THE GLUING OF LAMINATED PAPER PLASTIC (PAPREG)

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THE GLUING OF LAMINATED PAPER PLASTIC (PAPREG)[1]

By

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The Forest Products Laboratory has produced a laminated paper plastic (papreg)[2] of high tensile strength that is serving as a structural material in the fabrication of certain aircraft parts and in numerous other war products. Because of the expanding use of this material, a need has arisen for exact information concerning its gluing properties. Gluing tests were made at the Forest Products Laboratory to meet this need, and are herein reported.

These gluing tests were made with papreg produced from paper impregnated with an alcohol-soluble, phenol-formaldehyde resin, according to Forest Products Laboratory specifications. The resulting papreg had a specific gravity of 1.3 to 1.4, based on its weight and volume when tested, and a resin content of 30 to 35 percent.

The results obtained apply only to this particular papreg and the glue and gluing conditions used. Factors investigated included:

1. The preparation or production of suitable gluing surfaces.

2. The most satisfactory glues for bonding thin papreg to papreg.

3. The effect of gluing conditions on the quality of papreg-to-papreg glue bonds.

4. Gluing of thin papreg to wood.

5. Gluing of thick papreg to itself and to wood.

6. Nail gluing of thin papreg.

These studies are being continued to determine the durability of papreg-to-papreg and papreg-to-wood joints made with certain of the promising adhesives.

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[1]This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

[2]Forest Products Laboratory Mimeo, No. 1395 Revised, "High-strength Laminated Paper plastics for Aircraft."

The Preparation of Papreg Surfaces for Gluing

As they come from the hot press, papreg surfaces are glazed and covered with a thin coat of polymerized resin. Glues rarely adhere satisfactorily to surfaces of this type and usually such surfaces require special treatment to prepare them for gluing. The purpose of this part of the study was to determine the effectiveness of various mechanical and chemical treatments in improving the gluability of papreg surfaces.

In order to eliminate from the tests as much as possible the variable of incomplete surface contact, the papreg used was in the form of 1/16-inch sheets which flatten under gluing pressure to make complete surface contact. The fiber direction of each sheet of paper composing the papreg was parallel to that of all others. To prepare it for gluing, the papreg was conditioned for at least 1 week at 30 percent relative humidity and 80° F.

Surface Treatments

Surface treatments studied were sanding, benzene washing, carbon tetrachloride-acetone washing, alkali treatment, and acid treatment. These treatments were applied to all gluing surfaces of the papreg. In the sanding operation, number 1/2 garnet sandpaper was used with a portable belt sander, and approximately 0.002 to 0.003 inch was removed from the face of each panel. The washing treatments consisted of several washing applications of a cloth soaked in the solvent, followed by wiping dry with a clean cloth. Acid and alkali treatments consisted in soaking the panels for 5 minutes in a concentrated solution of the reagent followed by a running cold water rinse, after which they were wiped dry.

Type of Panel

Two types of panels were prepared for testing the joints between thin papreg sheets. The first type was of three-ply construction with the fiber direction of all plies parallel; the second type was similar except that it had only two plies. Two 4- by 8-inch panels of three-ply construction, or two 8- by 8-inch panels of two-ply construction were used with each gluing variable investigated.

The three-ply construction was first used because it was similar to the construction of the plywood panels frequently used in evaluating glue joint strengths. The two-ply type of panel was adoped after earlier work with the three-ply construction because (1) it required less material, (2) it gave higher test values and, therefore, provided a better test of the joint strength of a single glue line by a tension shearing force, and (3) it has been used to some extent by plastic manufacturers who are experimenting in the bonding of plastics.

Glues and Gluing Conditions

Two groups of glues were used in the study of the effect of surface treatments. The first group included hot-setting urea (Plaskon 201-2 with hardener 841), cold-setting urea (Plaskon 250-2), and hot-setting phenol (Bakelite 7381). Three-ply panels were glued with each of these glues using papreg of 4 different surface conditions, namely, untreated, washed with benzol, soaked in acid or alkali, and sanded.

