PROPERTIES OF SYNTHETIC RESINS USED AS WOOD-BONDING ADHESIVES

by

John Frank Logan

Date 5/29/49

Approved H. E. Troxell jr

A THESIS

Submitted in partial fulfillment of the
requirements for degree of
Master of Forestry in the
Division of Forestry
of
Colorado
Agriculture and Mechanical College
Fort Collins, Colorado
1949

ACKNOWLEDGEMENT

The writer wishes to express his appreciation to professor H. E. Troxell of the faculty of Colorado Agricultural and Mechanical College, Fort Collins, Colorado, for his assistance in the preparation of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES.--Continued

LIST OF FIGURES.--Continued

INTRODUCTION

The purpose of this thesis is to assemble all available data pertaining to the synthetic-resin glues and present a compendium that can be used as a convenient reference. The field of synthetic-resin glues is relatively new, and very much information has been obtained through use and experiment. This information has not been collected, sifted, and condensed into a single unit of information.

The increasing use of wood products and the decreasing supply of high grade timber has brought about the need for some method of utilization of lower grades of timber resources. A need has developed for methods of utilization of inferior species, small sizes of material, and products of the lumber industry that are ordinarily wasted. One of the answers to this need seems to be wood-bonding substances. Wood glues help in the saving of materials and in the production of articles of unusual form, dimensions, and properties. Nearly every article of glued-wood construction represents an economy in the use of timber resources.

It should be kept in mind when reading the following material on synthetic-resin glues, that they are important commercial products, and numerous glues are available on the market. All of these commercial synthetic resins can be classed as glue types. The material in this paper deals with each glue type, and the information given is based on impartial tests to which a number of commercial glues have been submitted.

The properties of each glue that fits into a type can be varied greatly by changing the kind and amount of filler, extender, hardener, or solvent. The manufacturer states the type to which the glue belongs, but does not divulge the formula of the glue. So, in testing a number of commercial synthetic-resin glues it can be seen that the results will vary over a range of conditions as to their durability, curing temperature, assembly, etc. The information in this report is based on that range of results as obtained by impartial scientific tests. As such, it is evident that the information embodied within this paper does not endorse any commercial product.

GLUE BACKGROUND

Many wood-bonding glues had been used before the advent of the synthetic-resin glues. These earlier wood adhesives can be considered in the five classes as follows: animal glues, liquid glues, casein and vegetable (starch) glues, blood-albumin glues. There are various other adhesive substances including silicate of soda, mucilages, pastes, rubber cements, cellulose cements, phenol-aldehyde compounds, asphalts, gums, and shellac, some of which are used to a limited extent for gluing wood; but the main wood-bonding glues can be considered in the five main classes listed above (36). 1/

ANIMAL GLUES

Animal glues have been used for several centuries. Their desirable qualities for woodworking are high strength in joints, free-flowing consistency, quick-setting, stainlessness, and adaptability to different use conditions. The cost of animal glue and the precautions necessary in applying it are the chief factors which limit its use. They also lack a desirable degree of resistance to moisture, and their operating

1/ Refers to literature cited.

characteristics are not suitable for fabrication operations (10, 36).

LIQUID GLUES

A high percentage of the glues sold in liquid form are made from the heads, bones, skins, trimmings, and swimming bladders of fish, and the whole class is often referred to as fish glues.

Some liquid glues, however, are made by treating animal glue with a chemical agent, usually an acid, and some are made from other raw materials. Only the best liquid glues are reliable enough to use in making wood joints. The chief advantage of these glues is that they come in prepared form, ready for immediate use, which makes them particularly suited for patchwork and small gluing jobs (36).

CASEIN AND VEGETABLE-PROTEIN GLUES

Casein glues were known for a long time, but their use in woodworking was not accepted until about 1915. Their great advantage is in their high water resistance - their ability to retain strength when wet. They also have a very low setting temperature, but set much quicker when higher temperatures are used (21). Casein glue ingredients are casein (prepared curd of milk), water, hydrated lime to give water resistance, and a fourth ingredient of trisodium phosphate or similar chemical is added to lengthen the working life. Among casein disadvantages are their dulling effect on tools, tendency to discolor wood, relatively short working life, and their high viscosity (36). Casein glues are among the better glues of those outside the field of synthetic resins. For comparisons with synthetic-resin glues see figures one through ten and figure thirteen.

Vegetable-protein glues such as soybean and peanut-meal glues ariginated on the west coast and were used in the plywood industry there. They are cheap but have not proved to be satisfactory for gluing all kinds of wood (17).

VEGETABLE GLUES

"Vegetable glue" is a term applied in the woodworking trades exclusively to glue made from starch. They are made from raw or processed starch and are clearly distinguished from pastes. They make strong joints, are cheap, can be used cold, can be kept free from decomposition, and can be kept in good working condition for days. For this reason they were extensively used. They are impractical for some uses due to extreme viscosity, lack of water resistance, stain certain woods, and set relatively slowly (36).

The principal raw material used in making vegetable glue is cassava starch, which is obtained from the roots of the cassava, a tropical plant. Potato, corn, wheat, and rice starches can be used as the base of vegetable glues, and of these potato starch is the most favored (36).

BLOOD-ALBUMIN GLUES

Blood-albumin glues have not been used extensively in this country, but they have seen more use in Europe and Asia (36).

Blood-albumin, a by-product of slaughter houses, has the property of coagulating and setting firmly at temperatures near 160°F. It has a good resistance to the softening effect of water, and this characteristic makes it desirable in the production of water-resistant plywood. The chief disadvantages in using this glue for woodworking are: the necessity for hot pressing, which requires expensive machinery and much handling; their usually low dry strength; and the fact that they cannot be marketed in a dry-mixed form ready for the addition of water. A highly water-resistant glue with moderate strength has been prepared which does not require hot pressing, but it does not give as uniformly good results as the hot-pressed glues (36).

The blood of cattle is generally used to make this glue. The albumin is separated from the other substances of the blood and then dried at a temperature below its coagulating point. There are many patented processes for blood-albumin glues, and some of them manage to get large amounts of water into the glue without destroying its jelly-like form. These blood-albumin glues with high proportions of water are often lacking in strength (36).

SYNTHETIC RESIN GLUES

The relatively new field of synthetic-resin glues was opened about 1932 when a phenol resin reached a price that allowed it to compete with other glues in the woodworking field. It proved to be the first woodworking glue capable of forming joints more durable under severe conditions than the wood itself. Since that time there has been rapid development in synthetic-resin adhesives. High-temperature-setting ureas and room-temperature-setting ureas followed the introduction of high-temperature-setting phenol-resin glues. Melamine-resin glues were made that cured at 180° to 300°F., and had glue lines of high resistance to extreme exposures. A resorcinol-resin glue became available in about 1943 that would cure adequately at room temperatures to form joints of high resistance (10).

The synthetic-resin glues made a good war record and now have many uses. They were used for war materials such as cargo planes, merchant ships, airplane parts, army skis and snowshoes, ponton bridges, laminated woodspans, and a number of other uses. They are now being used in any field in which laminated woods may prove economically successful such as plane parts, furniture, prefabricated housing, boats, structural materials and a host of other uses (24).

The synthetic-resin glues show great advantage over the older type glues in many ways. They can be used anywhere, indoors or outdoors, under any condition of exposure, above or below water, and above or below ground (22). They have the added advantage over glues from protein derivatives in being resistant to attack by bacteria, fungi, and molds. Their high water resistance is an advantage over most glues (24). They also resist damage from most chemicals, such as wood preservatives, fire-retardant chemicals, and oils. They stand up remarkably well under varying conditions of temperature and humidity (4, 10, 19).

GLUING TECHNIQUES

Success in bonding and joint strength depends as much on good gluing practices as on good glues (4).

SURFACING

Lumber surfaces should be clean, smooth and accurately machined, so that all parts involved in the joint will come easily into direct contact with each other. Wood should be surfaced when dry and preferably within a short time before it is glued (21). The moisture content should be controlled between time of surfacing and gluing. Planers or jointers are preferred for surfacing (4).

It is not generally recommended to glue sawed surfaces because of the difficulty of producing consistently good joints. Hollowground saws set to cut clean and to prevent crushing the wood fibers produce good gluing surfaces.

Sanding produces good results in plywood but is not recommended for structural members, because it tends to produce surfaces with irregular contours. Glazed surfaces can be improved by light sanding (4).

MOISTURE CONTENT

Careful control of moisture content in gluing is essential. Most glues make good joints over a wide range of moisture conditions, but moisture control is necessary to minimize shrinkage, swelling, and stresses in the wood that cause warping and twisting of the structure, cracks at the panel joints, or failure in the wood near the glue joints (4).

The desirable moisture content of wood at the time of gluing is that which will produce strong joints and, as nearly as practicable, approximate the average moisture content the laminated product will attain in service. In general, it is desirable to produce the laminated member at a slightly lower moisture content than that expected in service, and thereby not only avoid surface-drying in use, but a serious change in the entire member. Wood in dry heated buildings has been found generally to have a moisture content varying from 6 to 11 percent depending on the season of the year and geographical location. The moisture content of wood in dry unheated buildings is somewhat higher, probably 8 to 14 percent (21).

GLUE PREPARATION

Choice of glue is governed by the conditions under which the laminated product will be used. Extreme care should be used in mixing and preparing any glue. Directions for mixing are furnished by the manufacturer and should be carefully followed. All containers used for weighing different ingredients should be kept clean, and it is usually desirable to use a separate container for each ingredient (21).

Small amounts of glue may be mixed by hand, but larger batches require a mechanical mixer. Some resins tend to develop heat when mixed with the hardener, so that the manufacturer's instructions should be followed for keeping the materials cool during mixing (21).

Hardeners or catalysts are important in mixing all thermosetting resins, for they influence their rate of setting and the temperature at which setting occurs. Acids, acid salts, alkalis, formaldehyde, and paraformaldehyde are used as hardeners. The acids, acid salts, and alkalis act as catalysts; whereas, formaldehyde and paraformaldehyde enter into the reaction as resin-forming ingredients (19).

The urea-resin glues are invariably acid-catalyzed. The intermediate-temperature-setting melamine resins are catalyzed by acid, but the hot-press melamine resins are nearly neutral. The resorcinol and phenol glues are catalyzed by alkalis, but the setting of certain phenol glues also can be effected by acids. Resorcinol resins, as prepared by the manufacturers, are deficient in formaldehyde. Upon the addition of formaldehyde or paraformaldehyde to these resins, further reaction takes place, causing the resins to set (19).

SPREADING OF GLUE

It is necessary to spread evenly the right amounts of glue to get satisfactory joints. This is done with rollers in commercial laminations. Single spreading, where only one face of the two faces to be glued receives the glue spread, is satisfactory for many types of work. Where long assembly periods are used then double spreading, coating both the mating surfaces of a joint with glue, is recommended. The required amount of glue spread varies somewhat with gluing conditions and species of wood used. Porous woods usually require a heavier spread than do dense non-porous woods (21). Rate of glue spread is discussed under each glue type.

ASSEMBLY

A ssembly and pressing must be completed before the glue has developed an initial set, which is the result of both a chemical reaction and loss of solvent to the wood and air. Permissible assembly time will vary with the gluing temperature. At low temperatures, a considerably longer assembly time may be allowed than under hot dry conditions. Proper regulation of the assembly period is very important, since application of pressure either too soon or too late may result in unsatisfactory bonds (4).

Most assembly operations consist in part of open and in part of closed assembly, in which cases the allowable assembly time for a particular operation can be computed by the general rule that one minute of open assembly results in as much thickening of the glue as two minutes of closed assembly (19). Assembly periods will be discussed under each glue type.

WORKING LIFE

The time after the mixing of a glue that it remains usable is known as the working life of a glue. The working life of each glue type varies. It is shortened as the temperature rises (4). Of several glue characteristics studied, namely, acidity, working life, non-volatile content, insoluble content, and joint strength the characteristic of working life appeared to be the only one regularly and seriously affected by storage. Although, the working life of some glues did not definitely change during the 12 to 17 months of study (29). Working life will be discussed under each type of glue.

CURING

Synthetic-resin glues cure at relatively low pressing temperatures, but higher temperatures greatly accelerate their setting and reduce the periods needed for pressure. In a curing operation where an actual glue line temperature of 190° F. is required, it is most practical to operate the chamber at 210° to 215° F. At temperatures above 215° F., it is difficult to maintain the proper relative humidity, and the use of such temperatures is not recommended (21). Whenever assemblies of an appreciable size are to be heated in a curing chamber, it is usually most practical to maintain the chamber temperature about 20° F. above the required glue-line temperature. If a smaller differential is used, longer curing cycles that may be impractical will be required (21). Curing will be discussed under each type of glue.

GLUING PRESSURE

Adequate and well-distributed gluing pressure is one of the most important factors in producing good glue joints. The functions of pressure include spreading of the glue to form a continuous film between the wood layers, forcing air from the joint, bringing wood surfaces into close contact, and holding them in this position while the glue sets (21).

Best results in gluing are obtained when the pressure is distributed evenly over the entire joint area. Nonuniform gluing pressure may result in strong and weak areas in the same joint. The principal causes of unequal pressure on joint areas are: (1) irregular surfaces; (2) unequal dimensions of stock; (3) warped stock; (4) improper spacing of clamps, nails, or other pressure-securing devices; and (5) deformation, deflection, and other imperfections in press, clamps, or other equipment (4).

The minimum pressure permitted for any assembly is one that will insure close contact of the wood surfaces until the glue has set. Maximum pressure should not be so great as to crush the wood. Two hundred pounds per square inch is regarded as the upper limit; although, two humdred and fifty pounds per square inch is often used on dense hardwoods (4). Gluing pressure will be discussed under each glue type.

METHODS OF OBTAINING ELEVATED TEMPERATURES FOR GLUING

Some glues have been formulated to cure at room temperatures, but the greatest success has been at higher temperatures. Below are some methods of obtaining elevated glue line temperatures.

One method is to apply pressure in a jig by expanding a rubber tube, such as a fire hose, by means of steam. The heat from the steam provides the higher temperature at the glue joint. In this process, there is a definite relation between steam pressure and temperature corresponding to that given in steam tables (4).

Air pressure is sometimes used in jigs fitted with flexible tubes, and elevated temperature is obtained with electrical strip heaters placed against the work being glued at the point of application of pressure (4).

Conventional hot-plate presses can also be used to bond skins, such as plywood, to studs, joists, or other structural members.

High-frequency dielectric heating may be advantageously used to set glue joints in the assembly of prefabricated structural units where production requirements justify the cost of the generating equipment. The cost of electrical equipment can be offset to some extent by the use of low cost wood presses or jigs (21).

Electrical field heating can be most economically applied parallel to the glue line or by stray field heating where access to the glue lines cannot be readily accomplished. That is, if the electrodes cannot be placed in direct alignment with the glue joints, they may be offset, within limits, and the electric field will divert through the glue line because of its greater conductivity, thus causing the glue to set (4).

SYNTHETIC-RESIN GLUES

The background of synthetic-resin glues was discussed previously in this paper. Synthetic-resin glues on the basis of chemical properties may be grouped as thermosetting or thermoplastic; on the basis of constituents they are classified as phenol, vinyl, melamine, urea, and resorcinol resins; and on the basis of operating characteristics they are classified as room-temperature-setting, intermediate-temperature-setting and high-temperature-setting (10).

Glues in this work are classified according to curing temperatures as follows (21):

CLASSIFICATION	CURING TEMPERATURES (21)
Hot-setting, hot-press, or high-temperature-setting	Requires temperatures above 210° F. for setting
Intermediate-temperature-setting	Range is usually considered as being between 80° and 210° F.
Room-temperature-setting	Range is about 65° to 80° F. Some authorities consider 70° F. as the minimum limit
Cold-setting	Range of setting is from 32° to 65° F. It is confusing that this term is often used in connection with room-temperature-setting

This classification is made for convenience in discussing the glues and does not imply that every glue represented as belonging to a certain class necessarily cures at every temperature within the range given for the class. Types of glues may vary as to minimum curing temperatures. The glues may vary in their setting temperatures according to the species of wood that is being glued (21).

THERMOSETTING GLUES

Synthetic-resin glues belonging to the thermosetting group cure completely at a definite temperature or within a narrow range of temperatures, and if the temperatures are later raised to or beyond this curing temperature, the glue does not again soften. The thermosetting group is composed of the phenol-formaldehyde resins, urea-formaldehyde resins, melamine-formaldehyde resins, and resorcinol-formaldehyde resins (3, 10, 19).

HIGH-TEMPERATURE-SETTING PHENOL RESINS

PROPERTIES

These glues are formed by the reaction of phenol or cresol with formaldehyde, and the reaction is stopped at an intermediate stage to give proper qualities for woodworking glues. Phenol-resin glues have a pH range of 1.7 to 8.4, but most of the high-temperature-setting phenols are alkaline. It is important to choose glues that are not too strongly acid or alkaline for woodworking to prevent the joints from being weakened by corrosive action. Phenol glues absorb less moisture from the air than wood does (3).

Hot-press phenol glues are marketed in three forms: (a) as a resin-impregnated paper film, (b) dry powders to be suspended in water or in water and alcohol, (c) as water or alcohol solutions. Separate hardeners are sometimes supplied with the powder and liquid forms for addition when the glues are prepared for use (19).

HARDENERS

A number of hardeners are used. The type of hardener may be important by properly influencing the pH of the glue. The glues with the pH approaching neutrality are usually more satisfactory for forming wood joints (6). See page 11.

FILLERS

Walnut shell and wood flours are the most common fillers, but wheat or rye flour, starch, Douglas-fir bark, and vegetable and animal proteins may also be used (31, 34).

SOLVENTS

Solvents for hot-press phenols may be water, alcohol, water-alcohol mixtures, dilute caustic soda, acetone, or water-acetone mixtures (3).

EXTENDERS

Hot-press phenols may be extended with a number of materials. Corn gluten and soybean meals have been found to be satisfactory extenders for phenol-resin glues. Carbon disulphide is used in the preparation, because it reacts with the high protein content of these materials and decreases the water-absorbing capacities. Glues extended with large amounts of proteinaceous materials often weaken in damp surroundings due to the action of micro-organisms (5).

Linseed meal is permissible as an extender in only small amounts, because of its high water-absorbing capacity. Douglas-fir bark, English walnut shell flour, and black walnut shell flour have proved to be suitable extenders (11).

WORKING LIFE

The working life of hot-press phenols varies over a great range, but for most of them it is relatively long. It usually ranges from about eight hours to several days (3).

RATE OF SPREAD

Liquid phenol glues are usually applied by means of mechanical spreaders with rubber-covered rollers. On a dry weight basis the normal rate of spread of high-temperature-setting phenol-resins is about ten to twenty pounds per one thousand square feet of single glue line. For the dry-film form of phenol-resin glue it is necessary to have a very smooth and well cut wood surface to get best results due to the relatively light spread of glue. The film weighs about 12.5 pounds per thousand square feet, and as one third of this weight is paper a very light spread is obtained. On thicker, rougher veneers better results are obtained by using two sheets of film per glue line (19).

ASSEMBLY

Permissible assembly periods vary greatly. Some of the hot-press phenols require relatively short times, less than an hour, whereas others give better results when assembly periods of several hours or several days are used. Phenol glues with long assembly periods are preferred for bag-molding operations for which the laying up procedure takes considerable time. In the manufacture of flat plywoods, glues are preferred that permit hot-pressing after short assembly periods of a few minutes to an hour (19).

MOISTURE CONTENT

With the phenol-film glue the best results are at moisture conditions of eight to twelve percent. The film adds no moisture to the wood and does not give good results with moisture conditions below six percent. A moisture content too high may cause blisters, excessive bleed-through, and starved joints; one that is too low may cause dried joints of low strength. Some moisture is lost from the panels during pressing, and to regain a moisture equalization the panels should be sprayed or dampened by some similar process (19).

The liquid hot-press phenols are not so critical in their moisture content requirements. They glue well over a greater range and especially at moisture contents below six percent, because they add moisture to the panels (31).

GLUING PRESSURES

Gluing pressure depends on the species. The gluing pressure of both hot-press liquid phenols and the dry-film form are similar. Pressures in common use for denser woods such as yellow birch and hard maple are 200 to 250 pounds per square inch; for sweetgum, Douglas-fir, and mahogany, 150 to 200 pounds per square inch; for yellow-poplar 150 pounds per square inch; and Sitka spruce and basswood, 100 to 125 pounds per square inch (37).

CURING TEMPERATURES

The platen temperatures generally recommended for gluing with phenol-film glue are from 280° to 320° F. Temperatures within this range must be developed at the glue line farthest from the platens for several minutes to cure the glue adequately. The required curing schedules vary with veneer thicknesses and can be obtained from the glue manufacturer. Most liquid hot-press phenols cure at 240° to 280° F. (19).

STORAGE LIFE

Storage life of hot-press phenols are usually longer than the intermediate-temperature-setting phenols which range from two to six months at room temperatures. Their useful life can be prolonged at lower storage temperatures (21).

