lengths as short as three feet are cut for cross-bands.

The bark is next removed from the log. The methods vary from hand debarking to the use of mechanical and hydraulic debarkers. The logs may or may not be steamed, depending on species.

Cutting. The cutting operations depend on the type of veneer to be produced. In the production of decorative veneer, almost exclusively from hardwoods, *rotary peeling* is the most common. A knife, equal in length to the width of the veneer, produces a more or less continuous sheet of veneer of uniform thickness in a manner similar to the unwinding of a roll of paper. The knife is parallel to the axis of the log, and a peculiar, wavy grain pattern is produced. In *cone cutting* the knife is at an angle, so that the operation resembles the sharpening of a pencil. A beautiful grain design is produced, but the veneer is brittle and short fibered, making it difficult to handle, so that the method is not often used.

In hardwood-plywood cutting for decorative grades, except for those that are mass-produced, methods are used to accentuate grain design and enhance the beauty of the unusual patterns in knots, burls, and crotches, but there is a limit because of the difficulty of producing plywood from the special cuts, and production is therefore

highly customized. Just about all softwood species are rotary peeled, although so-called vertical grain fir and spruce, which are quite attractive, can occasionally be purchased on order.

In rotary peeling the thickness of the sheet usually is in the range of 1/45 in. to 1/5 in. Veneers greater than 1/5 in. in thickness are occasionally sawn but production is very minor. Specialty veneers, 1/85 in. thick, are mounted on fabric and hung like wallpaper rather than made into plywood. Thickness variations are, of course, controlled by the setting of the lathe. Speed of rotation depends upon species.

The nonuniform character of wood does not permit the production of uniform veneer by any method of cutting. The large defects and unusable sections are clipped out. Length is determined by the length of the bolt cut from the log and not by clipping. Generally, face and centers are cut on one lathe and cross-bands on another. Some very fine decorative veneers are often book-matched in making a panel, which means every other piece is turned over, and, for some of the best custom work, sequence matching in which all of the veneer on one log, known as a flitch, is utilized in making panels which are then installed in sequence just as they came from the log. Such veneer, of course, must be sliced rather than rotary peeled, otherwise the effect is lost. Such a procedure as this is done with a few softwood veneers, notably sliced pine.

The veneer of hardwood species is generally sorted to separate heart and sapwood. This is also true of Douglas-fir production. Hardwood sapwood does not have the normal color expected of the species. Therefore, sapwood in a panel must have separate staining treatment to make the appearance uniform. Better grades are thus separated completely; less expensive panels allow sapwood in the panel and spot staining on the prefinishing line is necessary.

Drying. The type of veneer frequently determines the method of drying and the equipment used. Thus, highly figured decorative veneers may be air-dried or loft-dried in heated rooms, later to be plate-dried in special quick-acting hot presses to remove air-dry cockles (defects). The more common method for heavier veneers is to dry in specially designed veneer dryers. These are long (25 to 300 ft) tunnel-type driers often having multiple tiers (up to six or eight). The veneer is moved continuously on rolls or belts along each tier. The drying time is controlled by the speed of the belts. The big problem is moisture equalization, and substantial amounts of veneer are often overdried in order to make sure that the wetter portions are adequately dried. A great deal of study is going into this operation as it affects both the economics and the gluing problem. In Douglas fir, drying may be as long as 10 min for 1/8 in. stock and 15 min for 1/6 in. material. The operating temperature ranges from 330 to 360°F, being generally highest at the wet end, or entrance, of the dryers. In hardwood mills, drying temperatures are substantially lower, although still above the boiling point of water. Sudden violent shrinkage can disrupt some of the delicate patterns and make subsequent veneer handling difficult. In hardwood plywood, the desirable moisture content after drying will depend upon the adhesive used. In general, it is 3–6% for aqueous glues and 8–12% for film glues (very thin sheets of paper impregnated with phenol–formaldehyde resin).

moisture after drying

Sorting and Patching. The veneers are next sorted into various grades. Since veneer suitable for faces is relatively scarce and, consequently, most valuable, every possible method is used to produce the maximum amount of this grade. Sheets smaller than the full panel size are taped or edge-glued together to produce the required size. In the case of decorative veneer, this taping or edge-gluing may be done in such a way

as to produce matched or contrasted grain designs as mentioned above. Veneers with small defects are patched and used in faces in certain utilitarian types of plywood. The veneer not suitable for faces is graded for use as back, cross-band, or center. These grades are patched or unpatched, depending on the specification of the particular panel being produced. Patching is the operation of removing a defective area by routing or punching and replacing it with a patch of sound wood of exactly the same size.

