Dry Film Gluing in Plywood Manufacture

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Better Plywood Adhesives Needed

THE limitations of recognized plywood adhesives have been a severe handicap to the veneer and plywood industries, seriously retarding their development of known and promising plywood types and products. The recognized commercial wood adhesives in the United States, until within the last two years, might be termed *wet glues*, and consist chiefly of either animal or vegetable matter. All of these fluid glues, animal, vegetable, casein, albumin, soya bean, and their combinations, have been found inadequate to meet the wonderful opportunities in the plywood fields immediately ahead.

Partly for this reason, and partly because of inefficient promotion, the veneer and plywood industries have been severely restricted in their growth, while the metal and synthetic sheet material industries, with broader vision, have made big inroads into the well-recognized woodworking fields. It is a truism that an inferior but well-promoted product will often be accepted in place of an intrinsically better product that is not well presented. It is seldom possible to find new uses or new fields for plywood products because of the lack of proper adhesives and the dearth of necessary industrial research. It has been well said that plywood is no stronger than its glue line, and a glue of limited scope is a severe handicap in every way.

It is a fact that today, and for some time to come, the facilities for producing plywood are far in excess of the demand, and unless new uses and new fields are found, the industry faces a drastic curtailment of volume. Consequently it is incumbent on the industry to carefully analyze and evaluate all new materials offered to determine to what extent the old limitations are overcome.

Plywood Progress Assured by Dry Glue Film

The ideal wood adhesive is one which is of a uniform quality, which can be laid or spread in an even coating, which gives a perfect glue bond, and which can be applied economically. *Dry glue film* stands ready to meet all of these conditions in an efficient way. The dry glue film process eliminates many complications that beset the manufacturers of fine veneered work because dry glue film is simpler to apply than wet glues; in fact, all of the untidy and unpleasant mixing and spreading operations in wet gluing are wholly removed from the plywood factory by the use of dry glue film. Properly manufactured glue film contains in each square foot of surface precisely the same quantity of glue, of equal quality, of uniform composition, of exactly the same bond strength, and of the same standard thickness.

The entire industry is certain to benefit greatly by the introduction of dry glue films for the fabrication of veneers, nonporous substances, and insulating materials into a new and wider range of plied-up combinations. The extent of the benefit to the industry will depend upon the degree that this dry glue film overcomes the known limitations of the commonly used wet glues.

Problem of Wood Moisture in Plywood Gluing

The industry has long known that warping, winding, and twisting in plywood is greatly influenced by the *moisture content* of the wood. It is also true that the strength of plywood varies widely with its moisture content. Only when properly dried wood is used can an acceptable product be obtained. It is much easier to dry the individual plies before gluing, such as lumber cores, veneer cores, or outer veneers, by an efficient and reliable drying process, than it is to dry the jointed, glued, and veneered plywood.

When using fluid glues containing a high percentage of water, which we have termed wet glues, these problems will be particularly great. The percentage of water contained in glues cannot be kept uniform nor can it be kept within certain limits. There is no possibility of regulating the influence of moisture on the glued plies. How deep the glue moisture penetrates into the plies to be glued depends greatly on the structure, dryness, thickness, density, and temperature of the wood, as well as on the consistency and composition of the glue. It is of prime importance in gluing to have not only even spreading, but also standard quality and predetermined consistency of the glue. It is known that many variations occur when glue is mixed in a plywood factory, regardless of the care exercised in its preparation.

The industry has been aware of the many disadvantages of wet glues and has tried to find or to perfect ways of evaporating part of the glue moisture after spreading and pressing, but with only mediocre success. These endeavors have inevitably opened the field to the development of the dry glue film.

Early Development of Dry Glue Film

In the early development of *dry glue film* it was discovered that it was impractical to produce a dry glue film having as a base the ordinary wood adhesives. The possibilities of dry glue films have had the attention of various individuals for a number of years, and as a result a dry glue film has been gradually developed, improved, and finally marketed.

The adhesive power to wood of phenol-formaldehyde condensation products has long been known, but their general use or commercial application has been prevented because of the expense or cost.

The qualities offered by phenolic resin as a wood adhesive were quickly recognized, and attention was then turned to the application of the resin product, whether as a colloidal solution, dry film, or powder. Many attempts were made by industries, both in this country and in Europe. About nine years ago a German research and chemical manufacturing company set out to perfect the use of phenolic resin as a commercial wood adhesive, which meant bringing it to the simplest form of application and within a cost range for general adoption by the plywood industry. The final result, after seven years of research, was the development of a phenolic resin dry glue film. Dry glue films have proved to be very simple, clean and quick in their application, and to eliminate many of the disadvantages unavoidably involved in the wet glues of today.

Because it is the first scientifically manufactured form of adhesive which at all times has the correct quantity and quality of glue, and sets up for the first time a scientific method of plywood manufacturing, it presents a distinctly new method which promises to revolutionize the present form of applying and using wood adhesives. There being but one dry glue film commercially recognized and used today, it may be considered typical of a class that is in the development stage.

As mentioned before, the industry has long felt the need of

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better adhesives which would permit it to seek new uses and new fields for its products. It has been repeatedly shown that many new outlets for plywood are necessary in order to enable the industry to continue its sturdy progress. The newly developed dry glue film answers this need and permits the industry to proceed to enter these new markets.

Types and Grades of Dry Glue Film

The dry glue film, as marketed today, might well be termed a sheeted synthetic or phenolic resin film because, as mentioned, it is a phenol-formaldehyde condensation product. The film is to be had in various weights, to meet a wide range of requirements. For example, what is termed a standard film which meets all ordinary conditions as an adhesive for plywood, is a 60-gram film. This means that over a given area the film contains by weight 40 grams of resin and 20 grams of paper, which is the carrier required in producing the film. This paper or carrier must be thin, porous, and fibrous, so as to permit a uniform impregnation of adhesive on both sides. It must be tough enough not to break in handling and so porous that under the influence of heat and pressure the adhesive will thoroughly penetrate the carrier and eliminate any tendency for the glue joint to separate. Film can be furnished with a greater or less amount of resin, according to the requirements demanded as an adhesive and the type of materials to be laminated. The shear values resulting from such variations are shown in Table 1.

TABLE 1 SHEAR VALUE OF TEGO GLUE FILM BOND

(In pounds per sq in. as influenced by different proportions of resin on the same carrier)

Pressure: Mahogany 142, and Birch 284 lb per sq in.
Time in Press: 10 min
Temperature: 130 C
Moisture Content of Veneer: Approximately 10%

Resin coating per sq meter, gr	Mahogany 3-ply, 5/64 in. Dry	Wet	Birch 3-ply, 1/4 in. Dry	Wet
21	154	107	261	193
23	182	123	312	237
26	209	145	336	228
28	222	162	321	239
32	253	204	325	239
40	308	266	396	330

The standard glue film, described as 60 grams, is the last in the table, having 40 grams of resin and 20 grams of paper carrier.

TABLE 2 SHEAR VALUE OF SINGLE AND DOUBLE LAYERS OF TEGO GLUE FILM BOND

(In pounds per square inch)

3/16 in., 3-ply, All Birch
Pressure: 284 lb per sq in.
Time in press: 10 min
Temperature: 130 C
Moisture Content of Veneer: 10%

Resin coating per sq meter, gr	Single layer	Double layer	Increase, %
21	248	312	26
40	298	445	49

In case more than 40-gram coating is required, as in gluing metal to wood, it is practicable to use two sheets of dry film glue in each joint. While this does not double the bond strength, still it does result in a substantial increase, as shown in Table 2. It is frequently advisable to use double layers where the surfaces are rough, requiring more glue bulk, or where veneers vary slightly in thickness.

The standard width is 51 in., but can be made up to 82 in. Rolls will average over 3900 ft in length, and a 51 in. × 3900-ft roll will weigh 225 lb crated, containing approximately 17,000 sq ft.

Application of Dry Film Glues

The assembling of veneer into plywood with dry glue film methods demands an entirely different technique than that which has been commonly employed with the usual wet glues. The dry film glue, being a phenolic resin, is thermoplastic and thermosetting, which now permits the fabricating of plywoods without the introduction of water into the carefully dried veneers, as is necessary with the wet glues.

The film glue being thermoplastic and thermo-setting, the bond is accomplished with heat and pressure, requiring a hydraulic hot plate press. With the application of both heat and pressure at the same time, as is had uniformly with the modern type of hydraulic hot plate presses, the resin film polymerizes and becomes both insoluble in water and chemically inert. This method of producing a bond with the dry film glue might be termed "vulcanizing," and has for the first time set up a laminated panel in which the fibers of the adjacent plies are brought directly in contact with one another. In fact, the adjacent plies might be said to be welded to each other. Thus the bond obtained has in reality converted the several original plies into an ultimate panel of solid material, and this has been done without the internal stress and strain which is often so troublesome.