DURABILITY AND STRENGTH

Extensive tests show that these glues form extremely strong and durable joints. Well made joints withstand without delamination prolonged exposure to cold or hot water, to alternate soaking and drying, and to varying temperatures and humidities. They are highly resistant to heat and break down only when the temperatures reach the ignition point of the glue, which is usually above the charring point of wood. Joints made with these glues are not weakened by fungi, bacteria, or other micro-organisms, and the joints themselves are avoided by termites. Completely cured phenol-resin joints are highly resistant to the action of solvents, oils, acids, alkalis, wood preservatives, and fire-retardant chemicals. In general hot-press phenol glue joints are hard to destroy without destroying the wood itself (4, 10, 19, 21).

An alkaline hot-press phenol was tested for fatigue stressing. An electric motor making 1790 revolutions per minute furnished the vibrations. The specimens were allowed to remain under stress up to 10, 000,000 cycles if they did not break. 16 specimens showed an average breaking point of 6,120,900 cycles, and some of the specimens withstood 10,000,000 cycles without breaking. The average glue line thickness of these specimens was .002 of an inch (26).

For strength and durability comparisons with other glues see figures one through ten and figure 16.

ECONOMIC POSSIBILITIES

High-temperature-setting phenols are the most important and most widely used of all synthetic-resin glues, especially in the plywood industry. They are used principally in the manufacture of plywood and related products that can be heated in hot presses or autoclaves. This is necessary because of their requirements for a high curing temperature. The dry-film form of phenolic-resin glue is extensively used for the manufacture of aircraft plywood and other products for which its use has certain advantages over liquid glue. It is particularly well adapted to the gluing of thin veneers, because there is no spreading problem, and the danger of glue bleed-through is less. Liquid phenol-resin glues and the powder form are widely used in the manufacture of plywood for marine and other exterior uses where durable glue bonds are required (19, 34).

Because of their high-curing-temperature requirements, these glues are not well adapted for laminating lumber or heavy materials. They have been found very successful in gluing barrel heads and barrel staves by one company (31).

On the basis of 1946 prices phenol glues as a class cost approximately 12.5 cents per pound (25).

EXTENDED HOT-PRESS PHENOL RESINS

PROPERTIES

These glues are very recent and extensive data have not been recorded for them. Considerable work is now in progress on the use of such modifiers or extenders for these glues as vegetable proteins, bark fiber, and starches. The primary objective of glue extension is to reduce costs, for which extended phenol glues are promising in uses where the good characteristics of their bonds are desirable, but maximum durability is not required (19).

Preliminary studies have shown that extensions to a very great extent of hot-press phenols was unsatisfactory for use in wood bonding. Failures were due to insufficient plastic flow of the glue which resulted in poor contact between glue and veneer. Several methods are available for improving the flow properties of a combination of resin and protein mixtures: (a) addition of a plasticizer, (b) modification of the protein by hydrolytic treatment, (c) use of a resin of low molecular weight, (d) a combination of the suggested methods. The best method to improve flow properties was found to be the use of a low molecular weight resin (6).

The following data were obtained from the testing of two low molecular weight phenol resins. The glues were made up of 40 to 53 percent solids depending on the resin content of the glue. The two hot-press phenols tested had ratios of phenol to formaldehyde of 1:1.5 and 1:2.5. The phenol, formaldehyde, and hardener were mixed carefully and were carried to a temperature of about 200° to 212° F. The total time of the reaction was held to 60 minutes or less (6).

HARDENERS

The hardener used in the glues for this test was sodium hydroxide, but there are many other materials that could serve equally as well. See page 11.

FILLERS

Walnut shell flour makes a good filler, but satisfactory results were obtained by allowing the carbohydrate content of the extenders to replace the walnut shell flour as filler (6).

SOLVENTS

Water or water-alcohol mixtures were used for solvents (6).

EXTENDERS

Several extenders may be used, but in this experiment only proteinaceous materials were tested. The ma terials were corn gluten, soybean, and linseed meals, with protein contents of 35 to 70 percent. The protein fraction plays the most important part in extending the glue, since it takes part in both the flow and adhesive properties. Extenders of 45 to 60 percent protein gave good results as extenders. Higher protein materials give better results, but their added cost is not commensurate with the added strength given the glue joints (6).

Limitations in the amount of extender that may be used in meeting waterproof specifications also apply to spreadibility of the glue. With increasing amounts of proteinaceous materials it is necessary to lower the solid contents of the glue to obtain proper consistency for glue spreading. When the ratio of resin to extender is higher than 1:2, the spreadibility of the glue on rollers becomes difficult (6).

The properties of proteinaceous materials which have the most influence on the quality of the final glue product are protein value, content of water-soluble constituents, water-absorbing or water-holding capacity, and plastic flow characteristics. Proteinaceous materials high in protein content and low in water soluble constituents are best suited for phenolic-resin extenders. Linseed meal can be used in only small amounts as extender due to its high water-holding capacity. It contains mucilagenous carbohydrates though, and is desirable in small amounts because it improves the spreading characteristics of the glue. Soybean meal from which the water-soluble fraction has been removed is satisfactory for extender. Corn gluten meal makes good extender, for it is almost entirely free of water-soluble components (6).

WORKING LIFE

Working life of these glues may be compared to hot-press phenols. It is not critical (3).

RATE OF SPREAD

A satisfactory rate of spread for these glues was found to be 10 to 14 pounds of glue on a dry weight basis to 1000 square feet of single glue line (6).

ASSEMBLY

An open assembly of one hour is recommended, but open assemblies up to twenty-four hours were found to be equally effective (6).

MOISTURE CONTENT

The moisture content of the wood to be glued gave the best results within the range of two to eight percent. The glues can be used on a greater range of moisture content (6).

GLUING PRESSURES

Satisfactory gluing pressures on lighter woods (yellow poplar) are 150 to 175 pounds per square inch. On denser woods (birch) 200 to 250 pounds per square inch are successful (6).

CURING TEMPERATURES

The curing temperatures for these glues ranged from 280° to 300° F. Optimum curing times for phenols extended with corn gluten meal is about 4 minutes, and with soybean meal about 3.5 to 6 minutes. To increase the rate of cure, ammonia may be added to the glue preparation at the rate of 90 grams of 28 percent ammonia per 1000 grams of liquid resin (6).

STORAGE LIFE

Sufficient data have not been developed on storage life of these glues. The glue whose ratio of phenol to formaldehyde was 1:1.5 showed little change in properties after being stored for 60 days. The glue with a ratio of phenol to formaldehyde of 1:2.5 was usuable up to 33 days of storage. Both glues were stored at 77° F. Their storage life would be longer at lower storage temperatures (6).

DURABILITY AND STRENGTH

It is not recommended to use glues with an extension of proteinaceous materials greater than 50 percent (two parts resin to one part extender). Test specimens bonded with a glue of resin and extender ratio of 2:1 showed good resistance to micro-organisms after 17 months of exposure. Under severe weather conditions as approximated by laboratory tests, the wood deteriorated, but there were no signs of delamination. Other specimens exposed for 12 months to outside conditions showed no loss of shear strength. After three hour boiling tests on several woods glued with extended hot-press phenols, the bonds met army-navy aeronautical specifications. They showed an extremely high percent of wood failure and met shear strength qualifications which require 290 pounds per square inch for birch, 210 pounds per square inch for mahogany, and 130 pounds per square inch for poplar (6).

ECONOMIC POSSIBILITIES

These glues are new and are not proven as to their capabilities. They do meet standards for exterior-grade plywood, and with their saving in glue line cost should find considerable use in the commercial field.

INTERMEDIATE-TEMPERATURE-SETTING PHENOL RESINS

PROPERTIES

These glues may or may not be blends of phenol or resorcinol. If phenol-formaldehyde is used as a glue the reaction is stopped at an intermediate stage in which the material is still soluble in water or other mixtures. The glue is marketed in this intermediate stage as either a solution or powder. The reaction between the phenol and formaldehyde is completed by heating during the gluing operation. These glues are formulated to cure at intermediate temperatures, otherwise they resemble hot-press phenols in their properties (10). They have a disadvantage for some operations due to wood staining (34).

HARDENERS

Intermediate-temperature-setting phenols may have a number of hardeners such as calcium hydroxide, sodium carbonate or sodium hydroxide (34). See page 11.

FILLERS

Walnut shell and wood flours are most commonly used as fillers, but wheat or rye flour, starch, Douglas-fir bark, and vegetable and animal proteins may also serve as fillers (34).

SOLVENTS

Water, alcohol, and water-alcohol mixtures serve as solvents for these glues (3).

EXTENDERS

Walnut shell flour and Douglas-fir bark have seen limited service as extenders. Linseed meal can be used in only small amounts due to its high water-absorbing capacity. Corn gluten and soybean meals have been used to extend these glues. Carbon disulphide is used in the preparation, because it reacts with the high protein content of the extenders and decreases the water-absorbing capacity (5).

WORKING LIFE

The working life of intermediate-temperature-setting phenols has a usual range of 2 to 8 hours at 75° F. (19).

RATE OF SPREAD

Most of these glues are used to laminate heavy members, and their spreads are heavier than hot-press phenols. Wet spreads of 40 to 60 pounds of glue are used per 1000 square feet of double glue line (19).

ASSEMBLY

Assembly periods vary greatly within these glues, but most of them permit one to two hours of closed assembly at 75° F. (21).

MOISTURE CONTENT

These glues perform satisfactorily on wood with moisture content values of 2 to 20 percent (4).

GLUING PRESSURES

Gluing pressures for hardwoods should not be less than 100 pounds per square inch and can range up to 300 pounds per square inch at local pressure points. The usual range is 200 to 250 pounds per square inch. In softwoods pressures may range from 100 to 200 pounds per square inch (18).

CURING TEMPERATURES

These glues were made to cure at intermediate temperatures, but they can be greatly accelerated in their curing if higher temperatures are applied. In gluing white oak ship keels a temperature of 190° F. at glue line for 10 hours was found necessary for the production of joints that show little delamination under outside exposure conditions. For Douglas-fir and

Central American mahogany a curing period of 10 hours at 140° F. is adequate to give strong joints. For work other than laminating the temperatures and times may be reduced, but the glues must always be well-cured if the joints are to have high durability (18, 19).

STORAGE LIFE

These glues have a relatively short storage life of 2 to 6 months at room temperatures, but cold storage (30° to 50° F.) prolongs their useful life (21).

DURABILITY AND STRENGTH

The strength and durability of intermediate-temperature-setting phenol-resin glues compare favorably with that of the hot-press phenols. See durability and strength under hot-press phenols.

In tests on fatigue stressing a slightly alkaline glue showed good durability, but a highly acid glue showed fairly low durability. The weakening effect of the acid phenol on the wood may have influenced the durability of the joints. The failure was more in the wood than in the glue. A fatigue-testing machine operating at 1790 revolutions per minute was used for the tests. Thirty-two specimens of the alkaline glue were tested. They showed an average breaking point of 4,431,000 cycles, with some of the specimens standing

10,000,000 cycles without breaking. Part of the specimens had a glue line thickness of .003 of an inch, and they showed greater durability than specimens with a glue line thickness of .035 of an inch. The highly acid phenol showed an average breaking point of 397,300 cycles with a glue line thickness of .003 of an inch and 628,400 cycles with a glue line thickness of .044 of an inch. None of the specimens withstood the maximum of 10,000,000 cycles without breaking (26).

For strength and durability comparisons with other glues see figures one through ten and figures fourteen, sixteen and seventeen.

ECONOMIC POSSIBILITIES

These glues are used for laminating heavy members, to some extent in the assembly gluing of aircraft, and in other operations demanding durable glues, but not permitting the use of hot-press temperatures (19).

On the basis of 1946 prices phenol glues as a class cost approximately 12.5 cents per pound (25).

HIGH-TEMPERATURE-SETTING UREA RESINS

PROPERTIES

These glues are formed by the reaction of urea with formaldehyde and the reaction is stopped at an intermediate stage to form the urea-resin glues used in wood bonding. These glues are invariably acid. The urea resins have a pH ranging from 1.9 to 5.7, but the hot-press ureas are less acid than the room-temperature-setting ureas. Hot-press urea resins are marketed either as dry powders, with hardeners either separately supplied or incorporated, or as water suspensions of 60 to 70 percent solids with separate hardeners. The powdered glues are prepared for use by mixing with water, or with water and hardener if the hardener is separately supplied (10, 19).

HARDENERS

Hardeners for these glues are acids or acid-producing salts, and the amount of hardener often distinguishes between the type of urea-resin glues. The more acid hardeners are used to make the intermediate-temperature-setting urea resins (19).

FILLERS

These glues usually contain some filler; the most common are walnut shell and wood flours (21).

SOLVENTS

The most common solvents for hot-press ureas are water or water-acetone mixture (3).

EXTENDERS

Wheat and rye flours are the most common extenders used, but good results have also been obtained with tapioca flour (3).

WORKING LIFE

Hot-press urea resins usually have a working life of 8 hours or more, so that it is not necessary to cool the container in hot weather in order to obtain a satisfactory working period (19).

RATE OF SPREAD

This glue is best applied by means of rubber-covered rollers, but it can be brush spread. Wet spreads of 30 to 45 pounds, equivalent to about 18 to 30 pounds of dry glue, per 1000 square feet of single glue line are recommended. Heavier spreads may be necessary on thick or rough veneers (19).

A SSEMBLY

Assembly times vary over wide limits, but they are mot critical. Some glues may be used with an open assembly time of 24 hours or more. Individual glues differ and the manufacturer's recommendations should be followed (19).

MOISTURE CONTENT

Moisture content of veneer is not particularly critical for hot-press urea resins. Desirable moisture conditions will ordinarily be governed by other considerations, such as the use to be made of the product, and the danger with the higher moisture contents of blistering in the hot-press. Moisture contents over a range of 2 to 20 percent can be used (19).

GLUING PRESSURE

Time under pressure, as with all glues, is dependent on the distance of the glue line farthest from the platen, moisture content of the wood, species, thickness of the veneer, and number of glue lines. Pressures in common use are 200 to 250 pounds per square inch for sweetgum, Douglas-fir, and mahogany; 150 pounds per square inch for yellow-poplar; and 100 to 125 pounds per square inch for Sitka spruce and basswood. Typical recommendations for curing times are 3 to 5 minutes for panels with a total thickness of 3/16 inch or less, and 8 to 15 minutes for panels with 1/4 inch faces on 1/2 inch cores, when the platen temperature is 260° F., and one panel is glued per press opening (19).

CURING TEMPERATURES

Hot-press urea resins set at temperatures somewhat below that of hot-press phenols. Platen temperatures ordinarily recommended by manufacturers range from 230° to 260° F. (19).

STORAGE LIFE

Storage life for liquid hot-press urea resins is usually from 2 to 3 months at 70° to 75° F., that of powdered urea resins with a catalyst incorporated is usually at least one year when kept dry in closed containers at room temperatures, and that of powdered urea resin with separate catalyse is over a year in dry closed containers at room temperatures. The storage life can be increased if the glues are kept stored at lower temperatures (21).

DURABILITY AND STRENGTH

Well made joints with hot-press urea-resin glues are characterized by high original dry strength and high wood failures, good resistance to soaking in cold water, fair resistance to continuously high relative humidity, and alternately high and low relative humidity, and good resistance to cyclic soaking and drying exposures, if the test pieces are in the form of plywood or thin members. There is only moderate resistance if the pieces are heavy laminations of dense woods. The hot-press urea resins are the most durable of any of the urea resins except the fortified urea resins. They are low in durability against high temperatures, especially when combined with high relative humidity. There is a gradual weakening of joints under dry conditions at 160° F. Urea resin bonds delaminate when exposed to fire, because the glue is destroyed at temperatures that char wood (10).

Plywood panels made with unfortified urea resins show delaminations under outside exposure in 2 or 3 years. Under exterior exposures and where high temperatures are involved, the durability of urea resin glues is markedly inferior to that of phenol-resin, melamine-resin, or resorcinol-resin glues.

Sufficient results are as yet unavailable to permit conclusions regarding the durability of urea-resin glue joints under conditions such as may exist inside buildings. In one indoor test, after 8 years of exposure at 80° F., and during which relative humidity varied between 30 and 80 percent, urea-resin joints in laminated southern yellow pine and Douglas-fir beams showed high joint strength and high wood failure (19).

For durability and strength comparisons with other glues see figures one through ten and figure sixteen.

ECONOMIC USES

Hot-press urea resins are not used in the manufacture of softwood plywood as extensively as phenol resins, but they are used extensively in the manufacture of hardwood plywood. Other principal uses are in assembly gluing and in laminating (19).

On the basis of 1946 prices urea-resin glues as a class are the cheapest of the synthetic-resin glues. Their cost is approximately 12 cents per mixed pound (25).

ROOM-TEMPERATURE-SETTING UREA RESINS

PROPERTIES

The properties and preparation of these glues closely resemble those of the hot-press urea resins. These glues are more strongly acid than the hot-press ureas, and current specifications limit the use of these glues due to their high acidity. They are highly acid due to the formulation to bring about lower curing temperatures (21).

HARDENERS

Hardeners for these glues are acids or acid producing salts, and the amount of hardener often is the determining factor as to whether the glue will be high-temperature-setting or low-temperature-setting (4).

FILLERS

The most common fillers for these glues are walnut shell and wood flours (4).

SOLVENTS

Data on a large number of commercial room-temperature-setting urea-resin glues show that water is the only solvent used (3). Other solvents may be in use, but there is no indication of such in materials on glues.

EXTENDERS

Rye and wheat flours are common extenders for these glues. English walnut shell and black walnut shell flours also find some use as extenders. Among the wheat flours hard wheat flour is preferred (11).

WORKING LIFE

The working life of room-temperature-setting ureas depends upon the glue temperature. If, for example, a mixture has a working life of 6 hours at 70° F., its working life will be about 3 hours at 80° F., 1.5 hours at 90° F., and 3/4 hours at 100° F. To increase the working life of these glues during hot weather, it has been found desirable to keep the glue container in water cold enough to maintain the temper ature of the glue at about 70° F. (19).

RATE OF SPREAD

These glues can be spread by brush or machine, and spreads of 40 to 50 pounds of wet glue per 1000 square feet of single glue line are generally recommended (4).

ASSEMBLY

Application specifications usually limit these glues to a maximum assembly period of 20 minutes if entirely closed and 10 minutes if entirely open. Good results are obtained with assembly times of 5 to 15 minutes. The assembly periods should be decreased somewhat if the wood is very dry, or if the temperature of the wood and that of the gluing room is higher than 75° F. (16, 19).

MOISTURE CONTENT

Moisture content of wood in using these glues is more critical than for the hot-press ureas and phenols. Most of these glues produce joints of higher quality on wood with 8 to 12 percent moisture content.

Failure to recognize the importance of moisture content in the use of these glues has contributed to difficulties encountered when they have been used on very dry wood (4, 19).

GLUING PRESSURES

The minimum pressure period depends upon the type of material and the temperature of the wood and the room at time of gluing. At 75° F., pressure should be maintained for at least 4 hours on thin straight members and for at least 5 to 7 hours on heavy or curved members. In no case should the pressure be released until the squeeze-out is hard. By raising the temperature of the glue after it has been put under pressure, the required time under pressure can be reduced approximately one-half for each 10° F. increase in the glue line temperature above 75° F. Pressures of 150 pounds per square inch have proved successful on a wide range of species when pressure was kept for 16 hours (16, 19).

CURING TEMPERATURES

These glues are formulated to cure at a minimum temperature of 70° F., at which many hours are required before pressure can be released. The cure can be hastened at higher temperatures. See gluing pressures above.

In a test for curing temperatures, specimens were cured for 8 hours at 80° F.; 25 minutes at 160° F.; 9 minutes at 180° F.; and for 7 and 35 minutes at 250° F. Data from tests on these specimens showed no significant difference in the quality of the joints made at the various temperatures (7).

Members glued with urea resins at room temperature require a conditioning period of about a week at room temperature for the development of maximum joint strength and water resistance (21).

STORAGE LIFE

The storage life of these glues are similar to storage life of hot-press urea resins.

DURABILITY AND STRENGTH

In general the durability and strength of room-temperature-setting urea-resin glues compare with the strength and durability of the hot-press urea resins. They do show significant decreases in joint strength when exposed to normal room temperatures and humidities over periods of several years, indicating loss of strength with aging (4).

These glues show a low ability to withstand fatigue stresses. Twenty-three specimens were tested on a fatigue-testing machine that operated at 1790 revolutions per minute. There was an average failure of 306,900 cycles for specimens with a glue line thickness of .003 of an inch, and an average failure of 20,200 cycles for specimens with a glue line thickness of .032 of an inch. No specimen withstood the maximum of 10, 000,000 cycles without breaking (26).

For durability and strength comparisons with other glues see figures one through eleven and figure sixteen.

ECONOMIC POSSIBILITIES

Results are insufficient to allow definite conclusions, but evidence of their poor durability under moderate conditions for long periods of time seems to indicate a doubtful suitability of these glues for use in constructions such as houses (4).

These were the first synthetic-resin glues developed for use at room temperatures and have been extensively used in the assembly gluing of aircraft and truck body parts, and for other purposes where the application of high temperature is not always feasible. When properly used they form strong joints with good resistance to cold water but poor resistance to hot water. Because of the speed with which these glues set at temperatures above 75^{o} F., they have been used extensively for assembly gluing in hot presses, heated jigs, in high-frequency electric fields, and in heated rooms (19).