Assembling. The aqueous adhesives are applied by means of machines called glue spreaders which have a series of rubber-covered grooved application rolls that apply the glue to the sheet of veneer. The number of grooves per linear inch (of the length of the roll), their depth, and the viscosity of the aqueous adhesive control the amount of material applied per unit area. The general practice is to spread the adhesive on two sides of one ply and place it between two plies of unspread veneer in the panel assembly. The amount of adhesive used, called the spread, is usually expressed as the weight of liquid adhesive per thousand square feet of glueline for hardwood species and per thousand square feet of double glueline for softwood species.

The method of assembling veneers prior to pressing the plywood, taking a five-ply construction as an example, is as follows:

A back, which will have its grain direction parallel to the long axis of the plywood panel, is placed on the assembly table. The next veneer will be a cross-band carrying adhesive spread on both surfaces. The cross-band has its grain direction perpendicular to that of the back. Next comes the center in which the grain is perpendicular to the cross-band and parallel to the back. Above this, comes a cross-band with adhesive spread on both sides and finally, the top or face which, of course, like the back, has its grain direction parallel to the long axis of the plywood panel. Thus, the construction of this panel may be a $\frac{1}{8}$ in. center, two $\frac{1}{8}$ in. cross-bands, and a face and back each $\frac{1}{10}$ in. thick. Note, however, that the construction must be symmetrical; each layer, except the middle, must have a corresponding layer on the other side of the same thickness and same grain direction. Failure to have this symmetrical or balanced construction leads to excessive warpage. It should also be noted that the plies need not all be of the same thickness. The only requirement is that the construction be symmetrical about the neutral axis which lies in the plane of the panel, in other words, the center. The construction of a plywood will affect its properties somewhat although the effect of species predominates. The construction will, of course, affect its cost.

Press Curing. The laid-up assembly of veneers is transformed into plywood by bringing all faying (close fitting) surfaces into intimate contact with each other. This is done either by cold pressing or hot pressing.

Cold-press curing of adhesives in the manufacture of plywood accounts for a relatively small portion of present-day production. Electric screw presses are commonly used especially in the furniture plywood industry. These cold presses, or baling presses, are used to compact the load of veneer assemblies, after which tie rods adjustable by turn buckles and I beams, arranged opposite each other, top and bottom, maintain the pressure on the bale until setting is accomplished. Depending on the adhesive, this may vary from four to twenty-four hours but is generally considered to be an overnight operation.

By far the largest production is in a hot press in which thermosetting resins are the adhesive basis. The hot presses are hydraulic, and generally steam heated, so that the minimum temperature is 235°F.

Hot platen presses for hardwood plywood will have from five to sixteen openings. For softwood plywood, presses up to thirty openings are used. The minimum press size of any consequence is 3 ft by 7 ft. The maximum, except for special cases, is 5 ft by 12 ft.

Temperature in the manufacture of softwood plywood is generally about 280°F and the press time in the range of 5–7 min, or more for greater thicknesses. In the case of hardwood plywood, temperatures will vary from 235 to 290°F, with press times from 5 to 10 min. In furniture plywood manufacture 180°F is often used, in which case hot-water-heated presses are used. Press pressures depend on species. They are generally chosen so as to bring about compaction (all plies brought into intimate contact) and, above that, 4% compression.

In softwood-plywood manufacture, the practice of hot stacking is common. Hot stacking, out of the press, retains the heat which has been imparted to the panel and cure of the adhesive proceeds in the stack. This is a substantial effect and shortens the required time in the hot press appreciably. Since, in a well-designed plant, the hot press is the natural bottleneck, it is economic wisdom to keep the press periods as short as possible.

TRIM + SANDING

After press curing, the plywood is trimmed to proper size and sanded to desired thickness except in the case of very popular rough-textured panels for siding or structural applications. Any defects that are discovered in inspection are repaired. Patching is done if necessary and the panels are inspected and graded.

Adhesives. By a large margin, the great bulk of adhesives used in the manufacture of plywood are based on either phenol–formaldehyde or urea–formaldehyde resins. A small and growing amount of melamine–formaldehyde resin is used for severe exposure where the phenol–formaldehyde color is objectionable. Resorcinol–formaldehyde and phenol–resorcinol–formaldehyde resins are used in patching and in scarfing to make panels of extra size. Melamine resins are the most costly of the major types, if we eliminate resorcinol–formaldehyde. Phenolics are next and ureas, least. Phenolic resin adhesives generally darken in color and may stain if they bleed through the face veneer. Melamine and urea adhesives do not. Hybrid adhesives, known as melamine–urea–formaldehyde adhesives, are a compromise in both quality and cost and are being used in hardwood interior grade plywood of the better grades.

