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SYNTHETIC-RESIN GLUES

Abstract

Summarizes the general properties and use characteristics of each of the principal types of synthetic-resin woodworking glues. It also reviews the gluing process used with these glues.

SYNTHETIC–RESIN GLUES[1]

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The term “synthetic resin” was first used to describe synthetic chemical compounds that resembled natural resins in their general appearance. As more synthetic resins were developed, the term came to include many products bearing little, if any, resemblance to the natural resins. At present, it is applied to a wide and heterogeneous group of materials with many uses, all the products of the modern chemical industry. Often the term “synthetic” is omitted, and these glues are merely referred to as resin glues.

Several synthetic resins have found widespread application as woodworking glues. Each type of synthetic–resin glue develops approximately the same initial dry strength when used under the proper conditions. Each is capable of producing joints that are as strong as the wood itself of various species. The principal advantages, therefore, of some of the resin glues are the high degree of durability that they can impart to the joint when properly used, their adaptability to high–volume production, and, in some cases, favorable cost. Their high durability has permitted the use of these glues in production of glued products for much more severe service than was possible with the older nonresin glues. Plywood for buildings, signs, railroad cars, and other exterior uses, laminated ship keels and frames, and other laminated members for use under severe service conditions, wood aircraft, and prefabricated house panels assembled with resin glues are among the many products whose manufacture has been facilitated or whose performance has been improved through the application of synthetic–resin glues.

Nearly all of the important synthetic–resin woodworking glues now in use develop their strength and durability in joints by undergoing a chemical reaction

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

called curing: the rate of curing, like that of all chemical reactions, is dependent on the temperature of the glueline, Raising the glueline temperature speeds the rate of curing and of strength development. This has been a valuable aid in adapting gluing processes to high-speed production techniques, such as use of steam-heated platens and of high-frequency heating circuits.

Classification of Synthetic-Resin Glues

Synthetic resins are usually divided into two general groups, thermoplastic and thermosetting. The thermoplastic resins never harden permanently, but soften or melt when the temperature is raised and harden again when cooled. This reversible hardening process involves no actual chemical reaction. The thermosetting resins, however, undergo irreversible chemical reactions either at room temperature or at elevated temperatures to develop their strength and durability. After this reaction has occurred, the resin cannot be dissolved or melted again without degrading the resin. These two types will be discussed separately,

The resins in both of these general groups are further classified according to their composition, to the range of temperature required to set them, and as to whether fortifiers or extenders are ingredients. The more important synthetic-resin glues are usually classified as follows:

Thermosetting Resin Glues

Phenol-formaldehyde: Include high-temperature-setting (or hot-press), intermediate-temperature-setting, modified, and extended phenol-resin glues,

Resorcinol-formaldehyde: Include primarily room-temperature-setting glues.

Urea-formaldehyde: Include hot-press, room-temperature-setting, fortified, and extended urea-resin glues.

Melamine-formaldehyde: Include hot-press and intermediate-temperature-setting melamine-resin glues.

Thermop1astic-Resin Glues

The only important group of thermoplastic resin glues used in woodworking at present are the water emulsions of polyvinyl acetate and other similar thermoplastic resins. Since the actual composition of these emulsions is not disclosed by the glue manufacturers, they are often referred to as polyvinyl-resin emulsion glues, and they will be so considered in this report. Thermoplastic resins such as polyvinyl acetate, polyvinyl formal, or polyvinyl butyral are often used along with other thermosetting resins in formulating special adhesives for bonding metals or plastics to wood.

In regard to the foregoing classification, it should be pointed out that the composition of many adhesives therein is not fully indicated by the names in common usage. For example, some glues of the phenol-formaldehyde type may contain cresol or an aldehyde other than formaldehyde; also, some phenol may be present in glues designated as resorcinol; and resorcinol may be present in glues designated as phenol. The thermosetting resin glues are usually spoken of simply as phenols, ureas, resorcinols, or melamines, with formaldehyde common to all.

A number of synthetic-resin glues have been developed for bonding wood and wood products to metal, plastics, and other materials. The composition of these adhesives is rather complex, being generally combinations of thermosetting and thermoplastic resins with various additives incorporated for special properties required.

Characteristics Common to All Synthetic-Resin Glues

Synthetic-resin glues may consist of a single resin dissolved or dispersed in water or other solvent. However, many of these glues may also include fillers to control penetration or spreadability, extenders to reduce glueline costs, or catalysts and hardeners to control the rate of chemical curing reaction. Some glues may involve combinations of two or more resins.

Manufacture and composition.--Synthetic-resinglues may be supplied to the user as liquids, powders, or in film form. The resins themselves are produced by controlled chemical reaction of the necessary reagents, such as phenol and formaldehyde or urea and formaldehyde, under the proper conditions of temperature and time, and in the presence of the necessary solvent and catalysts. The reaction is stopped when it has reached the desired stage, and the intermediate product, usually an aqueous solution, may be spray-dried, concentrated to a viscous sirup, or used to impregnate paper. The resultant products are marketed in powder, solution, or film form.

The glue user takes these materials, prepares them for use according to the manufacturer's instructions, which may involve dissolving the resin in water or other recommended solvents, or adding the stated amounts of other components supplied separately. The prepared mixture is then applied to the wood much as with the earlier nonresin glues. After pressure is applied to the joint, the final chemical curing reaction then takes place by the action of an agent added to the glue in mixing or by the application of heat to the glueline, or by both means.

Because of the chemical nature of the resin glues, the glue manufacturer can formulate a variety of glues from one basic resin to provide the desired working properties to meet the plant requirements of the user. This is accomplished by incorporation of different additives to the resin, either by the manufacturer or by the user according to the manufacturer's recommendations.

The manufacture of the resins themselves requires a knowledge of chemical technology and use of special equipment. Thus it is not generally feasible for the glue user to attempt to make his own resin glues, The glue manufacturer is also generally in the best position to reformulate his resin glues for special requirements of the user. The prospective user should therefore supply details on his production operation to the glue supplier when ordering glue for a given purpose.

A special terminology and some factors characteristic of resin glues are discussed in the following section.

Hardeners.––Hardeners, often called catalysts and sometimes curing or setting agents, are the agents that produce the final chemical curing reaction needed to harden the glue in the joint. They thus develop the desired joint strength and durability. These agents may be present in the resin as supplied, or they may be furnished separately for addition by the user before use. The term hardener is more general than catalyst and covers both the true catalysts, which increase the rate of the curing reaction without themselves being consumed, and the setting agents, which are actually reactants in the final curing reaction.