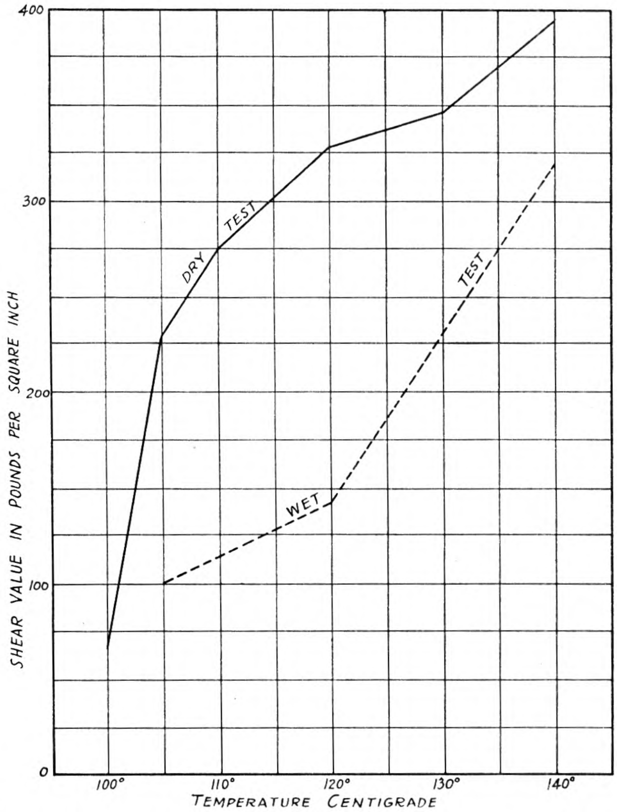


CHART 1 INFLUENCE OF TEMPERATURE ON GLUE FILM JOINTS 3/16 IN., 3-PLY BIRCH

(Glued at 10% moisture content in 10 min time, with 284 lb per sq in. Dotted line is test after immersion. Full line is dry test before immersion.)

The dry glue film process eliminates the expensive redrying methods which have to follow gluing with wet glues. The industry has spent a great deal of time and money to set up proper methods for this subsequent redrying necessary to remove the glue moisture. Woods vary in their structure and density, making it impossible to accurately control the drying process, which is often the cause of distorted plywood and checked faces.

Inasmuch as the dry glue film is only 0.005 in. thick, entirely new demands must be made as to the pressure required. The hydraulic hot plate presses must be designed and built to new standards of accuracy as to the deflection of its members. The maintenance of proper temperatures on the entire surface of the plates is of extreme importance.

Relation of Heat, Moisture, Pressure, and Time

When gluing with dry glue film there are four variables to be considered, namely, *temperature* or heat, *moisture*, *pressure*, and *time*. All are closely related to one another in producing a satisfactory bond with resin adhesives, but it is best to consider the influence of each factor separately. The strength value of each of these variables in relation to the others has been accurately determined and charted. The accompanying charts 1, 2, 3, 4 show definitely the strength of the bond obtained when varying the factors and prove conclusively that the laminating of plywood with dry glue film may be considered a scientifically controlled process. A careful study of the series of charts will readily show that when the same combinations of variables are repeated, the value or strength of the bond obtained comes within close limits, if the same or similar woods are used.

1 *Influence of Temperature or Heat.* The dry glue film, being a phenolic resin and thermoplastic, requires a definite amount of heat and a predetermined time to set up or produce polymerization.

Chart 1 clearly indicates the influence of heat for a given period of time, and demonstrates the greater shear values of the bond as the temperature is increased. In preparing these charts it will be noted that certain standard time, pressure, moisture, and heat factors have been established, to show relative comparative values with one another. The construction of the plywood used is a 3-ply panel, 3/16 in. thick, all plies 1/16 in. birch.

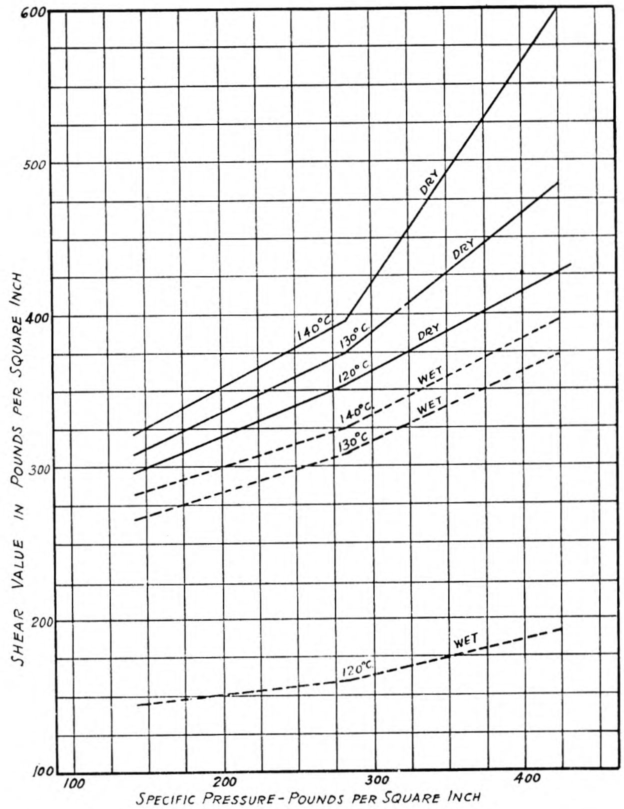


Chart 3 Influence of Pressure on Glue Film
3/16 In., 3-Ply Birch

(Glued in 10 min time, with 10% moisture content in veneer. Dotted lines are tests after immersion. Full lines are dry tests before immersion.)

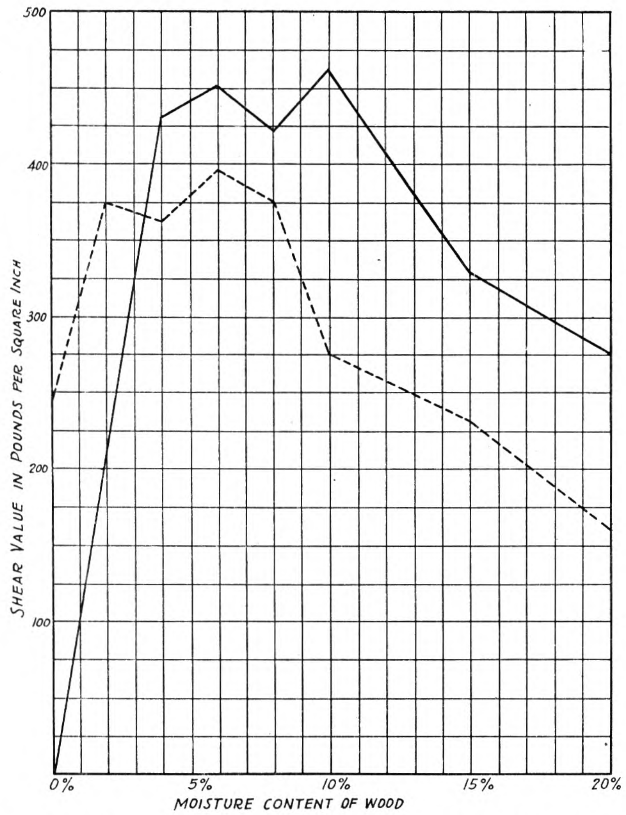


Chart 2 Influence of Moisture Content of Wood on Glue Film Joints
3/16 In., 3-Ply Birch

(Glued at 130 C, 284 lb per sq in., 10 min time. Dotted line is film 14 days old. Full line is film one year old.)

The solid line indicates the strength of the bond when testing the plywood in a dry state, having an average moisture content of 7 to 8 per cent. The dotted line indicates the strength after soaking in water at room temperature for 48 hr. It will be noted that while the value obtained when testing the bond after soaking is somewhat lower than the dry test, this does not mean that the glue line has weakened to this extent, but rather that the tensile strength of the fibers of wood are lower in a wet state. It is also a fact that the shear value of the dry glue film bond always increased when redried after soaking.

In studying this chart it will be readily observed that the increase of temperature in a given time materially increases the strength of the glue bond. For instance, a panel glued at a temperature of 100 C for 10 min at a pressure of 284 lb per sq in. and with a moisture content of 10 per cent, has a shear value of 66 lb per square inch. With all other factors remaining the same and the heat increased to 140 C, the shear value increases to 396 lb per sq in. The same increase is proportional to a lesser extent in the wet test. Increase of heat in a given period of time always produces a better glue bond.

