A

STUDY OF MODERN WOODWORKING ADHESIVES AND GLUING TECHNIQUES

-by-

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A STUDY OF MODERN WOODWORKING ADHESIVES

Part I INTRODUCTION

The purpose of this study is to present the more recent developments and improvements in the field of woodworking adhesives developed during the war years and over the post war period. It will also cover the newest method of curing and setting glues through the use of radio frequency wave lengths.

The origin of glue dates back to ancient Egypt and the Nile, back to the days of the Pharaohs and since then glues have undergone various stages of development (30). In 1914 glues were used mostly for veneer work and bonding plywood. They were made from either vegetable matter, such as starch, or from animals and fish. However, these glues were not water resistant, and for this reason were confined to certain fields. In use, the glues tended to break down over long periods of time and allowed the plywood lamina to separate. If time didn't accomplish this, bacteria and fungi would, being attracted by the high protein content of the glues (25).

Even as well advanced as the art of gluing is today, the development of glues and processes in general are undergoing one of the most active research stages in the history of their development. An example of this might well be the extensive developments made on plywood glues and gluing techniques alone in the past decade (30).

The use of glue in the fabrication of wood products brings about a more complete utilization of wood material through the use of lower grades, poorer species, and smaller sizes of material. It conserves the supply of the better grades and of scarcer and more valuable species for uses best suited to them. Nearly every article of glued wood construction represents an economy in the use of lumber resources (29).

To most people, glue has always been a material secured from animal, vegetable, or chemical derivatives, intended for use in the assembly or repair of a limited number of products, with varying degrees of success, and with little or no assurance of permanence (25). However, today this is not true. With the introduction of resin adhesives it has been possible not only to improve gluing methods and reduce costs but also to improve the quality of the bond and resulting product (30). These glues, developed in the past few years, especially the war years, not only create a permanent bond between two substances but actually, in many cases, may even outlive the material which they hold together.

Synthetic resins, which are the most modern glues, have come into use as wood adhesives in the past 14 years. The first resin glue used in this country was a phenolic film form which was imported from Germany. Following this came a whole string of resins including ureas and melamines. The most recent and modern of all the resins are those which have phenol-resorcinal or resorcinal bases. These have come into use only in the past five or six years (24).

As World War II drew to a close, the woodworker had available a wide choice of glues. These included the, above mentioned, older animal, starch, casein and seed meal glues, together with a variety of newer adhesives of the synthetic-resin type. In the phenol and melamine types, adhesives were available that allowed the convenient manufacture of highly serviceable plywood by hot-pressing. The resorcinol glues produced durable assembly joints at room temperatures and, by the use of the intermediate-temperature-setting phenol and melamine resins and phenol-resorcinol-resin blends, laminated units that were highly durable could be produced. For the first time in woodworking history the manufacturer, by using the proper glues, was able to produce joints that were as durable as the wood itself (9).

Since the durability of glues, for most purposes, is adequate, post war development in adhesives has been along the lines of improving operating characteristics and of cutting down the glue line costs.

Among the developments toward improving operating characteristics or increasing availability were the polyvinyl-resin emulsion glues, the separate-application resorcinol resin glues, synthetic resins formulated for use with high frequency circuits, further changes in the formulation of separate-application urea-resin glues, and new developments of modified blood-albumin glues. The efforts to reduce glue-line costs have included investigations on the extension of phenol-resins with corn gluten, soybean and linseed meal, and with Douglas fir bark; the extension of resorcinol-resin glues with corn gluten, and continued investigations on the effect of extending urea-resin glues with flour (9).

The answer to holding down production costs and at the same time turning out quality work on a competitive basis, lies in the utilization of better methods and improved processes (28). With the advent of the radio frequency equipment for use in gluing, it has been possible to bond thick sections and irregular glue line surfaces that would, under other conditions, be impractical, uneconomical, or even impossible (30).

The study will be presented in five parts. The first, to deal with tests used to measure the strength of various glues. The second section will present conditions necessary to produce good-quality joints. The third part will cover the resinous types of glue, their manufacture, and their uses. The fourth part will deal with the non-resinous types such as casein glue and blood-albumin glue. Finally the fifth section will discuss pertinent facts about high frequency gluing and the glues used in connection with it.

This study is entirely empirical and will not try to cover the chemical or physical theories behind these adhesives or methods of adhesion.

Part II STRENGTH TESTS

Comparatively little work has been done on the development and standardization of testing methods for determining the fundamental physical properties of adhesively bonded joints (27).

At present there are only two widely used methods for testing adhesives. They are the block shear test and the plywood shear test.

Block Shear Test

The block shear test is the method most widely used for evaluating the bonding strength of glues to wood. The specimen is broken by the application of a compressive load. The following procedure is used in making block shear tests (1) (20) (See Fig 1):

(1) Use sugar maple selected to obtain material of a specific gravity of at least 0.65 (oven-dry weight and volume), of straight grain and free from defects. Condition to a moisture content of about 7 percent.

(2) Cut the material into pieces about 1 by 2.5 by 12 inches or of other such width and length as to provide at least four specimens of the dimensions of 2 x 1-3/4 x 3/4". Surface the pieces smoothly to a uniform thickness and glue promptly after surfacing.

(3) Glue at least two joints for each test.

(4) Follow manufacturer's directions in mixing the glue. Weigh component parts. Do the gluing during the second hour after mixing.

(5) Spread the glue evenly on one of the two pieces at the rate of about 35 grams of wet glue per square foot of glue joint and apply pressure uniformly to the joint when the glue is the proper consistency. The quantity of the spread can be determined by weighing the pieces immediately before and after spreading.

(6) Apply a pressure of 150 to 200 pounds per square inch and leave the tests blocks under pressure not less than four hours and condition them for six additional days at room temperature before testing.

(7) Cut the blocks into specimens and test on a Universal testing machine equipped with a shearing tool. Apply the load to the specimens at a rate not greater than 0.0125 inch per minute.

(8) Record for each specimen tested the breaking load and approximately the percentage of wood failure occurring over the glue line area. Compute the breaking load in terms of pounds per square inch of glue-line area.

(9) Reject the glue if the average breaking strength of the joints is less than 2800 pounds per square inch. Whenever a specimen fails at a load of less than 2800 pounds per square inch and the failure occurs 50 percent or more in the wood, the specimen will be disregarded in computing the average.

Plywood Shear Test

The plywood shear test specimen consists of a three-ply wood laminate in which the grain of the center ply is at right angles to the two-face plies. The specimen is prepared by milling a groove two-thirds through the core on each of the face plies. The specimen is broken under a tensile load in special grips (27). The following procedure is used in making plywood shear tests (1) (20) (See Fig 2):

(1) Glue at least 4 three-ply panels with the grain of the face plies at right angles to that of the core. Use one-sixteenth inch yellow birch veneer selected for firmness, straightness of grain, and freedom from defects.

(2) Each panel should be of a size sufficient to produce at least 10 specimens. A panel measuring 4 inches with the grain and 12 inches across the grain of the faces is a convenient size for cutting the required number of specimens.

(3) Condition the veneer to a moisture content of about 7 percent.

(4) Follow the manufacturer's directions in mixing the glue.

(5) Glue one-half of the panels at the end of the first hour after mixing the glue and the other half at the end of the fifth hour after mixing.

(6) Glue the plywood under carefully controlled conditions.

(7) Leave panels under pressure for at least three hours and then condition them for at least three additional days at room temperature before testing.

(8) From each panel cut ten specimens. Number the specimens from each panel successively from one to ten.

(9) Test in the dry condition the odd-numbered specimens from each panel in a cement briquette testing machine equipped with special grips. Apply the load to the specimens at a rate between 600 and

1000 pounds per minute.

(10) Soak the even-numbered specimens in water at room temperature for 48 hours and then test them as soon as removed from the water in the same manner as described in sub-paragraphs 9 above.

(11) Record for each specimen tested the breaking load and the approximate percentage of wood failure occuring in the test.

(12) Reject the glue if the average breaking strength, either wet or dry, is less than the specified values (at present 340 pounds per square inch dry and 140 pounds per square inch wet). Whenever a specimen fails at a load less than the specified value and the failure occurs 50 percent or more in the wood, the specimen shall be disregarded in computing the final average.

In testing glued joints in shear it is very difficult to attain pure shear conditions. Hence, a variety of methods, other than the two just mentioned and described above, have been proposed for the determination of this property. Some of the methods which have been used will be briefly reviewed (27).

<u>Single Lap Joint Shear.</u> The single lap joint specimen has been widely used for the measurement of adhesion to metals. The specimen is broken under a tensile load.

<u>Double Lap Joint Shear.</u> The method was developed to overcome the unequal distribution of stresses encountered in the single lap joint specimen.

<u>Scarf Joint Shear.</u> This specimen is difficult to prepare but the shearing stresses developed in the glue line are more uniform than for any other type of shear test. If

the two adherents are of equal modulus, the single scarf joint is adequate. The specimens are broken under a tensile load.

Cylindrical Single Shear. This test was used by McBain to reduce the amount of wood failure in the glue line. By means of a special adjustment it is possible to vary the angle 0. It was found that the most reproducible values were obtained when 0 = 6.0°. The specimen is broken under a compressive load.

Johnson Double Shear. This test consists in rigidly clamping the outer sections of the specimen in the shearing tool and applying a compressive load upon the shear member which applies an evenly distributed load to the central portion of the specimen. It is necessary that the two glue lines be accurately placed in the shearing planes of the instrument. Thus very careful machining of the specimen is required for reproducible values.

Cylindrical Double Shear. This method is similar to the Johnson test. The essential difference is that the cylindrical specimen is broken by a tensile load.

A special test may be made called the tensile strength test. This test measures the tensile strength of an adhesive rather than the shearing strength. The test specifies that self-alining grips shall be used in order to assure loading exactly normal to the glued surfaces (27).

Part III USE & WORKING CHARACTERISTICS

The production of high quality glue joints in wood products requires the full recognition of all the factors that may enter into joint quality. This is as necessary with synthetic resins as with the older glues of animal and vegetable origin. The resin adhesives vary with respect to such factors as storage life, preparation for use, working life, rate of spread assembly time, moisture content of wood, and during temperatures.

Storage Life

The storage life of glue varies from a few weeks for some to a number of years for others. The higher the temperature the shorter the storage life. The most pronounced change in the resin adhesives occurs in their working life (glue-pot life) (19).

The form in which the glue is marketed has a great deal to do with its storage life. Liquid resins in some cases must be stored under refrigerated conditions. Powdered glues require storage in tight containers and in dry places so they will not absorb any moisture and cake. The storage life of powdered ureas is longer than that of the liquid form, however, powdered ureas without catalysts (hardeners) last longer than those that contain this ingredient. The melamine powders behave in much the same manner as the ureas. The storage life of high temperature-setting resins tend to be longer than that of intermediate-temperature-setting resins of like kind. Resorcinol solutions usually have a very long storage life in tight containers from which the solvent can not evaporate.

Preparation For Use

The proportions of ingredients (resin, hardener, solvent, etc.) should be accurately measured. Foams, lumps, too thin, or too thick a consistency can be as harmful to the quality of a joint made with a resin glue as to joints made with starch and casein glues (19).

Working Life

The working life is the time after mixing that the glue remains usable (glue-pot life). For resin adhesives it varies from a few hours for some to days or weeks for others (19), becoming shorter as the temperature rises. The working lives of resins also shorten as they approach the end of their storage life (4).

In general, it has been found that high-quality glue joints can be produced so long as the glue can be readily spread, although the assembly time may be affected by the length of the working life. Because heating accelerates and cooling retards the setting reaction of thermosetting glues, their working life can be increased by being kept cool (19).

The working life of a glue can be tested by preparing a small batch in a beaker and observing the time elapse between the mixing of the glue and the thickening of the glue to a point where it is no longer spreadable (4).

Rate of Spread

The rate of spread varies among glues and that most desirable depends on the amount of solid content in the glue and the species and type of material being glued. Because of the higher solid content of resin adhesives, wet spreads are usually lower than those required with casein, soybean, starch, or animal glues, but this difference is not quite so great when reduced to a dry glue weight basis. Although most resin adhesives can be brush spread, it is possible to obtain more uniform results with less glue by using mechanical spreaders with rubber-coated rollers (19).