The second group of glues included hot-setting phenol (Bakelite 7381); hot-setting phenol film (Tego No. 2); low-temperature phenol, acid (Durez 12041); low temperature phenol, alkaline (Cascophen LT-67); low-temperature resorcinol (Penacolite G-1124); hot-setting urea (Plaskon 201-2, hardener 841); cold-setting urea (Uformite CB-551), and casein (Lauxein 888).

Two-ply panels were made with these glues, using papreg with sanded and unsanded surfaces. Some of the specimens glued with the Tego glue were first washed with a dewaxing solvent (carbon tetrachloride and acetone).

Spreads and assembly times used were within the ranges recommended by the glue manufacturers for use on wood. All gluing was done at pressure of 150 pounds per square inch.

The hot-setting phenols were cured for 10 to 15 minutes at 315° to 325° F., the alkaline low-temperature phenol for 16 hours at 180° F., and the acid low-temperature phenol for 16 hours at 160° F. The hot-setting urea was cured for 10 to 15 minutes at 240° to 260° F., and the other glues were cured for 16 hours at 75° F. All glued panels were conditioned for at least 1 week at 80° F. and 30 percent relative humidity.

Testing

Following the conditioning period, the three-ply panels were cut into specimens similar to the standard plywood shear specimen shown in figure 1,A, and the two-ply panels were cut into lap-joint specimens of the type shown in figure 1,B. Thus 7 test specimens were obtained from each three-ply panel and 10 to 14 from each two-ply panel.

Specimens were tested dry on a plywood testing machine which loaded the specimens in tension at a rate of 700 to 800 pounds per minute.

Results

The results of the shear tests made on the two- and three-ply specimens are shown in table 1. The results on the two-ply specimens were slightly higher than those obtained with the three-ply specimens.

With the untreated surfaces, only the liquid, hot-setting, phenol glue gave consistently strong joints. Tego gave erratic results on these surfaces,

but this may have been due in part to waxes deposited on the faces from cauls used in the pressing operation, for better bonds were obtained with Tego on the panels which had first been washed with a dewaxing solvent. With all of the other glues used, except casein, the untreated surfaces were so poorly glued that the cured glue film could be removed from between the sheets of papreg. Casein glue gave unsatisfactory bonds on the untreated surfaces.

The benzene washing did not improve the gluing characteristics significantly.

Acid treatment of the surfaces lowered the joint strength obtained with the hot-setting, alkaline phenol glue but improved that gained with the two acid ureas. With the hot-setting urea, very good results were obtained following the acid treatment. The durability of glue joints between surfaces given an acid treatment is not known, however, and this method of preparing surfaces cannot, therefore, be recommended until such information is available.

The alkali-treated surfaces gave weak joints when glued with urea-resins but good strength with the hot-setting phenol glue.

The surfaces that had been sanded were found to be well glued with all of the adhesives used in this study, although sanding did not improve the results with the hot-setting liquid phenol glue. Sanding appears to be the only generally satisfactory method found to date for preparing papreg surfaces for gluing with a variety of glues.

Comparison of Glues for Bonding Papreg

The performance of a variety of glues in papreg gluing was compared. Panels 4 by 8 inches or 8 by 8 inches in size were made by gluing together 3 plies of 1/16-inch, parallel-laminated papreg with the fiber direction of all plies parallel; four panels of the larger size or eight of the smaller size were assembled for each glue. The papreg was the same type as that used in the study of surface treatments, but it was necessary to use material from several lots, one of which was molded at a slightly higher pressure. All surfaces were lightly sanded with No. 1/2 garnet sandpaper before the glue was spread.

Glues and Gluing Conditions

The 27 glues used in these tests are listed in table 2. The gluing conditions used with each glue were within the limits recommended by their manufacturers for use on wood and are also shown in table 2. Before being glued into three-ply panels, the papreg sheets were conditioned at 30 percent relative humidity and 80° F. The glued panels were similarly conditioned after removal from the press.

One of the problems met in gluing laminated paper plastic with high-temperature glue is the tendency of the panels to blister in the hot press when a normal closed assembly period is used. Blistering occurred particularly with Cycleweld C-3, Bakelite 7381, and Worden's Resin under the normal closed assembly periods. By using an open assembly and increasing the assembly period, the tendency to blister was reduced. When Bakelite 13268 and Bakelite 16200 resins were used with a long open assembly, the result was a thick glue line which was relatively weak despite the fact that a large amount of paper fiber adhered to the glue.