Acids and acid–producing substances are commonly used as catalysts for increasing the curing speed for urea–resin glues. Either acids or alkalies are used for catalysts with phenol–resin glues, depending upon the type of resin Melamine–resin glues, on the other hand, are cured in a nearly neutral state, Alkalies are sometimes used as catalysts for resorcinol–resin glues. Resorcinol–resin and phenol–resorcinol resins are so reactive that if all the necessary reactants were present in storage, their usable life as liquid glues would be excessively short. For this reason, the resin manufacturer commonly prepares his resorcinol or phenol–resorcinol resin with a considerable deficiency of formaldehyde and then provides the additional formaldehyde separately as formalin solution or paraformaldehyde, so that the user can add it just before use. Such a formaldehyde product, added for this purpose, is more properly a curing agent or hardener than a catalyst. Many resin glues, with catalysts added by the manufacturer, do not require additional catalysts. Because these catalysts and hardeners are so important to the final curing reaction, which affects both the strength and durability of the glue joint, it is very important that the glue user should always use the proper agent supplied with the resin and mix it in the recommended amount.

Fillers and extenders.--Fillers are generally rather inert materials, having little or no adhesive value themselves, that are added to the glues in rather small proportions, primarily to improve spreadability or to control penetration of the glue into the wood. Examples are English walnut-shell flour and other nutshell flours. Typical proportions for fillers are 10 to 20 percent by weight of the dry resin solids. Extenders, on the other hand, are low-cost materials usually added in rather large proportions primarily to reduce glueline costs. The most common extender at present is wheat flour added to urea-resin glues to reduce cost in plywood manufacturing. Rye flour and other cereal flours have also been used for this purpose. Douglas-fir bark, wood-hydrolysis residues, lignin, dry soluble blood, and other natural products have been used as extenders for phenol- and urea-resin glues. Typical extensions are from 50 to 150 percent by weight of resin solids.

Solvents.--Solvents are incorporated by the manufacturer in glues marketed in liquid form, or they are added during the mixing of those marketed as powders. Water is the most common solvent used. Some thermosetting resin glues, such as phenol resins, are supplied in alcohol solution; otherwise, the dry resin must be dissolved in alcohol or a water-alcohol mixture to prepare it for use.

Fortifiers.--Fortifiers are used primarily to increase the boil resistance and durability of hot-setting urea resins. Fortifiers in common use for this purpose are melamine resin and resorcinol. They may be incorporated in the resin when received or may be supplied separately for addition to the resin by the user.

Pigments and dyes.--Small amounts of pigments or dyes are sometimes added to resin glues for their identification or for easier inspection during the spreading operation.

The Gluing Process With Synthetic–Resin Glues

Regardless of the type of glue, the quality of the glued joint will depend both on the quality of the glue used and on the control of the gluing conditions used. The production of high–quality glue joints in wood products, therefore, requires the full recognition and control of all factors that may affect joint quality. This recognition is as necessary with synthetic–resin glues as with the older glues of animal and vegetable origin. In general, the gluing process is much the same for both types of glues. However, resin glues introduce certain special problems such as those involved in controlling curing at different temperatures. The resin glues vary with respect to such factors as storage life, methods of mixing or preparing for use, working life, rate of spread, assembly time, permissible moisture content of wood, and curing temperatures. For this reason, it is possible only to generalize on these points, and the glue user must follow the glue manufacturer's instructions closely to obtain the most satisfactory results with a particular glue. The following special terms are important with resin glues.

Storage life.––The storage life of resin glues, or the period during which the glue may be safely stored before use, varies greatly within a range as low as a few weeks for some to as high as a number of years for others. The higher the temperature, the shorter is the storage life. Generally, the faster curing, more reactive resins will have shorter storage lives than slower curing resins. The most pronounced changes that occur in resin glues as they age in storage are an increase in consistency before mixing, and a shortening of the period that the mixed glues will remain usable. Some of the liquid resins require storage under refrigerated conditions to retard reaction of their ingredients and to prolong their usable life. Powdered glues, particularly those with incorporated hardeners, such as the ready–mixed, room–temperature–setting urea resins, require a storage in tight containers under dry conditions to prevent them from absorbing moisture and caking in the container. The storage life of powdered resins is usually longer than that of the liquid resins, and that of the powdered resins without incorporated catalyst is usually longer than that of the powdered resins with catalyst incorporated. Resin shipments should normally be used in order of receipt, the oldest shipments first.

Working life.––Working life or pot life is the time after mixing that the glue remains usable. Soon after mixing thermosettig-resin glues, a chemical reaction begins that ultimately ends in the curing and hardening required to develop joint strength. For resin glues, the working life varies from a few hours for some room–temperature–setting urea– and resorcinol–resin glues to days or weeks for some of the hot–press phenol– and melamine–resin glues. Because heating accelerates and cooling retards the chemical setting reactions of thermosetting-resin glues, their working life can be increased by cooling; for example, by keeping the mixed glue in a cold-water-jacketed container or in a refrigerated room. Likewise, the working life will be shorter as the temperature increases.

In general, it has been found that high-quality glue joints can be produced with resin glues as long as the glues, when mixed in the normal way, can be readily spread. However, if stiff glues are still spreadable, it may be necessary to shorten the period between spreading and pressing from that used with a fresh glue mixture in order to get satisfactory joint quality. The practice of thinning glues that have thickened due to aging is not recommended. Thermosetting-resin glues must be cleaned from mixing and spreading equipment and from the operator's hands before the end of this working life, since after they have hardened to their insoluble, durable, cured state, solvents and even abrasion cannot easily remove the glues.

Following is a general discussion of the gluing process applicable to all of the conventional thermosetting-resin glues. The factors are considered in their normal sequence,

Preparation of the wood for gluing with resin glues.--Most resin glues will give satisfactory joints when used on wood over a wide range of moisture contents. However, to produce glued articles as free as possible from stresses set up by changes in dimension, the wood must be at the right moisture content at the time of gluing. Optimum joint quality is obtained with most resin glues within the range of 6 to 12 percent moisture content. High moisture content wood must be avoided in hot-pressing plywood panels because of the danger of resultant blisters and blowups in the panel. Uniformity of moisture content between laminations or members glued is important in all gluing operations.

Requirements for machining wood surfaces prior to gluing with resin glues are essentially the same as for older nonresin glues. Generally, wood should be surfaced just prior to gluing to avoid undesirable distortions due to any subsequent moisture content changes; and it should be smooth, clean, and true so that the two surfaces fit uniformly in intimate contact. Irregular surfaces that result in thick glue joints, crushed surfaces with weakened fibers adjacent to the joints, and glazed, contaminated, or other defective surfaces are as objectionable when using resin glues as when using glues of animal and vegetable origin.