In the manufacture of dry glue film the resin has been precured to a definite point, and it will be observed on all the charts that a temperature no higher than 140 C has been shown. Tests have proved that no material increase in the bond is found at temperatures beyond 140 C, but any increased temperature above this has no detrimental effect upon the curing of the resin. The wood itself is the item that must be kept in mind when employing high temperatures. The gluing temperature of 140 C

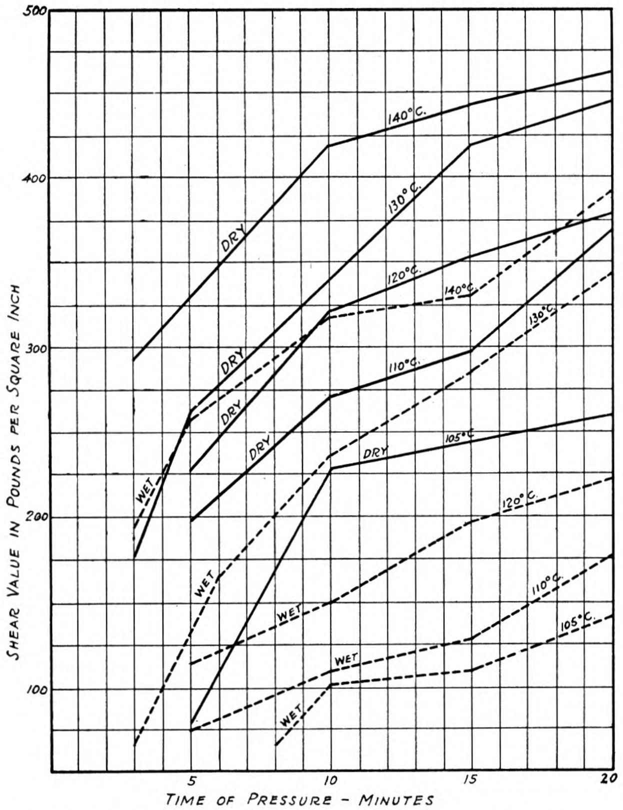


CHART 4 INFLUENCE OF TIME OF PRESSURE ON GLUE FILM JOINTS $^3/_{16}$ IN., 3-PLY BIRCH

(Glued at 284 lb per sq in., and 10% moisture content. Full line is dry plywood test. Dotted line is plywood test after 48 hr immersion. All temperatures are given in Centigrade.)

required for dry glue film does not damage the quality of the wood.

This has been proved by a number of tests, especially those of Professor Dr. Otto Gerngross of the Technical University of Berlin, as shown in Table 3. While the table refers only to birch and fir, these are taken as typical of the hardwoods (deciduous) and the softwoods (coniferous). It is to be noted that both species have a strength increment of more than 10 per cent due to simultaneous heat and pressure. The heat alone on the birch does not alter the strength value, but heat alone on the fir will carry the strength value to that of combined heat and pressure. This is due to the natural rosin content of the coniferous wood that is equalized and hardened by the heat.

TABLE 3 EFFECT OF HEAT, WITH AND WITHOUT PRESSURE, ON TENSILE STRENGTH OF SINGLE-PLY VENEER

Specimens tested: $1^1/_8$ in. × 4 in. × $^5/_{64}$ in. Birch and Fir veneer
Temperature: 140 C
Pressures and tensile strength given in lb per sq in.

Species	Specific pressures	Time, min	Tensile Strength Before heat	Tensile Strength After heat
Deciduous (Hardwoods)				
Birch....................	0	45	7892	7864
Birch....................	142	15	8788	8674
Coniferous (Softwoods)				
Fir......................	0	45	5631	6897
Fir......................	142	20	6541	6826

Adapted from article in "Sperrholtz," 1930 (S-382) by Prof. Otto Gerngross, of Berlin, Germany.

When gluing with dry film glue it is always safer to employ the higher temperatures, but seldom over 140 C. This usually depends on the type of material to be laminated.

2 *Influence of Moisture Content in Wood.* Methods of gluing with dry glue film differ from those of ordinary wet gluing because the natural moisture in the wood is not increased by glue water. Experiments have shown that, regardless of the type of glue used, warping and wavy surfaces in lumber core plywood are not only caused by irregular thickness and resistance against compression by the core, but that they also occur if the moisture content of the core exceeds 5 to 6 per cent. This limit of moisture content, however, does not apply to cross-banding and outer veneers.

It will be noted from chart 2 that the shear value or bond strength depends to a great extent on the moisture content of the veneers. A careful study of the chart shows the bond that can be obtained when using a dry glue film that is several months old, which is the average age of the film when used. This is indicated by the solid line, while the dotted line represents the bond obtained when using a freshly manufactured film about ten to fourteen days old.

A certain amount of moisture is necessary to plasticize the resin, and this moisture may come either from a freshly made glue film or from the veneer. Consequently it is important to regulate the moisture of the veneer within safe operating limits. The chart indicates that freshly made glue film must be used where veneers are substantially less than 4 per cent moisture content, but that even better joint strength is obtainable from aged glue film when the veneer is between 4 and 12 per cent m.c., which is the normal condition found in veneer as stored in the average warehouses. It is obvious that this eliminates the ordinary redrying required prior to wet gluing.

Experience has proved that the most useful medium for the moisture necessary in plasticizing dry glue film is the cross-banding in 5-ply construction. This is so situated in the assembling operation as to supply the required moisture to the dry glue film adjacent to both the core and face. It has been pointed out that excessive moisture in a lumber core is dangerous, and it is apparent that surplus moisture in face veneer may result in open joints or hair lines and checks.

It might be mentioned that in gluing very fragile face veneers, such as highly figured crotches and burls, tests have shown a moisture content of about 6 per cent to be the most satisfactory.

3 *Influence of Specific Pressure.* The pressure applied on the surface of the plywood is the *specific gluing* pressure, or, as it is frequently called, the platen pressure in pounds per square inch and should not be confused with the higher pump pressure that is required. The application of pressure with dry glue film is no different than when gluing with wet glues, except that wet gluing usually requires 75 to 150 lb specific pressure, while dry gluing ranges from 150 to 250 lb and in some instances up to 300 lb per sq in. The amount of pressure exerted on a panel depends on the density of the wood and the construction of the plywood.

It is also indicated on chart 3 that the strength of the glue line increases with additional pressure. The maximum pressure depends upon the compression loss in plywood thickness that can be allowed. Some woods and synthetic boards will crush under 50 lb, while denser woods and non-porous synthetic products will permit greater pressure. Consequently the adhesion on the softer products will not be as great as on the harder materials. The average compression percentages on the commoner woods are given in Table 4.

4 *Influence of Time of Pressure.* The time required to complete the bond, which is often referred to as gluing time, is generally understood to be the time that elapses after obtaining the correct specific pressure and until the reopening of the press. It is also essential that the temperature of the plates is secured before closing the press. The gluing time depends chiefly upon the time necessary for the heat to penetrate from the steam-

heated platens through the aluminum cauls, the outer veneer and crossbanding, or to the film farthest from the source of heat.

Mention has been made of using aluminum cauls. They retard the penetration of heat but a very few seconds and are used to facilitate the handling of the stock in and out of the press.

Chart 4 readily indicates that a strong bond can be obtained in 3 min when employing temperatures in excess of 130 C. The ordinary $^{13}/_{16}$-in., 5-ply construction as is commonly manufactured for tops, requires an average of 12 min to complete the bond. It will be noticed from this chart that the increase of time materially increases the strength of the glue line.

TABLE 4 COMPRESSION FACTORS IN PLYWOOD

Construction: 3-ply
Time of Pressing: 10 min
Temperature: 130 C
Moisture: 10%
Pressure: Lb per sq in.

Species wood	Plywood thickness	Specific pressure	Compression, per cent
Mahogany	$^1/_8$"	142	6.2
		213	6.8
		284	32.0
Fir	$^1/_8$"	142	9.5
		213	15.3
		284	39.0
Alder	$^3/_{32}$"	142	2.4
		213	3.1
		284	9.3
Beech	$^3/_{64}$"	142	7.8
		213	9.1
		284	15.2
Birch	$^1/_{16}$"	142	4.5
		213	4.5
		284	13.3

Again it is shown that the waterproofness of the glue line increases with the gluing temperature and elapsed time the material remains under pressure.