Testing

The panels were cut into shear specimens of the type shown in figure 1,A, so that the tension when testing was parallel to the direction of the paper fibers in all 3 plies. Fifty-six shear test specimens were obtained for each glue, and were divided into three groups of 18 or 19 specimens each. One group was tested dry, the second group was tested wet after 48 hours' soaking in water and the third group was boiled for 3 hours and then tested wet.

Results

The results of the tests are presented in table 2.

Most of the glues produced joints in which more than 80 percent of the failure occurred in the papreg. With the type of specimen and the papreg used in these tests, the average dry shear strength value of a well-glued joint was about 500 to 600 pounds per square inch although two of the glues gave averages of over 700 pounds. Boil-test and wet-test specimens often gave higher results than the dry tests, perhaps because of better curing or because the fibers when at a higher moisture content allowed better distribution of stresses.

Dry shear test values with Monite Casein, Tego, Durez 11427, and Cycleweld C-3 were higher than 600 pounds per square inch, but the papreg stock used in these tests was manufactured under higher pressure and the material itself might have had a higher shear strength for this reason. Penacolite G-1124 and Bakelite 16257 produced bonds with shear strengths of less than 500 pounds per square inch, but the joints showed almost complete failure in the papreg so these somewhat lower strengths were probably due to the properties of the papreg rather than those of the glue bonds.

The following glues did not produce good joints on papreg under the conditions used: Worden's Resin, Vinylseal MA-28-18, DuPont 4624, Butacite 4639, Bakelite 11753, and DuPont J-4600-X-5150. Most of these glues were of the thermoplastic or partially thermoplastic type. Some of these glues have shown promise in the gluing of materials similar to papreg and might give good joints under gluing conditions more favorable to them.

Joints made with casein glue, which does not have high water resistance, and cold-setting urea glues, which are not resistant to boiling water, were found to give boil and wet tests equal to those of the more resistant glues if

properly applied. This is probably attributable to the low permeability of properly cured papreg, which reduces the rate at which water reaches the glue joints. The one instance in which the boiling test lowered the strength of a cold-setting, urea-resin bond may have been caused by the use of papreg which was not completely cured.

Gluing Conditions for the Bonding of Papreg to Papreg

It is probable that, in the practical use of papreg, including secondary gluing operations, the cold-setting and low-temperature glues will prove of greatest utility in bonding operations. Hence, a group of tests were made primarily to determine the most satisfactory gluing conditions for these glues. The gluing conditions investigated included spread, assembly period, pressure, and curing time at several temperatures. In addition, the effect of the moisture content of papreg on the quality of glue joints made with Tego glue was studied.

The glues used in this study were Uformite CB-551, Cascophen LT-6, Durez 12041, Lauxein 888, Plaskon 250-2 (used only to study the effect of spread) and Tego (used only to study the effect of moisture content).

The 1/16-inch papreg used was of the same type as that employed in the preceding studies. In preparation for gluing, the papreg was conditioned for at least 1 week at 30 percent relative humidity and 80° F. before being surfaced. The surfaces were then sanded sufficiently to remove the glossy appearance.

Two pieces of this papreg were then glued together to form a glued panel 5 by 12 inches in size, with the fiber direction of each ply parallel. The fiber direction was parallel to the shorter panel dimension.

Following gluing and after conditioning periods of at least 1 week at 80° F. and 30 percent relative humidity, 10 specimens of the two-ply type, (fig. 1,B) were cut from each panel.

Dry tests only were made on these specimens, using a plywood testing machine which loaded the specimen in tension at a rate of 700 to 800 pounds per minute.

Effect of Glue Spread on the Quality of Papreg-to-Papreg Joints

The specific gluing conditions involved in the study of the effect of glue spread on the quality of papreg-to-papreg joints were:

Assembly time - 10 minutes, closed.

Pressure - approximately 150 pounds per square inch.

Temperature and pressing period - 20 hours at 75° F. for the casein and urea-formaldehyde, and 24 hours at 160° F. for the low-temperature phenols.

Spread - Five ranges of single brush spread used with each glue, from very light to very heavy.

Three panels were prepared for each glue at each condition of spread. From each set of 3 panels, 30 specimens were cut and tested.