On the basis of 1946 prices urea-resin glues as a class are the cheapest of the synthetic-resin glues. Their cost is approximately 12 cents per mixed pound (25).

EXTENDED UREA RESINS

PROPERTIES

Extended urea-resin glues may be either hot-press or room-temperature-setting ureas, and as such have much the same properties as these glues. Extensions can be made by adding several different materials, but the usual extenders are wheat or rye flours. Flour imparts some adhesiveness to the glue, but its primary purpose in extending urea resins is to reduce glue costs (19).

HARDENERS

The hardener depends on the glue used. See hardeners under hot-press and room-temperature-setting urea resins.

FILLERS

Fillers such as walnut shell or wood flours may be used, but with the large amount of extender incorporated into these glues it is possible to allow the carbohydrate content of the extender to act as a filler (6).

SOLVENTS

Water is used as solvent, and due to the added extender usually being somewhat water-absorbing, the extended glues will require more solvent than the unextended urea resins (19).

EXTENDERS

Wheat and rye flours are the most common extenders for these glues. Very little information is available as to the best types of flour to use as extenders, but it seems that hard wheat flours are preferred. Different grades of flour affect the working properties of the glue differently, particularly their consistency and tendency to foam. Extended glues are usually more viscous than unextended glues. Recently, urea resins have been formulated for use with a variety of flours. Sodium bisulphite is sometimes added to the extent of about 1 to 2 percent of the weight of the flour to reduce viscosity by peptizing the gluten in order to help overcome the differences in flours and reduce the water requirements of the glue (19).

The amount of flour extension permissible varies to some extent with the glue, but it is primarily determined by the type of product being manufactured, and by conditions under which the product will be used. The most common range of extension is 25 to 100 parts of flour to 100 parts of dry resin, but urea-resin glues with as much as 200 percent flour have been used (19).

The effects of rye flour extenders on hot-press ureas as shown by several tests, seems to indicate that: (a) the effect of extension of urea-resin glue with rye flour on durability was most pronounced when the joints were exposed to warm damp conditions favoring the development of micro-organisms, (b) the effect of extension on the resistance of joints to wetting and drying cycles was not as great as when exposed to dampness, (c) a decrease, but not a marked one, was noted on initial dry and wet strengths, and on resistance to continuous soaking (11).

One of the main objections to high degrees of protein extender is the susceptibility of the glue to attack by micro-organisms.

WORKING LIFE

It was found with one extended hot-press urea resin glue that the working life diminishes as more extender is added. The working life of the glue was 24 hours unextended, 24 hours with 100 percent extension, 10 hours at 140 percent extension, 6 hours at 280 percent extension, and 5 hours at 430 percent extension. The working life seems to diminish only after extreme extension, so the working life of extended urea resins can be compared to the type of glue to which they belong, namely, hot-press or room-temperature-setting ureas (33).

RATE OF SPREAD

Somewhat higher spreads are needed with these glues than with unextended urea resins, because they contain more solvent. The amount of increase will depend on the amount of extender used and the increased amount of solvent. The spread of glue will be somewhat greater than 40 to 50 pounds of wet glue per 1000 square feet of single glue line. The proper spreads will be given by the manufacturer of the glue (19).

ASSEMBLY

Tests on an extended hot-press urea-resin glue showed that the assembly time was relatively short. Optimum closed assembly ranged from 30 minutes for a glue with a mix of 70 parts resin to 20 parts flour to

10 minutes for a glue with a mix of 70 parts resin to 200 parts flour (33). Assembly times will vary as to the type of glue extended. See assembly under hot-press and room-temperature-setting urea resins.

MOISTURE CONTENT

These glues will require a moisture content somewhat lower than the moisture contents for hot-press and room-temperature-setting urea resins due to the increased amount of solvent held by the extender (19). See moisture content under hot-press and room-temperature-setting urea-resins.

GLUING PRESSURES

See gluing pressures under hot-press and room-temperature-setting urea resins. There is no definite information as to gluing pressures needed for varying extensions of urea resin glues.

CURING TEMPERATURES

Extended urea-resin glues have been formulated to cure through a range of temperatures from 70° to 310° F. They are also used in high-frequency gluing (20). One commercial extended urea resin showed a good cure at 240° to 260° F.

STORAGE LIFE

Extenders are mixed with the glues when they are ready for use and would not affect their storage life. See storage life under hot-press and room-temperature-setting urea resins.

DURABILITY AND STRENGTH

Tests made with a hot-press urea resin extended with rye flour showed that the wet joint strength falls off slowly as more flour is added; until 50 to 100 percent of extender, based upon the weight of dry resin, had been added; however, no important decreases in water resistance were apparent. The dry joint strength decreased still more slowly, and joints containing twice as much flour as dry resin exhibited high joint strength in the dry condition. When exposed to high relative humidity and other conditions conducive to the development of molds and other micro-organisms, however, the tests showed that the urea resins extended with more than 25 percent flour were attacked, and that the attack was particularly rapid on those glues with the greater extensions of flour (19).

Recent preservative tests showed that the mold resistance of flour-extended urea resins could be greatly increased by adding chlorinated phenols to the glue in amounts equal to 5 percent of the flour by weight.

Concentrations of less than 5 percent appeared to offer less protection, but there seemed to be little advantage in increasing the concentration above 5 percent (19).

For durability comparisons with varying extensions see figure twelve.

ECONOMIC POSSIBILITIES

Extended urea resins are used to make hardwood plywood to some extent. All uses of this glue should be for laminating or gluing materials that have normal indoor use, because their durability is poor under exterior conditions (20).

FORTIFIED UREA RESINS

PROPERTIES

These glues have been formulated by additions of melamine or resorcinol resins to hot-press urea-resin glues. They were developed to improve the resistance of the hot-press urea resins to boiling water and to a combination of high temperature and high humidity. They are prepared for use the same as the hot-press ureas plus the addition of the fortifier. There is so close a correlation between the boil resistance of the glue joints and the amount of fortifier added that when 40 or 50 percent of the total weight of glue solids consists of a fortifier, the boil resistance may approach that of melamine, resorcinol, and phenol glues. Room-temperature-setting fortified urea-resin glues have not been developed (19).

HARDENERS

See hardeners under hot-press urea-resin glues.

FILLERS

See fillers under hot-press urea-resin glues.

SOLVENTS

Water is the chief solvent for fortified urea-resin glues (3).

EXTENDERS

See extenders under hot-press urea resins.

WORKING LIFE

The working life of the mixed glue depends upon the temperature of the glue and varies with the formulation, but it usually is within the range of 2 to 6 hours at ordinary room temperatures. The glue container may be kept in cold water to maintain the temperature of the glue at about 70° F. to increase the working life in hot weather (21).

RATE OF SPREAD

The rate of spread of fortified urea resins on a dry weight basis is 18 to 30 pounds of resin per 1000 square feet of single glue line. For heavy laminations 45 to 65 pounds of wet glue per 1000 square feet of single glue line are recommended (21).

ASSEMBLY

The maximum permissible assembly time for these glues is usually about 20 minutes at 70° F., but this will vary according to the temperature of the room and wood, the moisture content of the wood, and the remaining working life of the glue (21).

MOISTURE CONTENT

Strong bonds are obtained with a moisture content between 7 and 15 percent. These glues often behave unfavorably on woods with a moisture content below 6 percent (21).

GLUING PRESSURES

100 to 200 pounds per square inch are recommended for softwood species and 150 to 250 pounds per square inch for hardwoods (21). Also see gluing pressures under hot-press ureas.

CURING TEMPERATURES

Fortified urea resins should be cured at high temperatures. They may be set at temperatures of 90° to 160° F., but it takes a pressure period of several hours. It is best for them to be cured at temperatures from 220° to 310° F. (20).

An experiment with one commercial intermediate-temperature-setting melamine fortified urea showed that it cured near maximum strength on yellow birch plywood in 10 hours at 130° to 140° F., and in 4 hours at 170° F. (12).

STORAGE LIFE

The storage life of these glues may vary as to the amount of fortifier added. See storage life under hot-press urea, resorcinol, and melamine resins.

DURABILITY AND STRENGTH

The fortified urea resins are the most durable of any of the urea-resin glues. Tests on these glues have shown that the melamine-fortified ureas are more durable than the resorcinol-fortified ureas. When exposed to high and low humidity cycles the melamine ureas maintained strength and wood-failure values comparable to the phenol or melamine resins, whereas the resorcinol ureas were somewhat lower in strength and showed a trend toward decreasing woodfailure values. It appears from present data (1946) that melamine ureas are nearly as durable as the phenol, melamine, and resorcinol resins. The amounts of fortifier included in the resorcinol-urea type, although improving resistance to high humidity slightly, were not sufficient to show significant improvements over the hot-press ureas in resistance to high temperatures (37).

For durability and strength comparisons with other glues see figures one through ten and figure fifteen.

ECONOMIC POSSIBILITIES

Many of these glues were developed for special purposes. They are used in circumstances where urea-resin glue joints need greater resistance to hot water. Some formulas were developed primarily for the gluing of curved plywood by the bag-molding technique (3).

These glues improve the durability of urea resins, so that they can be used for exterior purposes, but it must be remembered that the added fortifier increases the price of the glue (20).

HIGH-TEMPERATURE-SETTING MELAMINE RESINS

PROPERTIES

These glues are produced through the reaction of melamine and formaldehyde that is stopped in an intermediate stage to form a woodbonding adhesive. These glues are almost white in color, but the addition of fillers often gives them a tan color. Most of these glues are marketed as powders and are prepared by mixing with water and sometimes with a hardener and a filler. When ready for use, they contain 60 to 75 percent solids (4, 21).

Synthetic-resin glues are cleaned from gluing equipment by use of water, but most melamine glues are difficult to remove from gluing equipment if water alone is used for cleaning. Cleaning of mixers and spreaders is facilitated by the use of dilute acetic acid. Soap suds or 30 percent calcium chloride solution has also been recommended (21).

HARDENERS

All of these glues do not require hardeners. Those that do may have a variety of hardeners. See page 11.

FILLERS

The most common fillers are walnut shell and wood flours (21).

SOLVENTS

Water and alcohol are used as solvents for these glues (3).

EXTENDERS

These glues are relatively new in the wood-bonding field, and there is no definite data as to the effect that extension would have upon their quality. Some authorities think that they may react to extension the same as the hot-press phenols.

WORKING LIFE

The working life of hot-press melamines is usually not critical. The working life ranges up to 36 hours for some of the glues (19).

RATE OF SPREAD

The rate of spread for these glues is about the same as for hot-press phenols (10). See rate of spread under hot-press phenols.

ASSEMBLY

A ssembly times are not critical for hot-press melamines. The assembly time may extend from a few days to several months (3).

MOISTURE CONTENT

These glues can be used on wood with a moisture content from 2 to 20 percent, but the best results are obtained with a moisture content above 6 percent (4).

GLUING PRESSURES

The gluing pressures for hot-press melamines are the same as for hot-press phenols (10). See gluing pressures under hot-press phenols.

CURING TEMPERATURES

The hot-press melamines are ordinarily cured at temperatures ranging from 230° to 300° F., although some of them can be cured at temperatures as low as 150° F. if kept under pressure for several hours (19).

STORING LIFE

When kept inclosed in containers under dry and cool conditions, the melamine resins have a storage life of 6 months to a year or more (21).

DURABILITY AND STRENGTH

Hot-press melamine glues have not been in service long enough to furnish complete records as to their durability, but all indications point to their being as durable as the hot-press phenols. The strength of hot-press melamine glue joints is comparable to the strength of the joints glued with hot-press phenols.

Hot-press melamine glue joints show excellent resistance to high temperatures, high relative humidity, continuous soaking, cyclic soaking and drying, and to most chemicals including wood preservatives and fire retardants, and to oils. The plies of melamine glued plywood do not separate when the plywood is exposed to fire (19).

For durability and strength comparisons with other glues see figures one through ten.

ECONOMIC POSSIBILITIES

Due to the high curing temperature requirements and the relatively high costs of these glues, they have not been used extensively in the commercial field. They are used in wood bonding work in which the cost of the glues are secondary in importance. They have been used to a small extent in the gluing of hardwood plywood. One of their main uses is for fortifying the cheaper urea resin glues to increase their durability (10).

Based on 1946 prices the cost of melamine glues as a type is about 30 cents per mixed pound (25).

INTERMEDIATE-TEMPERATURE-SETTING MELAMINE RESINS

PROPERTIES

Intermediate-temperature-setting melamine resins have the same properties and preparation procedures as the high-temperature-setting melamines. The only difference being that intermediate-temperature-setting melamines are catalyzed by a slightly acidic salt, so that they will set more quickly at lower temperatures (19).

HARDENERS

Hardeners may or may not be used with these glues. They are catalyzed by a slightly acidic salt. See page 11.

FILLERS

The most common fillers for these glues are walnut shell and wood flours (4).

SOLVENTS

Water, alcohol, or water-alcohol mixtures may be used as solvents (3).

WORKING LIFE

These glues have a relatively short working life of 2 to 4 hours at ordinary room temperatures (19).

RATE OF SPREAD

For various types of wood laminations a wet spread of 40 to 60 pounds of glue per 1000 square feet of double glue line is generally recommended. In laminating ship keels a wet spread of 60 pounds of glue per 1000 square feet of double glue line is commonly used (15).

ASSEMBLY

Assembly time for these glues should be less than one hour closed or one-half hour open at 70° F., and these assembly times are even less at higher temperatures (19).

MOISTURE CONTENT

These glues can be used on wood with a moisture content from 2 to 20 percent, but the best results are on woods with moisture contents from 7 to 15 percent (4, 10).

GLUING PRESSURES

Gluing pressures for these glues are similar to those for intermediate-temperature-setting phenol resins.

CURING TEMPERATURES

These glues are ordinarily cured at temperatures ranging from 120° to 200° F. They require considerable heating to develop high strength and water resistance. A curing period of 10 hours at 190° F. for white oak and 10 hours at 140° F. for Douglas-fir is recommended for uses intended for severe exposures. Shorter curing periods can be gained by the use of higher temperatures, but for a curing period of 10 hours it seems inadvisable to employ curing temperatures above 210° F. (21).

DURABILITY AND STRENGTH

In laboratory tests well made joints of intermediate-temperature-setting melamines show excellent resistance to high temperatures, high relative humidity, continuous soaking, cyclic soaking and drying, microorganisms, and to most chemicals, including wood preservatives, fire-retardant chemicals, and oils. The plies of melamine-glued plywood do not separate when exposed to fire. From information gathered to date it is believed that intermediate-temperature-setting melamines are slightly less durable than hot-press melamines (4, 10).

These glues show a high test for fatigue stressing. Thirty specimens bonded with these glues were tested on a fatigue-testing machine that operated at 1790 revolutions per minute. Their average breaking point was very high and some of the specimens withstood a maximum of 10,000,000 cycles without breaking. Specimens with a glue line thickness of .003 of an inch showed superiority over specimens with a glue line thickness of .03 of an inch (26).

ECONOMIC POSSIBILITIES

These glues are recommended for use for gluing materials that will see exterior service and where cost is secondary. They have been used for marine structures, aircraft, laminated crossties, and bridge timbers. They have found especial use in ship construction for gluing such things as boat keels, frames, stems, skegs, and planking. One authority suggests that these glues can be used for the same purposes as the intermediate-temperature-setting phenol resins (10, 15, 20).

On a basis of 1946 prices the melamine glues as a type cost about 30 cents per mixed pound (25).

RESORCINOL RESINS

PROPERTIES

These glues are compounded from the reaction of resorcinol, a chemical that is closely related to phenol or carbolic acid, and formaldehyde. At ordinary room temperatures resorcinol and formaldehyde react to form a dense hard mass that is very resistant to further chemical or physical change. The reaction is stopped at an intermediate stage and is held as a partially polymerized resorcinol resin in a mixture of alcohol and water. The solid contents of the glue are about 60 percent by weight. The glues are marketed as liquids and must be mixed with a hardener and a filler. The glues are dark red in color (4).

Resorcinols have a pH ranging generally from 4.8 to 6.3, and as such are not critically acid for use in making wood bonds (1).

HARDENERS

Hardeners are usually formaldehyde and paraformaldehyde, but sometimes formalin is used. At 40° to 50° F. resorcinol-resin glues with aqueous formaldehyde hardener appear somewhat more capable of curing to higher strengths than those in which paraformaldehyde was used as hardener, although there seems to be no difference at 70° to 80° F. (27).

FILLERS

Fillers are usually walnut shell or wood flours (4).

SOLVENTS

Solvents for resorcinol resins are alcohol and water (3).

EXTENDERS

Corn gluten and soybean meal have been experimented with. Corn gluten meal shows the best promise, because of its greater dispersibility in the alcohol solution of the resorcinol resin. Extension with corn gluten meal was found to be most readily accomplished when the resin was prepared in the ratio of one mole resorcinol to .6 mole formaldehyde, and the resin adjusted to a pH of 7.5. When the resin was so prepared, it appeared that an addition of corn gluten up to 80 percent of the dry weight of resin had no marked effect on the initial dry strength and water resistance of the joints in birch plywood (11).

WORKING LIFE

The working life of resorcinol resins varies from 2 to 5 hours at 70° to 75° F. The working life is greatly reduced at higher temperatures (21).

RATE OF SPREAD

The rate of spread for resorcinols varies from 10 to 20 pounds of dry resin per 1000 square feet of single glue line (19).

ASSEMBLY

Permissible assembly periods vary, depending on the glue, type of assembly, whether one or both surfaces are spread, and the temperature. A t 70° with both surfaces spread, open assembly periods of 30 minutes and closed assembly periods of 1 to 2 hours have been used with good results. Very short closed assembly periods are not as satisfactory as longer ones (19).

MOISTURE CONTENT

The resorcinols produce strong joints on wood with a moisture content within the range of 2 to 25 percent, but optimum results are gained with moisture contents from 6 to 17 percent (4, 10).

GLUING PRESSURES

A pressure of 100 to 200 pounds per square inch for low density woods and 150 to 250 pounds per square inch for high density woods are recommended for resorcinols. Pressures should be maintained for 5 to

8 hours when the temperature of the room and the wood is at 75° F. The full joint strength is not developed within this period, but the joints will continue to cure and gain strength for several days after pressure is released (10).

CURING TEMPERATURES

Resorcinols are commonly cured at temperatures of 75° to 80° F. They cure more rapidly at higher temperatures and can be used for assembly gluing in heated jigs, hot presses, high-frequency fields, and heated rooms. Higher temperatures are recommended for gluing heavy laminated members of such dense species as white oak for use under severe exposures. Curing for 10 hours at a glue line temperature of 140° F. for white oak and 10 hours at 80° F. for southern yellow pine and Douglas-fir produce joints that resist delamination under severe exposure conditions (21).

Resorcinol glues will harden at temperatures below 70° F. to form water resistant joints that are as strong as low density species of woods, but at these temperatures the rate of curing is greatly retarded, and the ultimate joint strength is usually not as great as that of joints formed at 75° F. or higher (30).

STORAGE LIFE

Resorcinols possess a long storage life. In testing a number of commercial resorcinol resins stored at 80° F., the results after 12 to 17 months of storage showed that their properties had decreased very little (29).

STRENGTH AND DURABILITY

Results of durability tests on well made resorcinol-resin glue joints resemble those made with phenol and melamine resins. They have excellent resistance to deterioration by moisture, shrinking and swelling stresses, high temperatures, chemicals, and micro-organisms. The plies of resorcinol-glued plywood do not separate when the plywood is exposed to fire. Under severe conditions the glue bonds lose no more strength than the wood itself (10).

In tests for fatigue stressing the resorcinols showed greater durability than any other synthetic-resin glue. A fatigue testing machine making 1790 revolutions per minute was used for the tests. 28 specimens glued with resorcinol resin and with a glue line thickness of .039 of an inch were tested. Every specimen withstood a maximum of 10,000,000 cycles without breaking (26).

For durability and strength comparisons with other glues see figures one through ten and figure seventeen.

ECONOMIC POSSIBILITIES

The high costs of these glues, 45 to 50 cents per mixed pound, limit them to uses where the cost is secondary, such as the aircraft and boat building industries. They found great use in the United States Navy's boat building program, expecially for gluing heavy timbers. Because of their high durability and low setting temperatures, resorcinol glues are particularly promising for many gluing operations where high curing temperatures cannot be used, but where glue joints resistant to most deteriorating agencies are desired (19, 23, 25, 34).

THERMOPLASTIC GLUES

The thermoplastic glues, in contrast to the thermosetting group, do not cure at a definite temperature but harden gradually over a range of temperatures, and if, after hardening, the temperature is again raised to or beyond a critical range the resins will again soften and lose strength and rigidity (10).

The thermoplastic glues for this reason have not been widely used in the woodworking field. They have been used, however, for bonding wood to other materials such as metals and plastics because thermosetting resins are not suitable for this purpose. Some thermoplastic-thermosetting combinations have been developed. The thermoplastic conponent supplied the ability to adhere to the different surfaces involved and the flexibility desirable in bonding rigid materials to each other or to wood, while the thermosetting component supplied a degree of resistance to temperature and a degree of firmness to the joint (10).