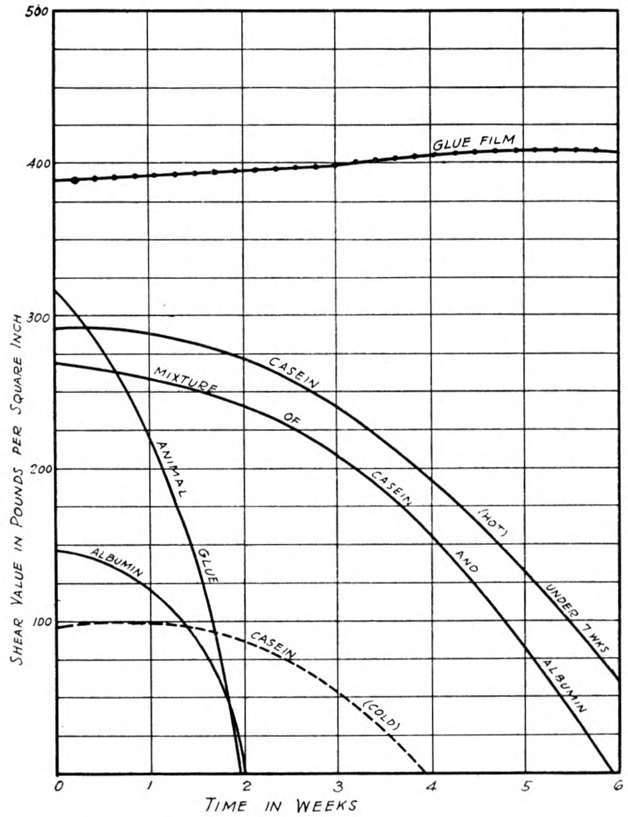


CHART 5 INFLUENCE OF MOLD AND FUNGI ON DIFFERENT PLYWOOD GLUES

(Dotted line, wet glue in cold press. Full lines, wet glue in hot press. Full line with dots, dry film glue in hot press.)

Hydraulic Hot Plate Press

The hydraulic hot plate press is not a recent development. Its origins, as adapted to plywood, date back some fifty years in Europe. The modern hot plate press is the result of the progressive development of the plywood industry based on scientific and practical research. The comparatively recent development of dry glue film has revolutionized this press industry in the United States, since the low unit pressure of wet gluing processes permitted a comparatively light-weight press, while dry gluing requires higher pressures and sturdier presses.

1 *Plate Design.* The modern hydraulic hot plate press for high pressure is fitted with plates of special alloy steel having good heat conductivity and high compressive strength. The steam channels, bored in the plates, are accurately drilled and properly spaced to insure uniform distribution of heat on both surfaces. The maintenance of equal heat is essential in dry glue methods and this type of plate fully answers these requirements. This is in contrast with the old style plates used for low pressure in gluing with thermo-setting wet glues, which consisted of relatively thicker (2 to 4 in.) sections with unevenly distributed steam channels. The high tensile strength of the alloy steel plates permits the use of thinner plates, averaging $1^1/_2$ in., substantially increasing press capacity. The surfaces must be machined accurately so that their parallelism insures uniform pressure on the plywood, otherwise a serious variation of thickness (crushing) and uneven glue bonds might occur in the finished plywood. Step devices are provided to suspend the plates in the open press.

2 *Upper and Lower Platens.* The press head, or the upper platen, should be a one-piece heavy steel casting to insure a maximum deflection of 0.003 in. The deflection in the cold press is seldom serious since it is distributed over 30 in. of content, or a clamped bale, while in the hydraulic hot plate press, there is usually but one panel between each pair of plates, or a content of less than 1 in., and the whole deflection may come in each panel. The lower platen, or head, should also be a one-piece casting and together with the plates should be well aligned and guided during the opening and closing of the press to insure against displacement.

3 *Pump System.* The modern hot plate press must be equipped with a satisfactory hydraulic pump system to insure rapid closing in not more than 30 sec and also to maintain accurate continuous pressure. The temperature of the plates is usually thermostatically controlled to maintain a constant heat. The pump system should be so designed that after reaching the maximum pressure it will ease off smoothly.

4 *Mechanical or Manual Loading.* While many of the smaller presses are manually operated, as to loading and unloading, the larger presses are equipped with automatic charging devices as illustrated in Fig. 7. In some instances the charging equipment is designed to operate similarly to the lumber lift. This permits the loading and unloading of the openings, or "day-lights," of the charging device at the level of the truck or table used.

5 *Cauls.* Aluminum cauls, usually $^1/_{16}$ in. thick, are used to facilitate the loading and unloading of the assembled plywood. The aluminum caul is a good conductor of heat, requiring but a few seconds for attaining the temperature of the steam-heated platens, especially when under pressure. For this reason the aluminum caul should not be used to retard the penetration of heat, or to compensate for slow acting pump systems.

Technique of Processing

The preparation of the face veneer, cross bands, and cores does

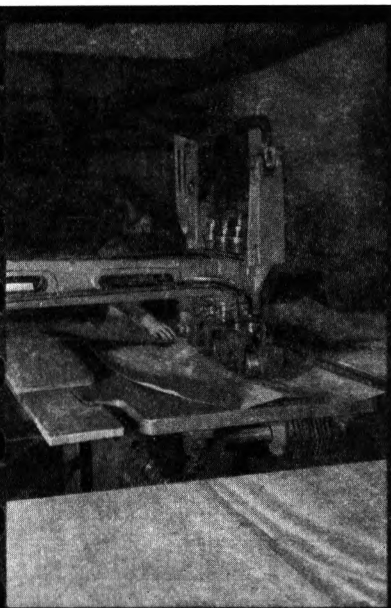


Fig. 1

Fig. 2

Fig. 3

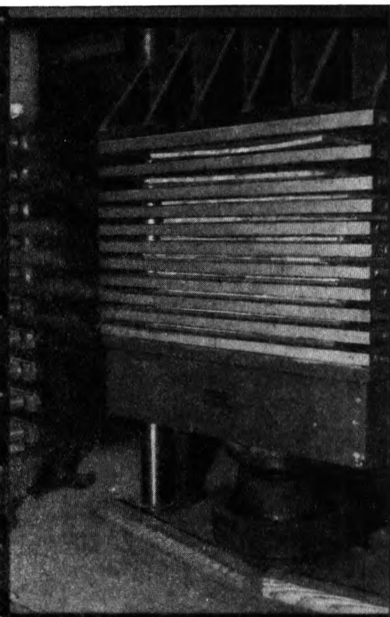


Fig. 4

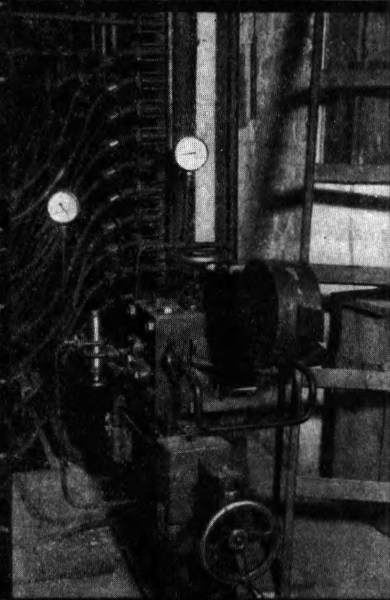


Fig. 5

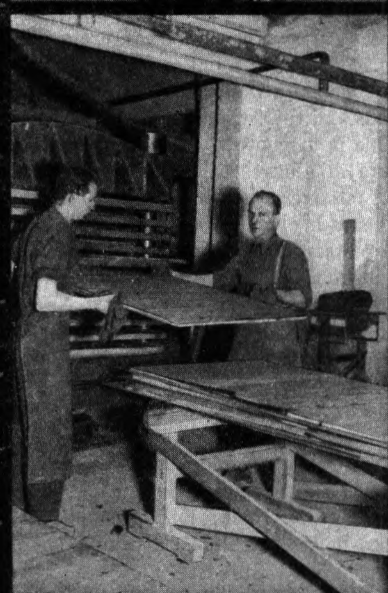


Fig. 6

not differ from regular methods employed for ordinary wet gluing, except as to the moisture content of cross bands and face veneers.

1 *Tapeless Face Jointing.* A great deal of time and attention has been devoted to discovering some means of eliminating the paper veneer tape used in splicing face veneers and cross bands. Attempts have been made to perfect a thin fibrous paper tape to be applied to the under side of face veneers, so that when the gluing operation is completed the surface of the plywood will require no sanding other than the ordinary polishing for finishing purposes.