Preparation of the glue.--Since hardeners, catalysts, and other glue components control the amount, type, and rate of the important chemical curing reaction, glues should always be prepared in accordance with the manufacturer's directions. The proportions of ingredients (resin, hardener, solvent, etc.) should be accurately weighed; measurement by volume should be avoided. Foams, lumps, or glue that is too thick or too thin can be as harmful to the quality of joints made with resin glues as they are to joints made with starch and casein glues.

Amount of due spread.--The amount of spread varies among glues, and that most desirable for any one glue depends upon such factors as the solids content of the glue and the species of wood and type of material being glued. Because of the higher solids content of resin glues, the wet spreads required with them are usually considerably less than those required with casein, soybean, starch, or animal glues. This difference, however, is not so great when reduced to a dry-glue weight basis. Wet spreads of as little as 30 to 35 pounds per 1,000 square feet of single glueline may be sufficient for some unextended resin glues in plywood made from well-cut veneers. As much as 60 pounds may be needed for other glues of lower resin content in cold-pressing plywood of average or lower quality veneers or for resin glues on such exacting products as laminated timbers. On a dry-glue basis, spreads of about 22 to 30 pounds per 1,000 square feet of single glueline are generally satisfactory. Although most resin glues can be brush spread, it is possible to obtain more uniform results with less glue by employing mechanical spreaders with rubber-covered rolls. Hand-operated paint rollers are sometimes more convenient than brushes for spreading glue in small-scale operations. Glue is usually applied only to one of the two mating surfaces. However, for heavy constructions such as in laminated timbers, or where wood surfaces are rough and assembly periods may be long, double spreading on both wood surfaces is desirable.

Assembly period.--Assembly time or assembly period is the interval between spreading the glue and applying the pressure. It is called "open assembly" if the surfaces spread with glue are open to the air, and "closed assembly" if the surfaces are in contact with each other. The maximum permissible assembly period represents an interval beyond which the glue cannot be depended upon to wet the adjacent surface adequately, and after which the glue is too thick to penetrate properly and to be distributed uniformly over the entire joint area by application of gluing pressure. Maximum permissible closed-assembly periods vary from as little as 20 to 30 minutes for the room-temperature-setting, urea-resin glues to as long as several days and even more for some hot-press phenol- and melamine-resin glues. Like the working life and the curing reaction, the permissible assembly period for any thermosetting-resin glue, during which it gradually cures and thickens, is dependent on the temperature of the glue film. The higher this temperature, the shorter will be this permissible assembly period. Permissible open–assembly periods are generally much shorter than permissible closed–assembly periods. Most assembly–gluing operations consist in part of open and in part of closed assembly. As with the older nonresin glues, permissible assembly periods are also affected by such factors as the moisture content of the wood, the age of the glue in the pot, and by whether one or both surfaces are coated with glue. The assembly time becomes more critical and usually must be shortened as the wood becomes drier and as the glue approaches the end of its working life. Since in general, partially dried glue films adhere better to each other than to an uncoated wood surface, maximum permissible assembly periods are usually somewhat longer for double spreading than when single spreading is used.

Curing of resin glues.––As has been previously said, all thermosetting–resin glues develop their strength and durability in joints by undergoing a chemical curing or setting reaction. The thermosetting–resin glues are rather naturally divided into those formulated primarily for curing at normal room temperatures and those for which some type of additional heating of the glueline is necessary. The rate of the curing reaction depends on the catalysts added during mixing and on the glueline temperature. The higher this temperature for a given glue, the more rapid is the curing reaction and the shorter the time required to develop sufficient joint strength to permit release of pressure on the joints. Conversely, the lower this temperature, the longer will be the pressure period. Below a certain minimum temperature for each such resin glue, the curing reaction is so slow that it cannot be depended upon to bond adequately to the wood surfaces and to cure adequately for obtaining the initial joint strength and durability characteristic of the same glue at higher glueline temperatures. These minimum curing temperatures for room–temperature–setting glues have not always been well established. However, resin–glue manufacturers have not recommended curing their urea–resin, resorcinol–resin, or phenol–resorcinol resin glues below 70° F. Urea–resin glues formulated for hot–pressing and most melamine–resin glues are normally cured at glueline temperatures of 240° to 260° F. Phenol–resin glues for hot–pressing are usually cured at glueline temperatures of 280° to 320° F. Some phenol–resorcinol resin glues are cured at glueline temperatures of 120° to 160° F.

It should be noted that the glueline temperature, and not the platen temperature or other external temperature, controls the rate of the curing reaction. Since wood is a poor conductor of heat, a definite time interval must be allowed for the glueline to reach the desired curing temperature. This interval will depend on the type of heating and the amount of heat applied externally, the distance through which the heat must penetrate, the moisture content of the wood, and other factors. Actual glueline temperatures can be conveniently measured with thermocouples and potentiometers. Glue manufacturers can recommend different curing periods for different constructions of plywood at a given platen temperature to include a period for heating the wood as well as the actual curing period. Any thermosetting-resin glue can be made to cure faster by raising the glueline temperature. Thus any room-temperaturesetting urea-resin or resorcinol-resin glue will cure more rapidly by heating the glued and clamped assembly in a hot chamber, or by means of electrically or steam-heated platens or jigs. High-frequency heating is of particular interest for such applications, since under the proper conditions it can raise glueline temperatures to the desired point in a matter of seconds instead of minutes or hours. Once at the curing temperature, the glueline will cure at the same rate as when heated to the same temperature by other conventional methods.

A problem in hot-pressing is that of precure of the glue during the warm-up period and before full gluing pressure is applied to the joint. This condition corresponds to an assembly period at an elevated temperature. Precuring is most common in hot-pressing a large number of plywood panels with thin faces with a reactive urea-resin glue in a multiple-opening hot press when loading is unduly delayed. In this case, the first panels loaded may be in contact with the hot platen for a minute or more before the last panels are loaded and pressure is applied. Precured glue joints no longer have the proper flow characteristics when full pressure is applied, and thus the glue will not properly wet the opposite surface and be adequately distributed. The result is spotty and erratic adhesion and poor joint quality. The use of hot metal cauls in such a multiple-opening press operation may also result in precuring problems. In such cases, several sets of cauls should be available so that one set is cooled while another is in use.

The polyvinyl-resin emulsion glues develop their strength by a partial loss of water from the emulsion to the wood that causes a gelling, rather than by undergoing a chemical reaction in the joint. Therefore the previous comments about the dependence of curing periods on temperature are not applicable to these emulsion-type glues.