Assembly Time

Assembly time is the period between spreading the glue and applying the pressure.

It is called "open assembly", if the surfaces spread with glue are open to the air. If the surfaces are in contact it is a "closed assembly". Maximum permissable closed assembly times vary from as little as 20 to 30 minutes for room-temperature-setting, ureas to as long as several days and longer for some hot-press phenols and melamines. Permissable open assembly times are shorter than closed assembly periods, often only one-half as long (19).

Resin glues differ more with respect to assembly periods than do animal, starch, and casein glues. As with older glues, however, the periods are affected by such factors as the moisture content of the wood, the temperature of the wood and gluing room, the age of the glue in the pot, and by whether one or both surfaces are coated (19).

Casein and urea-resin adhesives, which permit short assembly periods, can be used as long as they are spreadable. Some phenols have assembly times much longer than their working lives, whereas resorcinols have an assembly period little more than the working life (4). The assembly time becomes more critical and usually must be shortened as the glues approach the end of their working lives (19).

Most gluing operations involve combinations of open and closed assemblies, and the allowable interval will usually fall between the limits for closed and open assembly. In order to estimate this allowable limit it is usually assumed that one minute of open assembly is equal to two minutes of closed assembly (4).

Moisture Content

The moisture content of wood at the time of gluing is more important with some resins than with others (1336), however, most glues are capable of producing good joints over a wide range of moisture contents (4). But moisture content should be controlled through proper seasoning practices if satisfactory results are to be obtained.

Uniformity of moisture content between laminations glued is important. Optimum results are obtained with most resin glues within the range of 6 to 12 per cent moisture content (19).

Moisture control is to minimize shrinking, swelling, and stresses which cause warping and failure of joints or of the wood near glue joints (4).

Curing Temperature

Suitable curing temperatures for resin glues vary from a minimum of 70° to 75°F. for room-temperature-setting, urea-resins, to 280° to 320°F. for some hot-press phenols. The rate of setting for all thermosetting glues can be greatly accellerated by the use of higher temperatures (19).

Since room-temperature-setting adhesives continue to cure after the source of heat is removed, it is possible to remove pressure and handle joints before complete curing has resulted.

Surface Condition

The condition of wood surfaces at the time of gluing is important. Irregular surfaces that result in thick glue lines, crushed surfaces with weakened fibers adjacent to the joints, and glazed contaminated, and other defects are as objectionable when using resins as with animal and vegetable glues (19).

Lumber surfaces should be clean, smooth, and accurately machined, so that all parts involved in any joint will come easily into direct contact with each other. Wood should be surfaced when dry, preferably just before gluing. This avoids the chance of warping or twisting by further drying (4).

There is no objection from the standpoint of glueability to sanding the surfaces, and sanded plywood may be glued with good results. However, sanding may produce irregular surfaces which will not be close fitting (4).

Gluing Pressure

Necessary pressures vary more with the product or article being glued than with the glue. Pressures must be sufficient to bring the members into close contact and to hold them in this position during the setting period, or until glue is strong enough to hold them (19).

Non-uniform pressures commonly result in weak and strong areas in the same joint. The principal causes of unequal pressure on joints are:

(1) Irregular surfaces of the pieces being glued.

(2) Unequal dimensions of stock.

(3) Warped stock.

(4) Improper spacing of clamps, nails, or other pressure devices.

(5) Deformation, deflection, and other imperfections in press, clamps, or other equipment (4).

The pressure should not be great enough to crush the wood. In general, the pressure required with resin glues is determined more by the thickness of the laminations, the species of wood, and the nature of the assembly, than by the glue (19).

Part IV RESINOUS ADHESIVES

The term "synthetic resin" first described chemical compounds that resembled natural resins in their general appearance. Several of these synthetic resins have found widespread application as woodworking glues. Their use has resulted in improved performance of many glued-wood products, has facilitated the adaptation of such materials to new uses, and has developed new wood products. Plywood for exterior uses such as aircraft, structures for use under severe service conditions such as laminated ship keels, and radio masts for tropical use, are among the many products whose performance has been facilitated and improved through the application of synthetic resin glues (19).

Before entering into a discussion of the resins themselves, it may be well to acquaint oneself with the other ingredients which go to make up the completed glue, such as hardeners, fillers, extenders, solvents, and fortifiers.

It also might be well for one to understand something of the working characteristics of these glues and of the tests which are made upon the cured adhesive.

Composition

In preparing resins for use as adhesives, the reaction between the chemicals is stopped in an intermediate stage (17). The intermediate product, usually an aqueous solution, may be spray dried (powder form), concentrated to a viscous syrup (solution or liquid form), or used to impregnate paper (film form) (19).

The formation of the final resin is completed through the application of heat (high temperature-setting or hot-press resin glues), by the action of special hardeners that are added (cold or room temperature setting resin glues) or by means of both (19).

Hardeners

Hardeners are often called catalysts, and are important ingredients of all thermosetting resin glues. They influence the adhesives' rate of setting and the temperatures at which curing or setting occurs.

The term hardener covers such materials as acids, alkalies, acid salts, formaldehyde and paraformaldehyde. The acids, acid salts, and alkalies act mainly as catalysts, but formaldehyde and paraformaldehyde enter into the reaction as actual ingredients of the resin (19).

Hardeners may be added to the glue by the manufacturer, an example might be powdered, room-temperature-setting, urea formaldehyde resins, or maybe furnished as separate powders or liquids to be added at the time of mixing the adhesive (19).

Fillers

Fillers are often in mixture with the hardeners, in order to modify or improve the working properties and performance of the glue. Fillers may be one or a mixture of the following; walnut-shell flour, wheat, or rye flour, starch, finely ground resins, Douglas-fir bark, vegetable and animal proteins and inorganic materials.

A material is a filler as long as it is of such a nature and is present only in such quantity as to improve the quality of the glue joint without sacrificing durability (19). After a consultation with representatives of the glue manufacturers, the upper limit in Army and Navy aeronautical specifications was set at 20 per cent of the weight of the dry resin for all resins (21).

Addition of too much filler, of the above mentioned types, may lay the glue line open to attack and breakdown from molds and bacteria as is the case with casein and soybean glues. This is due to the fact that food materials suitable to these micro-organisms are present in sufficient quantity in these fillers.

Extenders

Extenders are primarily intended to reduce glue costs, and they normally make up a larger percentage of the glue than fillers (19). Fillers, if used to excess, may be considered as extenders.

In the addition of extenders, the problem is the same as with fillers, it is again one of adding sufficient inexpensive extenders to reduce significantly the cost of the glue line, without effecting the working properties or reducing the quality and durability of the joint (9).

The use of extenders became important soon after the introduction of synthetic resin glues, but it is not limited to these adhesives. Materials for the extension of animal and casein glues are also available. The greatest use of extenders, however, has been with resins and since the war developments have concentrated on that field (9).

It has been shown that soybean meal, linseed meal, and corn gluten may be used to extend phenol resins. Work in this line has indicated that high protein content and low water-absorbing capacity are desirable properties in extenders, that the extender be low in water-soluble constituents, and that the resin should be low in molecular weight (5).

Douglas-fir bark has been developed as an extender for phenol-resin. It is a proportioned blend of the three constituents of tree bark; cork, bast fiber, and amorphous powder. The finely powdered bark is first thoroughly mixed with alkali, heated, and then cooled before mixing into the resin (9). English walnut shell flour is also widely used as an extender for resin glues and lately it has been found that a black walnut product will serve equally as well. Blood-albumin adhesives are also used as extenders and fillers for resin glues.

Solvents

Solvents are incorporated in glues marketed in liquid form, and they are added during the mixing of powdered glues. Water is the most common. Some glues, however, contain alcohol or acetone as their solvent or these must be added, usually along with water, in preparing these glues for use (19).

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 and resorcinol resins (19).

Types of Synthetic Resin Glues

Synthetic resins are usually divided into two general groups (19).

(1) Thermoplastic - These resins soften when temperatures are raised above a certain range characteristic for

each resin. They have found limited use in special products, the utility of which is not hampered by the softening of the resin at high temperature.

(2) Thermosetting - These resins harden by an irreversible condensation reaction and will not soften even when temperatures exceed the original setting temperature.

The majority of the more important synthetic-resin, woodworking adhesives belong to this last mentioned group. As implied by the term, thermosetting, their curving if effected by the application of heat. These resins may cure slowly and sometimes unsatisfactorily at temperatures below the range characteristic to the adhesive, but the rate of setting can be greatly increased by increasing temperature ranges (1336).

The resins in both of these general groups are further classified according to their composition, setting temperatures, and as to whether fortifiers or extenders are used in them.

The important resin adhesives are usually classified as follows (19):

I Thermosetting-Resin Adhesives.

A. Phenol-formaldehyde; - Includes hot-press, intermediate-temperature-setting, modified, and extended phenol glues.

B. Urea-formaldehyde; - Includes hot-press, room-temperature-setting, modified, and extended phenol glues.

C. Resorcinol formaldehyde: - Includes room-temperature-setting, and cold-temperature-setting resorcinol glues.

D. Melamine formaldehyde: - Includes hot-press, and intermediate-temperature-setting melamine glues.

II Thermoplastic-Resin Adhesives

A. Polyvinyl acetate: - Includes solutions and emulsions and special modifications with rubber thermo-setting resins, and other ingredients.

B. Polyvinyl butyral: - Includes solutions, emulsions, and special modifications with rubber, thermosetting resins, and other ingredients.

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 not generally known, although some of them are thermosetting, thermoplastic, or thermosetting-thermoplastic mixtures.

Phenol-Resin Adhesives

Phenol-resin adhesives usually fall into two general groups; (1) hot-press or high-temperature-setting, and (2) intermediate-temperature-setting. In general, those adhesives which cure at temperatures above 210° F. are considered high-temperature-setting and those which cure between 80° F. and 210° F. are called intermediate-temperature-setting.

Hot-Press Phenol Resins

These adhesives are generally marketed in three forms:

(1) as a resin-impregnated paper film, (2) as dry powders, and (3) as water or alcohol solutions. Separate hardeners are usually supplied with the powder and liquid forms for addition to glues when they are used.

The dry film form is extensively used in the manufacture of aircraft plywood. It is very good for thin veneers, because there is no spreading problem and less danger of bleed-through. The best wood moisture content is obtained between the range of 8 to 12 percent (1). A moisture content too high may cause blisters and excessive bleed-through; one which is too low will result in dried joints of low strength (19).

Veneer stock should be smooth since extra glue cannot be added to take care of roughness or irregularities (1).

The veneer and film may be assembled quite some time prior to pressing. However, when the pressing begins full pressure must be reached quickly so as to avoid precuring. The temperature of the platens should be between 280° F. and 320° F. for this type glue. Pressures usually depend on the type and species of material, ranging from 100 to 140 pounds per square inch for basswood and sitka spruce up to 200 to 250 pounds for yellow birch and hard maple. Moisture lost from the wood in the process may be replaced by spraying or dipping the panels in water (19).

Liquid phenol-resin glues are widely used in making plywood for marine and other exterior uses where durable bonds are needed. Hardeners and fillers are often added during mixing. Most of these glues are alkaline in reaction and are applied by means of mechanical spreaders with rubber covered rollers. Moisture content control is not quite as exacting and percentages may run from 1 to 12 per cent, however, some blistering may occur above 5 or 6 percent moisture content (1) (19).

Assembly times of these hot-press phenols vary greatly from less than an hour up to as long as a week. Long assemblies are preferred for bag-molding processes but in flat plywood manufacture short assembly period of a few minutes to an hour are much more suitable (19). Some of these liquid phenols require the same curing temperatures as needed by the films 280° F. to 310° F. Pressures are similar to those used for film forms (19).

In some cases hot-press phenol adhesives have been extended with blood-albumin in an effort to lower glue line costs.