Joints made with thermoplastic-thermosetting combinations can be expected to be somewhat more flexible and to yield to continuously applied loads to a greater degree than joints made with thermosetting resins alone. The joints may also be expected to be somewhat less resistant to elevated temperatures and to water than the purely thermosetting resin glues (10).

Requirements and tests for thermoplastic glues in the woodworking field are not yet well standardized, and no generally applicable specifications have been developed, so little information is available as to their properties for wood bonding (10).

There are two types of these glues as concerned with woodworking. They are the polyvinyl-resin emulsions and the polyvinyl-resin solutions (19).

POLYVINYL-RESIN EMULSIONS

PROPERTIES

These glues are vinyl derivatives such as polyvinyl butyral or polyvinyl acetate. These glues are finely dispersed in water to produce an emulsion with a consistency and nonvolatile content generally comparable to the thermosetting resins. They are about 60 to 70 percent solids, and are marketed as a milky white or brownish liquid to be used at room temperature in the form supplied by the manufacturer (19).

The setting of these glues takes place when the water of the emulsion partially diffuses into the wood, whereupon the emulsified resin coagulates. There is no apparent chemical curing reaction as with the thermosetting glues, thus there is no particular advantage in the application of heat in setting. The coagulation of the emulsion appears to be partially reversible. The set resin absorbs water, softens, and at least partially redisperses if it becomes wet. Most of these glues are slightly acidic although some may be slightly alkaline (19, 28).

HARDENERS

Hardeners are not needed with these glues as there is no apparent chemical reaction in the curing process.

FILLERS

There is no indication that fillers would improve these glues if they were used.

SOLVENTS

Water, alcohol, alcohol-methyl acetate mixtures, acetone, and ethyl acetate have been used for solvents (3, 31).

EXTENDERS

Extenders are not used with these glues.

WORKING LIFE

Polyvinyl-resin emulsions have an indefinitely long working life (19).

RATE OF SPREAD

Information as to rate of spread is furnished by the manufacturer for each formulation of polyvinyl-resin glue. Their rates of spread, under similar conditions, compare with the rates of spread of the thermosetting glues.

ASSEMBLY

These glues do not seem to perform on short assembly periods as well as on longer assembly periods. A 10 minute open assembly or 30 minute closed assembly seems to work for some of these glues, but assembly times are not critical. On most glues the assembly period may extend for several days (3, 28).

MOISTURE CONTENT

These glues make good joints on woods with moisture contents from 2 to 15 percent, but the best results seem to be on woods with a moisture content from 5 to 11 percent (3, 28).

GLUING PRESSURES

The setting rate of these glues is relatively fast allowing the release of the clamping pressure in a half hour or less at 70° F. In tests on some polyvinyl-resin emulsion glues pressures of 150 to 200 pounds per square inch were used successfully (19, 28).

CURING TEMPERATURES

These glues are ordinarily used at room temperatures, but some are used at temperatures from 190° to 325° F. They can be used as hot-setting glues, but the temperature has to be lowered while the materials are still in the presses to allow the glues to cure. By this method it takes the blue bonds longer to reach ultimate strength (11, 31).

STORAGE LIFE

These glues have a long storage life if kept in tight containers, but coagulation of the emulsion in storage by evaporation or freezing must be avoided (11).

DURABILITY AND STRENGTH

There is a great variation of performance in glues of this type. The different commercial polyvinyl-resin emulsions vary considerably in hardness, and the harder glues usually form the stronger joints. These glues have very little water resistance due to the softening of the glue caused by water absorption, and the joints lose much of their strength when subjected to conditions of high relative humidity. Some of these glues soften and lose much of their strength at 110° F., and the strength of most polyvinyl-resin emulsion glues are reduced seriously at 160° F. One of their most serious limitations in woodworking is their lack of resistance to continuously applied loads (19).

In tests at 80° F. and 65 percent relative humidity, several of these glues failed to support as much as 25 percent of their ultimate load in shear static loading for 10 days. None of the glues would support 50 percent of their load for 10 days, and only one would support as much as 37 percent of the ultimate load for 10 days. Similar joints with casein and animal glues retained 50 percent ultimate load for at least 10 days in all cases. Mechanical stresses exerted on the glue joints as the result of moisture content changes in normal service apparently caused separation of the joints, or independent movement of the adjacent wood members that resulted in uneven surfaces and cracked finishes (19).

ECONOMIC POSSIBILITIES

Most of the uses for these glues are found in fields other than woodworking. Their advantage is in their versatility. They form bonds with nearly all materials such as metals, glass, and thermosetting plastics (13).

The polyvinyl-resin emulsions were formulated as an alternate material for the dwindling supply of cabinet maker's glue and may find some use in that field (13).

One of their main uses now is for use in making thermoplastic-thermosetting combinations to give greater versatility to the thermosetting resin glues (10).

POLYVINYL-RESIN SOLUTIONS

In solution form, the polyvinyl-resins are dissolved in alcohol, acetone, ethyl acetate, or other organic solvents and are marketed as syrups. Thinners are used to adjust their consistency to use requirements. Several coats of the solution are usually applied, each of which is permitted several hours of drying before the next is applied; and several hours to several days are allowed to elapse between the last application and pressing. The materials are pressed in hot presses or by other means at temperatures of 195° to 320° F., with the temperature used being determined by the softening point of the resin. The application of heat causes the glue to soften or flow, and setting or development of joint strength occurs upon cooling. The necessity of cooling the work under pressure is one of the chief objections to the use of these glues (19).

It can be seen from these serious drawbacks that the glue could have only limited application in the commercial field. It has not been used enough in the wood-bonding field to afford any definite conclusions as to its properties and abilities.

COMMERCIAL GLUES

All of the data concerning glues in this paper have been taken from impartial tests on commercial products. I have not dealt with any particular commercial glue, because they are proprietary. All commercial glues are sold under trade names, and each company advertises the quality of its glues. Being as each company stresses the good points of its product, that information cannot be inserted into a paper of this type that is dealing with strong and weak points of each glue, which have been arrived at by impartial tests.

It is necessary to obtain commercial glues by use of trade names. As an aid to buyers the Forest Products Laboratory has issued a table giving the designated trade names of most of the commercial glues and some of their characteristics. Table 1 gives the trade name of the commercial glues, and their type, hardener, form, cleaning solvent, solids content, working life, assembly time, curing temperature, and the favorable moisture content of the wood for gluing.

CONCLUSIONS

It is not known just how long ago glues were first formulated, but there is proof that they were in use about 1500 B.C. Through the many centuries that glues have been used they were never developed to the point of being completely free of limitations. With the relatively development of the synthetic-resin glues, and their expansion of uses during World War II, it seems that a completely trustworthy and versatile set of glues have been found that will permit extensive use in commercial enterprises.

The dwindling supply of virgin high-grade timber has mecessitated a search for some way to utilize the inferior timber products, and the normally waste materials that are burned at mills. Glue seems to be the answer, and the synthetic resins are proving their worth in the wood-bonding industries.

The future of synthetic resins is very bright as shown by present trends. The United States Tariff Commission report for 1946 showed that 12.2 percent of all synthetic resins produced were used for adhesives and laminations. This amounted to 114,775,000 pounds of resin valued at $28,290,000. In 1947 a plant in Seattle, Washington, produced 15,500,000 pounds of synthetic-resins, and the demand was so great that the plant planned a future operation on a 7 day week at top production rates. Estimates indicate that the Northwest alone will be using 100,000,000 pounds of synthetic resins by 1950 in their extensive plywood industries.

After surveying the properties and characteristics of the various synthetic-resin glues, it is necessary to be able to draw some conclusions as to the best glue to use for any one purpose. The correct choice of an adhesive may be made on the basis of cost, color, use, and ultimate durability. The following characteristics should be checked in choosing a glue:

1. Urea Resins
   a. Most versatile
   b. Lowest cost, approximately 12 cents per mixed pound
   c. Highly sensitive to electronic curing
   d. Colorless glue line
2. Phenol Resins
   a. Most difficult to use
   b. Require high curing temperatures
   c. Sometimes require special solvents
   d. Reddish-brown glue line

e. A rc easily

f. Cost approximately 12.5 cents per mixed pound

3. Resorcinol Resins

a. Highly adaptable

b. Fast curing

c. Can be obtained non-arcing or variable in conductivity

d. Red to reddish-brown glue line

e. Cost 45 to 50 cents per mixed pound

4. Melamine Resins

a. Fast curing

b. Colorless glue line

c. Cost approximately 30 cents per mixed pound

For extreme durability, unprotected outdoor exposures, use resorcinol, melamine, or phenol; for all general purposes, indoor articles, use ureas; do not use phenol for edge gluing with electronic heating.

The synthetic-resin glues have shown miraculous results in extensive applications and tests. The versatility, strength, durability, and relatively low cost of these glues have made them desirable and satisfactory for almost any use in the wood-bonding industries.

The qualities of the thermoplastic glues prevents their use to any great extent for wood bonding. They are not durable under conditions where they may come in contact with water or high relative humidities.

One of their greatest uses has been in making thermoplastic-thermosetting combinations. The combination increases the versatility of the thermosetting glues. They show promise in gluing combinations of materials such as wood to metal. They also form good bonds between glasses or plastics.

LITERATURE CITED

1. Anonymous. For plywood strength avoid strongly acid or alkaline adhesives. Southern Lumberman, P 54, February 1, 1949.

2. ________. Resin statistics from tariff commission. Modern Plastics, 26:79, January 1948.

3. Army-Navy-Civil Committee. Wood aircraft inspection and fabrication. ANC Bul. No. 19:157-163, December 1943.

4. Arneson, G. N. Glues and gluing in prefabricated house construction. Reprint, Cosgrove's Magazine, pp 1-4, 1946.

5. Babcock, G. E. and Smith, A. K. Extending phenolic resin plywood glue with corn gluten and soybean meal. U. S. Dept. of Agri. ALC Bul. No. 65:2-3, 1944.

6. ________________________. Extending phenolic resin glues with proteinaceous materials. Industrial and Chemical Engineering, 39:85-88, January 1947.

7. Black, J. M.; Olson, W. Z. and Bruce, H. D. Effects of elevated curing temperatures on strength and durability of yellow birch plywood joints made with room-temperature-setting urea glues. Forest Products Laboratory Report No. 1339. pp 2-3, 1945.

8. Blomquist, R. F. Effect of high and low temperatures on resin glue joints in birch plywood. Forest Products Laboratory Mimeo. No. 1345, Revised. pp 7-40, 1944.

9. Breskin, C. A. What plastics mean to plywood. Scientific American, 176:115, March 1947.

10. Brouse, Don. Glues for use in building construction. Report for Presentation to the Second Annual School for Building Inspectors, Chicago, Illinois, pp 1-32.

11. __________ and Blomquist, R. F. Postwar developments in woodworking glues. Forest Products Research Society, Preprint. pp 4-11, 1947.

12. Bruce, H. D.; Olson, W. Z.; Black, J. M. and Rauch, A. H. Gluing with low-temperature-setting phenol, resorcinol, and melamine glues. Forest Products Laboratory Report No. 1531. pp 1-4, 1944.

13. De Lollis, N. J. Industrial adhesives-1. Product Engineering, 26:138, November 1947.

14. ______________. Industrial adhesives-2. Product Engineering, 26:121, December 1947.

15. Dosker, C. D. and Knauss, A. C. Laminating lumber for extreme service conditions. Forest Products Research Society, Paper No. 44-A-31. pp 6-10, 1944.

16. Eickner, H. W. The gluing characteristics of 15 species of wood with cold-setting, urea-resin glues. Forest Products Laboratory Report No. 1342. pp 1-4, 1942.

17. Forest Products Laboratory. Casein glues: their manufacture, testing, and preparation. Forest Products Laboratory Mimeo. No. R280. pp 1-10, 1939.

18. ________________________. The laminating of timber products with low-temperature, phenolic-type resin glues. Forest Products Laboratory Mimeo. No. R1437. pp 10-27, 1944.

19. ________________________. Synthetic-resin glues. Forest Products Laboratory Tech. Note No. 1336, Revised. pp 1-21, 1948.

20. Hamilton, J. F. Method for selecting the right adhesive. National Hardwood Magazine, 22: 25-28, July 1948.

21. Knauss, A. C. and Selbo, M. L. Laminating of structural wood products by gluing. Forest Products Laboratory Mimeo. No. D1635, Revised. pp 1-45, 1948.

22. Leicester, W. F. The influence of modern glues on the utilization of wood. Address Delivered at the Wood Products Conference, New York State College of Forestry, Syracuse, New York. pp 1-7, October 1944.

23. Leicester, W. F. The new glues hold anything. Science Illustrated, 1:106-109, April 1946.

24. Libby-Owens-Ford-Glass Company. The interesting story of plaskon resin glue. pp 1-21, 1944.

25. Marra, A. A. The technology of the glue line in electronic edge-gluing of lumber. Forest Products Research Society, Preprint 25 A. pp 7-8, March 1948.

26. Olson, W. Z.; Bensend, D. W. and Bruce, H. D. Resistance of several types of glue in wood joints to fatigue stressing. Forest Products Laboratory Report No. 1539. pp 1-4, 1946.

27. ____________ and Blomquist, R. F. Development of strength in yellow birch lap joints glued with six resorcinol-resin glues at temperatures from 40° to 80° F. Forest Products Laboratory Report No. 1565. pp 1-4, 1947.

28. ____________ and Bruce, H. D. Polyvinyl-resin emulsion woodworking glues: a study of some of their properties. Forest Products Laboratory Report No. R1691. pp 1-4, 1947.

29. ____________ and Cahodas, Leah. Stability of low-temperature-setting phenol, resorcinol, and melamine resin adhesives stored at 80° F. Forest Products Laboratory Report No. 1532. pp 1-5, 1945.

30. ____________ and Soper, V. R. Development of shear strength in maple block joints made with resorcinol glues at temperatures from 40° to 80° F. Forest Products Laboratory Report No. R1486. pp 1-3, 1945.

31. Paustian, John. Synthetic resin glues for wood. Industrial Arts and Vocational Education, 36:42A-44A, March 1947.

32. Perry, T. D. Modern wood adhesives. New York, Pittman Publishing Company, 1944. 208 p.

33. Resinous Products and Chemical Company. New plywood adhesive designed for high flour extension. The Resinous Reporter, 7:13-14, February 1946.

34. Sawyer, F. G.; Hodgins, T. S. and Zeller, J. H. Phenolic resin glues for plywood. Industrial and Engineering Chemistry, 40:1011-1018, June 1948.

35. Stamm, A. J. Wood. Industrial and Engineering Chemistry, 39:1256-1261, October 1947.

36. Truax, T. R. The gluing of wood. U. S. Dept. of Agri. Bul. No. 1500. pp 1-12, 1929.

37. Wangaard, F. F. Summary of information on durability of woodworking glues. Forest Products Laboratory Report No. 1530, Revised. pp 1-11, 1946.

APPENDIX

TABLES

TABLE 1. – Synthetic-resin glues classified as to type, form, and general operating characteristics[1]

Designation	Hardener or modifier	Type[2]	Form	Cleaning solvent	Approximate solids content mixed for use	Approximate working life at 75° F.	Closed assembly time at 75° F. Minimum	Maximum			Curing temperature	Favorable moisture content of wood
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)				(9)	(10)
					Percent	Hrs.	Min.	Min.	Hrs.	Days	°F.	Percent
Amberlite[3] PR-14	Incorporated	Hot-press phenol	Powder	Water	40 - 65	4	30			Many	250 - 320	6 - 10
Amberlite[5] PR-83	Q-108	...do...	...do...	...do...	40	6	5	25			260 - 285	0 - 5
Amberlite PR-115	P-117	Resorcinol	Liquid	...do...	65	4	20	60			Minimum 70	6 - 15
Amberlite PR-245	Q-108	Intermediate-temperature phenol	Powder	...do...	40 - 45	5 - 6	30			Several	160 - 320	4 - 10
Arabol EM-67	None	Thermoplastic vinyl emulsion	Liquid	...do...	56	6		[7]10			50 - 110	4 - 15
Bakelite BCU-1	Separate	Room-temperature urea	Powder	...do...	65	4		30			Minimum 70	6 - 15
Do.	...do...	Hot-press urea	...do...	...do...	65	8			48		260	6 - 15
Bakelite BCU-5	Incorporated	Room-temperature urea	...do...	...do...	65	4		30			Minimum 70	6 - 15
Bakelite BCU-12	Separate	...do...	Liquid	...do...	50	4		30			Minimum 70	6 - 15
Do.	...do...	Hot-press urea	...do...	...do...	50	10			10		260	6 - 15
Bakelite BCU-12772	...do...	Room-temperature urea	...do...	...do...	65	4		30			Minimum 70	6 - 15
Do.	...do...	Hot-press urea	...do...	...do...	65	12			72		260	6 - 15
Bakelite[3] BC-16529	Incorporated	Hot-press phenol	Powder	...do...	50	8+	60			3	180 - 270	2 - 10
Bakelite BC-17613	BK-17618	Resorcinol	Liquid	...do...	72	4			2		Minimum 70	6 - 15
Butacite 4639	None	Thermoplastic vinyl solution	...do...	Alcohol	18 - 20	6				Many	250 - 300	6 - 15
Butacite 4644	...do...	...do...	...do...	...do...	18 - 20	6				Many	250 - 300	6 - 15
Cascamite ANS	Incorporated	Room-temperature urea	Powder	Water	65	4		20			Minimum 70	6 - 15
Cascamite[6] TS-16	H-21; LU-7	Hot-press urea	...do...	...do...	53 - 57	8 - 24			Several[7]		About 300	6 - 15
Cascamite 12	Incorporated	Room-temperature urea	...do...	...do...	65	5 - 6		20			Minimum 70	6 - 15
Cascamite 66	M-16	...do...	...do...	...do...	65	4		20			Minimum 70	6 - 15
Do.[9]	H-19	Fortified urea	...do...	...do...	71	8+			4		260	4 - 12
Cascamite 77	M-20	Room-temperature urea	...do...	...do...	61	5 - 6		20			Minimum 70	6 - 15
Cascamite 151	M-8	...do...	...do...	...do...	67	1-3/4		20			Minimum 70	5 - 15
Cascamite 153	H-11	Hot-press urea	...do...	...do...	67	22			5		230 - 250	5 - 15
Do.	H-7-3	...do...	...do...	...do...	69	44			12		230 - 250	5 - 15
Do.	H-27-L	...do...	...do...	...do...	65	75			72		230 - 250	5 - 15
Cascophen[3] BG-17	H-23	Hot-press phenol	Liquid	...do...	50	4	15			4	220 - 300	6 - 12
Cascophen HP-402	H-31-L	...do...	Powder	...do...	55	10				3 - 4	240 - 300	4 - 12
Cascophen LT-67	M-18	Intermediate-temperature phenol	Liquid	...do...	71	4 - 5		75			150 - 200	8 - 15
Cascophen RS-216	FM-60	Resorcinol	...do...	...do...	68	3-3/4		90			Minimum 70	6 - 15
Do.[11]	K-14-L; FM-60	Separate application resorcinol	...do...	...do...	68	3-3/4		[7]10			Minimum 70	6 - 15
Cascophen RS-224	FM-84	Resorcinol	...do...	...do...	59	3 - 4		30			Minimum 70	6 - 15
Cascophen RS-232	FM-60	...do...	...do...	Alcohol and water	58	4	15	105			Minimum 70	6 - 15
Do.[11]	K-14-L; FM-60	Separate application resorcinol	...do...	...do...	58	4		[7]10			Minimum 70	6 - 15
Casco Resin No. 5	FM-50	Room-temperature urea	...do...	Water	64	4		20			Minimum 70	6 - 15
Do.	FM-62	...do...	...do...	...do...	64	5 - 6		20			Minimum 70	6 - 15
Casco Resin 135	FM-100-C	...do...	...do...	...do...	60	8 - 9		30			Minimum 70	7 - 15
Cascorez CV-703	None	Thermoplastic vinyl emulsion	...do...	...do...	59	6		[7]10			50 - 110	4 - 15
Catabond 590	No. 1	Intermediate-temperature phenol	...do...	Alcohol	62	2		20			150 - 200	2 - 12
Do.	No. 7	...do...	...do...	Water	62	2	15	60			150 - 200	2 - 12
Catabond 591	No. 3	Hot-press phenol	...do...	...do...	62	8+				Several	300 - 320	6 - 15
DuPont 4624	Incorporated	Modified thermoplastic vinyl	...do...	Alcohol and water	20	6				Many	250 - 300	3 - 18
Durez[3] 196	...do...	Hot-press phenol	Powder	Water	60	24+	15			7	250 - 300	3 - 15
Durez 12041	7422	Intermediate-temperature phenol	Liquid	Alcohol	67	7			2		150 - 200	2 - 12
Durez 12533-34B	Incorporated	...do...	...do...	Water	73	6 - 7			1-3/4		150 - 200	6 - 15

Report No. 1336-A

Z M 71777 F

(Sheet 1 of 4)

TABLE 1. – Synthetic-resin glues classified as to type, form, and general operating characteristics[1] (continued)