Gluing pressure.--Necessary gluing pressures vary more with the type of product to he glued than they do with individual glues. Gluing pressures with resin glues are essentially the same as for nonresin glues used on the same species and in the same type of construction. Pressures should always be uniformly distributed over the entire joint area and be sufficient to bring the members into close contact and to hold them in this position during the setting period, or until the glue has gained enough strength to hold the members together. The pressure, however, should not be so great as to crush the wood.

Maximum permissible pressure will then be dependent on species. Pressures in common use for yellow birch and hard maple are 200 to 250 pounds per square inch; for sweetgum, Douglas-fir, and mahogany, 150 to 200 pounds per square inch; and for Sitka spruce, yellow-poplar, and basswood, 100 to 150 pounds per square inch. Thin members or joints of small area are successfully glued with low pressures, such as those obtained by nail gluing and some types of bag molding. Flat-panel plywood and such thick products as laminated beams for arches and ship timbers require higher pressures. Higher and more uniform pressures are obtained by presses or special clamps.

Conditioning of glued products.--As with nonresin glues, glued articles made with resin glues should remain for a certain period at normal room conditions or in a special conditioning room before further machining and processing. This will permit the desired distribution of moisture throughout the panel and thus reduce future distortion, sunken joints, and similar problems. In hot-pressing with resin glues the wood is likely to be dried to a lower moisture content than desirable, so that it may be necessary to add water by spraying or dipping, or by conditioning panels at a higher relative humidity than normal. As with casein, vegetable, and animal glues, resin glues containing high proportions of water add excess water to glued products, particularly in panels of thin veneers and many gluelines, and this moisture must be removed and equalized. Some additional curing and development of strength may also occur during conditioning after removal from pressure.

General Properties of Different Types of Resin Glues

Phenol-Resin Glues

Phenol-resin glues are commonly divided into two groups, hot-press or high-temperaturesetting, and intermediate-temperature-setting. Although there is often no sharp distinction between these groups, in general usage those glues that require temperatures of more than 210° F. to effect their cure in a reasonable period of time are considered high-temperaturesetting; and those that require temperatures between about 80° and 210° F. (temperatures that can be attained in a heated chamber) for satisfactory curing are considered intermediate-temperature-setting. Some phenol-resin glues, with special acid catalysts, are reported to be suitable for curing at or near normal room temperatures.

High-temperaturesetting or hot-press phenol resins.--Hot-presspheno1-resin glues are marketed in three forms: (1) as a resin-impregnated paper film, (2) as dry powders to be suspended in water or in water and alcohol, and (3) as water or alcohol solutions. All give dark reddish–colored gluelines.

These phenol–resin glues normally cure at 280° to 320° F., and thus require the use of steam-heated presses or other special heating equipment. As a result, their use is restricted almost entirely to gluing the more durable types of plywood and related thin products through which heat can penetrate rather rapidly to the glueline for proper cure. The liquid phenol–resin glues are used widely in the softwood plywood industry for gluing the exterior and boat–hull types of plywood. Their use in hardwood plywood is more limited. These liquid phenol resins for softwood plywood production are generally quite reactive and, as a result, have short storage lives. Where longer storage is required, the powdered phenol–resins are often used. These powdered glues are prepared for use by dissolving in water or in water and alcohol and, in some cases, may require addition of separate hardeners. All these hot–setting phenol–resin glues are normally alkaline in reaction, some of them containing fairly high proportions of alkali as a catalyst.

Phenol–resin glues are commonly used with some walnut–shell flour or other filler, but without extenders where highest joint durability is required. In recent years there has been considerable interest in the addition of fairly high proportions of extenders, such as ground bark, wood and nutshell flours, dry soluble blood, and certain agricultural residues, to phenol–resin glues for gluing interior–type softwood plywood in place of the conventional protein glues now used.

Like other widely used resin glues, phenol–resin glues can be formulated to provide the desired properties for efficient manufacture of the glued products. The curing cycle, or length of the pressure period in the hot press, can be controlled at least partially by use of the proper amount and type of catalyst and by the way in which the resin is made. Assembly periods are somewhat dependent on reactivity of the glue, but they can generally be controlled within suitable limits. In some formulations for high–speed flat–plywood production, assembly periods of 10 minutes at 70° to 80° F. are common. In other formulations an open assembly period of several hours or days can be allowed, as may be required in bag–molding operations where a long lay–up period may be involved. Such glues for bag molding must permit assembly of nearly tack–free glue–coated veneers and yet later flow adequately when heat and pressure are applied in the final curing operation. Phenol–resin glues can be formulated to cure as low as 240° F. in hot presses, but such glues are not in common use in this country.

The dry-film form of phenol-resin glue is a specialty type that is particularly well adapted to the gluing of thin veneers because there is no spreading problem and the danger of glue bleed-through is less. Since the film weighs about 12.5 pounds per 1,000 square feet and approximately one-third of this weight is paper, a relatively light spread of resin is obtained when a single sheet is used per glueline. Consequently, if film glues are to be used successfully, the veneer must be well-cut, smooth, and uniform in thickness. Since the film glue contains little or no water, all moisture needed for dissolving the resin and providing the necessary flow during pressing must come from the veneers themselves. For this reason the control of moisture content in the veneers is much more critical with a phenol-resin film glue than with conventional glues applied in liquid form. The film glues normally do not give good results on veneer at moisture contents of 6 percent or less. The most satisfactory moisture content of veneer for gluing with phenol-resin film varies somewhat with its species and thickness, but, in general, good results are obtained in the range of 8 to 12 percent. A moisture content that is too high may cause blisters, excessive bleed-through, and starved joints: one that is too low usually results in dried joints of low strength.

Intermediate-temperature-setting phenol resins.--The intermediate-temperature-setting type of phenol-resin glue is of more recent origin than the hot-press phenol-resin type. It was developed to fill the need for durable glues that could be cured at temperatures of 210° F, or less, as in heated chambers or with electrically heated jigs. Special formulations of phenol-resin glues were offered for this purpose, their greater reactivity at the lower curing temperatures being due mainly to the use of rather highly acid catalysts. For this reason this type of glue has often been referred to as acid-catalyzed phenol-resin glue. Some of these formulations are suitable for gluing plywood at temperatures as low as 80° F, if the pressure periods are overnight or longer, and if several days of additional conditioning are allowed before subjecting the plywood to severe service. These acid-catalyzed phenol-resin glues have been used to a limited extent for gluing prefabricated house and truck panels. They have also been used in similar applications demanding a durable glueline but not conveniently permitting the heating of the gluelines to 240° F, or higher. These glues are normally supplied as liquid resins with the acid catalyst supplied separately for addition at the time of use. Acid-catalyzed phenol-resin glues do not glue so well on wood at 6 percent moisture content as on wood at higher moisture contents.