Other adhesives once used in some volume but in steadily decreasing amounts are vegetable based such as soya-bean protein glues. Blood-albumen adhesives are used in some volume in softwood-plywood manufacture with or without soya protein as an extender. However, soya protein combinations are subject to mildew and bacterial deterioration and mixtures of blood albumen and phenol–formaldehyde resin are a means of obtaining better quality with little increase in cost. The blood albumen has the property of quick setting in the hot press and the slower phenol–formaldehyde resin finishes its cure in the hot stack. The quick set of the blood albumen is particularly helpful in keeping the time in the press short.

For hardwood interior the commonest adhesive is urea–formaldehyde although both melamine–formaldehyde and phenol–formaldehyde are used under certain conditions such as hardwood doors for exterior openings, interior marine work which is considered a severe exposure, and fire-resistant panels. Softwood exterior is almost exclusively made with phenol–formaldehyde adhesives. Softwood interior is made with phenol–formaldehyde adhesives, blood albumen, soya protein, and mixtures of the two with and without phenol–formaldehyde adhesives and occasionally, urea–formaldehyde adhesives.

Certain synthetic resins have the property of forming chemical bonds with the wood fiber (5). See Adhesives. Thus, the aim in bonding of all plywood is that the bond should be stronger than the wood itself. While certain materials such as hide glue can meet this requirement on a dry basis, plywood must also be water resistant, if not waterproof, and this requires resins of a thermosetting type which, after curing, are no longer soluble or fusible. Thus, permanency is achieved. The choice of adhesives for plywood otherwise has largely developed on the basis of volume availability and economics.

Finishing and Treatments. Historically, the plywood industry has been just that—the manufacture and distribution of plywood. Others finished the material, if the end use required it, and still others treated the plywood for various special properties. While this is to some extent still true, increasing amounts of plywood manufactured nowadays are, at least in part, prefinished and often given special treatments. A great deal of hardwood plywood is completely prefinished as it leaves the plywood factory. Note here, the terms "finishing" and "prefinishing." The finishing room in a plywood plant is that room which does trimming, the final sanding, patching if necessary, and general clean-up. When the industry began to put finishing materials on the finished panels, they found it necessary to coin a term to distinguish the two final operations. Thus, the term "prefinishing" means applying finishes at the mill as opposed to field application. This leads to the anomalous situation that, in a plywood factory, "finishing" is *followed* by "prefinishing."

Interior use almost always involves clear, or natural, finishes which may be over the usual fillers, toners, and stains. In other words, good furniture finishing practice is extended to the prefinishing of hardwood plywood. The two most common types are cellulose nitrate lacquers and conversion varnishes.

Application is done on prefinishing lines containing the necessary elements of automatic machinery. Materials may be applied by airless spray, curtain coater, or some form of roller coater. Wiping, if necessary, is accomplished by rotary brushes: rubbing and polishing by various abrasive methods, but all with automatic machinery. Finishes are dried, or cured, in either convection ovens or infrared ovens, and occasionally combinations. So-called jet-zone drying is a common combination of high-velocity air with infrared ovens.

Exterior finishes, on the other hand, are mostly opaque or, at best, translucent. The translucent finishes are the various shingle stains used for textured forms of plywood siding. They consist of durable pigment dispersions in various oil vehicles but without fillers, and the pigmentation, or pigment volume concentration, is low enough for the wood to show through.

Opaque prefinishing in volume production has been limited to prepriming. The topcoat is applied in the field after the plywood is installed. One notable exception to this is the overlaying of plywood siding with pigmented films of poly(vinyl fluoride) having, as far as is known, unlimited durability.

Completing the finish in the field is generally done with high-grade housepaints in the usual manner. If the panels are completely prefinished at the mill, the most successful types presently are based on oil-modified alkyd resins although the new acrylic latexes are catching up fast because of the porosity which discourages blistering.

Treatments vary from overlaying the plywood to impregnation. Overlays can be structural or decorative or may be simply means for improving the plywood surface to receive and retain paint. Overlays, most commonly, are some form of plastic or com-

bination of plastic resin and paper. Three rather arbitrary divisions are medium-density, high-density, and decorative high-pressure plastic overlays. A large-volume use is superior-grade, concrete-formboards made out of plywood overlaid with high-density overlay. Such a construction yields smoother concrete and the panels last longer.

Impregnation. Some plywood is impregnated. The only limitation this places on the construction of the plywood is that the glue must be capable of withstanding the effect of impregnation and a very few species which are not easily impregnated must be avoided. The impregnation of plywood follows closely the art of the impregnation of wood. A great deal has been written in this field but there is no single adequate text which covers the subject. See also Wood.

Impregnation is always for the purpose of achieving some special effect, such as to increase the dimensional stability, for decoration, for fire resistance, for decay resistance, for greater hardness, for special color effects, and even for forming finishes in situ.