As the plywood comes from the hot plate presses when glued with aluminum cauls, the surface has a very high sheen or polish and requires no sanding by the plywood manufacturer if the face veneers are free of tape. Some recent developments have been made in perfecting a tapeless veneer splicer as shown in Fig. 1. This machine has been designed along the lines of the ordinary veneer splicers. Prior to splicing the faces, the edges of the veneers are coated with a good grade of animal glue and allowed to dry. The glue is usually applied immediately after jointing and before the pressure is released in the jointer. The veneers are passed through the splicer and under heat units, which redissolve the animal glue and set it. The speed at which the stock can be jointed or welded depends on the number of spindles built in the machine. For example, a four-spindle machine will weld approximately 35 lineal feet of $^1/_{16}$-in. veneer a minute.

The elimination of taped faces will greatly reduce the cost of plywood manufacturing, especially in the sanding departments. It also permits the manufacture of plywoods, utilizing narrow veneers, with absolutely waterproof joints, having no tape remaining under the joints to decrease the strength of the dry glue bond.

Development work is now being carried on to produce a veneer tape manufactured from dry glue for use on the standard paper tape veneer splicer.

2 *Dimensioning the Dry Glue Film.* There has been some question as to the proper method of cutting dry glue film to dimension sizes. This is clearly illustrated in Fig. 2. Usually the operator cuts the film on the table, as shown, to multiple dimensions that will recut to several smaller sizes. The recutting is completed on an ordinary veneer clipper. It is not practical to attempt to cut the film to final size in single sheets on a veneer clipper because of the extreme thinness of this film. The film is supplied in various widths up to 82 in. wide; therefore the waste can be held down to a minimum.

Captions for illustrations appearing on opposite page

Fig. 1 A Four Spindle Tapeless Veneer Splicer for Edge Uniting Veneer Without the Use of the Conventional Veneer Tape. The Chain Feed Principle Is Shown Employing Steam or Electrically Heated Rolls for the Thermo-Setting Adhesive

Fig. 2 Method Employed in Cutting the Dry Glue Film. The Cutting Table Is Marked Off in Inches to Assist the Operator in Cutting the Film to Exact Dimension

Fig. 3 The Simple, Clean, and Quick Method of Assembling the Veneer, Cores, and Cross Bands, Prior to Pressing, Is Clearly Illustrated

Fig. 4 The Assembled Plywood Placed in the Openings of the Hydraulic Hot Plate Press Just Prior to the Full Closing of the Press

Fig. 5 Control Unit Employed on a European Hydraulic Hot Plate Press, Automatically Regulating the Temperature, Specific Pressure, and Time of Pressure

Fig. 6 Removing the Completed Panels From the Openings of the Hot Plate Press

3 *Laying the Film.* The laying of the dry film is very simple and requires a minimum time, as illustrated in Fig. 3. Piecing of the film or lapping of the joints can be done to utilize the small cuttings that might otherwise accumulate.

4 *Loading the Press.* As mentioned before, in loading the press the stock is placed between aluminum cauls. Fig. 4 shows a press loaded and in the process of closing. The charging of the different openings of the press, as well as the closing time, should be done as quickly as possible. With modern pumps the specific pressure required can be secured in 30 sec, avoiding any pre-curing of the film by heat before pressure is effective. An automatic control, regulating the pressure, temperature, and time, is shown in Fig. 5.

5 *Unloading the Press.* The manual unloading operation is shown in Fig. 6. In this instance aluminum cauls were not used, due to the use of non-figured thick face veneers. Automatic loading and unloading devices are extensively used in Europe and are shown in Fig. 7. This equipment conserves press time and reduces the labor of the press crew. During the time of pressing, the moisture content of the veneer has been reduced to some extent. It is a common thought that immediately after the plywood is removed from the press, it begins to take on moisture. This is incorrect, as it will continue to give off moisture until the temperature of the plywood has fallen below 100 C. To hasten the manufacturing time plywood may be passed through a bath of water immediately after coming from the press and allowed to temper for several hours in bulk, after which it is placed on sticks and weighted for equalizing temperature and moisture content.

Effect of Continued Heat Without Pressure

The problem of limited press output is certain to occur as the demand for dry glue film plywood increases. Two sheets of plywood can be placed in each press opening, provided suitable cauls are located *between* as well as *above* and *below* the plywood. Such a procedure is limited to plywood $^1/_8$ in. and thinner and will require only half as much additional time as a single sheet of plywood, increasing the press capacity 50 per cent.

Another method of conserving press time is that of placing plywood that has not been completely plasticized in the press in heat-controlled kilns immediately after removal from press. This has the effect of continuing the heat treatment to complete plasticization in the kiln, after the pressure element has completed its function.

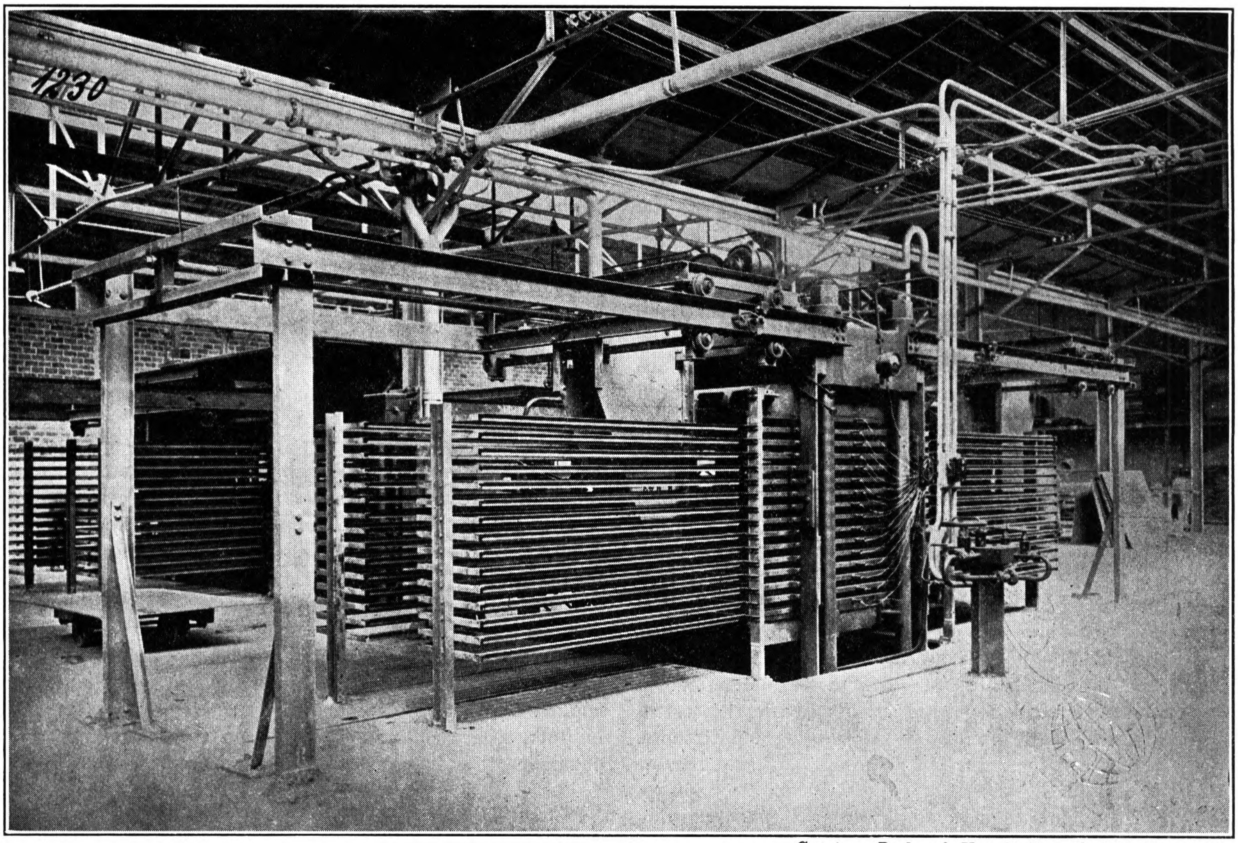
The results of a series of tests indicate that the pressing time can be reduced at least one-half without sacrificing bond strength. Table 5 shows the trends of such a procedure, with the press conditions in the left-hand side of the table and the kiln conditions directly across on the right-hand side.

Advantages of Dry Glue Film

There are many advantages to be secured when laminating with dry glue film. The process is simple and quick. The assembling of the layers can be done in a suitable room near the press, as the time between assembling and pressing is not limited. Care can be exercised in assembling of the veneers and cores, while the haste and rush now so characteristic of the glue room operations is overcome.