Since the introduction of the resorcinol-resin and the phenol-resorcinol-resin glues, the acid catalyzed, intermediate-temperature-setting phenol- resin glues have not been extensively used. The latter type are generally somewhat cheaper and are lighter colored as compared to the phenol–resorcinol and the resorcinol–resin glues, but they are not considered to be as durable as the resorcinol–resin types for long–time severe service, particularly under elevated–temperature exposures.

Resorcinol–Resin Glues

Glues based on resorcinol–formaldehyde resins were first introduced in 1943 and almost immediately found wide application in gluing wood aircraft and naval vessels, in which the combination of high durability and room–temperature curing were more important than cost of the glueline. Resorcinol, from which these resins are made, is quite similar chemically to phenol, and the resorcinol resins bear many resemblances to phenol resins. A principal difference is the greater reactivity of the resorcinol resins, which permits curing at lower temperatures. These glues are supplied in two components, as a dark reddish liquid resin with either a powdered or liquid hardener. These glues, like room–temperature–setting urea resins, cure at 70° F, or higher, but they are not recommended for use below 70° F. Straight resorcinol–resin glues, not containing significant amounts of phenol resin, have storage lives of at least a year at 70° F. Their working life is usually from 2 to 4 hours at 70° F. Assembly periods are not critical. At 70° to 80° F., with both surfaces spread, open–assembly periods of 30 minutes and closed–assembly periods of 1 to 2 hours have been used with good results. These properties make them ideal for laminating large timbers that require considerable time to assemble and bring under pressure. In some applications, such as laminating dense species, resorcinol–resin glues do not normally perform well under very short assembly periods. Less than 10 minutes closed assembly at 70° F. should be avoided.

Resorcinol–resin glues give high strengths in thin plywood and other light constructions of medium– or low–density species when cured at 70° F. For heavier constructions, such as laminated timbers of high–density hardwoods where subsequent internal stressing of the laminate due to moisture–dimensional changes in the wood in service are severe, experience has shown that curing at a somewhat elevated temperature is necessary. Thus white oak ship timbers are cured for several hours at 140° to 150° F. glueline temperatures in a heated, conditioned chamber such as a dry kiln. This is a general procedure that is also applicable to other room–temperature–setting thermosetting–resin glues.

Phenol–Resorcinol–Resin–Glues

These glues are modifications of straight resorcinol–resin glues produced by copolymerizing the two resins during the original process of manufacture of the resins. Proportions of the two resin components in the copolymer are not revealed by their manufacturers. Like their components, the copolymer resins are dark reddish liquids and are prepared for use by adding powdered hardeners. The principal advantage of the copolymer resin glue over straight resorcinol resins is their somewhat lower cost. This is apparently achieved without any significant losses in joint performance. Phenol–resorcinol–resin glues have shorter storage lives than straight resorcinol resins, generally somewhat under 1 year at 70° F. On the basis of rather limited experience, other properties of the phenol–resorcinol resins may be considered to be approximately the same as for straight resorcinol resins.

Urea–Resin Glues

The urea–resin glues were introduced shortly after phenol resins assumed importance in woodworking. The urea resins usually are light colored or colorless and are used extensively in the manufacture of hardwood and furniture plywood. Other principal uses of these glues are in assembly and edge gluing, particularly when used in conjunction with high–frequency heating to cure the glue. They are also supplied in small retail package units, by at least two manufacturers, for home workshop use.

Urea resins are marketed either as dry powders or as water suspensions. Resin suspensions are now supplied in two ranges of concentrations, one known as “high solids” (60 to 70 percent solids), and the other as “low solids” (45 to 50 percent solids). Both concentrations are used mainly in preparing the lower–cost, flour–extended formulations. The principal advantage of the low–solids–content type is the greater fluidity, facilitating bulk shipment in tank cars and trucks and bulk storage by the user. The powdered glues are prepared for use by mixing with water, or with water and hardener if the hardener is separately supplied. In general, powdered urea–resin glues with separate hardeners have longer storage lives than the liquid urea resins or the powdered urea resins in which hardeners are incorporated. A successful film form of urea–resin glue has not been produced commercially in the United States.

Urea resins differ from phenol resins in that the same resin, as received from the manufacturer, can be formulated for either room–temperature–setting or for hot–pressing by addition of the proper catalyst. Some manufacturers, however, supply different resins for hot–pressing and for room–temperature use. Species formulations have been developed for use in high–frequency–heated equipment, particularly for edge gluing lumber cores for furniture and door panels, and for tapeless splicing of veneers.

Both the room–temperature–setting and hot–press urea–resin glue formulations can be extended with cereal flour to reduce glueline costs where maximum joint strength is not required and exposure of the product will be mild. Wheat and rye flours are most commonly used. Extensions up to 100 parts by weight of flour to 100 parts dry resin (100 percent extension) are common in room–temperature–setting or cold–pressing of hardwood plywood, and extensions up to 150 parts flour per 100 parts of dry resin (150 percent extension) are used in hot–pressing hardwood plywood. Entirely adequate information on the best types of flour for such extension of urea resins is not available. Various grades of wheat flour affect the working properties of the glues differently, particularly their consistency and tendency to foam, and may affect their catalyst systems. Flour extension is likely to make the glues more viscous, the degree of change depending on the amount and type of flour and probably on the protein constituents of the flour. One to two percent of sodium bisulfite by weight is sometimes added to the flour in mixing with the resin to help overcome differences in flours and to reduce the amount of additional water that might otherwise be needed to make a spreadable mixture. Such addition of sodium bisulfite may affect the catalyst systems of some glues. The user should obtain the recommendations of the glue supplier for extension for his own purpose. Generally, if a suitable grade of flour is obtained, it is best to continue to use this one grade from one supplier rather than to substitute different flours indiscriminately. Extended glues often require somewhat heavier wet spreads and shorter assembly periods than the corresponding unextended glues.

Urea–resin glues for edge gluing, assembly, veneer splicing, or laminating of furniture parts are not normally extended with cereal flours, but they do contain some walnut–shell flour as filler to improve working properties.

Urea–resin glues are normally not recommended for use on wood below 6 percent moisture content. This limitation appears to be related to the porosity of the species and to the rate at which moisture is absorbed from the glue by the wood.