Intermediate-Temperature-Setting Phenol Resins

This type of phenol glue is of a more recent origin than the hot-press type and has been developed to fill the need for durable glues that can be cured at temperatures of 210° F. or less (4). The curing of these adhesives may be accelerated greatly by temperatures above

200° F. and at 240° F. to 300° F. they may set in a few minutes (19).

These resins are marketed as powders or liquids, with separate hardeners. Some filler, usually walnut-shell flour, is often added with the hardener (4) (19). These glues may be alkaline or acidic. Alkaline or neutral reacting glues are usually preferred since acidic glues tend to deteriorate and weaken the wood adjacent to the glue line (31).

The usual working life of this type of adhesive is 2 to 8 hours at 75° F. Assembly periods vary, but most of them permit 1 to 2 hours of closed assembly at 75° F. Since most of these resins are used for laminating heavy members, double spreading and spreading both surfaces is commonly practiced (19).

Moisture content is not overly critical and these glues appear to perform well on wood with 2 to 20 percent moisture content, however 8 to 15 percent seems to produce the strongest joints (4) (18). A gluing pressure of 150 pounds per square inch is usually recommended as the minimum for laminating (19).

Room-temperature (65° F. to 80° F.) or cold-setting phenol resins (below 65° F.) that are satisfactory for general use have not yet been developed (4) (19).

Well made and adequately cured phenol-resin adhesive joints will withstand, without delamination, prolonged exposure to cold and hot water, cyclic soaking and drying, continuous or alternately high and low temperatures and both high and low relative humidities (4).

These glues are highly resistant to dry heat. They will breakdown only when temperatures near their ignition point, which is above the temperature at which wood chars. For this reason, plywood made with a phenol adhesive will not come apart when exposed to fire (19).

Phenols are not weakened by molds, bacteria, or other micro-organisms. However, this does not mean that these glues will act as preservatives and protect the adjacent wood from decay.

Completely cured joints are also resistant to solvents oils, acids, alkalies, wood preservatives, and fire retardents. In general, joints made with these glues are difficult to destroy without destroying the wood itself.

Urea-Resin Adhesives

Urea-resins were introduced into the woodworking industry shortly after phenols assumed importance and are used extensively in making hardwood plywood.

Urea-resin adhesives are placed on the market as powders or liquids. With the powders, hardeners may be included or may come separate; in the case of the liquids, hardeners are almost always separate (19). The water suspensions usually have 60 to 70 percent solids present (18). Powders usually have walnut-shell flour as a filler and it may be contained in the hardener. A powder with a separate hardener usually has a longer storage life than a liquid urea or powdered with incorporated hardeners (19).

Most urea adhesives are made for use at room temperatures, however, some are formulated for use at higher temperatures and are known as hot-press urea resins. One of the chief differences between these two is the amount of hardener which is incorporated in them. Hardeners are either acids or acid-forming salts and the glues tend to have an acidia reaction, lower temperature-setting resins usually being more acid than the hot-press type (19).

Many of these adhesives can be and are extended by the addition of wheat or rye flour, these glues are termed extended urea resins. Materials such as melamine and resorcinol resins are added to hot-press ureas to act as fortifiers and increase the resistance of the adhesive boiling water and high temperatures (19). This treatment is sometimes called "craze-proofing" and tends to delay the resins crystallizing (24). Urea-resin glues treated in such a manner are commonly called fortified urea resins, but may sometimes be referred to as craze-resistant urea glues (7).

Hot-Press Urea Resins

The working life of hot-press urea resin adhesives is usually about 8 hours or more. Assembly periods for these glues ordinarily are not critical and may be varied over wide limits. Some may have an open assembly time of 24 hours or more (19).

The moisture content of veneer is not a critical condition with hot-press ureas, however, too high a percentage will cause some blistering as with the phenols (1). These glues may be spread with a brush but mechanical spreaders seem to do a better job. Heavier spreads are needed with rough or irregular veneer (19).

Most hot-press ureas cure at temperatures below those required for hot-press phenols. A range of from 230° F. to 260° F. is recommended for platen temperatures. Pressures are similar to those used with phenols although curing times depend on moisture content, species, thickness of veneer, number of glue lines, etc., they will range from 3 to 5 minutes for 3/16 inch panels or less to 8 to 15 minutes for panels with 1/4 inch faces on 1/2 inch cores (1336).

<u>Room-Temperature-Setting Urea Resins</u>

These glues cure or set around 70° F. or above. They show good resistance to cold water but deteriorate badly when placed in hot water.

The moisture content of the wood is more critical than with the hot-press types and the best joints are produced on wood at 8 to 12 percent moisture content than at 5 to 6 percent or lower (4).

The working life of these glues is very dependent on the temperature of the adhesive. In general, the higher the temperature, the shorter the working life. In hot weather the working life may be increased by keeping the resin in a water-cooler container at about 70° F. or 75° F. (1) (19).

Assembly periods are critical and range from a maximum of only 20 minutes if entirely closed, to 10 minutes if entirely open. Most operations consist of open and closed assembly. Generally, one minute of open assembly equals two minutes of closed assembly. These periods should be decreased if wood is very dry or the temperature of the wood and gluing room are above 75° F.

Minimum pressure periods depend on the type of material and temperature at 75° F. four hours of pressure were needed for thin straight members and 5 to 7 hours were needed for heavy or curved units. In no case should the pressure be released before the squeeze-out is hard (19). Experiments have shown that increasing the temperature greatly decreases the time that the joints require in the press (12). The required time can be reduced approximately one-half for every 10° F. increase in the temperature of the glue line above 75° F. (19).

Extended Urea Resins

These glues have had large amounts of wheat or rye flour added to them in order to reduce glue line costs. Both hot-press or room-temperature-setting ureas may be extended. Flour will impart some adhesiveness when hot-pressed. These glues are generally more viscous than the unextended types (19).

The amount of flour extension varies, but it is primarily determined by the type of product being manufactured and under what conditions the product will be used. The most common range of extension is from 25 to 100 percent (25 to 100 parts flour to 100 parts of dry resin) (19).

Danger exists in adding too much flour or in exposing extended resins to conditions favorable for fungus and bacteria attacks. Experiments have shown that under proper humidity and temperature conditions resins extended with more than 25 percent flour deteriorated very rapidly due to micro-organisms. However, resistance to molds and bacteria may be increased by adding chlorinated phenols in amounts equal to 5 percent of the flour weight.

Since these glues usually contain more water than unextended types heavier spreads are necessary. Assembly periods are generally shorter also (19).

Fortified Urea Resins

These ureas were developed to improve the resistance of hot-press ureas to boiling water and conditions of high temperature and high humidity. Such glues are sometimes called craze-resistant.

Bergin found by experimentation that at temperatures of 194° F. and 65 percent relative humidity normal urea adhesives broke down very rapidly. However, the craze-resistant gap-filling urea glues, although inferior to casein glues, gave test results comparable to them (7).

The resistance of these glues can be greatly increased by the addition of melamine or resorcinol resins. There appears to be a close correlation between the resistance and the amount of fortifier added. When 40 to 50 percent of the total weight of glue solids consists of a fortifier, the boil resistance may approach that of the melamine, resorcinol, and phenol adhesives (19).

The use and working characteristics are similar to those of the hot-press urea resins.

The ureas as a group are low in durability (with the exception of those fortified) under conditions involving moderately high temperatures, especially when high humidity is also present (4). Considerable weakening of urea-resin glue joints occurs under dry conditions at 160° F. and their rate of strength deterioration is even greater under moist conditions at this temperature (24).

When these joints are exposed to fire, they fail because the glue is destroyed at temperatures which char the wood, thus allowing the plies to separate (4).

In general, well made, new, urea-resin glue joints are characterized by high original dry strength, and good to fair resistance under test conditions to continuous soaking in cold water, cyclic soaking and drying, continuous high relative humidity, and alternately high and low relative humidity (19). But as good as urea-resins are, their all-around long-term durability has been somewhat disappointing. Generally speaking, joints made with urea-resins do not improve with age (24). Significant decreases in strength have been observed in urea-resin joints when exposed to normal room conditions, indicating a loss of strength with aging (4).

These adhesives are not to be considered outdated. Their low cost and easy handling will insure their large-scale use in the manufacture of furniture, laminations, and plywood which are not destined for continuous outdoor exposure (24).

Melamine-Resin Adhesives

There are two classes of melamine-resin adhesives, the hot-press type and the intermediate-temperature-setting type. The latter differ from the former in having a mildly acidic salt to catalyze the reaction so that they will cure more rapidly at lower temperatures (19).

Melamine resins spring from the same chemical family as urea resins, but are set at elevated temperatures only. They have the advantage over ureas of being boilproof and high in durability (24).

Most of these resins are marketed as powders. They are prepared for use by mixing with water and sometimes with the addition of a hardener. Fillers are also sometimes used, they consist usually of walnut-shell flour. The concentration of the mixture is usually within the range of 60 to 70 percent solids, about the same as that of most other resin glues. Pure melamines are nearly white but fillers impart a tan color to them (4).

Hot-Press Melamine Resins

The working life of these resins is about 36 hours at ordinary room temperature. The moisture content of the wood appears to be more critical with melamines than with phenols and better results are usually obtained with moisture content above 6 percent. Hot-press melamines are not critical with respect to assembly periods. These glues generally cure at temperatures of 230° F. to 300° F. but some may be cured at temperatures as low as 150° F. (4) (19).

Intermediate-Temperature-Setting Melamine Resins

The working life of intermediate-temperature-setting melamines is about 2 to 4 hours under ordinary room conditions. Assembly time should be less than one hour closed or 1/2 hour open at 70° F. and less at higher temperatures. These glues generally cure in about the same temperature range as the intermediate-temperature-setting phenols, 120° F. to 200° F. (19).

These resins are of very recent origin, most of the development having taken place since 1940. Hence only a limited amount of information is available as to their durability.

Laboratory exposure tests indicate that melamine durability is similar to that of phenol resins. Well made joints show excellent resistance to high temperatures, high relative humidity, continuous soaking, cyclic soaking and drying, micro-organisms, and to most chemicals, including wood preservatives, fire-retardent chemicals, and oils. The plies of melamine-glued plywood do not separate when exposed to fire (4).

Tests indicate that the durability of the intermediate temperature-setting melamine joints is somewhat less than that of hot-press melamine joints.

Resorcinol-Resin Adhesives

Adhesives derived from resorcinol and formaldehyde were first developed in 1943, and are the most recent of all the thermosetting, synthetic resin adhesives (19). These adhesives are marketed as liquids consisting of partially polymerized resin in a mixture of alcohol and water. When used they are mixed with a hardener, usually formaldehyde or para-formaldehyde. Fillers are usually walnut-shell flour. These glues are dark in color, resembling phenol adhesives in this respect (4) (19).

Moisture content of the wood is not a critical factor and strong joints may be produced within the range of 2 to 20 percent moisture content. Storage life is at least a year and may be as long as several years at room temperature. The working life of these glues vary from 2 to 5 hours at 70° F. to 75° F. It may be lowered by higher temperatures (19).

Assembly periods are dependent on the particular glue, type of assembly (open or closed), number of surfaces spread (one or both), and the temperature. At 70° F. to 80° F. with both surfaces spread, open assembly periods of 30 minutes and closed assembly periods of one to two hours have shown good results. These glues cure and set at temperatures of 75° F. to 80° F. Higher temperatures may be needed for heavy laminations of dense species. At room temperature pressure periods should be maintained for 5 to 8 hours (19).

Through experimentation by Babcock and Smith it was found that corn gluten could be used as an extender for resorcinol-resin adhesives. This was due to its greater dispersibility in the alcohol solutions of the resorcinol resins (9).

Investigations to date indicate that resorcinol-resin adhesives are comparable to phenol-resins in durability (4). And because of this high durability and low setting temperatures, these glues are particularly promising for many gluing jobs where high curing temperatures can not be used but where glue joints resistant to most deteriorating agencies are desired (19).

Thermoplastic Resins

The thermoplastic resins that have found use as woodworking adhesives are vinyl derivatives such as polyvinyl butyral and polyvinyl acetate. They come in two forms, emulsified and dissolved.