Designation	Hardener or modifier	Type[2]	Form	Cleaning solvent	Approximate solids content mixed for use	Approximate working life at 75° F.	Closed assembly time at 75° F. Minimum	Maximum			Curing temperature	Favorable moisture content of wood
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)				(9)	(10)
					Percent	Hrs.	Min.	Min.	Hrs.	Days	°F.	Percent
Dures 12688	12689	Resorcinol	Liquid	Water	66	3		90			Minimum 70	6 - 15
Durite 2982	2982-A	Intermediate-temperature urea	do.	do.	70	8			2		175 - 250	6 - 12
Durite 2984	2984-A	Fortified urea	do.	do.	76	8			1		200 - 250	6 - 12
Durite 2989	2989-A	Room-temperature urea	do.	do.	64	5		30			70 - 145	6 - 12
Durite 3026	3026-A	Resorcinol	do.	do.	64	3		60			Minimum 70	6 - 15
Fuller's No. 17	None	Thermoplastic vinyl emulsion	do.	do.	52	6		[7]10			50 - 110	4 - 15
Fuller's No. 512	do.	do.	do.	do.	58	6		[7]10			50 - 110	4 - 15
Glu-Bond	do.	do.	do.	do.	50	6		[7]10			50 - 110	4 - 15
Interlake 4282	NaOH; soda ash	Hot-press phenol	do.	do.	50	72		30			260 - 300	2 - 10
Kaseno 580	Incorporated	do.	do.	do.	41	4	5	20			270 - 300	4 - 8
Kaseno 580-472	472	do.	do.	do.	39	4	5	20			270 - 300	4 - 8
Kaseno[11] 2670-A	2670-B	Resorcinol	do.	do.	43	2		5			Minimum 70	8 - 15
Kaseno 2680	2680-B	Intermediate-temperature phenol	do.	do.	47	4	5	90			Minimum 140	8 - 15
Kaseno 2690	2690-B	Resorcinol	do.	do.	47	3	5	90			Minimum 70	8 - 15
Kaseno[12] 4510	4510-B	do.	do.	do.	62	4			2			8 - 15
Lauxite PF-4	PF4A	Hot-press phenol	do.	do.	44	48	30		24		220 - 280	1 - 10
Lauxite[5] PF-4X	PF4XW	do.	do.	do.	45	48			24		220 - 280	1 - 10
Lauxite PF-5	C, B	do.	do.	do.	42	24			24		220 - 280	1 - 10
Lauxite PF-5X	C, B, or PF-92	do.	do.	do.	43	24			24		190 - 280	1 - 10
Lauxite PF-10C	PF10C	do.	Powder	do.	58	16+	15		48		260 - 280	6 - 12
Lauxite PF-90C	PF90C	Resorcinol	Liquid	do.	61	3	5	90			Minimum 70	6 - 15
Lauxite[8] TS-1	Incorporated	Hot-press urea	Powder	do.	57	15			[7]8		About 300	6 - 15
Lauxite[3] 8-9XC-U	do.	do.	do.	do.	62	48	5		24		240 - 260	6 - 15
Lauxite 8-9XC-U, 250-L	250-L	Melamine-urea	do.	do.	62	4	5		24		240 - 260	6 - 15
Lauxite 89CU	Incorporated	Hot-press urea	do.	do.	62	48		20			240 - 260	6 - 15
Lauxite 9-2CU	do.	do.	do.	do.	63	16+			48		220 - 260	6 - 12
Lauxite[13] 72-X	do.	Room-temperature urea	do.	do.		2 - 5		20			Minimum 70	6 - 15
Lauxite 77-X	do.	do.	do.	do.	60	4		20			Minimum 70	6 - 1
Lauxite 81-MX	G, Y, or X and Y	do.	do.	do.	60	2 - 5		20			Minimum 70	6 - 15
Lauxite[11] 11	11	do.	do.	do.	62	48		5			Minimum 70	6 - 15
Lauxite 101	FW	Hot-press urea	Liquid	do.	60	24			24		220 - 280	5 - 15
Do.	YM	Melamine-urea	do.	do.	70	48			24		220 - 280	5 - 15
Lauxite[11 13] 203	203	Room-temperature urea	do.	do.		4		15			Minimum 70	5 - 1
Lauxite 224	224	do.	do.	do.	67	3		30			Minimum 70	5 - 1
Lauxite 250	Incorporated	Hot-press melamine	Powder	30 percent $CaCl_2$	65	10	15		24		240 - 280	6 - 12
Lauxite 252	252	Intermediate-temperature melamine	do.	do.	67	3 - 4	5	30			Minimum 110	6 - 12
Lauxite 260	Incorporated	Melamine-urea	do.	Water	63	16+	15		24		190 - 300	1 - 8
Le Page's Panite	do.	Room-temperature urea	do.	do.	65	4		20			Minimum 70	6 - 15
Melmac[3] 400	do.	Intermediate-temperature melamine	do.	Soap solution	60	36				30	190 - 240	6 - 1
Melmac 401	do.	do.	do.	do.	67	36				30	190 - 240	6 - 1
Melurac[3] 300	do.	Melamine-urea	do.	Water	60	10 - 12				7	200 - 240	6 - 1
Melurac 301	do.	do.	do.	do.	65	15+	60			10	200 - 260	6 - 1
Paisley #1	None	Thermoplastic vinyl emulsion	Liquid	do.	42	6		[7]10			50 - 110	4 - 1
Penacolite G-1124	G-1124B	Resorcinol	do.	do.	59	2 - 3	10	45			Minimum 70	4 - 1
Penacolite G-1131	G-1131B	do.	do.	do.	70	2-1/2 - 3	10	120			Minimum 70	6 - 1

Report No. 1336-A

Z M 71778 F

(Sheet 2 of 4)

TABLE 1.- Synthetic-resin glues classified as to type, form, and general operating characteristics[1] (continued)

Designation	Hardener or modifier	Type[2]	Form	Cleaning solvent	Approximate solids content mixed for use	Approximate working life at 75° F.	Closed assembly time at 75° F. Minimum	Maximum			Curing temperature	Favorable moisture content of wood
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)				(9)	(10)
					Percent	Hrs.	Min.	Min.	Hrs.	Days	°F.	Percent
Penacolite G-1215	G-1215B	Resorcinol	Liquid	Water	53	3			2		Minimum 70	6 - 15
Perkins L-100	0-2	Room-temperature urea	do.	do.	65 - 70	4		20			Minimum 70	6 - 12
Do.[12]	0-85	Intermediate-temperature urea	do.	do.	65 - 70	3 - 5			1		85 - 180	6 - 12
Do.	0-510	Room-temperature urea	do.	do.	65 - 70	1 - 4		30			Minimum 70	6 - 12
Do.	H-23	Hot-press urea	do.	do.	65 - 70	18			18		Minimum 220	8 - 12
Perkins D-110	0-23	Room-temperature urea	Powder	do.	60 - 65	5		20			Minimum 70	6 - 12
Perkins DO-246	Incorporated	do.	do.	do.	60 - 65	5		20			Minimum 70	6 - 12
Perkins M-411	do.	Melamine-urea	do.	do.	62	8	10		8		180 - 240	6 - 9
Perkins R-55	H-55	Resorcinol	Liquid	do.	60	2			2		Minimum 70	6 - 15
Perkins RP-60	H-55	do.	do.	do.	60	2			2		Minimum 70	6 - 15
Perkins VL-75	None	Thermoplastic vinyl emulsion	do.	do.	50	6		[7]10			50 to 110	4 - 15
Phenac Resin Adh. 703	700	Resorcinol	do.	do.	72	5		60			Minimum 70	6 - 14
Plaskon 107-2	B-7	Hot-press urea	Powder	do.	64	8+			24		220 - 240	6 - 12
Plaskon[13] 121-2	B-6	do.	do.	do.		Up to 8		20			220 - 240	6 - 12
Plaskon 201-2	A	Room-temperature urea	do.	do.	61	4		20			Minimum 70	6 - 15
Do.	C	Fortified urea	do.	do.	66	8+			24		220 - 240	6 - 12
Do.	D	Intermediate-temperature fortified urea	do.	do.	65	4+		20			140	6 - 15
Plaskon[13] 221-2	G-6	Room-temperature urea	do.	do.		4		20			Minimum 70	6 - 15
Plaskon[11] 231-2	J-20	do.	do.	do.	60	4		[7]15			Minimum 70	6 - 15
Plaskon 250-2	Incorporated	do.	do.	do.	60	4		20			Minimum 70	6 - 15
Plaskon[3] 700-2	700-2B	Fortified urea	do.	do.	78	4			72		200 - 250	6 - 12
Plaskon[3] 800-12	Incorporated	Hot-press phenol	do.	do.	50	4				14	250 - 290	8 - 10
Plaskon 810-12	do.	do.	do.	do.	40	4				14	280 - 300	8 - 12
Plyobond	None	Thermoplastic resin solution	Liquid	Ketones	20 - 30	6				Many	250 - 300	4 - 12
Plycozite	Incorporated	Modified thermoplastic resin solution	do.	118-C	20	6				30	250 - 350	4 - 12
Plyophen P-398	do.	Hot-press phenol	do.	Water	43	8+			24		240 - 320	2 - 12
Plyophen 6000	6002	Resorcinol	do.	do.	68	4			2		Minimum 70	6 - 15
Syntjoint Bonder	None	Thermoplastic vinyl emulsion	do.	do.	34	6		[7]10			50 - 110	4 - 15
Synvaren CP-5	Incorporated	Hot-press phenol	do.	do.	50	4	30			Several	280 - 300	4 - 12
Do.	LS	Intermediate-temperature phenol	do.	do.	50	8			4		Minimum 180	4 - 12
Synvaren FLS-A	RF37 or RF73	Resorcinol	do.	do.	60 - 70	3			1		Minimum 70	4 - 12
Synvarite PCP	Incorporated	Hot-press phenol	Powder	do.	40 - 60	4	30			Several	280 - 300	6 - 12
Do.	LS	Intermediate-temperature phenol	do.	do.	40 - 60	8			4		Minimum 180	4 - 12
Synvarite U	UPA	Room-temperature urea	do.	do.	70	4 - 5		25			Minimum 70	6 - 12
Do.	AFB	Hot-press urea	do.	do.	70	24			16		220 - 250	6 - 12
Synvarol WR-513	228-B	Room-temperature urea	Liquid	do.	65 - 70	2 - 3		15			Minimum 70	6 - 12
Do.	AFB	Hot-press urea	do.	do.	65 - 70	24			16		220 - 250	6 - 12
Tego[3]	None	Hot-press phenol	Film		100	15				15	280 - 320	6 - 10
Textolite 2163-A	2775	Intermediate-temperature phenol	Liquid	Alcohol	75 - 80	2 - 5			4		Minimum 110	3 - 11
Textolite 2168-A	2777	Melamine-urea	do.	Water	70 - 75	6 - 10			48		212 - 265	3 - 12
Uformite 430	Q-21	Hot-press urea	do.	do.	70	4 - 5	10	60			240 - 280	5 - 10
Do.	Y	do.	do.	do.	70	4 - 5	10	20			240 - 280	5 - 10
Do.	Q-116	Room-temperature urea	do.	do.	70	3 - 4		30			Minimum 70	5 - 15
Do.	Q-107 and Q-87	Fortified urea	do.	do.	70	4 - 8	120		24		250 - 300	5 - 10
Uformite 500	Q-87	Room-temperature urea	Powder	do.	70	3 - 4		30			Minimum 70	5 - 15

TABLE 1.- Synthetic-resin glues classified as to type, form, and general operating characteristics[1] (continued)

Designation	Hardener or modifier	Type[2]	Form	Cleaning solvent	Approximate solids content mixed for use	Approximate working life at 75° F.	Closed assembly time at 75° F. — Minimum	Closed assembly time at 75° F. — Maximum			Curing temperature	Favorable moisture content of wood
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)				(9)	(10)
					Percent	Hrs.	Min.	Min.	Hrs.	Days	°F.	Percent
Uformite 500	Q-116	Room-temperature urea	Powder	Water	70	3 - 4	....	30	....	....	Minimum 70	5 - 15
Do.[3]	Q-107 and Q-87	Fortified urea	...do...	...do........	70	4 - 8	120	....	24	....	250 - 300	5 - 10
Uformite 501	Incorporated	Hot-press urea	...do...	...do........	70	4 - 5	10	....	2	....	240 - 265	5 - 10
Uformite CB-552	...do........	Room-temperature urea	...do...	...do........	70	3 - 4	....	30	....	....	Minimum 70	5 - 15
USP Resorcinol	USP catalyst	Resorcinol	Liquid	...do........	70	3-1/2 - 4	....	....	2	....	Minimum 70	6 - 15
Urac[13] Resin 110	O-110	Room-temperature urea	Powder	...do........	....	2-1/2 - 4	....	30	....	....	Minimum 70	6 - 14
Do.[13]	WF-101	Hot-press urea	...do...	...do........	....	3 - 7	....	....	4	....	Minimum 140	6 - 14
Urac 180	59	Room-temperature urea	Liquid	...do........	70	4 - 5	....	20	....	....	Minimum 70	6 - 15
Urac Resin Adh. 185	185	...do........	...do...	...do........	85	4-1/2	....	30	....	....	Minimum 70	6 - 14
Vinylseal A-35	None	Thermoplastic vinyl solution	...do...	Acetone	35	[6]	....	....	....	Many	200 - 320	6 - 15
Vinylseal A-70	...do........	...do........	...do...	...do........	70	[6]	....	....	....	Many	200 - 320	6 - 15
Vinylseal MA-28-14	...do........	Thermoplastic modified vinyl solution	...do...	...do........	28	[6]	....	....	....	Many	200 - 320	6 - 15
Vinylseal MA-28-28	...do........	...do........	...do...	...do........	28	[6]	....	....	....	Many	200 - 320	6 - 15
Weldwood	Incorporated	Room-temperature urea	Powder	Water	60	3 - 4	....	20	....	....	Minimum 70	6 - 15
Wood-Lok A	None	Thermoplastic vinyl emulsion	Liquid	...do........	48	[6]	....	[7]10	....	....	50 - 110	4 - 15
Wood-Lok B	...do........	...do........	...do...	...do........	50	[6]	....	[7]10	....	....	50 - 110	4 - 15

[1] Information contained in this table is based on data supplied in part by the glue manufacturers, in part by the users, and in part by the Forest Products Laboratory. The listing of glues in this table is not a recommendation of their quality nor an indication that they meet current specifications. The limits given for curing temperatures and other details, have not, in general, been verified by tests at the Forest Products Laboratory.

[2] All glues listed are of the thermosetting type unless otherwise stated in this column.

[3] Glue suggested by manufacturer for use in bag molding.

[4] Several days.

[5] Designed primarily for Douglas-fir and similar woods.

[6] Indefinite.

[7] Open assembly.

[8] For use with tapeless splicer.

[9] Not recommended for use with fluid pressure.

[10] One week.

[11] Separate-application glue; hardener applied to one surface, glue to the other.

[12] For use in high-frequency gluing.

[13] Designed primarily for use with flour extender.

[14] Up to several weeks.

[15] Several months.

FIGURES

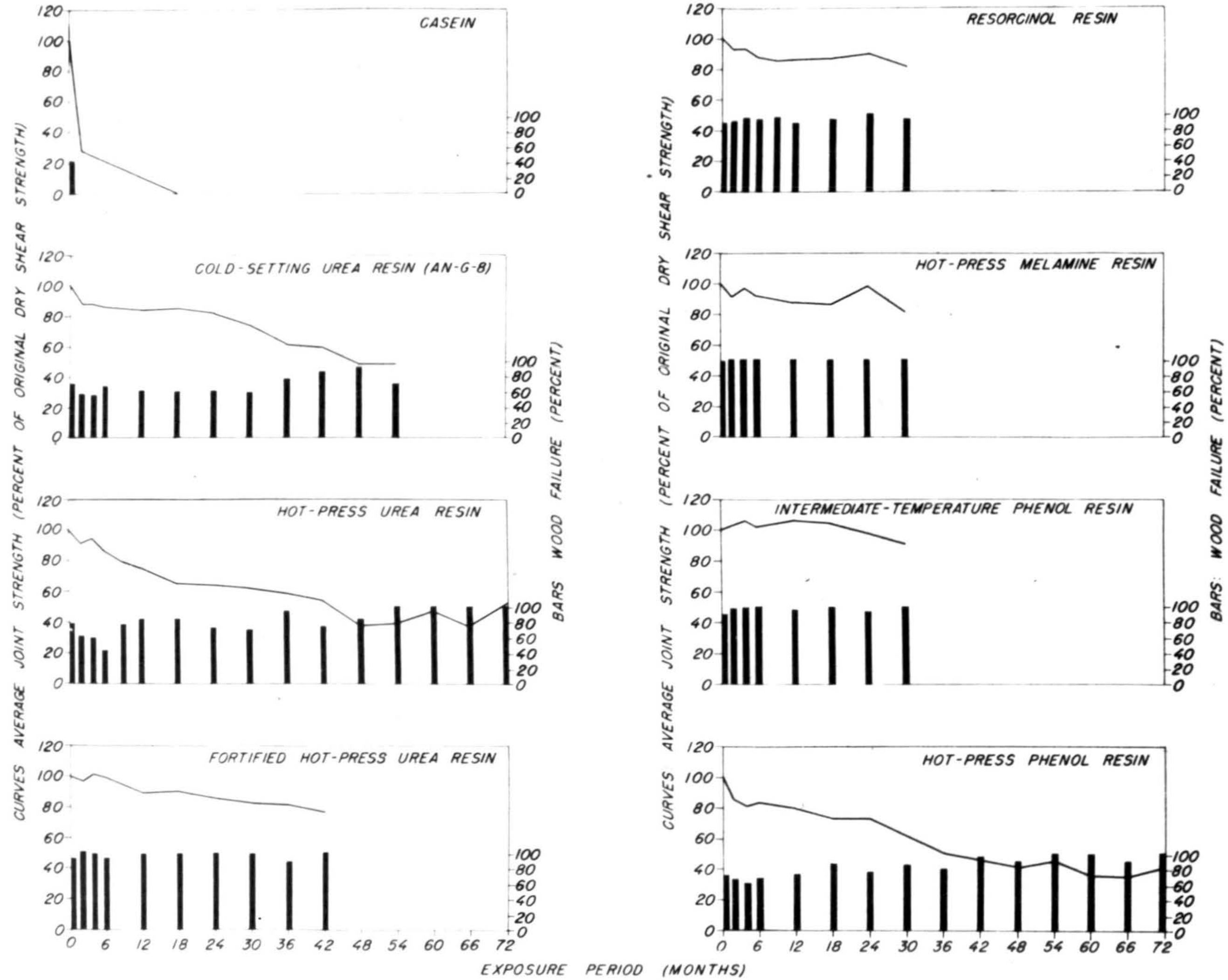


Figure 1.--Resistance of birch plywood joints, glued with eight types of glues, to continuous soaking in water at room temperatures.

Z M 71047 F

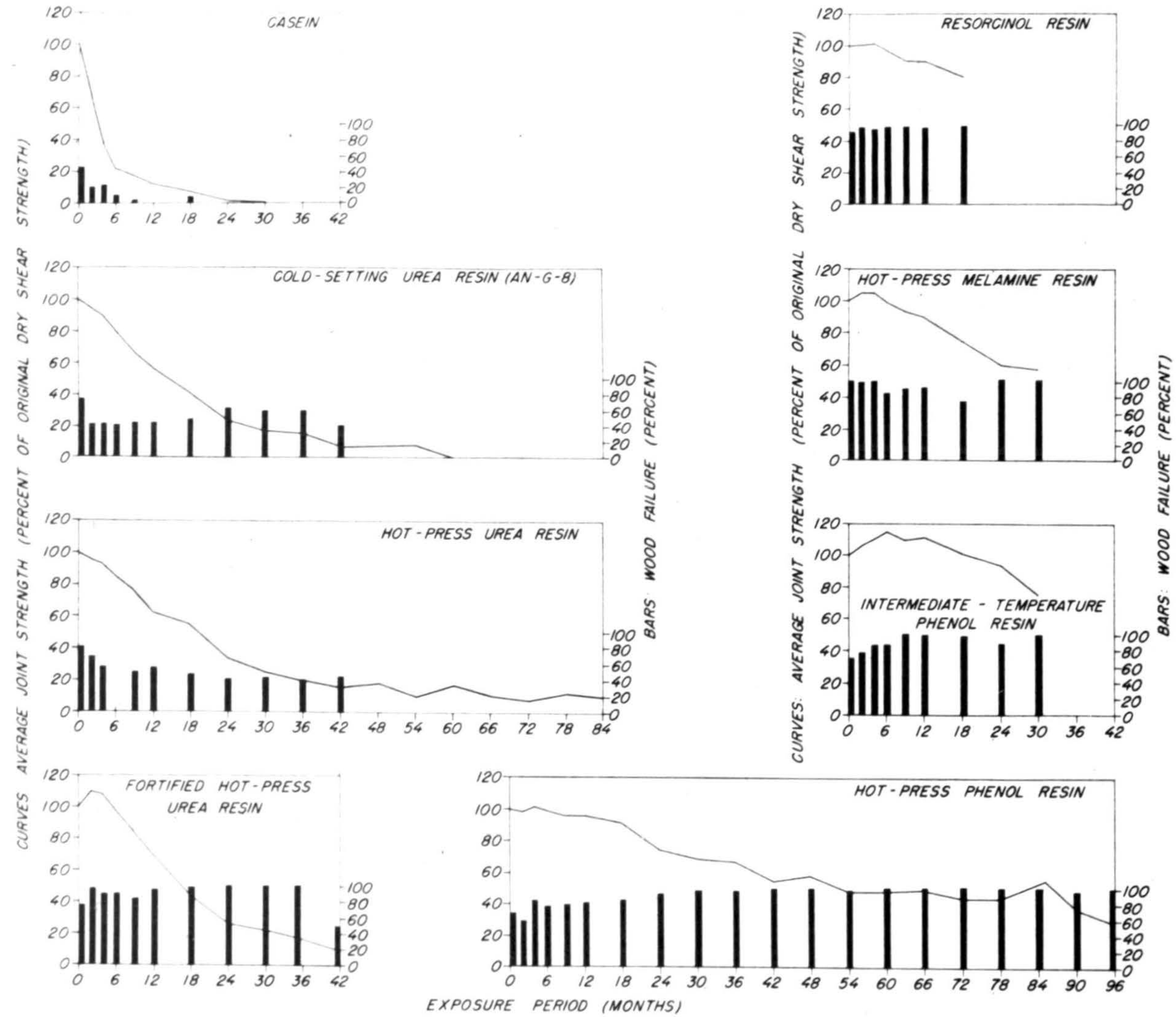


Figure 2.--Resistance of birch plywood joints, glued with eight types of glues, to continuous exposure at 97 percent relative humidity and 80° F.