<u>Hot–press urea resins.</u>––These glues are normally cured at 240° to 260° F. Assembly periods for hot–press urea–resin glues vary considerably for the different formulations. Many typical glues are formulated for assembly periods of 10 to 30 minutes, but special formulations may permit assembly periods up to 24 hours or more. Because of their relatively high reactivity, some urea–resin glues are subject to precuring on hot cauls or platens before full gluing pressure is applied. This can be avoided by use of cooled cauls and a well–organized press–loading operation. Urea–resin glues are much faster curing than phenol resins at the same temperature, which, together with their lower

cost when extended and their lack of color, makes them well adapted for gluing furniture and architectural plywood for interior use where the greater durability of the phenol–resin glues is not required. Typical recommendations for curing hot–press urea resins are 3 to 5 minutes for panels with a total thickness of 3/16 inch or less, and 8 to 10 minutes for panels with 1/4–inch faces on 1/2–inch cores, when the platen temperature is 260° F. and one panel is glued per press opening.

From time to time there has been an interest in improving the durability of hot–press urea–resin glues by incorporation of certain other more durable resins or special resin–forming ingredients with the urea resin. These additions are often referred to as fortifiers and the resultant glues as fortified urea–resin glues. Melamine resins and crystal resorcinol have been most widely used as fortifiers. Their amounts have varied considerably. Improvement in durability under more severe conditions, including outdoor weathering in plywood, has generally increased as the amount of fortifier increased. Because of the special interest in melamine–urea–resin glues, these are described separately. No entirely adequate room–temperature–setting fortified urea–resin glues have been introduced for industrial use at present.

<u>Room–temperature–setting urea resins,––</u>These glues are formulated to cure at 70° F. or higher. They were the first resin glues developed for practical use at normal room temperatures. They were extensively used in the assembly gluing of aircraft, small boats, and truck body parts before the introduction of the more durable resorcinol–resin glues for room–temperature setting. In addition to cold–pressing of plywood panels, by clamping in a hydraulic press and by the use of I–beams and retaining clamps after removal from the press, these glues are now used for edge gluing on clamp carriers, in various assembly operations, and for laminating of furniture parts. Their availability as dry powders, in small retail packages, that require only addition of water for use, makes them ideal for many small shop and home workshop uses.

The working life of a glue of this type will be from 3 to 5 hours at 70° F. and less at higher temperatures. Special warm–weather catalysts for the room–temperature–setting urea resins are available for plywood and other commercial applications in the summer months, when it may be necessary to increase the working life at the higher temperatures.

Assembly periods with these glues are fairly short, with maximum closed–assembly periods of 30 minutes at 70° F. for critical applications. In addition to the temperature, the maximum permissible assembly period will be somewhat dependent on the moisture content of the wood, amount of extension, and on the amount of glue spread.

The minimum pressure period depends on the type of glue product and upon the temperature of the wood and of the room, since these temperatures control the speed of the curing reaction. It should be noted that, because of slow heat transfer through the wood, spreading glue on cold wood from unheated storage and then clamping for a short time at 70° to 80° F. will generally result in inadequate cure with such room–temperature–setting urea–resin glues. At 70° F., pressure should be at least 4 hours on thin flat members, such as ply–wood, and for at least 6 to 8 hours on heavy or curved members. In no case should pressure be released until the squeezeout is hard. Room–temperature–setting urea–resin formulations are often used in special heat–curing operations with heated jigs and for high–frequency curing to get faster curing than with conventional hot–press formulations. Special attention must then be given to avoiding excessive assembly conditions and precuring of the glue.

These glues will harden at temperatures below 70° F., but at a very slow rate, and joints with erratic strength and durability may result. Curing below 70° F. is therefore generally not recommended.

In special applications where rapid strength development at room temperature is of primary importance, the normal room–temperature–setting urea–resin formulation may be applied to one wood surface and a special acid solution may be applied to the opposite mating surface. Sometimes this acid is applied in advance and air dried. The joint is then rapidly assembled and pressure applied. The additional catalyst is assumed to penetrate into the glue and to cause rapid setting. Such additional acid could not be incorporated in the glue before spreading because of the resultant very short pot life. This technique is referred to as the separate–application process. When properly conducted, it does result in a more rapid development of dry strength with a corresponding shorter clamp period. The process has not had wide acceptance, however, because it is diffi–cult to control the uniformity of acid application and erratic joint quality may result unless it is carefully controlled; moreover, the highly acid glueline does not seem to be as durable as gluelines with the same glue used conven–tionally without added separate catalyst.

Melamine–Resin Glues

Melamine–resin glues are normally hot–press glues, curing at 240° to 260° F., similarly to the hot–press urea–resin glues. Special formulations have sometimes been offered for curing at temperatures as low as 140° F., but they have not been widely used. Most of the melamine–resin glues are marketed as powders that are prepared for use by mixing with water and some–times with a separate hardener. Pure melamine–resin glues are almost white, but the addition of fillers usually gives them a light tan color similar to the urea–resin glues. The filler is usually walnut–shell or wood flour.

Melarnine–resin glues have been used to a limited extent for gluing hardwood plywood where the high durability of phenol resins is required but the dark color is objectionable. Melamine resins are considerably more expensive than phenol or urea resins. Melamine–resin glues have also been investigated for gluing heavy laminated ship timbers at curing temperatures of 160° to 190° F., an application for which they are suitable even though more expensive than phenol resins and slower curing than resorcinol resins. Otherwise, there are currently no significant commercial applications of melamine–resin glues in wood laminating. They have also been used successfully in high–frequency edge gluing and scarf jointing where a durable, colorless glueline is required, As a group, melamine–resin glues have pot lives of at least 8 hours at 70° F., and they tolerate rather long open– and closed–assembly periods.

Melamine–Urea–Resin Glues

This is a special group of hot–press glues produced by either dry blending of urea resins and melamine resins or by blending the two separate resins in liquid solution and then spray–drying the mixture. In either case the resins supplied by the manufacturer are powders to be prepared by the user by addition of water and catalysts. At present, the most common combinations are said to contain 40 to 50 percent by weight of melamine resin and 50 to 60 percent of urea resin on a solids basis. They are used in much the same way as the hot–press urea–resin and melamine–resin glues, curing at 240° to 260° F. The melamine–urea–resin glues offer a glue, suitable for hardwood plywood, that is colorless, more durable than urea resins, cheaper than straight melamine or resorcinol–resins, and capable of curing at lower hot–press temperatures than conventional phenol–resin glues.

Polvinyl–Resin Emulsion Glues

These glues are prepared by emulsion polymerization of the corresponding vinyl acetate and other monomers in water under controlled conditions. Since individual types of monomers are not identified by the manufacturer, this group is simply referred to as polyvinyl resins. In the emulsified form, the polyvinyl resins are finely dispersed in water with a consistency and nonvolatile content generally comparable to the thermosetting resin glues. They are marketed as milky white fluids to be used at room temperature in the form supplied by the manufacturer, normally without addition of separate hardeners.