Results.--The joint strength and amount of papreg failure for each range of spread are given in table 3 for each of the five glues.

The average papreg failure was 100 percent in all cases except one, which averaged 98 percent. The strength values were also uniformly high. This indicates that satisfactory results can be obtained in gluing sanded papreg faces with these glues over a wide range of spreads if other gluing conditions are properly controlled. Lauxein 688, a casein glue applied in spreads as low as 12.0 to 16.0 grams of wet glue per square foot, as well as the other glues in still lighter spreads, produced joints of high quality. Heavier spreads did not improve the strength of the joints.

The joint strength obtained was dependent upon several factors other than the quality of bond, particularly variations in the strength of the papreg. The average joint shear strength of papreg used in these studies was 600 to 700 pounds per square inch, but part of this study of spread was made with an earlier lot of plastic specimens having a joint shear strength of 500 to 600 pounds per square inch.

Effect of Assembly Time and Pressure on Quality of Papreg-to-Papreg Glue Joints

A range of pressures from 1.5 to 250 pounds per square inch, with closed assembly periods of 2 to 60 minutes, was studied to determine the effect of these variables on joint strength. The pressures and assembly periods used are shown for each glue in table 4.

Although the previous study on spread showed that the amount of glue spread is not critical, a controlled single spread of between 20 and 25 grams of wet glue per square foot was used.

Temperature and pressing period were 20 hours at 75° F. for the cold-setting glues and 24 hours at 160° F. for the low-temperature phenols.

For each glue and each gluing condition, three panels were made. Later each panel was cut into 10 shear specimens.

Results.--The results of this part of the study are given in table 4.

Within the pressure range of 25 to 250 pounds per square inch, and with all four glues used, the joints failed 97 to 100 percent in the papreg. When

the pressure was reduced to 1-1/2 pounds per square inch, the average failure of specimens glued with the resin glues was 94 to 99 percent in the papreg, and with the casein glue, 66 to 88 percent in the papreg. At this lower pressure, Cascophen and Uformite produced bonds of slightly lower strengths than did Durez. It should be pointed out in connection with the use of these low pressures, however, that the tests were on flat panels and little or no force was required to bring the surfaces into close contact. Such low pressures would be insufficient for gluing operations involving any surface curvature or large panels.

No optimum assembly period was found within the range of 2 to 60 minutes closed assembly and equally good results seemed obtainable throughout the range.

Nearly all of the tests on the papreg bonded with Uformite CB-551 and Lauxein 888 were within the range of 600 to 700 pounds per square inch. The same range was observed in the tests of bonds made with the two phenol glues, with the exception of the series at 25 and 50 pounds per square inch with Cascophen LT-67 and that at 1.2, 25, and 50 pounds per square inch with Durez 12041. The higher test values on these runs might be due to the higher shear strength of the papreg used in this group of tests or to the influence of slight variations in notch depth on the test result.

Pressure Period and Temperature Used in Making Papreg-to-Papreg Joints

The rate of setting of casein and urea-resin glues on wood at various temperatures is fairly well established, and similar studies are being made on the low-temperature phenol glues. A few tests were made to determine whether the rate of setting of these glues on papreg is the same as on wood.

The gluing conditions followed in these tests were:

Spread - 20 to 25 grams of wet glue per square foot.

Assembly time - closed assembly period of 10 to 20 minutes. The longer assembly periods employed with electrically-heated cauls.

Pressure - approximately 150 pounds per square inch.

Curing temperatures - a room was used to maintain temperatures of 75° F. and 90° F. At the higher temperatures of 140° F. to 200° F., electrically-heated cauls were used, and temperatures determined by thermocouples in the glue line. The spreading of glue for these high-temperature series was done at 75° F.

Curing periods - the curing period began when the pressure was applied, except on panels which were electrically heated. These panels required a heating-up period of 15 to 20 minutes and the time of curing was measured from the end of this heat-up period.

Conditioning period - 1 week at 80° F. and 30 percent relative humidity.