Polyvinyl-resin

The polyvinyl-resin emulsion was developed as a woodworking adhesive about 1945, when the supply of animal glue was insufficient to meet demands and a substitute was sought (9).

In the emulsified form, the polyvinyl resin is finely dispersed in water. It comes as a milky white or brownish liquid and may be used at room temperatures (19). The resin appears to be polyvinyl butyral, acetate, chloride, or mixtures in various proportions. Plasticizers, fillers, pigments, and other ingredients may be present in addition to the resin and water (9).

The type of resin was found to be quick setting like animal glue, easy to use, has an indefinitely long working life, and produces an almost invisible glue line which will not dull cutting tools. For these reasons it has gained rather widespread use (9). However, coagulation in storage, by evaporation or freezing, must be avoided (19).

These glues are used at room temperatures. The curing action takes place as the water in the glue diffuses into the wood, where upon the emulsified resin coagulates. This action, however, is partially reversible and the resin may absorb water, partially redisperse and soften if it becomes wet. Therefore current adhesives of this type have little water resistance (9). The set resins vary considerably in hardness, the harder the resin the stronger the joint (19).

All the polyvinyl-resin emulsion adhesives are slightly acid, with pH values between 4.2 and 5.3, except one which was slightly alkaline. Solid content of the glue range from 31.7 percent to 58.6 percent (9).

The following characteristics of these adhesives have been found to be true: (1) The working life is indefinitely long and the stability in storage in tight containers is good; (2) The consistency and the non-volitile content (generally between 50 and 60 percent) are comparable to other resin adhesives; (3) The dry joint strength varies widely; (4) The water resistance of the joints is low; (5) Thermoplastic properties are indicated by decreasing strength at elevated temperatures and by failure to sustain moderate loads over long periods under room conditions (9).

Polyvinyl-resin Solutions

These resins are dissolved in alcohol, acetane ethyl acetate or other organic solvents and are marketed in syrup form. Thinners are used to adjust the consistency for use. Several coats are applied, and several hours are permitted to elapse between the applying of one coat and another. Several days are allowed to elapse between the applicate of the last coat and pressing (19).

The resins are hot-pressed at temperatures of 195° F. to 320° F. depending upon the resin's softening point. The heat causes the adhesive to flow and setting occurs upon cooling. (19).

Thermoplastic-resin glue joints appear to be lacking in durability under conditions of swelling and shrinking of glued members. Exposure to temperatures within the softening range of these glues likewise produce marked strength reductions and may result in delamination.

Separate-Application Resin Adhesives

The principle of separate application, or applying one component to the other surface is not, by any stretch of the imagination, new. They were used as early as 1892 in Germany, an ammonical solution of casein and milk of lime being the components. Animal glues and formalin solutions have also been used in this respect. Lately this principle has been applied to urea and resorcinol resins (9).

Separate-Application Urea-Resin Adhesives

Some of the first room-temperature-setting urea resins used in this country were of the separate-application type. These glues have been more favorably received in Europe and are more commonly used there than in the United States. During World War II, the English developed glues of this type which met their aircraft specification (9).

Investigations made by the Forest Products Laboratory have shown that such hardeners as oxalic, formic, and phosphoric acids, and ammonium chloride, when applied to a surface induce a rapid setting of urea resins at room temperature. Tests showed that the joints produced were high in dry strength and initial water resistance. In an accelerated durability test the joints proved less resistant than those made with one-part urea adhesives. Weathering tests with various species of wood showed these glues to be equal in durability (9).

These glues may be the answer to the demand for faster curing glues but until experiments present conclusive proof as to their durability and uniformity they will never gain wide acceptance.

Separate-Application Resorcinol-Resin Adhesives

Recently, due to the demand for more rapid setting, low-temperature adhesives, separate-application adhesives have been presented to the woodworking industry based on resorcinol resins.

Limited tests have indicated that maple joints develop sufficient strength in 20 to 30 minutes to enable taking them from the presses. Tests show that these joints continue to cure and increase in strength over a period of days after removal from the presses (9).

Information on uniformity of joints, durability, operating technique, etc., is not available at this time. If, however, these adhesives are to compete on the market, with other glues they must be able to produce strong, durable joints more cheaply and easily than those put out by high-frequency heating or long-time pressure periods (9).

Adhesives For Wood-to-Metal Gluing

Special resin glues have been and are being developed for the bonding of wood to metal, plastics, and other materials. These glues may be thermoplastic, a mixture of thermoplastic and thermosetting resins, or a mixture of thermosetting resin and rubber.

These glues may be marketed in liquid and powder form. In 1946, films were being developed but were still in the experimental and testing stage and had not yet been put on the general market (26).

Wood-to-metal adhesives have tremendous strength. Experiments have shown that two square inches of wood and metal joints have held up weights as high as 2500 pounds. Other glued joints have held without buckling or slipping under strains which have sheared off normal riveted joints (3).

Since these glues are relatively new, little is known as to how they will react under various exposure conditions and durability tests. Early data, however, shows promising results.

The use of artificial resins as woodworking adhesives is still in the developmental stage with new products and modifications constantly appearing. Although service tests over periods of 3 to 5 years have demonstrated high resistances to severe exposure conditions, judgement of quality and usefulness of an adhesive must be restricted to individual compounds since no general statements will hold for the overall field (13).

Part V NON-RESINOUS ADHESIVES

Because of the rapid expansion and development of synthetic resins in the past decade and the ability of resin adhesives to stand up under nearly all kinds of conditions, adhesives of the non-resinous type are slowly being removed from the overall picture. The glues commonly classed as non-resinous include animal, vegetable (starch), casein, vegetable-protein (soybeans), and blood-albumin types. Of these three, casein, blood-albumin, and soybean are of special importance in the woodworking industry of today.

The glues cannot be called modern in any sense of the word, since all were being used in this country to some extent prior to 1920. However, new uses have been found for these glues, not as adhesives alone, but in conjunction with the synthetic resin adhesives. These glues are also used as criteria upon which to determine the relative values of the resinous adhesives. Therefore a brief summary of these adhesives and their properties is in order.

Casein Adhesives

Caseins as glues were used in the middle ages. The actual manufacturing of this type of adhesive originated in either Switzerland or Germany in the nineteenth century and was to a limited extent in the United States until 1917. Production expanded when water-resistant glues were needed for aircraft during World War I. The use of casein in woodworking industry is of a rather recent date, about 1935 (4).

Manufacture & Preparation of Casein & Casein Glue

The principal ingredient of casein glue is casein, which is the chief protein constituent of milk and is found in the curd. The steps in obtaining casein are as follows: (1) The precipitation of casein (in curd form) from skimmed milk, (2) Washing the curd to remove lactic acid and other impurities, (3) Pressing the curd to remove the excess water, (4) Drying the curd, and finally, (5) Grinding it into a powder (29) (15).

Besides casein, other ingredients of the adhesive are water, hydrated lime, and sodium hydroxide (15).

These glues are classified as "prepared" and "wet-mix." Prepared glues are marketed as powders and are mixed with water when ready to use (29). Adhesives containing sodium hydroxide, hydrated lime, and casein can be used as "wet-mix" glues only. This is due to the fact that the hygroscopic properties of sodium hydroxide cause deterioration and decomposition when in storage (15). Hence, these glues are made by the user from the various raw materials according to prepared formulas (29).

Use and Working Characteristics

Dry casein and casein adhesive in powder form will keep for long periods of time so long as they are stored in a cool, dry place. They should also be kept in tight containers so as to avoid infestation by moths (15).

The working life of these adhesives is dependent upon the following factors:

(1) The amount of high-calcium lime it contains.

(2) Consistency, which depends on:
   (a) The time interval between the addition of each component.
   (b) The amount of water present.

(3) Temperature of the room and water used in mixing the glue.

As a general rule the working life of a glue varies inversely to the amount of calcium hydroxide present. Also increased temperatures will tend to reduce the period of the working life (15).

These glues may be spread by brush or by mechanical spreaders. The assembly time is determined by at least four factors: (1) Moisture content of the wood (usually 3 to 10 percent) (16), (2) Consistency of the glue, (3) Quantity of the glue applied, and (4) Temperature of the wood and glue (15).

Assembly periods in excess of 20 minutes should be avoided when possible in the case of casein glue (16).

Pressures should be great enough to insure a good joint and complete contact between the glue and the plies, however, it should not be so great as to crush the wood or squeeze out too much glue. Good results may be expected with pressures of 150 to 200 pounds per square inch. These pressures should be maintained anywhere from 1/2 to 2 hours (15). These glues will set at ordinary room temperatures (16).

In general it may be said that in working life, assembly time, pressure and rate of setting these adhesives are similar to cold-setting urea resins and are subject to approximately the same limitations (1).

Durability

The main advantage of casein adhesives is their water resistance and their ability to retain strength when wet (29). However, this so-called advantage has become somewhat questionable in the face of recent laboratory experiments. Continuous exposure at 80° F. and 97 percent relative humidity resulted in a rapid breakdown of casein glued joints (31). In a series of soaking and drying tests all specimens glued with casein glue failed by the end of 15 weeks (8). In comparison to vegetable and animal glues casein is high in water resistance but when it is compared to synthetic resins it is very low in this request.

Casein glue joints when kept dry, however, are very strong, very long lasting, and very durable (4).

Experiments have shown also that under high temperatures (194° F.) and moderate relative humidity (65 percent) casein glues are least affected. It was also shown that certain urea resins will deteriorate much more rapidly than will caseins (7).

The deterioration of casein glued joints is also attributed to two other agents. They are, (1) hydrolysis of the glue and (2) attacks by micro-organisms, such as fungus and bacteria (4).

Experiments carried on by Christensen and Moses (10) showed that much of the deterioration attributed to hydrolysis was actually caused by molds and bacteria. The main mold flora was made up of Penicillum brevicaule and P. glancum together with bacteria which were present in the glue could cause complete delamination in 1 to 3 weeks (10)

It has been found that casein adhesives can be rendered highly resistant to the attacks of these micro-organisms by treatment with certain preservatives chemicals such as the chlorinated phenols (4). Under the severe exposure of laboratory tests, trichlorophenol and sodium trichlorophenate were the most effective of the preservatives extensively used (22). Sodium orthophenylphenate appeared more effective against the bacteria than against the fungus and sodium trichlorophenate prevented any weakening by either mold or bacteria (10).

The addition of preservatives to casein glues may affect slightly the consistency or viscosity of the glue mixture and the working life, but in general, those glues which contain preservatives are the same as those without (1).

The hardness of cured casein glues causes dulling to cutting tools. To date there is no satisfactory way of relieving this objectionable character (29) (15).

Staining is another objection to the use of these glues. All strongly alkaline adhesives stain certain species of wood. If lumber is dry and veneer re-dried this effect will be reduced. If stain is present it may be removed by sponging with a 1 to 12 solution of oxalic acid and water (15).

Blood-Albumin Adhesives

Efforts to produce acceptable woodworking adhesives from blood-albumin have been carried on for the past 30 years. During the period of the first world war some plywood was made by hot-pressing glues which contained a base of blood-albumin. Hot-press paraformaldehyde-blood compounds have been developed but were never used extensively in this country (9).

Blood-albumin has been used in conjunction with synthetic resins, as an extender for high-temperature-setting phenolic resins. More recent commercial developments in the use of blood has been the formulation of an intermediate temperature-setting adhesive from a blood fraction. Results from early and limited tests indicate very promising results (9).

Manufacture of Blood Albumin & Blood Albumin Adhesives

Blood albumin itself is a slaughterhouse by-product using generally the blood from cattle (29). The albumin is obtained by processing the fresh blood and removing the fibrin and part of the red corpuscles and then evaporating to dryness below the coagulating point of the albumin, approximately 160° F. (14).

The glue mixtures are not placed on the market as dry powders because of the decrease in solubility of the albumin with age (14). Instead of the raw products are usually mixed at the time of using. Other ingredients going into these glues are lime, caustic soda, sodium silicate, and paraformaldehyde. Although the glue may not be purchased dry the albumin itself is usually bought in this form (17).