The setting takes place when the water of the emulsion partially diffuses into the wood, whereupon the emulsified resin coagulates. There is no apparent chemical curing reaction, as with the thermosetting resin glues, Thus there is no particular advantage in the application of heat in setting, Inasmuch as the resins are thermoplastic, the use of heat in setting may be actually undesirable. The setting action is comparatively rapid at room temperature, and for some constructions it may be possible to release the clamping pressure in a half hour or less. Limited tests indicate that some of these glues set in the joints at 70° F, at a rate comparable to that of hot animal glue.

The glues have indefinitely long storage and working lives and can be used as long as the resin remains dispersed. Coagulation in storage by evaporation or freezing must be avoided. Special emulsions have been offered that are said to withstand repeated freezing and thawing. The set resins are light in color, often transparent, and result in gluelines that are nearly invisible. A considerable amount of variation has been observed in the performance of the different glues of this type. Some of the poorer ones gave considerably lower joint strengths and developed little or no wood failure compared to other types of nonresin and resin glues. On the other hand, some of the newer polyvinyl-resin emulsion glues gave unusually high shear strengths, although generally not high wood failures, results which might be expected of rather elastic-type, thermoplastic resin glues. The polyvinyl-resin emulsion glues have little dulling effect on the sharp edges of cutting tools, but a tendency to foul sandpaper has been reported.

Some of these glues soften and lose a portion of their strength at 110° F., and the strength of most of them is seriously reduced at 160° F. They are also generally weakened more by high relative humidity conditions than are the thermosetting resin glues. Probably the most serious limitation in the use of these glues in woodworking is their lack of resistance to continuously applied loads, or to "cold flow," which is the tendency for a glue to yield to, rather than resist, the stresses exerted on the joint at normal room temperatures. This limitation has been most serious when such glues have been used for edge gluing lumber for solid stock, particularly high-density hardwoods, not to be subsequently veneered. In such applications, the glueline is visible in the finished product, and there is no other restraining action to joint separation than that of the glue itself. The individual wood pieces are likely to swell and shrink due to moisture content changes in the wood from day to day and season to season. The resultant internal mechanical stresses on the joint may tend to make some of these polyvinyl-resin emulsion glues stretch out so as to allow the joints to open without either significant adhesive or cohesive failure of the glueline. This cold-flow limitation has encouraged considerable reformulation of these glues so that several of the currently available glues of this type appear to be suitable for such edge-gluing applications. However, since not all glues show such improvement and since no simple screening test is yet available for checking this property, the user must exercise caution in selecting such a glue for edge gluing solid stock, particularly for high-density hardwoods, and should try out prospective glues on a limited scale for a while before using them in full-scale production.

Certain studies[3] have indicated that some polyvinyl-resin emulsion glues are promising as replacements for animal glue in assembly joints such as dowel, mortise-and-tenon, and lock-corner joints. Their fast setting is an advantage, and the elasticity or cold flow in a nonexposed joint under dimensional changes in the wood may actually be an advantage.

Durability of Synthetic-Resin Glues

One of the principal differences between the various types of resin glues is the durability, or resistance to joint deterioration under typical service conditions. Generally, different glues of one type, produced by different manufacturers, are quite similar in durability. The following generalizations are based on numerous exposures, both laboratory-controlled and to the weather, at the Forest Products Laboratory.

The durability of moderately alkaline phenol-resin, resorcinol-resin, and straight melamine-resin glues is very similar. These glues, when properly used, are capable of producing joints that, under all severe conditions studied, are as durable as the wood itself. Thus joints properly made with these glues will withstand, without delamination or significant loss in strength, prolonged exposure to cold and hot water, to alternate soaking and drying, to temperatures up to those that seriously damage the wood, to high relative humidities where many untreated species decay, and to outdoor weathering without paint or mechanical protection from the elements. The plies of plywood made with these glues will not separate when exposed to fire. The glues are not weakened by fungi, bacteria, and other micro-organisms and are avoided by termites. Despite this immunity of the glues themselves, they do not offer any significant protection to the adjacent wood. Consequently, wood products glued with these glues should be considered no more decay- or insect-resistant than solid wood of the same species. Completely cured phenol-resin glued joints are highly

[3] Selbo, M. L. and Olson, W. Z. Durability of woodworking glues in different types of assembly joints. Forest Products Res. Soc., 3(5):50-60 (Dec.) 1953.

resistant to the action of solvents, oils, acids, alkalies, wood preservatives, and fire–retardant chemicals; similar properties of resorcinol– and melamine–resin glues have not been adequately evaluated. Thus, in general, well–made joints with phenol–, resorcinol–, and melamine–resin glues are difficult to destroy without destroying the wood itself. However, as with other types of glues, poorly made joints with these durable glues may fail in service under any of the aforementioned conditions. Based on available experience, the phenol–resorcinol–resin glues, when adequately cured, appear to have the same high–durability characteristics as straight phenol– or resorcinol–resin glues.

Acid–catalyzed phenol–resin glues appear to be just as durable as conventional neutral and moderately alkaline glues except under exposure to elevated temperatures, such as 158° F. Under this exposure joint quality is reduced more than for the conventional phenol–resin glues, but not so much as for urea–resin glues.

Durability characteristics of melamine–urea resin glues have not been adequately evaluated at present. Present indications are that such glues, containing approximately equal proportions by weight of both resins, are substantially more durable than straight urea–resin glues but are somewhat less durable than straight melamine resins under severe service conditions.

In general, well–made urea–resin glue joints are characterized by high original dry strength and high wood failures, good resistance to continuous soaking in cold water, fair resistance to continuously high relative humidity and alternately high and low relative humidity, and good resistance to cyclic soaking and drying exposures if the test pieces are in the form of plywood or thin members, but only moderate resistance if the pieces are heavy laminations of dense wood.

Of the urea glues, the fortified resins are the most durable under most of the exposure conditions named. They are followed, in the order of decreasing durability, by the hot–press urea resins, room–temperature–setting urea resins, and highly extended urea resins. Tests made with a hot–press urea–resin glue extended with rye flour showed that the wet–joint strength falls off slowly as more flour is added. Until 50 to 100 percent of extender, based upon the weight of dry resin, had been added, however, no important decreases in wet–joint strengths were apparent. The dry–joint strength decreased still more slowly, and joints containing twice as much rye flour as resin exhibited high joint strength in the dry condition.