Four panels were glued for each condition, two of which were placed in a room at 80° F. and 30 percent relative humidity immediately after removal from the press. The other two panels were allowed to remain at the pressing temperature for 24 additional hours in the same room for the 75° and 90° F. series or, in the case of the higher temperature series, in kilns maintained at the pressing temperature. These panels were then placed in a room at 80° F. for the remainder of the conditioning period. Ten shear specimens were cut from each of the panels.

Results.--The results of these tests are given in table 5. As the additional 24 hours at the curing temperature did not produce any significant change in the test results, tests of the specimens cured only under pressure and those cured for one additional day at the curing temperature were averaged together.

All the curing periods used with Cascophen LT-67 at the various temperatures produced joints in which more than 95 percent of the failure was in the papreg. The shortest curing periods found to be satisfactory at the respective temperatures were 8 hours at 75° F., 4 hours at 90° F., 1 hour at 140° F., 1 hour at 160° F., and 1/2 hour at 200° F.

With Durez 12041 approximately the same results were obtained, with the exception that the 4-hour period at 90° F. was insufficient to produce bonds which would fail mainly in the papreg. A curing period of 8 hours at 90° F. produced high-quality joints, and even 8 hours at 75° F. was very good.

These minimum curing periods, which gave good bonds in papreg with the low-temperature phenols, were shorter than are considered sufficient to produce bonds of maximum strength and durability in high-density woods with these glues at the temperatures used. Dry tests do not indicate whether these curing periods produce a fully cured glue bond capable of withstanding exposure to unfavorable conditions. From other work, however, it has been established that these low-temperature phenols when cured in this way were not fully cured and that, to obtain a joint that is durable under exposure to alternate soaking and drying, further heat treatment would be necessary. From the strength data gathered in these tests it would seem, however, that this further treatment might be made without the aid of clamps.

Uformite CB-551 and Lauxein 888 were pressed at 75° F. and 90° F. Periods of 4 hours at 75° F. and 1 hour at 90° F., followed by a conditioning period, produced high-quality bonds. The casein glue joints that were cured for 1 and 2 hours at 75° F. had high strength but the papreg failure was lower than is desirable. This is approximately the same time required to bond high-density woods with these glues.

Moisture Conditioning of Papreg when Gluing with Tego

In tests of the evaluation of glues, Tego formed good bonds in papreg which had been conditioned in a room maintained at 80° F. and 30 percent relative humidity. Since moisture content is usually considered to be rather

critical in gluing with Tego, 1/16-inch papreg sheets, 4 by 8 inches in size, were conditioned for 7 to 10 days in rooms maintained at 80° F. and 30, 65, 80, 90, and 97 percent relative humidity. They were then glued into three-ply panels with the fiber direction parallel in all 3 plies, using a platen temperature of 315° F. and a pressure of 150 pounds per square inch. Following the gluing operation, all panels were conditioned for 1 week at 30 percent relative humidity and 80° F. The results of dry plywood shear tests on specimens from these panels are given in table 6.

The specimens from the papreg that was conditioned at 30 percent relative humidity before gluing were the only ones to show any appreciable glue failure in the joints, and even in these specimens the average glue failure amounted to only 4 percent. Present evidence indicates that moisture content of the papreg, as affected by the conditioning treatments described, is not a critical factor in the gluing of this material.

Gluing Papreg to Wood

Gluing of Thin Papreg to Maple Blocks

In utilizing papreg in the fabrication of certain aircraft parts, it may be necessary to glue it to wood. The quality of the bond established between papreg and wood by a representative cold-setting, urea-resin glue was therefore explored to provide data for this purpose.

Type of Specimen

A 5- by 12-inch sheet of 1/16-inch papreg was bonded between two 3/4-inch sugar maple blocks, with the fiber direction of the papreg parallel to the grain of the maple blocks. In preparation for gluing, the papreg was conditioned for 1 week at a relative humidity of 30 percent and 80° F. and the wood for at least 1 month in the same room. The papreg was then lightly sanded and the maple lumber was planed.

Twelve assemblies of this type were prepared, from each of which were obtained 10 block shear specimens of conventional dimensions, as shown in figure 1, C. The specimens were tested in such a way that the shearing force was applied to one of the glue lines between papreg and wood.