The factor of time in gluing and conditioning plywood is reduced from days to a matter of hours. This time saving assists the manufacturer in meeting many urgent deliveries with utmost assurance of perfect material.

Dry glue film permits the gluing of *extremely thin, light-colored,* and porous veneers of all kinds without any staining effects. Because of this non-staining quality the beauty of the wood is



Courtesy, Becker & Van Hullen, Krefeld, Germany

FIG. 7 SHOWING LOADING AND UNLOADING DEVICES ON A HOT PLATE PRESS, CARRIED ON OVERHEAD CHANNEL RAILS

retained, finishing costs are lowered, and a rich, deep tone of artistic character is produced.

The bond effected with dry glue film resin is not only *water-resistant*, but is actually insoluble in water and chemically inert. Extensive tests have not only shown the glue line absolutely waterproof, but on redrying after immersion the bond always shows increased strength. Not only is the bond chemically inert but it is *resistant* and retardant to the attack of *mold, fungi,* and *bacteria*. Tests show that termites and wood vermin will not attack plywood laminated with a phenolic resin film when layers are $^1/_8$ in. or thinner.

Chart 5 shows the life of various wood adhesives when subjected to the attack of mold and fungi.[2] It should be mentioned that the time shown in weeks for full decomposition of the glues was partly absorbed by the building up of the mold culture. This time is shortened when subjecting the specimens to a culture of mold and fungi. For instance, in place of requiring approximately four weeks to decompose a casein glue line when applied in the cold method, the time is reduced to approximately ten days when subjected to a culture. It will also be observed that the hot plate press method of gluing with wet glues not only increases their water resistance but also improves their resistance to the mold attack. This shows that all of the wet adhesives are subject to full decomposition, while the bond made with the film resin is 100 per cent resistant to these attacks. Other tests show no deterioration to the bond after being exposed to the attack of mold and fungi for two years.

The old theory that plywood must be made with a *balanced construction* has been disproved. It is now possible to produce 2-ply panels with lumber core and face veneer with substantial economy and showing no distortion. Many new forms of construction not heretofore possible can be developed when gluing, without introducing moisture into the veneer or lumber.

After gluing, plywoods can be placed in hot water or steamed without injury to the bond. This permits use of flat plywood construction in the forming of *bent* and *curved* products, and the resulting work is very satisfactory.

The dry glue film bond will not react, thus eliminating a *corrosive attack*.

It also has the quality of extreme *flexibility*. There is no crystallizing and cracking, and the bond cannot be destroyed by distortion.

The dry film is completely dissolved under pressure and heat and for the first time has effected a bond which is *stronger* than the contracting and expanding power of wood, when subjected to excessive moisture. This is illustrated in Fig. 8, showing a 3-ply flooring test, using $^5/_{16}$-in. oak face and $^5/_{16}$-in. chestnut core and back. The outer surface expanded in a one year's immersion test some 5 per cent, while the glue side of the oak was held to approximately original dimension by the dry glue film bond.

Dry glue film is very adaptable for the gluing of *crotch* and highly figured veneers in either a 5-ply construction or a 2-ply reinforced face construction. It insures these veneers against checking because the adhesive bond is stronger than the expansive power of the wood. For the same reason it also eliminates

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[2] Since preparation of this article Naval Aircraft Specifications No. 39P13a, April 1, 1933, provide:

E-2c. The adhesive used shall be resistant to decomposition from mold, fungi, bacteria, and shall show a minimum average shear value of 250 lb per square inch when subjected to a culture of the above for a period of ten days.

the so-called hair-lining troubles which are so objectionable to all plywood and furniture manufacturers.

Another interesting feature is that dry glue film has made it possible to use the low-priced Western coniferous woods for core materials, and veneer over them with a thin face ($^1/_{56}$ in.) veneer without showing the *effect* of the *underlying grain* in the coarser woods. Absence of moisture in the gluing is the chief factor in making this possible.

There are many other advantages known and in the process of development, should space permit their discussion.

Recent Adaptations of Plywood to New Products

The plywood industry has been eager to enter broader avenues of trade, but up to the present time the handicap of the standard wet glues has seriously retarded such expansion. The wide range of opportunities for these newer types of plywood are briefly suggested.

1 *Construction Trades.* To the building trade, dry glue film products offer a new material heretofore limited. The increased use of Ferroclad materials to meet fireproof requirements has demanded an adhesive which will not corrode the materials and will not crystallize and decompose under rapid change of temperature and humidity. The adaptation of plywood to the building trade demands that the bond shall withstand all conditions of exposure, is not subject to vermin, termites, mold and fungi attack, is fully waterproof, and resistant to rapid change in temperature, both wet and dry. A few suggested uses are as follows:

Plywood flooring
Flush and panel doors
Veneer faced synthetic fiber boards
Prefabricated unit houses
Concrete forms
Paneling with built-in electrical heating units
Wall paneling.

2 *Automotive Industry.* The automobile industry is always searching for material of the greatest strength with the least weight. While plywood has been considered by designers in the past, the lack of waterproofness and resistance to decomposition by atmospheric elements, such as wet and dry decay, has retarded its adoption by the industry. The dry resin film has entirely overcome these difficulties and the designers are eager to specify plywood for the following items:

Floors, sides, and roofs of refrigerated and ordinary trucks
Roofs, floors, and interiors of buses
Roofs of closed passenger cars
Running boards and insulated floor boards
Battery separators and containers.

The plywood roof not only eliminates the deterioration now so common but supplies an unusual degree of rigidity.

The plywood battery separator and container offer a new and repetitive market to the plywood industry.

3 *Ship and Boat Building.* Due to the advent of the dry resin glue film the entire ship and boat building field is now open for plywood utilization. Waterproof plywood made possible the fabrication of canoes, racing hulls and outboard motor boats insuring greater strength and reduced weight. The new waterproof plywood insures indefinite durability under continuous immersion, and the bond is not affected by oil, acid, or salt water. Some of the watercraft applications are:

Canoes
Outboard motor boats and racing hulls
Ship bulkheads and partitions
Marine wall paneling
Ship furniture.

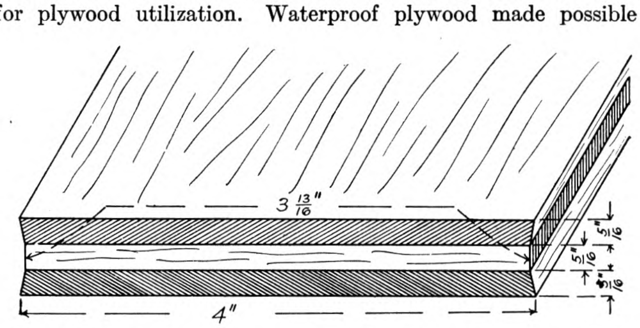

Fig. 8 Showing That the Widthwise Swelling of $^{15}/_{16}$-In., 3-Ply Oak Plywood After 1 Year's Submersion Is Held by the Dry Glue Film Bond Against the Core, but Assumes Normal Expansion at the Outer Surfaces

4 *Aircraft.* Innumerable tests in commercial and aircraft laboratories, both here and abroad, have conclusively established that the bond in phenolic resin plywood is far superior in strength and endurance to any type of plywood heretofore used.

The waterproofness of the bond, the absolute resistance to atmospheric elements, the tests that have proved the shear

TABLE 5 EFFECT ON PLYWOOD STRENGTH OF CONTINUED HEAT IN KILNS

(After removal from hot press)

Specific pressure in press: 285 lb per sq in.
No pressure in kilns
Shear tests: Wet or dry, in lb per sq in.
Wet tests after soaking in water at room temperature for 48 hr
Temperatures: Deg C, automatically maintained
Time: Hr and min

Pressing (before kilning)				Kilning (after removal from press)			
Time, H.—M.	Press temp., C	Shear dry	Shear wet	Time, H.—M.	Kiln temp., C	Shear dry	Shear wet
$^1/_4$ in., 3-ply, All Birch Plywood							
0— 3	130	Nil	Nil	0—30	140	253	253
		Nil	Nil			253	264
		Nil	Nil			176	275
						227	264
0— 4	130	110	77	0—30	140	264	341
		116	77			264	341
		143	99			286	301
		123	84			271	328
0— 5	130	160	112	0—30	140	286	286
		165	118			286	275
		187	143			281	264
		171	124			284	275
0— 6	130	206	176	0—30	140	220	294
		211	184			242	319
		242	184			330	319
		220	181			264	310
0— 7	130	242	206	0—30	140	253	268
		253	209			308	297
		259	209			330	297
		251	208			297	287
$^3/_{16}$ in., 3-ply, All Birch Plywood							
0—10	110	187	94	0—30	140	429	462
		220	140			506	462
		264	Nil			519	308
		224	78			485	410
Same	Same	Same	Same	2— 0	90	358	266
						358	279
						352	232
						356	292
Same	Same	Same	Same	17— 0	90	341	365
						484	407
						462	462
						429	411
$^3/_{16}$ in., 3-ply, All Birch Plywood							
0—10	110	187	94	0—10[a]	130	534	341
		220	140			484	319
		264	Nil			418	341
		224	78			478	334

[a] Re-pressed and re-heated by returning to press, as in case of underplasticized plywood, where kilns not available.

value of the bond to be the highest ever recorded, and the continuous increment of strength or frequent absorption of moisture all strengthen the hold of plywood in aircraft industry.