In order to mix dried albumin into solution, it is necessary to soak it for an hour or more in a cool place before stirring. After the solution has been obtained other reagents and ingredients may be added according to formulas. The addition of paraformaldehyde helps to decrease both the setting time but also the temperature (14).

Use and Working Characteristics

The working life of these adhesives will vary from several hours to several days depending on the amount of ammonia, lime or caustic soda added to the mixture (29).

The glue may be applied either with a brush or by a mechanical spreader (14). Assembly times will vary with the consistency of the mixture and may run from less than a minute to as long as 25 minutes (16). To set these glues, a temperature of at least 160° F. must be used to coagulate the blood. In order to cut down the pressing period, temperatures of 200° F. to 300° F. may be used. However, temperatures over 212° F. often cause blistering. Pressures of 100 to 200 pounds per square inch are commonly used (14).

Durability

The hot-press paraformaldehyde-blood glue showed very good resistance to moisture. Next to the synthetic resins they may be considered the most water resistant of woodworking adhesives. Tests showed that specimens glued with this adhesive held together for 2½ years and some as long as 3 years. However, they can not be considered waterproof since moisture changes over a long period will cause complete failure. Destructive humidities for these glues were between 90 and 97 percent (8).

Since these glues are high in protein content precautions must be taken to prevent their deterioration and decomposition by fungus and bacteria.

Soybean Adhesives

Soybean meal-representative of a large class of substances known as vegetable proteins, others are peanut and cottonseed meal, have been used considerably as a raw material and a base for woodworking glues (15).

These adhesives were first developed and introduced into the plywood industry of the Pacific coast where they have been used rather extensively (29). They may be used alone or in mixtures with casein glues (15).

Because of their high protein content, their glue making properties and characteristics are much the same as these of casein than those of the vegetable starch adhesives (29).

When continuously exposed to optimum temperatures and high humidities soybean glue joints are rapidly deteriorated by molds. Among the preservatives tested it was found that the chlorophenols, sodium chlorophenates, orthophenylphenol, and sodium orthophenylphenate were the most effective in preventing fungus growth. The addition of these preservatives did not effect the wet or dry strength or water resistance of these glues (23).

Although soybean adhesives tend to be cheap they have not yet proven to be completely satisfactory in gluing all types of wood and especially hardwoods (15) (29). However, they are gaining in popularity and are used quite extensively.

Part VI RADIO FREQUENCY GLUING

Operation

The principle of Radio Frequency heating may be explained as follows. When wood construction or any other non-conductive, solid material is placed in an electrostatic field through which electrical energy is alternated at Radio Frequency (one million or more cycles per second), the tendency to interrupt the field agitates the molecules of the wood and glue to the same frequency. This agitation causes molecular friction and generates heat throughout the material. This then is known as "dielectric" or high frequency heating.

The greater the density of the material the greater the number of molecules which are agitated and the more heat that is generated. As a result, a material of non-uniform density or moisture content when heated, heats and drys more quickly in the denser areas. Since glue (liquid) has a higher density than wood it tends to heat and dry faster (2).

Power for a Radio Frequency unit is supplied by a rectifier or power supply which converts the low voltage, alternating current (110-220 V.) into a high voltage direct current. The current is then picked up by an oscillator and is alternated at a very high frequency. It is then conducted to the ground and "hot" electrodes between which the work is placed (2).

The energy supplied by the generator may be divided into three parts. That which goes into the heating of:

(1) The insulation platens or electrodes.
(2) The wood stock.
(3) The glue line.

About 10 percent of the energy or current is lost in heating the insulators. The remaining 90 percent divides itself equally between the glue lines and the wood immediately adjacent to them. Since the glue lines are wet and uncured at the beginning of the cycle most of the energy is absorbed but as they dry the amount of energy absorbed decreases and this necessitates "tuning" the circuit for maximum efficiency (28).

The circuit of the oscillator should be kept "in tune" with the electrical capacity of the "load" or mass of material in the electrostatic field. As the heat increases, the material loses moisture, thus changing the capacity and its balance with the circuit. Some method of keeping the circuit in tune, either by manual or automatic means is desirable (2).

Equipment

Radio Frequency units are obtainable with various power output and frequency ranges. The purchaser should make thorough investigations of the product to be heated, the arrangement of the electrodes, and temperature requirements of the adhesives to be used. By combining these factors the purchaser may determine how much power will be needed and the best frequency range (2).

The 5 and 10 KW generators are the most popular size in radio and high frequency units. For smaller size panels up to 30" x 36", a 5 KW is usually recommended. Five megacycles is usually the frequency used since this low frequency is required to insure uniform heating over the boards (28).

There is a strong tendency at present to go to the higher frequencies, 13.7 megacycles, in order to speed up the curing time and to throw excessive power into the press so that the effect of thick and thin boards may be overcome. The maximum power is dependent upon the mass to be heated and is achieved by striking a proper set up between the voltage, per inch of thickness of the panel, the frequency, and the tuning characteristics of the unit. As the frequency is built up, the voltage and tendency for arcing is decreased (21) (28).

Personnel

Trained and skilled electrical engineers are employed by Radio Frequency equipment manufacturers to make studies of the prospective purchaser's individual arrangement and problems. These technicians will then recommend the most efficient type of unit to do the job and install it. The manufacturer's representative will also instruct the operators in the use of the unit. His recommendations should be followed closely (2).

The man who pushes the buttons can make or break the outfit and operation. Any person of average intelligence and ability can operate a unit after very little instruction. To start some of the new units one has only to push a button, with similar procedure for tuning, however, there is usually much more involved than mere button pushing. For really efficient production the operator should understand high frequency and radio, know the factors which influence the results, and be able to make small repairs when necessary. Many West Coast manufacturers have been using ex-Navy radio and radar operators, as well as electrical engineers and wood technologists, with gratifying results.

Method of Heating

The type of heating used depends on the arrangement of the electrodes; and this in turn, is usually determined by the nature of the construction or article to be produced, its size and shape, and the method of applying pressure to the joints. In general, there are three methods of electronic gluing; (1) Parallel heating, (2) Perpendicular heating, and (3) Stray-field heating (See

Fig. 3).

A. Parallel Heating. In parallel bonding or heating the glue lines are parallel to the flow of heat. This method is chiefly used for gluing core stock in a press.

There are two types of parallel bonding; the continuous process, involving application of heat while the clamped stock is moving under the electrodes as in Diehl-Dosker machines. A reversal of this method is now possible in which the electrodes are passed over the material while it remains stationary as in the lamination of beams, trusses, and rafters. The second type of parallel bonding is the intermittent batch method, in which the stock is stationary while being treated, as in Hart and Bell machines (28).

Parallel heating utilizes the greater conductivity of the moist glue line to concentrate most of the heat in the glue line itself. As a result, less power is used and very high glue-line temperatures are attained in a shorter period of time. This is also the case with nonarcing glues. Although these glues have low conductivity, they are more conductive than the wood. Because the glue line absorbs most of the energy in this type of heating, irregularities of moisture and thickness in this area have a more marked effect in causing temperature variations within it, with the thick areas curing slowly. For this reason, "parallel heating" is recommended only where the distance across the glue line from one electrode to another is small (2).

Glue requirements for parallel heating are much more exacting than for perpendicular heating. The glue must be of a cold-setting type and conductive enough to draw high frequency energy well, but not conductive enough to cause arcing (11).

Because of the direct contact between electrodes and the glue line, a nonarcing glue is recommended for most parallel heating applications. Where highly conductive adhesives are used it is best and usually necessary to leave an air gap between the platens and the glue line. However, this requires a greater amount of power to overcome the insulating effect and the resistance of the air.

B. Perpendicular Heating. Perpendicular heating indicates that the glue lines are perpendicular to the flow of heat. Plywood is made in this manner (28).

This method heats the entire mass between the electrodes with only slight variations in the temperature due to changes of density and moisture content in the wood. Since the entire mass is heated this system uses more power.

The relative uniform heating of the entire construction helps to keep the glue line at an even temperature, even though irregularities of thickness and moisture occur in the glue line itself. When platens or electrodes are long and there is a direct relationship between their length and the wave length, "standing waves" may occur causing dead spots where no heating takes place. This may also be found in parallel heating, it can be remedied by placing tuning stubs across the electrodes (2).

Almost any heat-sensitive glue can be used with perpendicular gluing. However, glues of the cold-setting type are more efficient from the production standpoint (11).

C. Stray-field Heating. This method is relatively new. It is used chiefly for continuous press operations and non-uniform shaped structures (28).

The "stray-field" system of bonding utilizes the "stray" part of the electrostatic field which is not directly between the electrodes. Since it uses only part of the electrostatic field, it is relatively high in cost in relation to the amount of joint heated and cured. This method is best applied in gluing small areas or portions of large areas, or inaccessible areas that cannot be located directly within the field or between the electrodes (2).

Cold-setting type glues, similar to those used in parallel heating work best in stray-field heating.

The efficiency of stray-field heating while quite high compared to perpendicular heating, is somewhat less than parallel heating (11).

Wood Requirements

Regardless of the type of electrode arrangement several requirements are necessary for successful radio frequency operation. These requirements are based on the character of the wood, properties of the glue, and the type of joint to be formed.

In looking at wood, there are two main properties to consider which are highly important to radio frequency operations, they are density and moisture content.

Dense woods such as oak, maple, and beech, require a longer time cycle (meaning the period of time necessary to cure the glue) than lighter materials, such as poplar and cottonwood. In some operations cherry, mahogany, and certain pines, have been difficult to glue. When mahogany is glued with high frequency the power must be kept low. Highly resinous pines with pitch pockets at the glue line may afford trouble. Gums that have an abundance of mineral streaks have a great tendency to arc (28).

Density of the wood used has a great effect upon gluing--low density woods are less critical with respect to the glue used. This is probably due to three things: (1) The wood is weaker and therefore requires less cure to show wood failure; (2) The electrode voltage is generally higher and (3) More uniform pressure is obtained (28).

Material used should have a moisture content of from 5 to 8 percent. Lower than 5 percent requires a longer time to heat the wood. Higher moisture contents above 8 percent may cause steam and water condensation on the electrodes, also forming wet areas on the wood which tend to overheat (2). Also, if the moisture content is too high, more heat is needed to cure the glue line. The lower ranges of moisture content have an additional advantage when highly conductive glues are used. The dry wood will absorb some of the water present in the glue, thus reducing the amount of squeeze-out and the tendency to arc (2). A board that has an uneven moisture content will tend to have a joint that is not square. A good square joint is absolutely necessary because a panel will not seat itself in a press as it will on a glue wheel (28).

The surface of the wood should be kept free from gross defects, such as large knots and worm holes, low spots, or other irregularities in which "pockets" of glue might collect. Such pockets tend to overheat, forming steam blisters. When a conductive glue is used, these pockets will also promote arcing (2).

Joint

The quality and type of joints to be glued by this process is also important. For example bevel joints never completely cure. A rough joint is easier to glue than a smooth one. If a jointer joint is used a very thin glue spread is necessary (28).

Stock of the same thickness will aid the quality of joints. A panel with thick and thin boards usually takes about twice as long to cure as one with boards of even thickness. This is due to the fact air gaps cause a drop in voltage and results temporarily in reduced energy absorption at the glue line. The uncured glue will then be found on both sides of the thin boards.

Thermal ~~Glue~~

The following is a formula for computing, approximately, the electrical power requirements to heat a given weight of material.

$$\frac{M \times Sp \times (t_2 - t_1) \times 2}{3413} = \text{required kilowatts per hour}$$

M is the weight, in pounds, of material to be heated. Sp is the specific heat of the material (.45 for wood). $t_2 - t_1$ is the desired temperature of the material minus the starting temperature in degrees F. 3413 is the number of BTU's (British thermal units) produced in one hour by one kilowatt of power. (2) is used as another factor in the equation because the energy is only about 50% efficient.

It should be noted that this is only a general and approximate method of computing power requirements (2).

It is necessary only to remember that it requires just as many BTU of radio frequency energy to raise so many pounds of material, so many degrees in temperature or to evaporate so many pounds of water, as it does when using steam or any other method of heating. It should also be remembered, however, that with radio frequency heating, the heat can be generated just where it is needed and losses from the system are minimized (6).