Gluing Conditions

Uformite CB-551, a cold-setting urea resin glue , was used under these conditions:

Spread - varied to determine the effect of variations within the range ordinarily used. Three assemblies were made at each of the following wet glue spreads: 17.0 to 18.5; 19.5 to 21.0; 23.0 to 24.0; and 30.0 to 33.0 grams of wet glue per square foot.

Assembly - a closed assembly period of 10 minutes allowed before applying pressure.

Pressure - 150 pounds per square inch.

Pressing time and temperature - 18 hours at 75° F.

Conditioning - 1 week at a relative humidity of 30 percent and 80° F. before cutting and testing the specimens.

Results

The results of block shear tests of the specimens are given in table 7. The gluing of 1/16-inch sanded papreg to well-planed maple lumber under the conditions of this experiment resulted in bonds sufficiently strong to develop practically the full strength of the papreg. At least 98 percent of the average joint failure occurred in the papreg. The glue spread, within the range used, did not appreciably affect the quality of the joint.

Gluing of Thick Papreg to Itself and Wood

In the preceding parts of this study, it was found possible to glue thin sheets of papreg satisfactorily. An additional study was made to determine whether thick papreg could be glued as successfully as the thin.

Materials.--Parallel-laminated papreg 9/16-inch thick was cut into blocks 5 by 12 inches in size. The blocks were cut so that the fiber direction of the papreg was parallel to the longer dimension of the block. Following a conditioning period of at least 1 week at 30 percent relative humidity and 80° F., all papreg blocks except one pair were milled on a milling machine. The pair not milled was lightly sanded. The papreg used in this part of the study was not of the standard type, but its gluing characteristics were practically the same as those of the standard material except that its shear strength is slightly lower.

Sugar maple and Sitka spruce lumber 3/4 inch thick was also cut into 5- by 12-inch blocks and conditioned in the same manner as the papreg. The wood was planed just before being glued.

Four glues, Uformite CB-551, Lauxein 888, Durez 12041, and Cascophen LT-67, were used in preparing joints of each type. Uformite CB-551 was also used in gluing together the pair of sanded papreg blocks.

Gluing Conditions.--One pair of blocks was glued together with each of the glues to make joints of papreg-to-papreg, papreg-to-maple, and papreg-to-spruce respectively. Following a conditioning period of 1 week at 30 percent relative humidity and 80° F., each pair of glued blocks was cut into 10 standard block shear specimens, as shown in figure 1, D.

The gluing conditions used were similar to those recommended for gluing wood with these glues. A pressure of 150 pounds per square inch was applied, following a closed assembly time of 10 to 20 minutes. Fifteen to 20 grams of wet glue were spread per square foot, with the exception of casein, which was spread approximately 30 grams per square foot. The urea and casein glues were cured for 20 to 24 hours at 75° F., and the two phenols 20 to 24 hours at 160° F.

Results.--Block shear test results for the joints are given in table 8. The failure in nearly every case was 100 percent in the papreg. The highest shear test results were obtained in the papreg-to-papreg specimens, which had an average shear strength of 1,817 pounds per square inch. The gluing of papreg to wood was equally as good as that of papreg to papreg judged by the amount of papreg failure, but the average shear strengths were lower. The set of blocks that was sanded but not milled showed some glue failures.

The general conclusion from this test is that thick papreg which has been machined to a true, flat surface can be glued equally as well as the thin papreg, and that any results of gluing tests on thin papreg should apply to thicker sections that have been properly surfaced.

Nail Gluing of Papreg

In aircraft fabrication it is common practice to use nails as a means of applying gluing pressure to joints between thin plywood and solid wood members. If papreg is to be used in this manner in place of plywood, it is desirable to know whether the nailing technique can be employed and what difficulties, if any, are likely to be encountered with papreg with this method of gluing.

The assemblies for this study were prepared by nail gluing a 1/16-inch papreg sheet (2-1/2 by 12 inches) to a 3/8-inch square cap strip of yellow birch or Sitka spruce. From each completed assembly, three conventional plywood cap-strip shear specimens were cut (fig. 1, E).

In preparation for gluing, the surfaces of the papreg were lightly sanded, and both cap strip and papreg were conditioned for at least 1 week at 30 percent relative humidity at 80° F.