Z M 71048 F

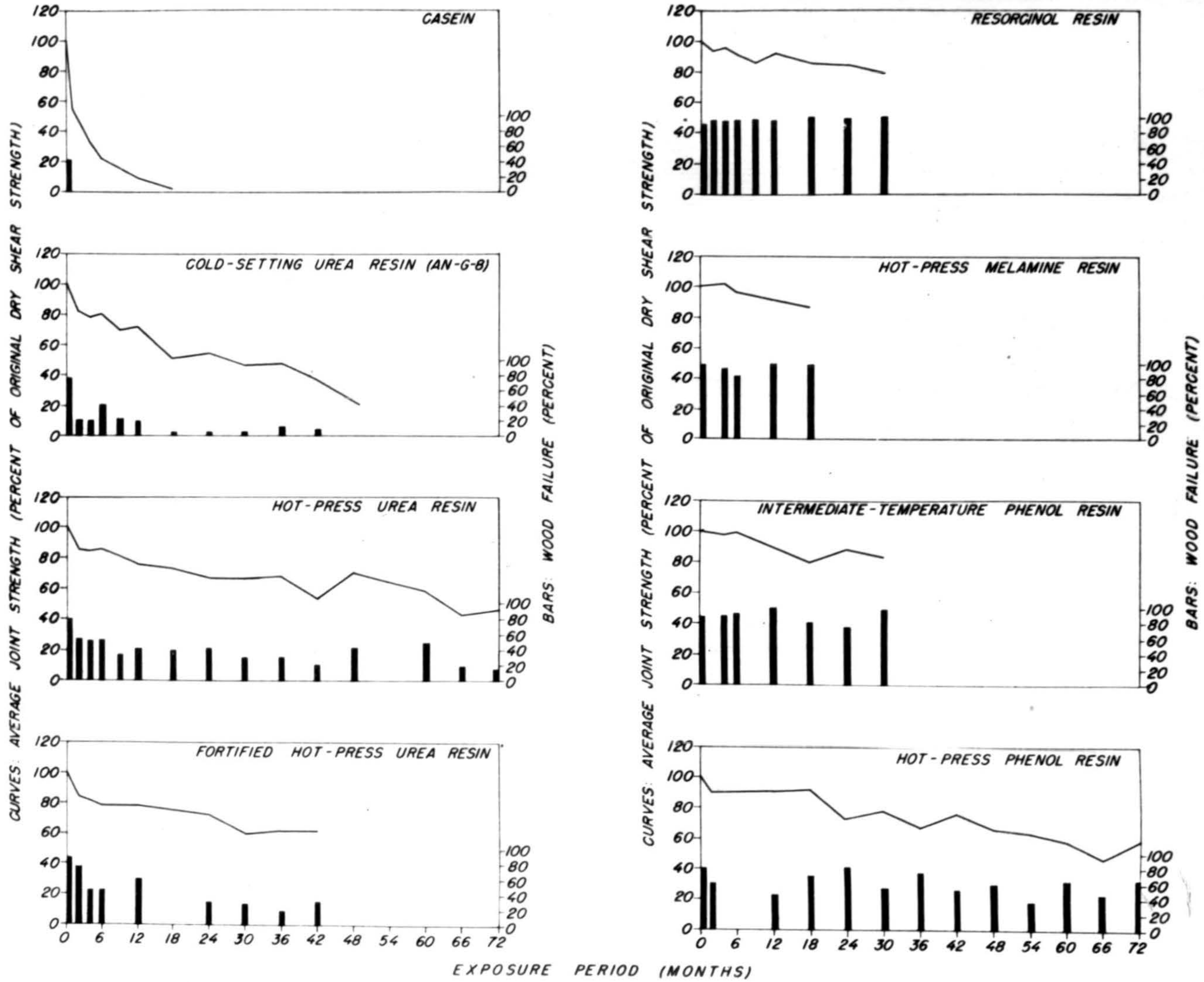


Figure 3.--Resistance of birch plywood joints, glued with eight types of glues and exposed to a repeating cycle of 2 days' soaking in water at room temperature followed by 12 days' drying at 80° F. and 30 percent relative humidity.

Z M 71049 F

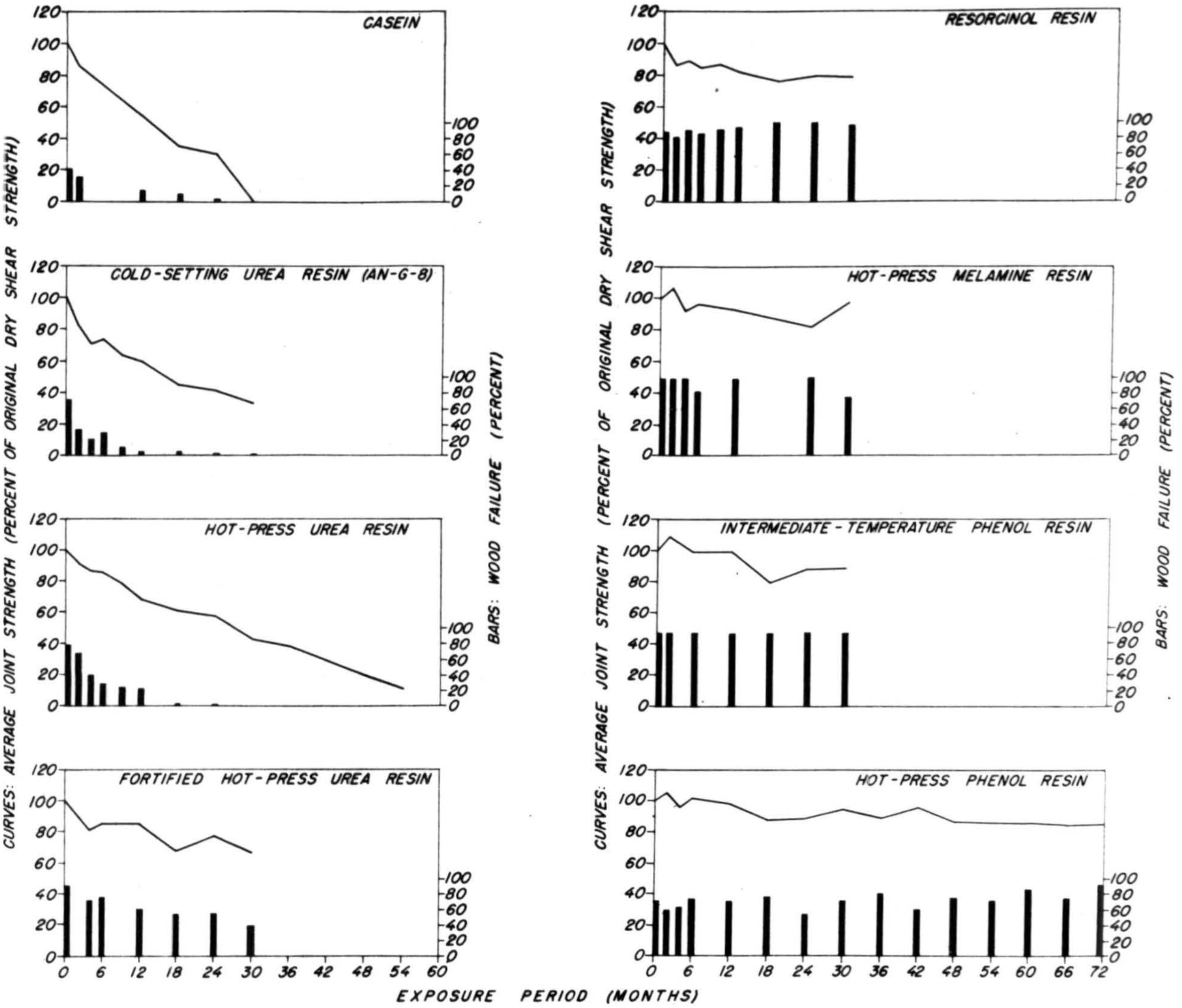
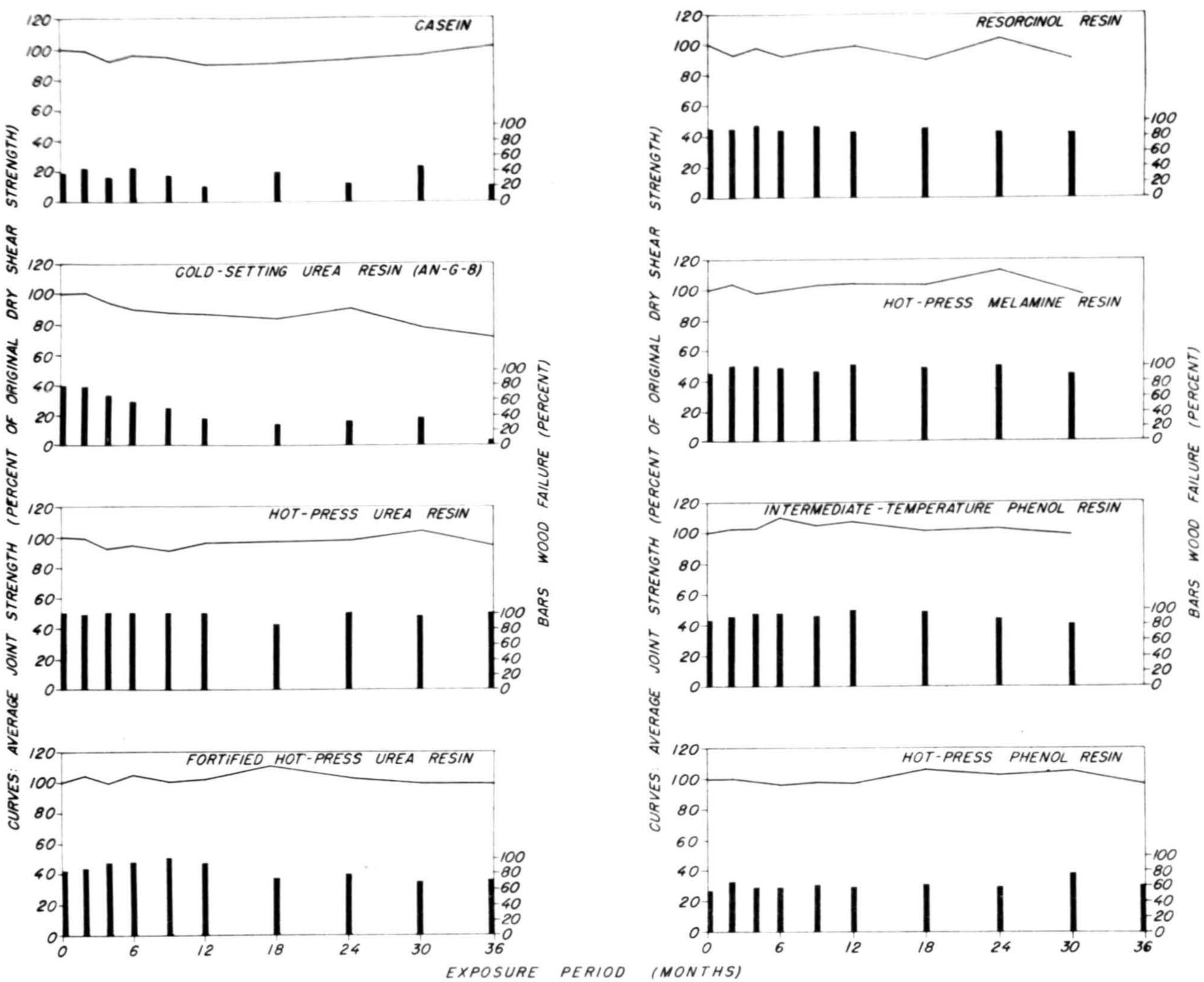


Figure 4.--Resistance of birch plywood joints, glued with eight types of glues, and exposed to a repeating cycle consisting of 2 weeks in 97 percent relative humidity at 80° F., followed by 2 weeks in 30 percent relative humidity at 80° F.

Z M 71050 F



Z M 71051 F

Figure 5.--Resistance of birch plywood joints, glued with eight types of glues and kept under continuous exposure at 80° F. and 65 percent relative humidity.

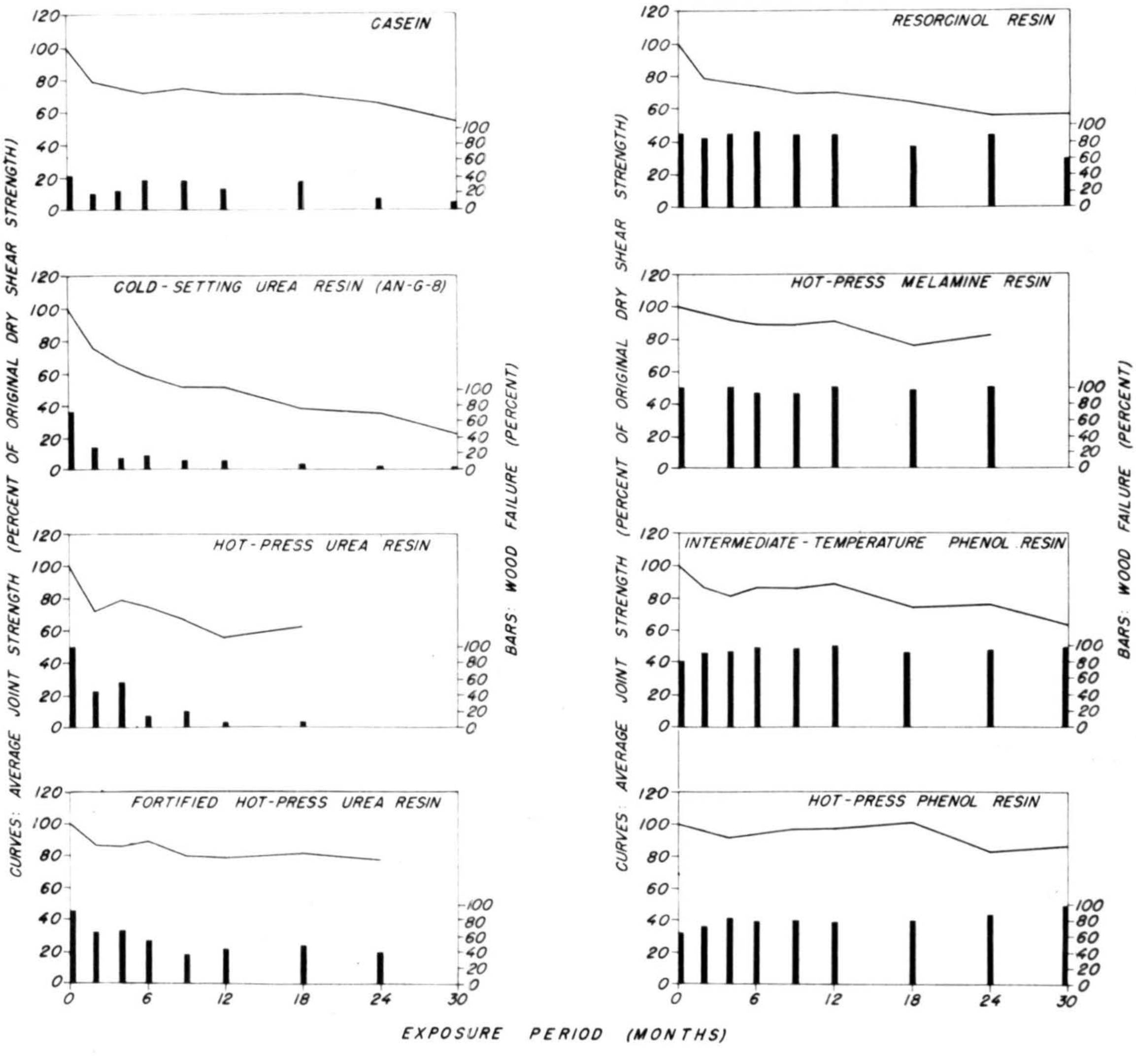
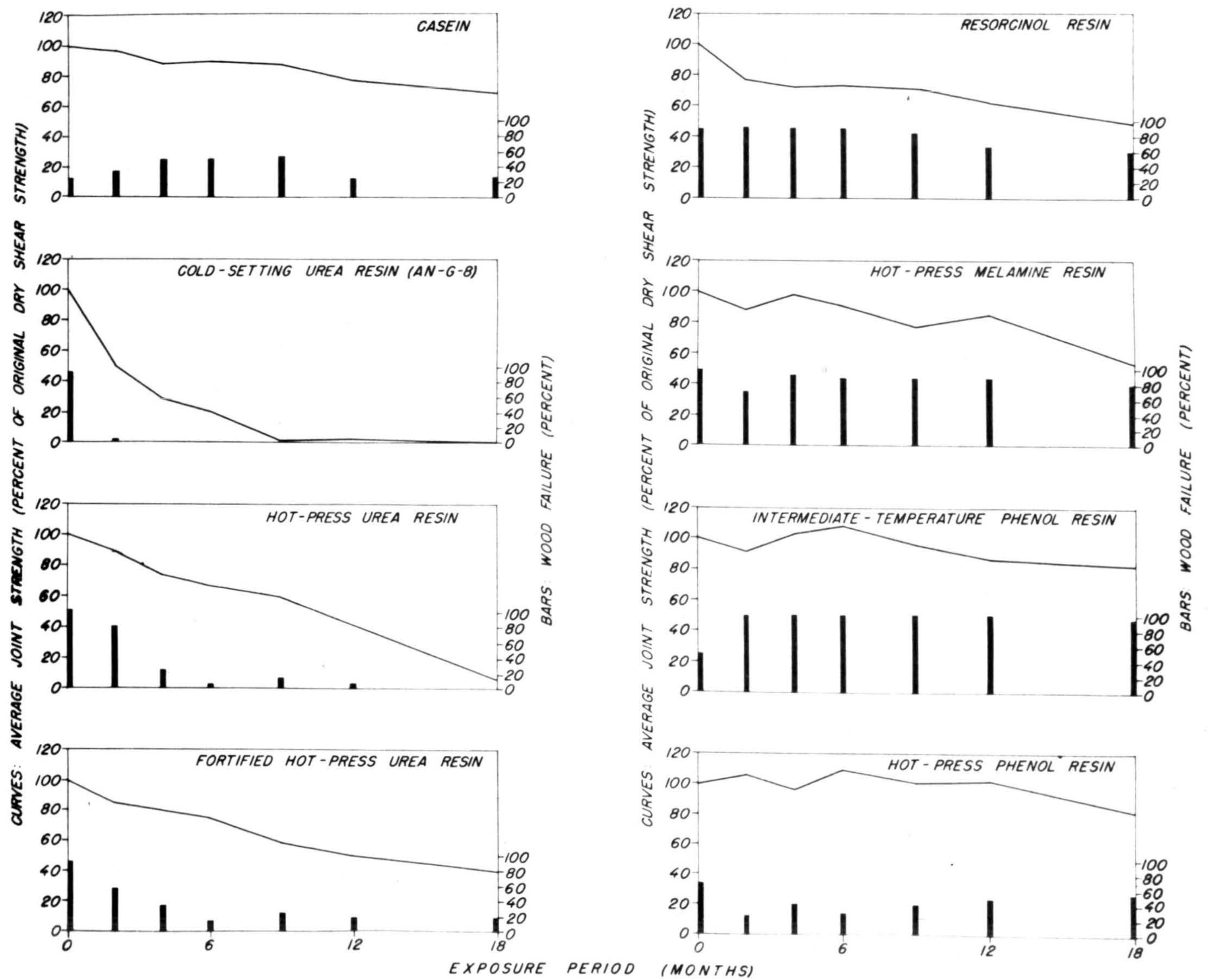


Figure 6.--Resistance of birch plywood joints, glued with eight types of glues and exposed continuously at 158° F. and 20 percent relative humidity.