When formulating an adhesive for use with radio frequency, an attempt to incorporate as many as possible of the following properties:

1. Fast Setting.
2. Freedom from arcing.
3. Long storage life.
4. Low cost.
5. Uniform dependable adhesion.
6. Easy handling at the consumers plant.
7. Freedom from stain.
8. Freedom from odor and hazard to the operators.
9. Capable of setting at room temperature.
10. Development of a permanent durable bond to meet use requirements for either interior or exterior use.

As with other products, it is difficult to find a glue which has all of the above mentioned requirements. Hence, most operators will accept a compromise which embodies at least the most essential properties required or desired (30).

Two of the most important properties which radio frequency glues should possess are the first two mentioned above, fast setting, and freedom from arcing.

Glues should be thermo-setting so that they will react quickly at high temperatures utilizing the equipment and power to the best advantage (2). Animal, vegetable, and resin glues of the polyvinyl type are entirely unsatisfactory since they tend to produce weak joints at high temperatures. Casein glues do not work successfully because the rapid heating causes the water to evaporate so that a foamy, low strength glue line is formed (28).

Part of the heat used in curing thermo-setting resins is expended in driving off excess moisture in the glue mixture. This difficulty may be avoided by two methods. The first is by means of a "delayed assembly". That is by increasing the assembly time of the glue. This causes the glue film to become drier and cure more quickly when heat is applied. Care should be taken, however, that the time is delayed so long that the glue is partially cured before the joint is pressed. When a room-temperature-setting glue is used, the film of glue should be still moist when heat and pressure are applied (2).

The second method in cutting down the moisture content of the glue mixture is by means of substituting alcohol for about 1/3 of the required amount of water. This also results in a quicker drying glue film and a shorter curing cycle.

The second most important property concerns freedom from arcing. In order to obtain high production most of the radio frequency power is concentrated in the glue line with very little going into the wood. Therefore the glue must be of such a nature that it is arc resistant and sets rapidly (28). Rapid setting may be obtained by use of the above mentioned methods.

If the set up is such that the squeeze out or the glue line itself will be in direct contact with an electrode (as in parallel heating), the glue mixture should have a low conductivity to prevent arcing and the resulting loss of power in the other areas of the glue joint or in the other glue lines.

Arcing occurs when squeezed out glue runs down and makes contact with an electrode. The current, following the wet, conductive glue, flashes into the joint and chars the wood. Once it has started the arc will continue and absorb practically all of the power. The result being that the rest of the glue line has no heat and therefore no bond is formed.

In severe arcing the carbonized wood may also create a conductive path for the current and the arc will continue until the material bursts into flames.

This phenomenon is also called "flash-over".

On the basis of experience various types of glues were classified by the Forest Products Laboratory, in regard to the trouble they gave with arcing, as follows:

Very good ---

Melamine resins

Acidic phenol formaldehyde resins

Good ---

Urea resins

Resorcinol resins

Bad ---

Intermediate-temperature-setting phenol resins

Casein glue

Soybean glue

Very bad ---

Alkaline hot-press phenol resins (9).

Although alkaline hot-press phenols produce a durable boil-proof bond they are very prone to arcing due to the strong electrolytes which they contain (2).

Under the conditions of the experiments these glues produced brown carbonized streaking perpendicular to the direction of the field was observed soon after the glue began to boil; then points in these streaks arced, spread laterally forming a deeply carbonized path parallel to the field, after which the wood burst into flame (30).

Hot-press phenols of several different degrees of alkalinity were tried. The more alkaline the glue, the more quickly did the brown perpendicular streaking and black parallel paths occur (30).

Urea resins do not produce as durable and heat-proof a bond as the phenols but are not liable to arc (2). The Forest Products Laboratory experiments showed that no arcing occured with ureas, melamines, acidic phenols, or resorcinols (30).

However, the conductivity of urea-resin mixtures depend, in a large part, on the type of catalyst used. As a rule, the faster setting mixtures tend to be more conductive than those which set more slowly (2). With the soybean, casein, and intermediate-temperature-setting phenolic glues some arcing and carbonization of the glue and wood did take place before the glue dried, after which the action ceased (30). Because of this conductivity and because they contain large quantities of water, therefore curing slowly in the radio frequency field, casein and soybean glues are generally not used for this method of gluing (2).

Recently, through research into problems of radio frequency adhesives, there has been developed a non-arcing glue of high value. This glue goes under the commercial title of "Coscophen RF-228", produced by the Casein Company of America. This unique resin will tolerate greater power densities at higher voltages than ordinary phenolic type resins. In most applications, it will not arc or burn, even when the electrodes are brought into direct contact with the glue line (2).

Although Cascophen is one answer to non-arcing glues it cannot entirely meet the demand. Until other glues like it are developed or this type is placed on the market in greater quantity, the glue user should choose between one of two things. Either use those types of glues for radio frequency curing that show little tendency to arc or content himself with slow curing conditions under which arcing will be encountered.

It is recommended that a room-temperature or intermediate-temperature-setting glue be used when practicable with radio frequency equipment. These glues offer a number of advantages. The curing time can be reduced by attaining only an initial set which bonds the surfaces well enough to permit handling, allowing the remainder of the cure to take place at room temperature. The joint may be "tacked" or cured at a number of small areas then stacked for further curing. Lastly, these resins which cure at lower temperatures insure a good final bond, even though temperature differentials, due to irregularities of spread or the condition of the wood, may occur during the curing cycle (2).

Glue pot life also has considerable bearing upon the speed of cure. As the glue becomes older it cures faster but control of spread is harder and a heavy spread takes longer to cure. Mixing the glue in small batches seems best (28).

Pressure

The application of pressure during gluing must be sufficient to produce tight joints while the glue is curing. Not only must the wood surfaces make direct contact with each other but pressures of 100 to 200 psi (pounds per square inch) should be maintained on the joints when gluing soft-woods, and over 200 psi when gluing hard-woods (30).

Low pressures, below 150 psi give good bonds on low density woods that have a good joint, but a wide glue line is obtained with these low pressures which make it unsuitable for face stock. With high pressures, over 250 psi, there can be allowed a greater degree of tolerance in the condition of the wood stock with respect to sawing, jointing, and worping, but this still leaves a panel (at least two pieces of wood glued together) that is under stress and which may open at the joints under future machining and manufacture. Top pressure of 1 psi and side pressures of 200 to 250 psi are recommended as best (2).

Safety of Units

When one hears about 7600 volts in a machine he begins to wonder as to its safety. Actually this equipment in production is one of the safest operations in a woodworking plant.

All the high voltage supply, oscillator and control circuits are enclosed in a cabinet. On the doors of this cabinet are safety switches that cut off the power when the doors are opened. The high frequency energy is carried to the electrodes by the co-axial transmission line. The high voltage leads consist of copper tubing running through a copper pipe, which is grounded. This, also, eliminates radiation which causes interference with broadcasting (28).

The presses are usually covered so that there is no danger of contact with the electrodes. Should a worker come in contact with an electrode, the only harm that can come to him is the burning of that portion of the body making contact. The resulting burn is similar to that received from a red hot stove or an electric iron. Shock or electrocution is not possible as it is with the familiar 60 cycle power lines. If the operator should stick his arm between the electrodes he would feel no more than a sudden heating of his arm (28). However, shut-off switches should be at convenient locations within easy reach, especially when the main control panel is located at some distance from the electrodes, or when automatic equipment is used (2).

As to sterility, there is no danger involved. The type of energy is very different from that of X-Ray and atomic radiation and equipment.

Cost

The one aspect of high frequency which is of most interest to operators is the cost.

Actual cost figures are very difficult to obtain since this is a rather new field. The figures which are available, however, should give a good indication of possible results (28).

A prospective user of radio frequency equipment should at least be familiar with some of the older methods of gluing so as to determine the most practical and best one for his operation and requirements. Such factors as (1) original cost of the machine and installation, (2) the purpose for which the product is intended, and (3) the overall economy and saving of such an operation, must be considered (2).

The initial cost, of course, is for the unit itself. It is recommended that units which are purchased be large enough to do the job. In one model the difference in the initial output between a 5 KW and a 10 KW unit is somewhere around $3000.00 (28). As a very rough estimate, one can assume that a radio frequency generator will cost about $500.00 per K.W. of output at ratings at 10 KW and above (6).

As for hourly operating costs, a 5 KW unit will run about 70¢ to the hour, while a 10 KW machine operates at 76¢ per hour (28).

Radio frequency equipment is not cheap but in many applications it is justified on the basis of high production obtained and on its ability to put heat where it is needed most (6).

The first major step in any application of radio frequency heating which appears technically feasible is an economic analysis to determine the cost per pound or the cost per piece of any given operation. If this seems favorable and reasonable in comparison to other methods for doing the same job, it is almost certain that one can then work out the technical details of the operation or application (6).

It follows then, that dielectric heating is most economically applied where thick sections, difficult to heat by other methods, are involved (6).

Comparative cost figures in one operation of making face panels using an 8 KW unit (28):

Direct Operating Costs	Dollars per 1100 ft.

	Clamp Carrier	High Frequency
Electrical Energy (one cont 1 KW hr.)	- - - - - - -	0.20
Tube Replacement (every 6000 hrs)	- - - - - - -	0.11
Maintenance	.03	.10
Direct Labor	12.00 (6 men)	4.00 (2 men
Glue	4.80	2.60
Total	16.83	7.01
Total Investment Cost	$3500.00 (2 clamp carriers at $1750 ea)	$12310.00 (unit,press, spreader)

Comparative Operating Costs

	Clamp Carrier	High Frequencey	Saving
Per Producing hr. (1100 BF)	16.98	7.53	9.45
Per 8 hr day	135.84	60.24	75.60
Per year	40,752.00	18,072.00	23,680.00

Operating costs are not only reduced on edge bonding but on a number of other specialized operations. The following figures show the saving on making bent rails using 4 KW unit.

Operating Costs/Rail	Cold Press	High Frequency
Unit cost	$0.00	0.02
Direct Labor	.11	.03
Glue	.05	.03
Total	.16	.08

Saving .08/rail $800/10,000 rails.

Advantages and Disadvantages

The obvious advantage of high frequency heating is its ability to generate heat inside the article which is being heated. Hence, when used to set glue in a thick stack of plywood, the center heats as soon and as fast as the outer surfaces. It is not necessary to wait a long time for the heat to soak in, as is the case with heated platens (steam, hot-air, etc) in contact with the surface layers of the article (6).

Other advantages of radio frequency heating are: (1) It produces rapid and relatively uniform heat; (2) With parallel heating, it concentrates this heat in the glue line without an appreciable loss in moisture in the stock; (3) It may be used to heat curved assemblies, where cost is high, steam heated forms might be prohibitive. Form for radio frequency heating may be made of wood or other durable material covered with a metal electrode (2).

When used with room-temperature-setting glues, radio frequency energy may be economically used to "tack" small areas of the joint sufficient to maintain pressure, allowing the remainder of the glue line to cure and set at room temperature (2).

The major disadvantage of radio frequency heating is the relatively high cost of the equipment and the power used. Even though this method is efficient in that it heats only the material between the electrodes, it is not an economical source of heat as compared to steam or hot-air.

Present & Future Uses & Improvements of Radio Frequency Heating

Experience has shown that there are only about three good reasons for considering high frequency gluing methods in comparison with others.

(1) High frequency may reduce the unit cost of a product through savings in handling. This comes about through quicker polymerization of the glue, lower clamping costs, and the saving of floor space.

(2) Because of better uniformity or selectivity of heat it is often possible to improve the quality of the product. Increase in quality means increase in value of the product. This in turn, means an increase in the margin of profit.

(3) Not infrequently high frequency does a job otherwise impossible (30).

If high frequency is unlikely to do one or more of the above for a specific gluing job, there is seldom any justifiable basis for its use. A number of radio frequency sets are now in use where the saving of decreased handling of the product is nullified by the increased handling of the set (30).