Plywood of unusual strength as thin as 3-ply, $^1/_{32}$ in., is now produced commercially for aircraft fabrication. This type of material now available to the industry permits the manufacture of aircraft at a reduced cost, with less weight, with increased strength, with longer life regardless of atmospheric conditions, and with a higher factor of safety. This will lead to greater demands for plywood and will mean the ultimate increase of the shear value of the glue bond in the present government and commercial specifications.

In addition to the major applications by industry, there are several outstanding combinations of dry glue film plywoods with synthetic sheet products which enter too many fields to permit such industrial classification.

5 *Asbestos Clad Plywood.* In the development of asbestos slate, manufactured under various trade names, phenolic resin plywood has again found many new applications.

Asbestos clad plywood, or plywood faced with asbestos slate, glued with dry glue film, has introduced many new possibilities for plywood for interior and exterior purposes. The slate can be had in various thicknesses from $^1/_{20}$ in. up, and can be nailed or riveted in a very satisfactory manner. As the slate is resistant to acids and alkalies, is non-porous, is incombustible, and has a smooth surface for paint or enamel, it may be used for either a face or a cross band. If used as a cross band, it can be faced with any type or thickness of fine veneers. With dry glue film unusually thin veneers can be applied to the slate without danger of staining the work. Tests show that the dry film bond is stronger than the slate. A few of its many adaptions might be listed as follows:

Wall paneling	Telephone booths
(Interior or exterior)	Laundry equipment
Hospital interiors	Air-conditioning units
Fireproof partitions	Electrical equipment
Greenhouse equipment	Elevator cabs
Lavatories and shower rooms	Railroad freight cars
Laboratory equipment	Ice cream cabinets
Kneading boards	Refrigerators.
Steaming rooms	

Rubber Vulcanizing Directly on Plywood. The vulcanizing of rubber directly on plywood is a recent development which opens another field for the veneer and plywood industries. The rubber research laboratories have been eagerly searching for a suitable wood product on which rubber may be vulcanized. It was found that neither solid wood nor plywood glued with wet adhesives would answer the requirements of the vulcanizing process.

Successful vulcanizing of rubber to wood demands that the wood shall not have more than 2 per cent moisture content, and that it must withstand a heat from 350 to 380 F, under a specific pressure of 250 lb for a time of 20 to 30 min. It is immediately realized that neither solid wood nor wet glued plywood can meet such exacting demands. A dry glue film bond does not deteriorate under this heat, and since it permits the manufacture of plywood with not more than 2 per cent moisture content under 250 lb specific pressure, the new plywood answers fully all the requirements for vulcanizing rubber to wood. Some of the many uses for this type of material are as follows:

Desk tops	Running boards (auto)
Rubber covered refrigerators	Toilet seats
Table tops	Chair and stool seats
Counter tops	Caskets
Floor boards (auto)	Flooring and tile.

Other Plywood Products. Dry glue film plywood applications for other new products, discussion of which space does not permit, might be enumerated as follows:

Agricultural equipment	Plywood milk racks
Brush backs	Archery bows
Athletic equipment	Golf shafts
Artificial blackboards	Fret molding plywood
Wood-metal desk tops	Tennis racket frames
Flameproof plywood	Hockey sticks
2- and 3-ply shipping containers	Curved and bent plywood.
Foundry pattern stock	

The phenolic resin bond of fret moldings from $^1/_{32}$-in. and $^3/_{64}$-in., 3-ply plywood has no injurious effect on the cutter heads or punches and dies. It is surprising to note the volume that can be made without renewing the cutting edges. The character of the phenolic resin glue line does not dull saws, knives, and cutter heads.

CONCLUSION

The development of dry glue film has introduced a number of distinct and definite advantages which the wet glues have not offered. The result is that new possibilities and applications for plywood are constantly being discovered and developed, and the horizon of the plywood industry is thereby greatly broadened.

Note: Various U. S. patents are applied for and pending on phenolic resin plywood, and prospective users should investigate carefully.

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Discussion

Charles B. Norris.[3] This is a valuable description of the use of phenolic sheet glue, particularly the technical data included in tables and charts. As Mr. E. H. Merritt has pointed

[3] Mechanical Engineer, Haskelite Mfg. Corp., Grand Rapids, Mich. Mem. A.S.M.E.

out,[4] the sheet glue process is only one of several processes of gluing made possible by the development of phenolic resins. Mr. Merritt favors a dry powder process. My company has developed a process of gluing with which the sheet glue could be used or, with the addition of some of Mr. Merritt's equipment, the dry powder could be used. However, we prefer using the phenolic resin in the form of a colloidal suspension in water.

In the process we have developed, the glue is spread upon the veneers by means of a glue roll of the usual design. Special rolls and scraper bars are necessary, and the condition of the air surrounding the rolls has to be controlled. The veneer passes directly from the spreader into a simple surface drier which we have designed. High-velocity air is passed over the surfaces of the veneer in such a way that even thin veneers ($^1/_{64}$ in.) are not disturbed. Fig. 9 shows the glue spreader and the entrance end of the drier. Fig. 10 shows the exit end of the drier. After the veneers leave the drier they are ready for the gluing process.

The gluing process is similar to the usual cold gluing process in that a stack of panels is formed and moved into the press. Thin electric heating elements are piled alternately with the panels, so that each panel has two heating elements adjacent to it, one on each side. The stack is moved into the press, pressure is applied, and the heating elements are energized. The pressing operation takes about 20 min. Fig. 11 shows one end of the press and the piling mechanism for placing the heating elements upon the stock. There is a similar unpiling device at the other end of the press. Fig. 12 shows the press-control apparatus, including an automatic valve for controlling the pressure and an automatic device for controlling the temperature. The apparatus shown makes panels 8 ft long and 6 ft wide. It has an output of 3000 sq ft of $^3/_4$-in. panel per hour. The full production possibilities of this method of manufacturing panels are shown by plans of a larger machine, which we have completed. This larger machine makes panels 10 ft square at a rate of 22,000 sq ft per hr.