Z M 71052 F



ZM 71053 F Figure 7.--Resistance of birch plywood joints, glued with eight types of glues and exposed continuously at 158° F. and 60 percent relative humidity.

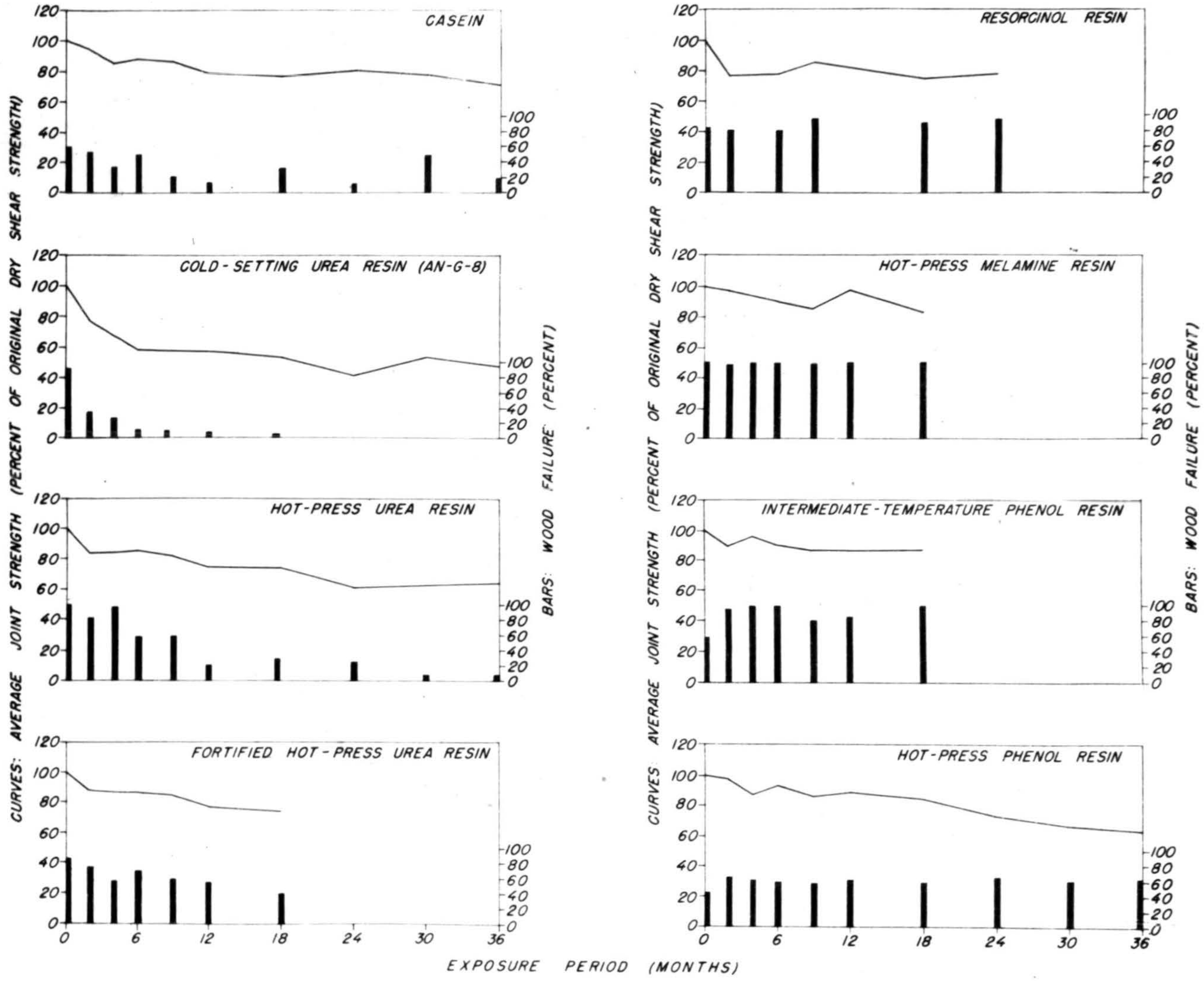


Figure 8.--Resistance of birch plywood joints, glued with eight types of glues and exposed to a repeating cycle of 8 hours at 158° F. and 20 percent relative humidity followed by 16 hours at 80° F. and 65 percent relative humidity.

Z M 71054 F

105

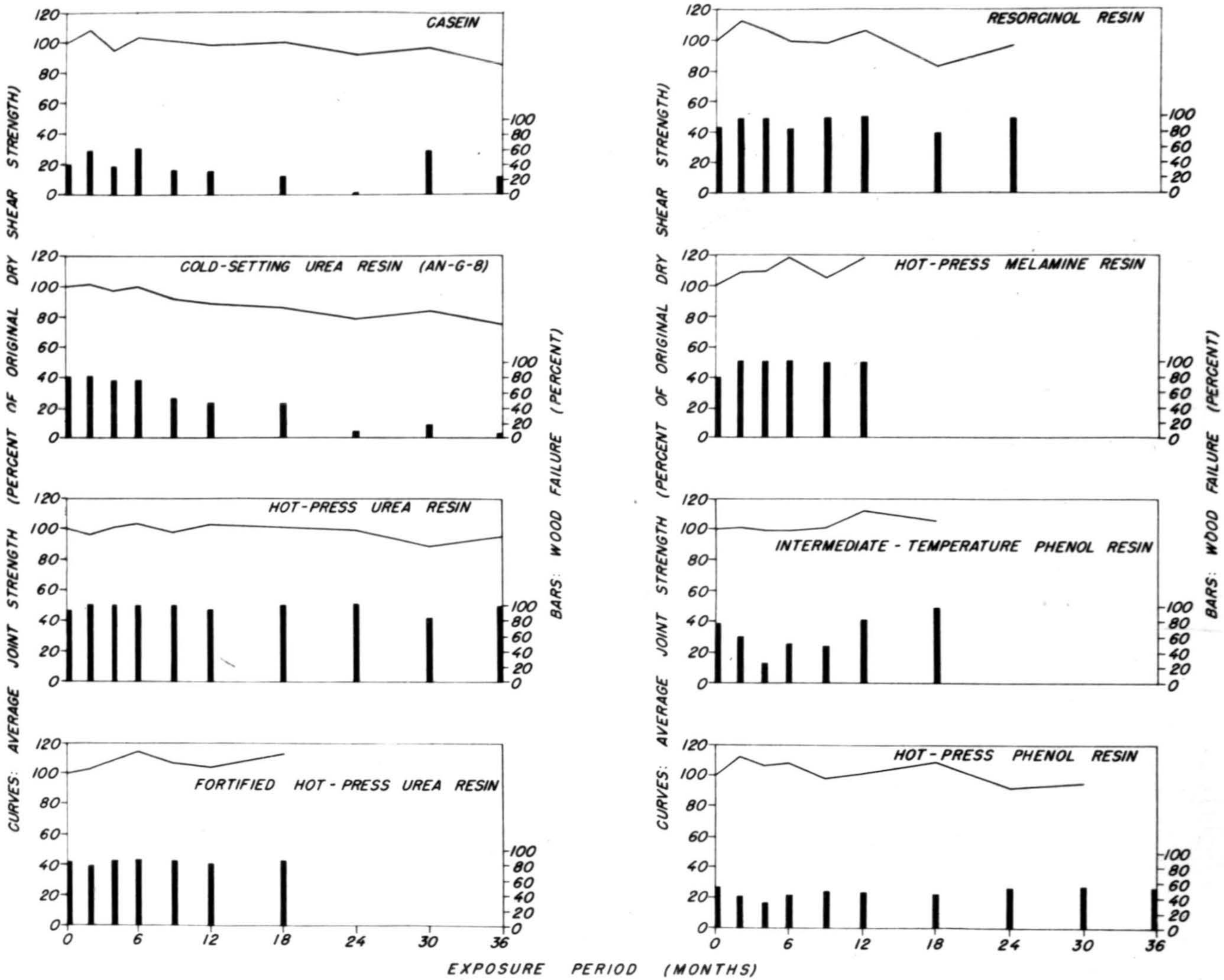


Figure 9.--Resistance of birch plywood joints, glued with eight types of glues and exposed to a repeating cycle consisting of 8 hours at -20° F. followed by 16 hours at 80° F. and 65 percent relative humidity.

Z M 71055 F

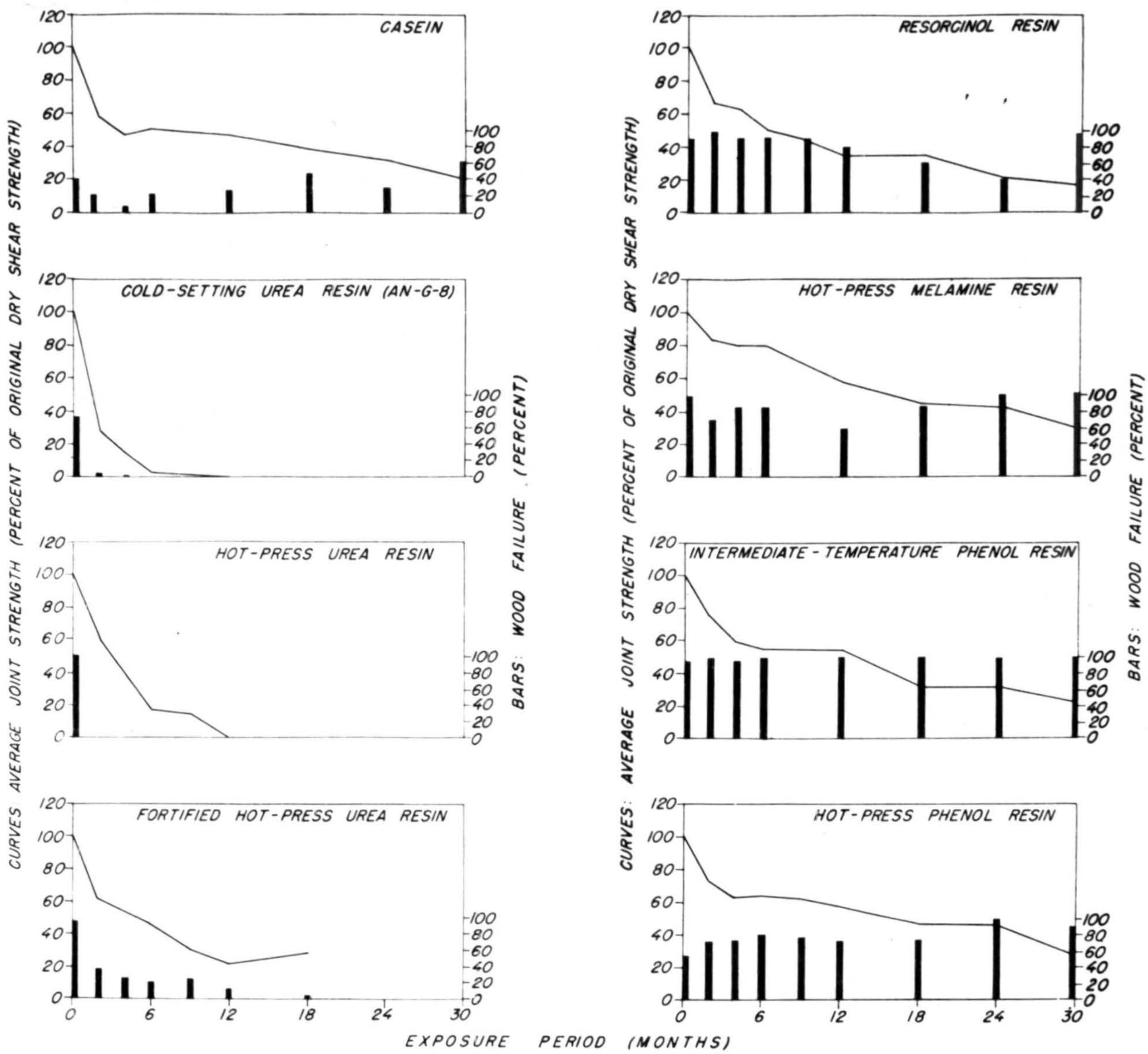


Figure 10.--Resistance of birch plywood joints, glued with eight types of glues, and exposed continuously at 200° F. and 20 percent relative humidity.

Z M 71056 F

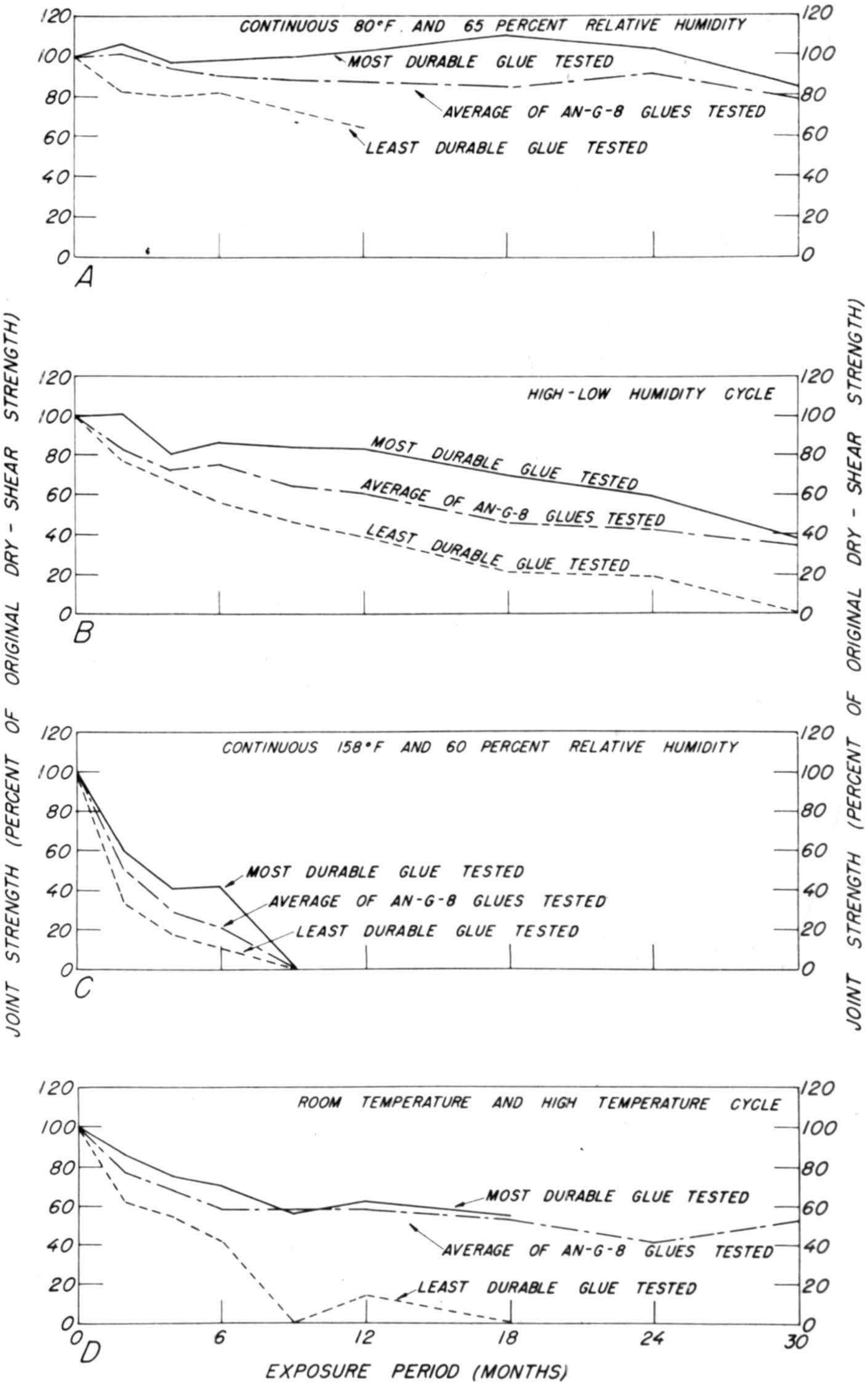


Figure 11.--Resistance of birch plywood specimens, glued with different cold-setting urea-resin glues, to (A) continuous exposure at 80° F. and 65 percent relative humidity, (B) repeated cycles of alternating high (97 percent) and low (30 percent) relative humidity at 80° F., (C) continuous exposure at 158° F. and 60 percent relative humidity, and (D) repeated cycles of exposure at room temperature and 158° F.

Z M 71057 F

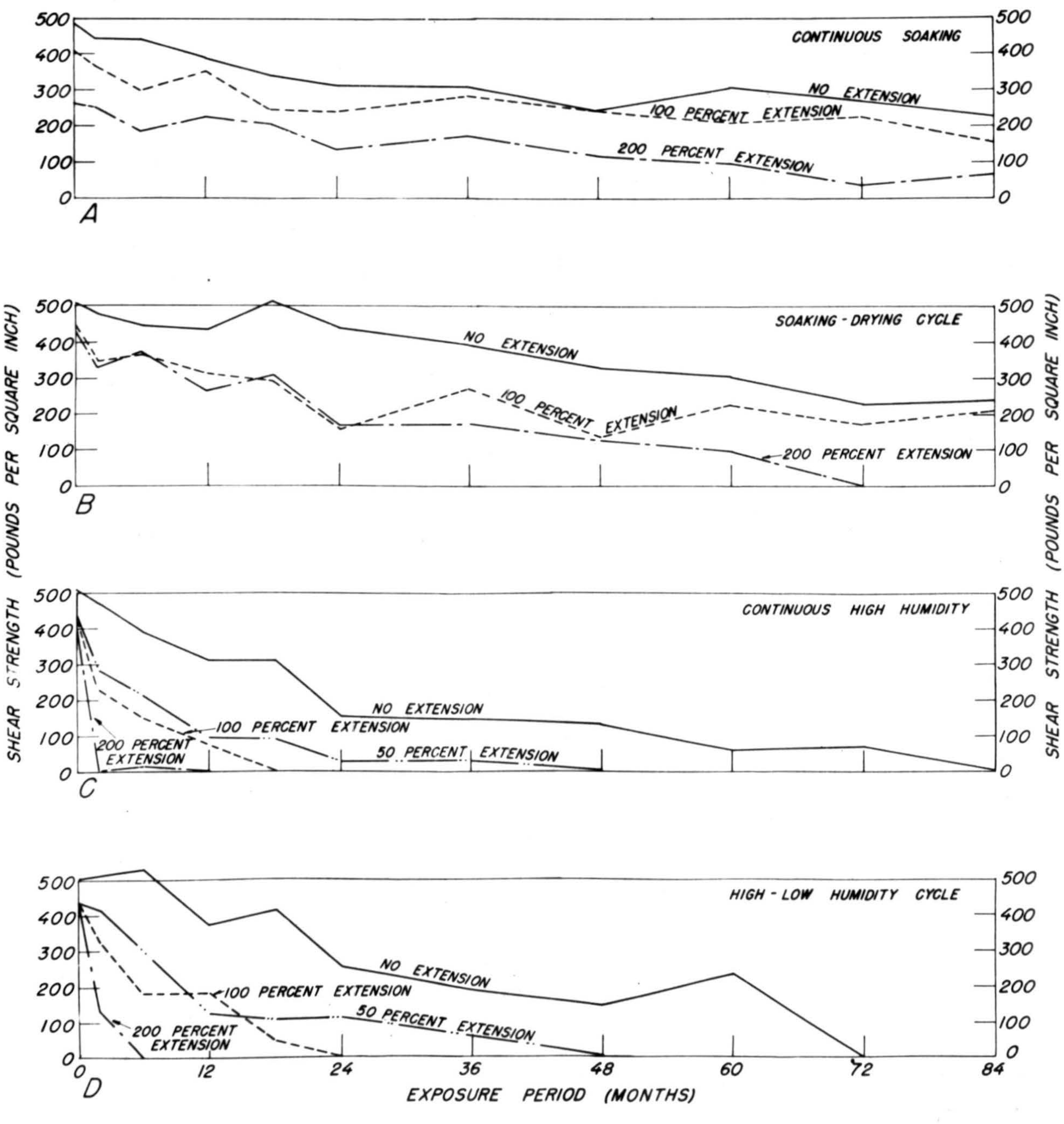


Figure 12.--Resistance of birch plywood specimens, glued with unextended and rye-flour-extended hot-press urea resin, to (A) continuous soaking, (B) repeated cycles of soaking and drying, (C) continuous exposure at 80° F. and 97 percent relative humidity, and (D) repeated cycles of high (97 percent) and low (30 percent) relative humidity.