Impregnation to increase dimensional stabilization is almost exclusively developed around the use of very low molecular weight, water-soluble phenol–formaldehyde resins which have the peculiar property of being able to diffuse through the cell walls and react to reduce the natural hygroscopicity of wood. Certain water solutions of polyethylene glycols which cannot be cured will also give dimensional stabilization but their principal purpose is to prevent end checking in heavy lumber sections and they have not been of particular value to plywood.

Fire resistance is achieved by a variety of inorganic salts, the most common ones being the ammonium phosphates and ammonium sulfate. Lesser portions of other inorganic salts are added such as borax, boric acid, zinc chloride, and potassium chromate for special effects such as reduction of hygroscopicity, increased resistance to leaching, and control of afterglow. See also Fire-resistant textiles.

Decay resistance is achieved by certain toxic agents such as pentachlorophenol and the lower chlorinated phenols, copper compounds, metallic salts of naphthenic acids, and arsenic compounds. See Fungicides.

Impregnation to achieve color effects is an old art which has never achieved a great deal of success but does have some promise in the staining of sapwood to make it more uniform with the normal color of heartwood. The dye solutions that have been used up to the present are vulnerable to fading, but the art may become more successful as some of the more durable coloring substances become available.

Contrary to certain unfortunate publicity, urea–formaldehyde resins are not reliable wood impregnants although great claims were made for the use of them to improve hardness. A new science has sprung up involving the rapid cure of monomers capable of free radical polymerization to useful resins when placed in the field of a linear accelerator or radiation from cobalt-60. This appears to be a real solution to the wood hardness problem if the economics can ultimately be solved. The original purpose was to achieve a superior finish but when it was found that these monomers could be impregnated into the wood, the resulting hardness increased interest in the phenomenon. Actually, both hardness increases and surface finishes can be achieved simultaneously, although to achieve a good surface appearance requires some skill.

A great deal has been published on the various methods of impregnation and among the most prolific and accurate sources of such information are the publications of the Forest Products Laboratory, United States Department of Agriculture, Forest Service, Madison, Wisconsin.

Production Volume for the United States

Tables 4–7 give the latest available figures for the production of softwood plywood and hardwood plywood in the United States. Certain approximations have been made in arriving at these estimates, particularly for hardwood plywood. It should be remembered that hardwood plywood is generally for interior use only.

Table 4. Softwood-Plywood Production Figures[a]

Year	Footage, 3/8 in. basis
1950	3,000,000,000
1955	5,000,000,000
1960	8,000,000,000
1962	9,000,000,000
1963	10,000,000,000
1964	11,000,000,000
1965	12,000,000,000
1966	12,000,000,000

[a] Reported on the basis of 3/8 in. thickness. Thus, 1000 sq ft of 1/4 in. thickness plywood is equivalent to 667 sq ft on 3/8 in. basis and 1000 sq ft of 3/4 in. is equivalent to 2000 sq ft on 3/8 in. basis.

Table 5. Hardwood-Plywood Production Figures[a]

Year	Footage, 1/4 in. basis
1960	1,800,000,000
1962	2,000,000,000
1963	2,200,000,000
1964	2,500,000,000
1965	2,700,000,000
1966	2,700,000,000

[a] Calculated in a similar way to 1/4 in. basis.

Table 6. Adhesive Consumption in Softwood Plywood in 1966,[a] tons

glue for exterior grade (mixed)	150,000
glue for interior grade (mixed)	360,000

[a] Glue consumption is calculated from plywood production figures.

Table 7. Adhesive Consumption in Hardwood Plywood in 1966, tons

urea–formaldehyde glues (mixed)	45,000
melamine–urea–formaldehyde glues (mixed)	15,000

Uses

The uses of plywood depend largely on the adhesive involved, though cost, strength, and appearance must also be considered. Some common uses are sheathing, roof-decking, concrete-formboards, house sidings and soffits, floors and diaphragms, containers, and of course, the all-important use as a decorative element.

Decorative forms, of course, depend on species, and are controlled by taste. They are, except for marine decorative grades, generally made in interior types. Floors and diaphragms, and occasionally sheathing, are made in interior grade but the rest must be exterior as must all marine grades.

A relatively new use of plywood is as a core. For example, Douglas-fir plywood, the workhorse of the industry, is very strong and very lightweight. Decorative veneers of the beautiful hardwoods can be glued to the face and back of the Douglas-fir plywood. The result is still plywood but a structural grade has been turned into a decorative and structural grade.

Strength and economics are the most important factors governing the use of plywood. Also important is the great variety available. For example, some woods are so rare that one could not afford to build panels for furniture from lumber of that species. Veneers, on the other hand, can be cut as thin as 1/85 in., often 1/35 in., or 1/45 in., and used as facing over less valuable wood, to conserve priceless species and configurations. Thus, our limited, desirable hardwood species supply is greatly extended by turning it into plywood.

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