At present there are a number of gluing applications where the use of high frequency seems to have a clear superiority on an economic and practical basis. They are as follows:

(1) Prefabricated housing. The possibilities of this application have long been apparent. The salient features of the electrode platen design are: (a) The generous use of resilient and electrically suitable materials to take care of dimensional tolerances; (b) A single platen design which will glue any type of panel which fits into the platen area, be it wall, window or door. A bond is obtained no matter where the stud is located under the plywood facing.

(2) Edge gluing of core lumber and hardwood panels. For production rates between 3000 and 55,000 BF per day, there is considerable evidence that presses used with radio frequency can out-perform clamp carriers. This is based not only on the reduction of the actual heating time to 5 to 20 seconds but upon production of a higher number of board feet per man-hour.

(3) Roof trusses, arches, barn rafters, and girders. The cost per foot of truss is very greatly reduced by continuous methods of applications of radio frequency power.

(4) Furniture assembly. Wherever the production vol-

ume of furniture pieces is reasonably high (a cut of 500 to 2000 sets at a time) there are very considerable advantages to be taken of the high frequency technique in reducing handling costs.

(5) Veneer patching. The setting up of the glue line beneath ordinary boat patches in 5 to 20 seconds is of great advantage. Small and portable equipment for this application is available (30).

The potentialities of high frequency heating in the wood-working industry as indicated by the successful applications already mentioned has created a great amount of enthusiasm. Wherever heat enters into the manufacturing picture the question is brought up, "Can radio frequency do the job better or cheaper".

At present there are a number of applications which are impractical for high frequency heating due to cost, mobility of equipment or increased or over handling of material and equipment. However, in the future these "bugs" of radio frequency heating may be ironed out so as to make these applications reasonable. The operations are as follows:

(1) Flat Plywood Manufacture. The basic advantage of high frequency heat is its ability to heat relatively thick sections quickly. Thin veneers less than one-half inch in thickness may be heated at less cost with steam platens,

though not quite so quickly.

(2) Low Volume Edge Gluing. Under 3000 BF per day, the initial cost of high frequency equipment is usually more important to operators than operating cost.

(3) Prefabricated Housing "On-the-Job" Assembly. This type of application demands unusual portability and ruggedness. These are not compatable with power requirements and size of equipment, at present.

(4) Mineral Insulation for Housing. To date, rock-wool and other mineral insulating materials have been ruled out due to the fact that they usually have too low a power factor to heat with any reasonable efficiency with high frequency.

(5) Kiln Drying. Although the principal of radio frequency heating is ideally suited to kiln drying lumber, the cost factor, both the initial output and the operating expense, is too high and at present uneconomical.

(6) Veneer-splicing. The same reasons apply here as apply to (1) Flat Plywood Manufacture.

(7) Drying Small Articles. Although high frequency is impracticle for large pieces, it may be effectively used for drying out small pieces of wood.

(8) Compreg and Impreg. Because there are few markets for such material, the output is small. Hence, the cost of high frequency again exceeds the margin of profit.

The future trend is toward lighter, more portable and more versatile units. They have a very definite place in the wood-working industry as evidenced by the aforementioned applications (30).

Part V SUMMARY AND CONCLUSIONS

The art of gluing and making glue is as old as the pyramids of Egypt, however, at no time since their beginning have woodworking glues enjoyed as much development as they have in the past decade, during the war years and the postwar period. At present, the plywood and furniture manufacturers have at their command more types of woodworking adhesives to meet the varying situations of their industry.

The development of synthetic resin adhesives has given to a series of woodworking glues which are very resistant to severe exposure conditions such as extreme temperatures fluctuations, moisture variations and attacks by micro-organisms.

Of the synthetic resins, those of phenol-formaldehyde bases have proved most resistant to all exposure condition. The phenol resins cure at very high temperatures (200° to 300° F.) and therefore expensive equipment capable of producing high temperatures are needed when using them. Urea resins have the lowest curing temperatures (70° to 75° F. and up) of any of the resin adhesives and enjoy widespread use because of the simple methods employed in their application and setting. These glues, however, have low resistance to moisture and breakdown over long periods of time. Tests (Bergin) have shown that even the older casein glues withstand higher temperatures than normal urea-resin glues.

The durability of urea-resin adhesives, in regard to high temperatures may be increased by adding melamine or resorcinol to the mixture. Resins treated thus are known as fortified urea-resins.

Even with the development of the resinous glues the woodworkers problems are not completely solved. The more resistant adhesives cure at high temperatures and therefore demand more expensive equipment. The lower temperature setting types are also of low durability. To offset this melamine and resorcinol resins have been developed. These glues are of the intermediate and low temperature-setting type (150° F.) but are relatively new and have not completely proved themselves as far as durability is concerned. Resinous glues tend to be expensive but by the use of filler and extenders, such as walnut shell flour, glue line costs may be kept to a minimum.

The development of resinous adhesives did not mean the end of non-resinous glues but these were restricted to certain fields. Of the non-resinous glues three tend to be rather outstanding, they are casein, blood albumin, and soybean glues.

Casein is a proteinaceans material extracted from the curd of milk which when mixed with lime and other chemical ingredients produce an adhesive of fair durability which would cure and set at room temperatures. These glues, however, breakdown under prolonged moist conditions though they do show marked resistance to high temperatures. Because of their high protein content they are prone to attacks by molds and bacteria and plywood glued with casein adhesives may be delaminated in this manner.

Blood-albumin is an extract from beef blood and when mixed with paraformaldehyde produces glue joints of high durability when subjected to hot-press or high temperature-setting methods. These are of protein material also, as is casein, hence, they too may be broken down through micro-organism attacks. A recent development of blood-albumin is use as an extender in conjunction with hot-press phenols.

Soybean meal adhesives were first developed on the Pacific coast and are used quite extensively on the plywood industry of that region. These glues are high in protein and durability is only fair.

The demand for better and faster drying adhesives not only gave rise to new glues but also to new methods of gluing. Among the newest methods is that of radio frequency heating.

This method employs "molecular friction" to create heat and set or cure the glue. A current is oscillated between two electrodes or platens at a high frequency (1,000,000 cycles per second). Whenever, a non-conducting material is placed between the electrodes, the molecules of the object are agitated to this same frequency and heat the material. The denser the material the more molecules present, hence, a greater amount of heat is produced. Thus glue being denser than wood generates more heat and dries more quickly.

Through the use of this procedure large laminated structures such as ship keels may be heated throughout and uniformly in a manner of minutes. Thus handling time of such stock is cut down, cutting down expense and increasing profits. Also there was an increase in production.

Experiments by the Forest Products Laboratory at Madison, Wisconsin, have been carried on to prove which types of adhesives are best to use with radio frequency gluing. Some glues have a tendency to arc more than others.

Arcing is an occurance caused by glue which is squeezed out from between the laminations and makes contact with the electrodes. The result is a short circuit which chars the wood and causes a very weak and uneven joint.

The experiments showed that the greater the alkalinity of the glue the greater the tendency to arc. As a result hot-press phenols were the worst while melamine and acidic phenol resins proved the best.

The results have presented a new problem to the field of gluing. That of producing a glue with the strength and durability of hot-press phenol resins but with little or no tendency to arc.

Two major objections and obstacles to using radio frequency gluing are the high initial cost and the lack of trained personnel to run the machines. Unless an operator is producing a large volume of goods it will hardly pay him to use high frequency gluing at present.

Personnel which operate the radio frequency units can either make or break a concern. These men must be well trained in wood technology, radio engineering, and should know something about gluing procedures in general. Such a combination is hard to find, however, Pacific coast operators have been using ex-Army and Navy radar and radio personnel with very good success.

Another objection to this method of gluing is the size and immobility of the present machines. The future trend, however, is toward smaller, more mobile, and more versatile units.

LITERATURE CITED

(1) ANONYMOUS.
December 1943. Wood Aircraft Inspection and Fabrication. Army-Navy-Civil Committee ANC Bul. No. 19. PP 162, 163, 165, 166, - Illus.

(2) ________.
May 1947. Radio Frequency Heating For Gluing Wood. The Timberman, Vol. XLVIII #7. Illus.

(3) ________.
March 5, 1945. Superglue. Life Magazine. PP 73-75.

(4) ARNESON, G. N.
1946. Glues and Gluing in Prefabricated House Construction. Reprint. Cosgrove's Magazine. PP 1-4

(5) BABCOCK, G. E. & SMITH, A. K.
1944. Extending Phenolic Resin Plywood Glue With Corn Gluten and Soybean Meal. U.S. Dept. Agriculture. AIC Bul. No. 65. P-1.

(6) BAKER, ROBERT M.
1948. Principles of Dielectric Heating. Forest Products Research Society. Preprint. PP 4,7.

(7) BERGIN, EARL G.
1946. The Effect of High Temperature on Casein and Cold-Setting-Urea-Formaldehyde Glues. Dominion of Canada Forest Service. Forest Products Laboratory. Mimeograph No. 120. Ottawa, Can.

(8) BROUSE, DON
April 1938. Serviceability of Glue Joints. Forest Products Laboratory Mimeograph No R 1172 PP 5-7.

(9) ________. and BLOMQUIST, R. F.
1947. Postwar Developments in Woodworking Glues. Forest Products Research Society. Preprint. PP 1-4, 7, 9.

(10) CHRISTENSEN, C. M. and MOSES, C. M.
June 1945. Mold and Bacteria That Delaminate Plywood Bonded With Casein and Soybean Glue

(10) U. S. Dept. Agriculture. Forest Pathology. Special Release No. 25.

(11) DIMOND, LLOYD E.
1948. Glues For Use With High Frequency Heating. Forest Products Research Society. Preprint. PP 2, 3, 6. Illus.

(12) EICKNER, HERBERT W.
November 1942. Rate Of Setting Of Cold-Setting Urea-Resin Glue Joints. Forest Products Laboratory. Mimeograph No. R 1422. PP 6, 7.

(13) FOREST PRODUCTS LABORATORY.
July 1939. Artificial Resin Glues For Plywood. Forest Products Laboratory. Mimeograph No. R 1055, Revised. P 3.

(14) ______________________.
July 1938. Blood Albumin Glues: Their Manufacture, Preparation, and Application. Forest Products Laboratory. Technical Note. No. R 281-2, Revised. PP 1, 2, 4.

(15) ______________________.
July 1939. Casein Glues: Their Manufacture, Testing, and Preparation. Forest Products Laboratory. Technical Note No. R 280. PP 1, 2, 6-10.

(16) ______________________.
August 1945. Control of Conditions In Protein and Starch Glues. Forest Products Laboratory Mimeograph No. 1340, Revised. PP 1-3.

(17) ______________________.
October 1941. Glues For Use In Aircraft. Forest Products Laboratory Mimeograph No. 1337. PP 1-3.

(18) ______________________.
January 1944. Laminating of Timber Products With Low Temperature, Phenolic Type Resin Glues. Forest Products Laboratory Mimeograph No. R 1437. PP 10-14.

(19) FOREST PRODUCTS LABORATORY
1947. Synthetic Resin Glues. Forest Products Laboratory Technical Note No. 1336. Revised PP 1-19.

(20) ______________________.
November 1941. Testing and Mixing Aircraft Glues. Forest Products Laboratory Mimeograph No. 1338. PP 1-3.

(21) GABRIEL, A. E. and COHODAS, LEAH E.
September 1944. Analysis For Filler Content of Urea Formaldehyde Glues. Forest Products Laboratory Mimeograph No. 1333 P 1.

(22) KOUFERT, F. H.
October 1943. Increasing the Durability of Casein Glue Joints. Forest Products Laboratory Mimeograph No. 1332. P 16.

(23) ______________.
March 1944. Experiments For Preservatives For Soybean Glue and Soybean-Glued Plywood. Forest Products Laboratory Mimeograph No. R 1447.

(24) LEICESTER, W.
1944. The Influence of Modern Glues on the Utilization of Wood. PP 4-7.

(25) LIBBY-OWENS-FORD-GLASS COMPANY
1944. The Interesting Story of Plaskon Resin. PP 3, 5, 6.

(26) RESINOUS PRODUCTS and CHEMICAL COMPANY
1946. Metal-to-Metal and Wood-to-Metal Gluing.