When exposed to high relative humidity and other conditions conducive to the development of molds and other micro–organisms, however, the tests showed that the joints made with urea–resin glue extended with as little as 10 percent flour lost strength more rapidly than those made with unextended glues, and that the loss was particularly rapid on those with the greater extensions with flour. Recent tests with preservatives showed that the mold resistance of flour–extended urea resins could be increased by adding chlorinated phenols to the glue in amounts equal to 5 percent of the weight of the flour. Concentrations lower than 5 percent appeared to offer less protection, but there seemed to be little advantage in increasing the concentration above 5 percent. These preservatives seem to delay the effect of the micro–organism damage, but they are unable to prevent it over long periods of exposure to high moisture conditions.

With the exception of the highly fortified glues, the urea resins as a group are low in durability under conditions involving high temperatures, especially when exposed to combinations of high temperature and high relative humidity. Gradual weakening of room–temperature–setting and hot–press urea–resin glue joints occurs under dry conditions at 160° F. A much less significant weakening of room–temperature–setting urea–resin glue joints has been observed in birch plywood under continuous exposure at 80° F. and 65 percent relative humidity. Their rate of strength loss is increased by high humidity at 80° F. Delamination usually occurs within a few hours in boiling water. When urea–resin–bonded plywood is exposed to fire, the plies delaminate because the glue is destroyed at temperatures that char the wood. Plywood panels made with unfortified room–temperature–setting and hot–press urea–resin glues have shown considerable delamination after 2 to 3 years of outdoor exposure at Madison, Wis. Panels made with fortified urea–resins have shown much less delamination in the same length of time. Under exterior exposures and where high temperatures, with or without high relative humidities, are involved, the durability of the urea–resin glues is markedly inferior to that of phenol–, melamine–, or resorcinol–resin glues.

Although urea–resin glue joints have shown somewhat larger decreases in strength than phenol–, resorcinol–, and melamine–resin glues after several years' exposure to less severe laboratory–controlled conditions, urea–resin glues do appear to be sufficiently durable for interior applications within the human–comfort range.

Polyvinyl–resin emulsion glues, being based on thermoplastic resins that do not actually cure chemically in developing joint strength, are considerably less durable than any of the thermosetting resin glues. They lack appreciable water resistance and resistance to high relative humidities, and a number of them are quite sensitive to thermal softening at somewhat elevated temperatures such as 110° and 160° F. Polyvinyl–resin emulsion glues resemble animal glues rather than casein glues in their water and moisture resistance. These characteristics limit the use of polyvinyl–resin emulsion glues primarily to interior applications, as in furniture manufacture.

Special Resin Glues

In recent years greater emphasis has been given to the bonding of wood to metals, plastics, and other materials to produce composite articles in which the good properties of both types of material are utilized. Examples include the bonding of metal or plastic–laminate faces to wood cores for doors, cabinet tops, and wall panels, fabrication of so–called cigarette–proof table tops with a thin metal foil bonded below the surface to distribute heat uniformly and reduce local overheating, and the bonding of various sandwich panels for housing and aircraft. Although some of the typical resin glues previously described, as well as casein and animal glue, may be suitable for some of these applications, they are generally inadequate because of poor adhesion to metals and similar materials. In some cases greater flexibility of the glueline is also desirable. Because of such requirements, a number of new adhesives and bonding processes have been developed for these applications. Some of the glues are of the thermoplastic type, and some are mixtures of thermosetting and thermoplastic resins. It is not yet possible to classify these glues by chemical type nor to discuss either particular methods of using them or the durability of their joints according to type, Because of current interest one particular application will be discussed briefly.

Adhesives for Bonding Metal to Wood

Generally, conventional resin woodworking glues do not adhere well to metals. However, there are a number of special adhesives that do adhere strongly to metals. The adhesion to the metal surface will depend on the type of metal, the smoothness of the surface, and the method used for preparing the surface for gluing. In some cases solvent cleaning, to remove surface oils and grease, may be sufficient to prepare the surface for gluing. In other cases the surface should be chemically treated in order to improve actual adhesion or to provide the necessary corrosion resistance for the metal. The recommendations of the manufacturer of the adhesive should be followed here. Many of these same adhesives also show good adhesion to wood, a fact that permits the use of a single adhesive, or a so–called "one–stage" process, for bonding metal to wood. At the present time nearly all of these one–stage adhesives require the application of some heat in curing, and many require temperatures of 300° to 325° F., similar to those used with hot–press phenol resins, for bonding wood to wood.

In bonding metal to wood in this one–stage process, the glue is usually applied to both the wood and the clean metal surfaces. It is often necessary to apply several coats by brushing, spraying, or roller coating, and to allow an air–drying period after each coat to permit volatilization of the solvent. When the thickness of the resultant film is sufficient, the metal and wood may be assembled and pressed under heat immediately; but in some cases the assembly is heated without pressure for a time, the so-called "precure," before pressure is applied with the continued application of heat, There are available a number of special adhesives developing strength by solvent evaporation at room temperature that can be used for bonding metal to wood where high strength and durable joints are not so important as convenience of use.

Because of the need for hot presses, as well as because of the undesirable dimensional changes that may result in cooling large metal-to-wood panels from the press temperature to room conditions, the use of the one-stage process is somewhat limited and a "two-stage" process is employed. In this latter process, two adhesives are used. One of these, often designated as the "primary" adhesive, may be very similar to the adhesives used in the one-stage process. This primary adhesive, or "primer," is applied to the clean metal surface only. It is then cured by heating at the required elevated temperature in an oven or other chamber without application of pressure. The cured adhesive film is then usually sanded lightly, and a so-called "secondary" adhesive is applied to the wood surface or to both the wood and the primed metal surface, and the joint is assembled and cured. In most cases at present, the secondary adhesive is one of the typical room-temperature-setting resin glues previously described for wood, and the process of bonding the primed metal surface to the wood is the same as for bonding together two pieces of wood.

Adhesives for bonding metal to wood by either of these two processes vary considerably in their chemical composition, their limitations of use under factory conditions, and the quality of the original joints as well as the durability of these joints. The production of high-quality joints between metal and wood requires good control of gluing conditions just as it is required for producing high-quality joints between two pieces of wood. Proper assembly and precuring conditions are particularly important with many of these adhesives in order to insure the necessary flow characteristics of the adhesive when pressure and heat are applied.

The long-time durability characteristics of wood-to-metal joints made with these special adhesives have not yet been adequately established. However, there are definite indications that some of these one- and two-stage processes will give joints of high durability when the bonding processes are properly controlled. Other adhesives, however, may have limited resistance to moisture and water, to organic solvents, and to softening or degradation at elevated temperatures,

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