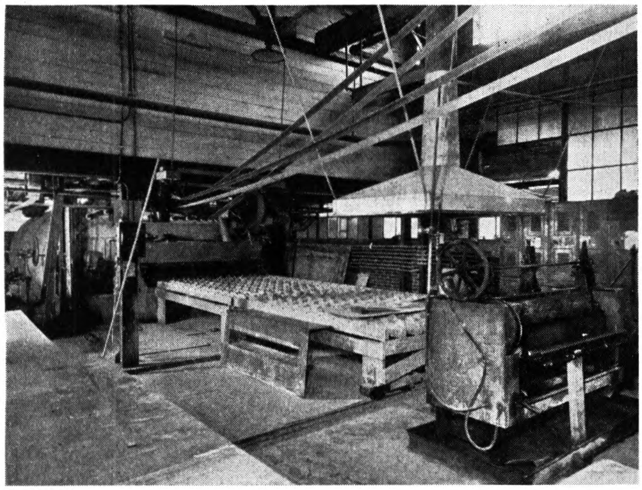

Fig. 9

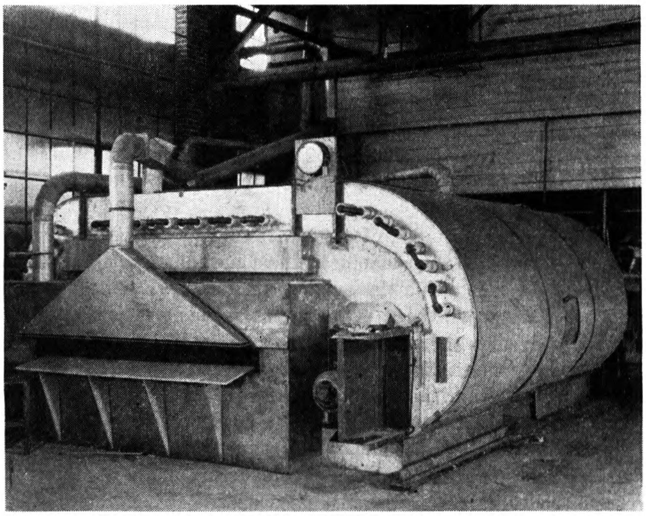

Fig. 10

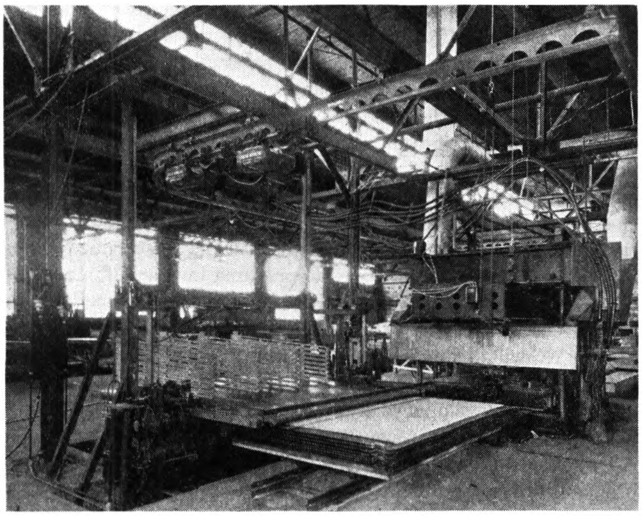

Fig. 11

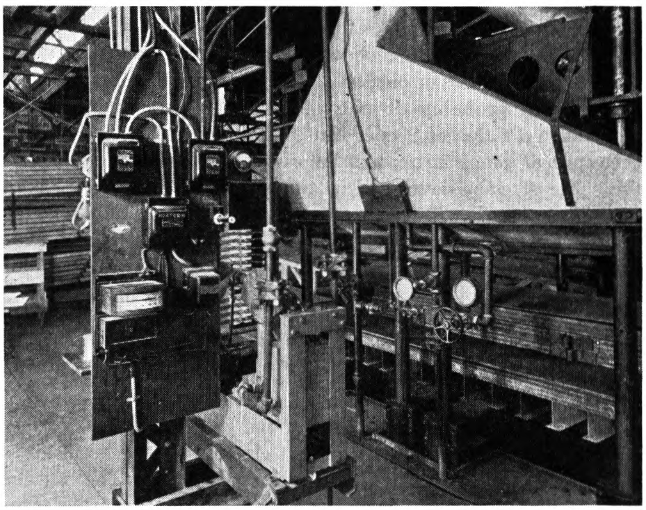

Fig. 12

The author describes the ideal wood adhesive as "one which is of a uniform quality, which can be laid or spread in an even coating, which gives a perfect glue bond, and which can be applied economically." There are also other requirements which it should meet. There is almost an infinite number of possible chemical combinations of phenol and formaldehyde. In making a phenol formaldehyde glue it is possible to end up with any one of a great number of these compounds by slight changes in the

[4] "Laminating With Phenolic Resins," Trans. A.S.M.E., paper no. WDI-55-3 (June 30, 1933).

temperature-time relations of the process. It is very unlikely that the manufacturer of the glue will ever make two batches of glue that are chemically identical. Luckily the user of the glue is not interested in its chemical nature but in its physical properties. Uniform gluing results cannot be expected unless the physical properties of the glue are uniform. The user should be in a position to test these properties himself. The form in which he receives the dry glue film makes this almost impossible. We have developed simple physical tests which can be applied to the colloid glue to tell whether the glue is suitable for our purpose.

Regarding the uniformity of glue spread, in using a liquid glue we have at our command all the experience gained by the printing industry in spreading inks uniformly. We find that we can obtain very uniform spreads indeed. We also found that the dry glue film made by the author's company is not uniform in thickness. Fifty measurements taken around the edge of a piece 18 in. long and 5 in. wide show an average thickness of 0.00229 in., a maximum thickness of 0.0029 in., and a minimum thickness of 0.0020 in. This is a variation of 30 per cent above the average and 12 per cent below.

A further requirement of an ideal wood adhesive is that it should make as good a glue joint at the center of a thick panel as it does near the face. If a thick panel is placed between the plates of a hot plate press, the wood near to the plates is heated much more rapidly than the wood near the center of the panel. Therefore a glue line near the face of the panel is subjected to conditions different from those of a glue line near the center of the panel. The glue must be such that a good glue joint is obtained under both these conditions. The author does not give any data showing the properties of dry glue film joints made at different rates of heating.

Another requirement of an ideal wood adhesive is that it should give good results over quite a range of moisture content of the wood. A plywood panel should be glued up at a moisture content which is the mean moisture content the panel will obtain in use. For example, if a general purpose panel is to be made, it may be used indoors or outdoors. Indoors in winter its moisture content will probably drop to 4 or 5 per cent. Outdoors it may reach a value of 20 per cent. The panel should be made, therefore, at a moisture content of about 12 per cent in order that the shear stresses developed in the panel at the low and high moisture contents will not be great enough to cause failure of the wood. Chart 2 of the paper shows that the dry glue film is suitable for this purpose. In our process the water is dried out of the spread colloid so rapidly by the surface drier that the moisture content of the wood is not materially changed.

So far as we know there are only three reasons for the introduction of phenolic resin glues into the plywood industry: the greater strength of the glue joint, the greater water resistance of the glue joint, and the immunity of the glue to attack by fungi and bacteria. All other advantages claimed for the resin glues are obtainable with the older forms of glues. The author stresses the advantages of gluing with "dry" glues rather than "wet" glues, saying that the amount of water contained in glues cannot be kept uniform and that there is no possibility of regulating the influence of moisture upon the glued plies. We believe that these statements are an exaggeration of the facts. We have been controlling these factors in the use of blood-albumin glues for a number of years.

The warning that very excellent hot plate presses are necessary for making plywood is timely. However, we do not agree with the reason given regarding the extreme thinness of the dry glue film.

An elementary discussion of the theory involved will show the reasons for the need of very excellent presses when any kind of glue is used. We can assume that the modulus of elasticity of wood is 80,000. If we assume also the variation in the press of 0.003 in. that the author allows, we find that the variation in pressure upon a plywood panel $^1/_4$ in. thick is 960 lb per sq in. That is, under normal gluing pressures certain parts of the plywood receive no pressure whatever. If it were not for the fact that wood becomes somewhat plastic when it is moist and hot, the steam platen method of gluing plywood could not be successful. It is a precarious method at best. The process we have developed has the advantage of the cold process method with regard to pressures. Under the same condition of 0.003 in. variation in the press, the variation in pressure is only 3 .b per sq in., figured by the method outlined.

The impression is gained from the paper that it is not practical to glue thick panels with the dry glue film if some of the glue lines are near the center of the panel. This is a real difficulty that is very often encountered with the use of phenolic resins. However, this difficulty can be overcome, and in fact is being overcome in our factory.

We are in perfect accord with the author that the phenolic resins make remarkable glues and that the dry glue film is a very good glue indeed. We think, however, that the use of the colloid overcomes some of the difficulties encountered in the use of the other forms of the resin and that our gluing method overcomes the difficulties inherent in the hot plate process.

A. J. Norton.[5] There are now three commercially developed methods of using phenolic resin glue lines. In addition to the film glue discussed by the author, there is the dry-powder method of spreading resins which was discussed by Mr. Merritt in the October meeting at Jamestown, and the method of spreading the synthetic resin in colloidal form as was brought out by Mr. Norris, of the Haskelite Company.

The colloidal method of spreading has proved satisfactory in large-scale production and lends itself to commercial operation very satisfactorily. The spreading equipment is slightly different from that already used, and hot plate presses, steam or electric, are the same as are used in any hot press gluing operation. The colloid lends itself to more widely diversified types of application, due to the ease of spreading low or high amounts of resin, and while it was not brought out at the meeting, we have since shown that the colloid works successfully over a lumber core under usual operating conditions. It was brought out at the Chicago meeting that the use of the colloid on sheet lumber might develop a panel core which would compete actively with the lumber core in construction work.

Dry resin and colloid are manufactured by General Plastics, Inc., and these products have sold under the trade name of Durez.

With the three methods of using phenolic resin glue line, and with the merits of such a glue line definitely established, there seems to be no doubt of a distinct and revolutionary change taking place in the lumber field.

[5] General Plastics, Inc., North Tonawanda, N. Y.