Z M 71058 F

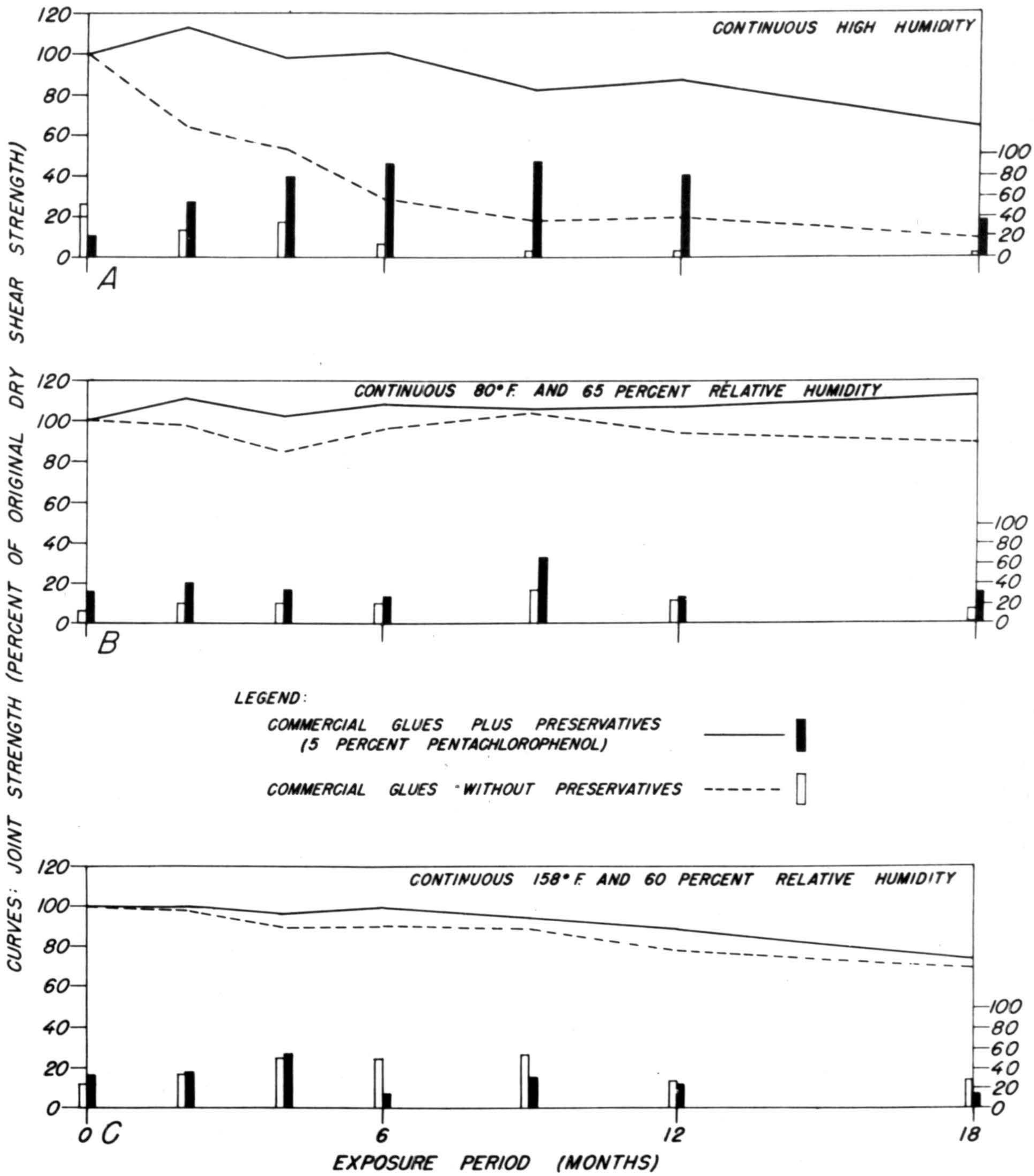


Figure 13.--Resistance of birch plywood joints, glued with different casein glues, with and without the addition of pentachlorophenol under (A) continuous exposure at 80° F. and 97 percent relative humidity, (B) continuous exposure at 80° F. and 65 percent relative humidity, and (C) continuous exposure at 158° F. and 60 percent relative humidity.

ZM 71059 F

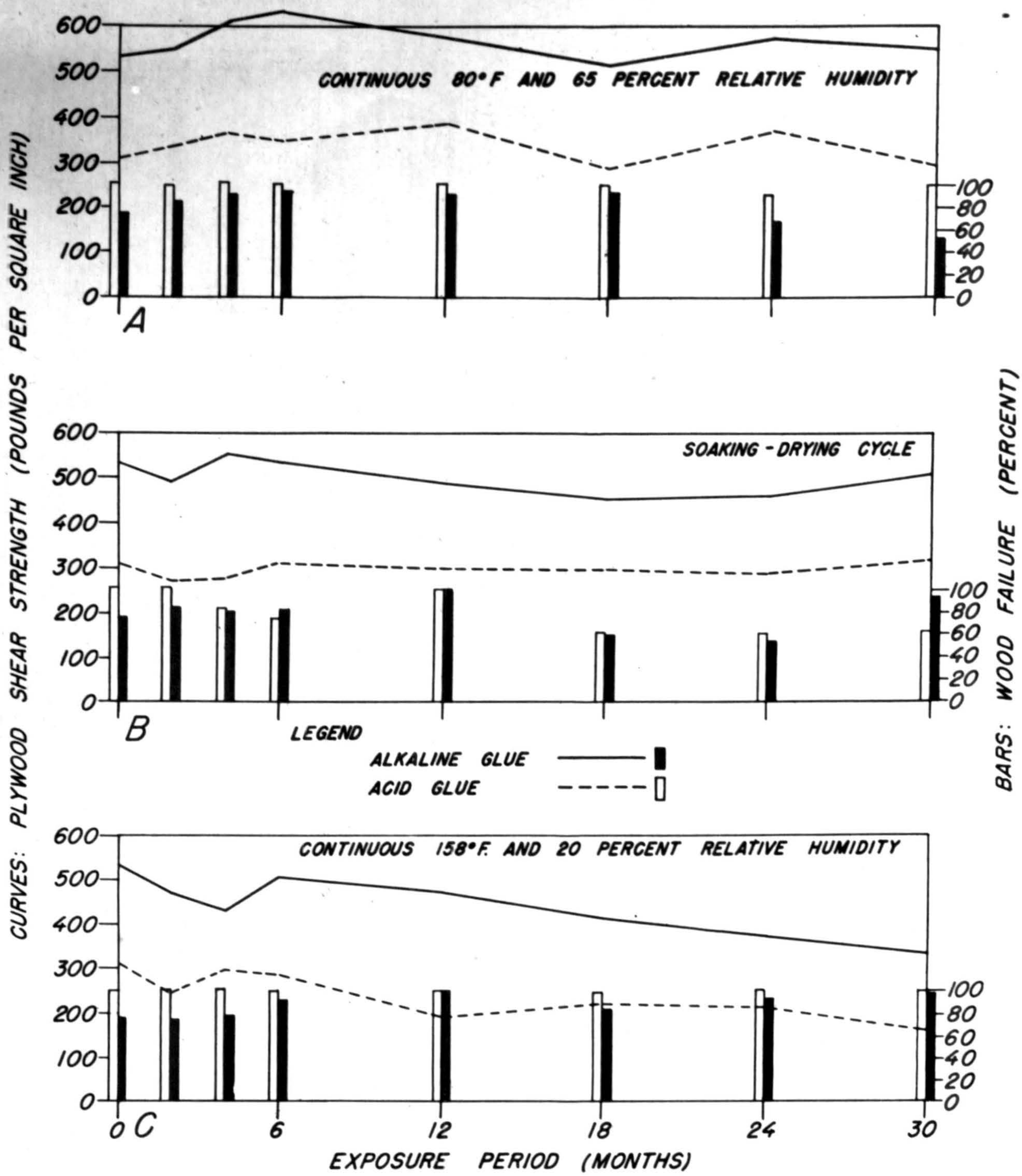


Figure 14.--Resistance of birch plywood joints, glued with alkaline and acid intermediate-temperature phenol resins, under (A) continuous exposure at 80° F. and 65 percent relative humidity, (B) repeated cycles of soaking and drying, and (C) continuous exposure at 158° F. and 20 percent relative humidity.

Z M 71060 F

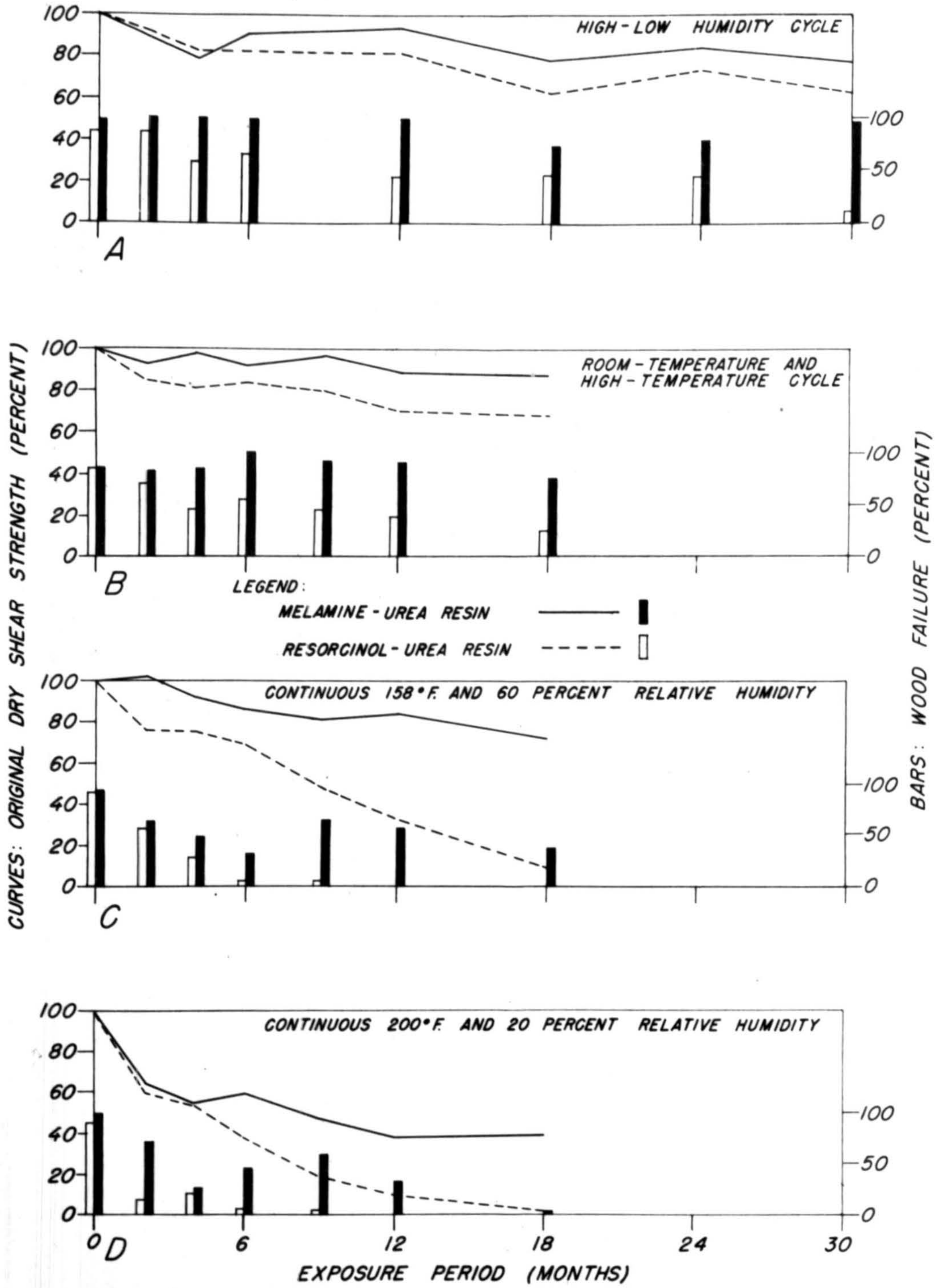


Figure 15.--Resistance of birch plywood joints, glued with melamine- and resorcinol-fortified urea resins, under (A) repeated cycles of exposure to high and low humidity, (B) repeated cycles of exposure at room temperature and 158° F., (C) continuous exposure at 158° F. and 60 percent relative humidity, and (D) continuous exposure at 200° F. and 20 percent relative humidity.

Z M 71061 F

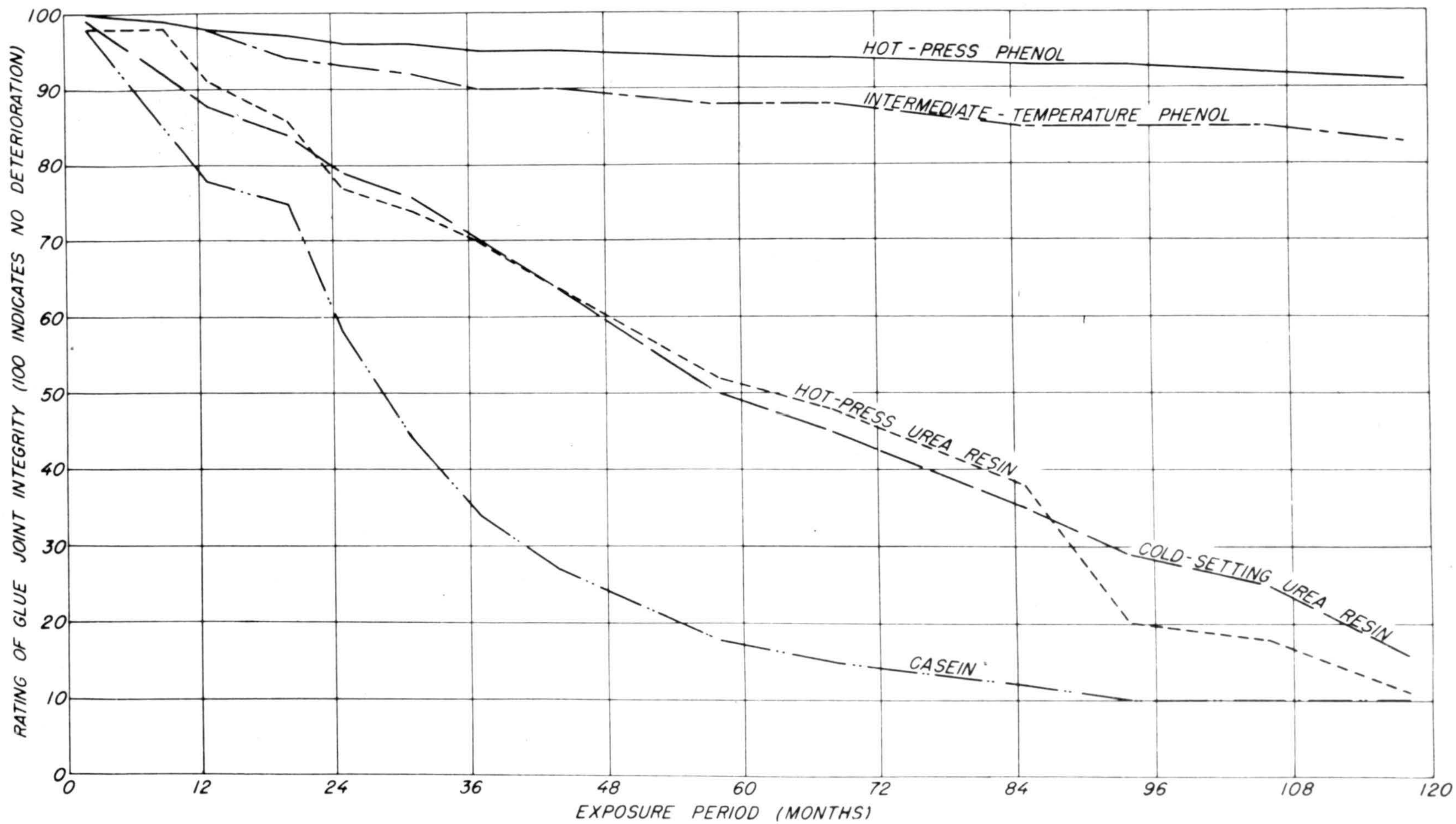


Figure 16.--Relative durability of glued joints in unprotected plywood panels subjected to weathering.

Z M 71062 F

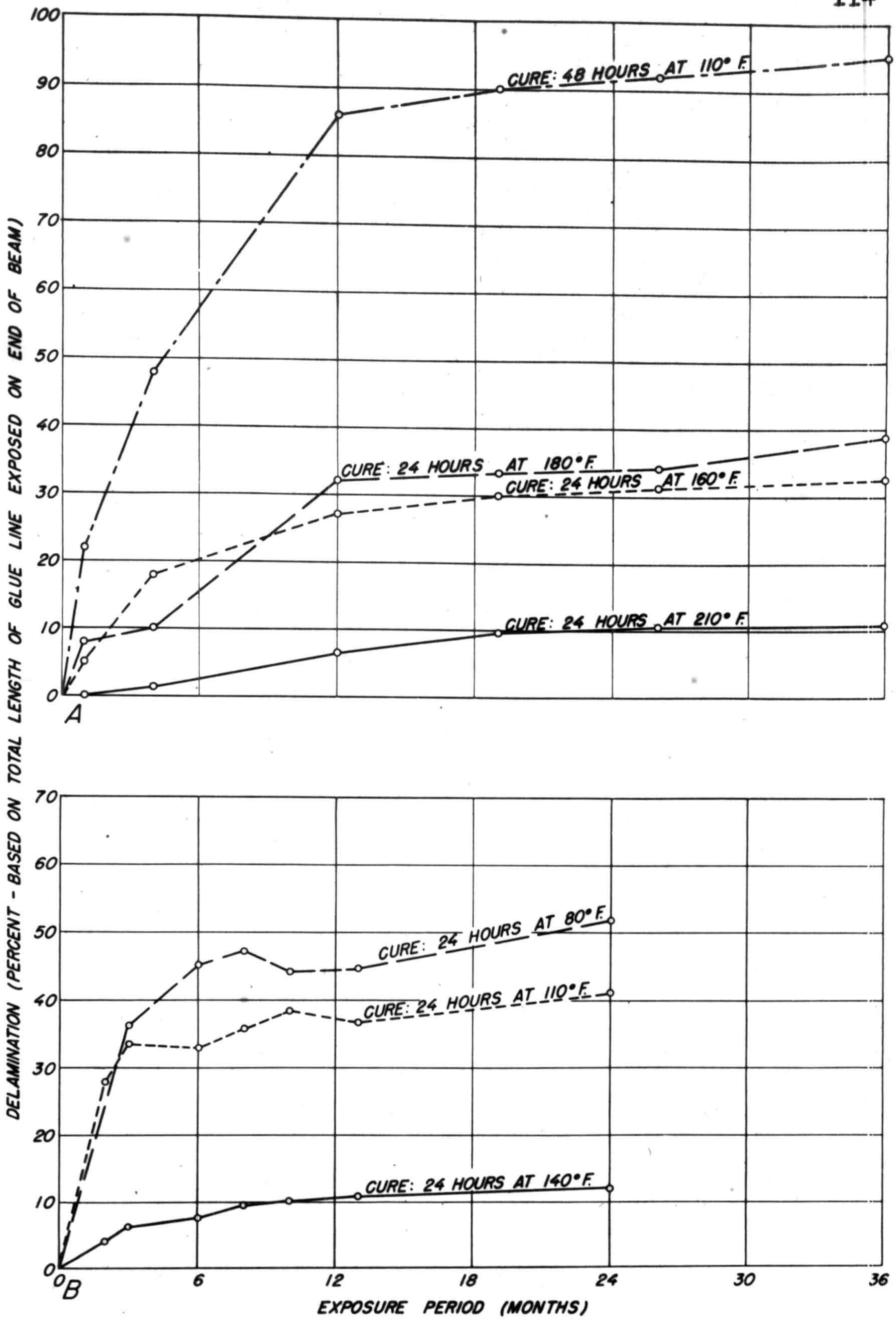


Figure 17.--Resistance to delamination of glue joints in white oak beams cured at various temperatures and exposed to the weather without protection, (A) intermediate-temperature phenol-resin glue, (B) resorcinol-resin glue.

Z M 71063 F

GLOSSARY

ASSEMBLY TIME--Period between spreading the glue and the appliance of pressure. See page 12.

BLEED-THROUGH--Glue deposits on the surface of plywood panels that result from the penetration of the glue from the joints during hot-pressing.

CATALYST--See hardener.

COLD FLOW--Tendency for a glue to give to, rather than resist, the stresses exerted on the joint at normal room temperatures.

COLD-SETTING--See page 18.

EXTENDER--Materials added to glues primarily to reduce glue costs. Usually make up more than 20 percent of the glue.

FILLERS--Materials used in glues to modify or improve their working properties. Usually less than 20 percent of the glue.

FORTIFIERS--Melamine and resorcinol added to hot-press ureas to increase their boil resistance.

HARDENER--Often called catalyst. Refers to chemicals added to thermosetting glues to influence glue setting.

HIGH-TEMPERATURE-SETTING--See page 19.

HOT-PRESS--See high-temperature-setting.

INTERMEDIATE-TEMPERATURE-SETTING--See page 18.

ROOM-TEMPERATURE-SETTING--See page 18.

SOLVENTS--Substances used to aid in mixing glues.

THERMOPLASTIC--See page 73.

THERMOSETTING--See page 19.

WORKING LIFE--Time after mixing a glue that it remains usuable.