(27) RINKER, R. C. and KLINE, G. M.
August 1945. A Survey of Adhesives & Adhesian. National Advisory Committee for Aeronautics Technical Note No. 989.

(28) THURNER, J. T.
February 1, 1948 Should I Use High Frequency. Southern Lumberman. Vol. 176, No. 2204.

(29) TRUAX, T. R.
1929. The Gluing of Wood. U. S. Dept. Agriculture. Bulletin No. 1500. PP 1.

(30) UNIVERSITY of WASHINGTON, COLLEGE of FORESTRY
1947. Conference on Radio Frequency and Its Applications in Gluing Wood. Bulletin No. 2. PP 6-9, 21, 28, 49, 50, 59.

(31) WANGAARD, F. F.
December 1946. Summary of Information on the Durability of Woodworking Glues. Forest Products Laboratory Report No. 1530, Revised. P 9.

APPENDIX

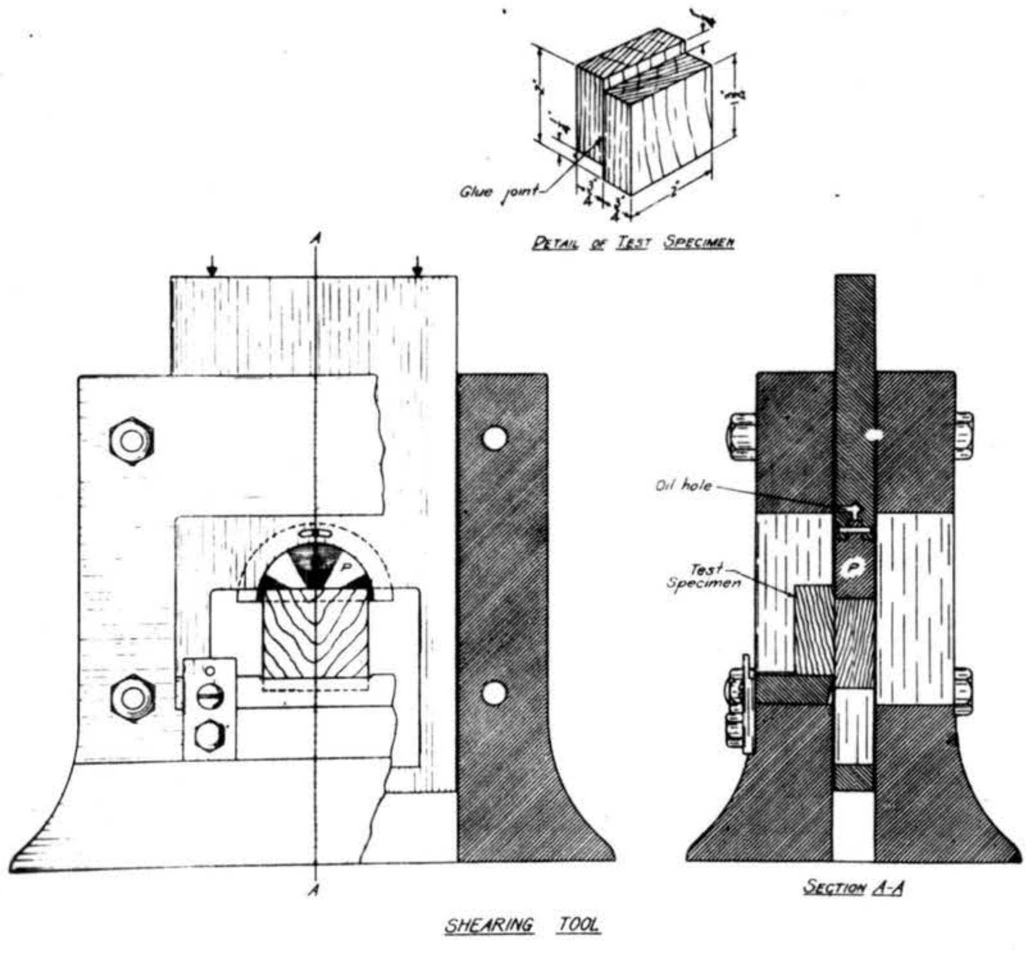

Fig. 1 - Specimen and shearing tool used in the block-shear test (20).

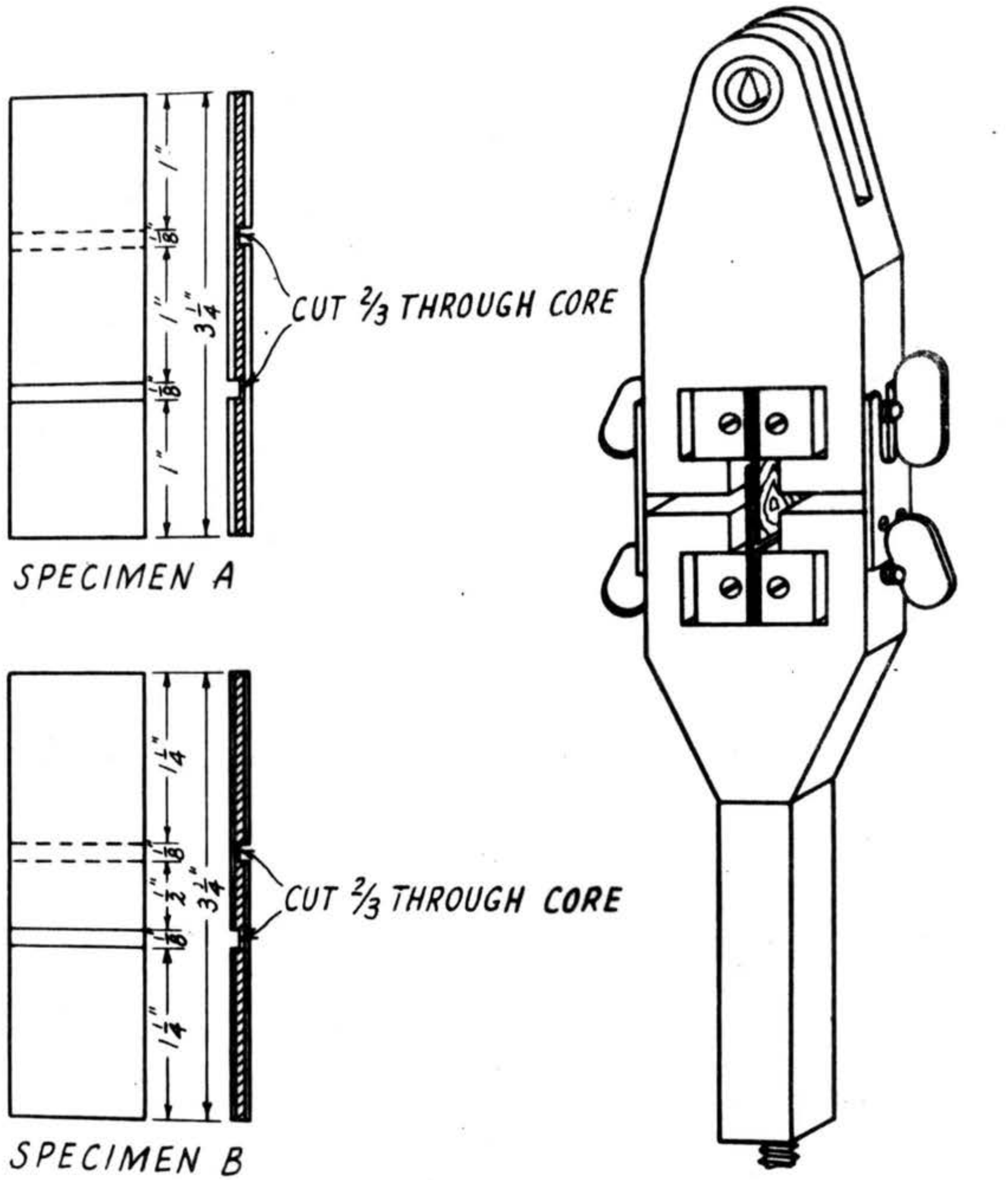

FIGURE 1 - PLYWOOD GLUE SHEAR-TEST SPECIMENS

FIGURE 2 - TESTING GRIPS

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Fig. 2 - Specimens and testing grips used in the plywood-shear test (20).

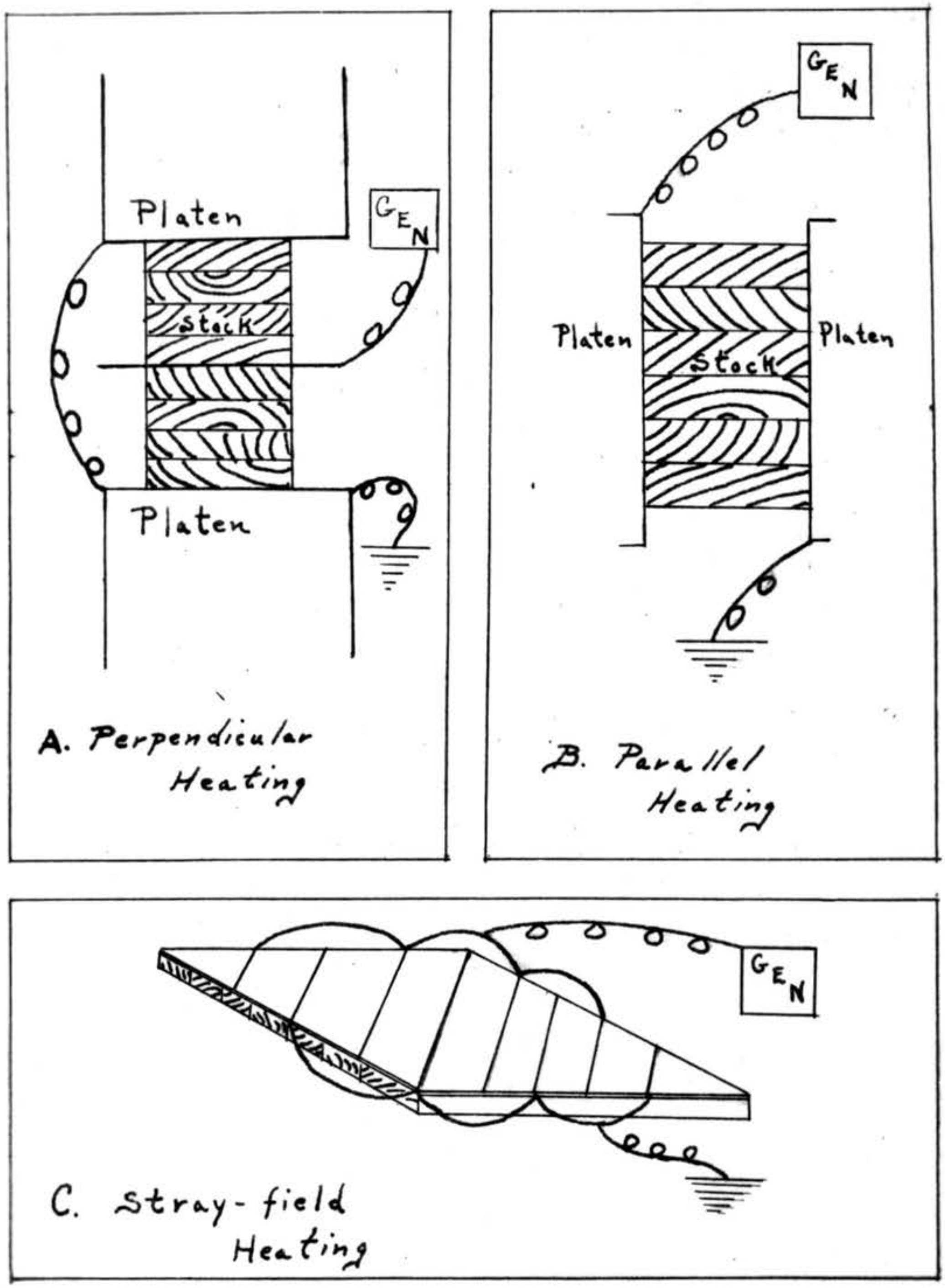

Fig. 3 - Electrode arrangements used in high-frequency gluing (2).