When driven through a sheet of papreg, the nails produced a burr on the exit side of the sheet, as shown in figure 2. Because of the likelihood that this burr might interfere with distribution of pressure, some of the panels were prebored with a drill of nearly the same diameter as No. 20 nails.

Uformite CB-551 was used to glue the specimens under the following conditions:

Spread - light, 7 to 15 grams; medium, 16 to 24 grams; heavy, 30 to 35 grams of wet glue per square foot. Brush spread on cap strip only.

Assembly times - 1, 2, 10, 30, and 60 minutes open.

Gluing temperature - The temperature of the room was 75° F. when the specimens were glued.

Pressure period - The nail pressure was allowed to remain on the assembly for 24 to 48 hours before being removed.

No. 20 gauge cement-coated nails 5/8 inch long were used to apply the pressure. The nails were spaced 1-1/2 inches apart and were first driven through a white pine nailing strip 3/16 by 1/2 inch in cross section and then through the papreg into the cap strip.

After gluing, the panels were conditioned for at least 1 week in a room at 80° F. and 30 percent relative humidity.

Following the conditioning period, the specimens were tested in tension in a standard plywood testing machine.

Results.-- The gluing conditions and the shear test results on these nail-glued specimens are summarized in tables 9 and 10. Normal nail gluing produced weak joints between the papreg and birch because of the papreg burr and resulting poor contact between the surfaces. The bonds between papreg and Sitka spruce were somewhat better than with birch, however, because the burr was partially forced into the softer wood. On both species of wood used as cap strips, the heavier spreads and shorter assembly periods produced the better quality bonds.

With the normal nail-gluing procedure (without preboring), the results were not reliable enough to be considered satisfactorily safe.

With the preboring procedure, heavy spreads gave good bonds over the entire range of assembly times used. As the glue spread was decreased, the allowable assembly time in which good joints could be obtained was also found to be somewhat shortened.

In general, the joints between the cap strips and papreg were satisfactory when the papreg was prebored, whereas, without preboring, the results were not satisfactory even on such soft wood as Sitka spruce. These findings indicate that application of papreg sheets by nail gluing is impractical and suggest the need for pressure jigs in assembling papreg skins to wood frameworks, as in aircraft construction.

Summary

The gluing of the untreated papreg surfaces was accomplished satisfactorily only with a high-temperature phenol glue; moreover, care must be taken in gluing such surfaces to remove any waxy materials with solvents. Chemical treatments with acid and alkali reagents were found to improve the gluing

characteristics with certain glues but sanding proved to be the most generally satisfactory of the surface treatments studied.

On sanded papreg surfaces, satisfactory bonds were obtained with 21 of the 27 glues tested. Joints made with these glues, which included a number of cold-setting, low-temperature, and hot-press glues, developed sufficient dry strength to cause failures that were more than 80 percent in the papreg.

In gluing thin, sanded panels of papreg together, a wide range in gluing conditions for four cold-setting and low-temperature glues was found to produce joints with high dry strengths. Spreads ranging from very light to heavy gave joints which failed almost 100 percent in the papreg. At closed assembly periods of 2 to 60 minutes and under pressures of 25 to 250 pounds per square inch the average papreg failure was 97 to 100 percent. With these thin, flat laminations, the resin glues produced bonds at 1-1/2 pounds per square inch which were almost equal in quality to those made at higher pressures, the papreg failure being 94 to 99 percent.

With the two low-temperature phenolic glues, the required curing period was shorter than is normally considered sufficient for gluing high-density woods. When made at shorter pressing periods, however, these joints were undoubtedly undercured and would lack resistance to unfavorable exposures. The cold-setting, urea-resin and casein glues used required approximately the same pressing period as when used to glue wood.

With high-temperature glues containing a large amount of solvent, it was found desirable to use longer open assembly times than are normal in the gluing of wood in order to prevent blistering. When using these longer assembly periods, however, it was necessary to keep the spread light so as to avoid thick glue joints.

The moisture content of the papreg panel was not found to be critical in the gluing with Tego. Joints of good quality were obtained with Tego on papreg panels that were conditioned at relative humidities from 30 to 97 percent at 80° F.

The results of gluing tests on thin papreg panels were found to be applicable to the gluing of papreg to wood and in the gluing of thick papreg as well.

In nail gluing thin papreg to wood cap strips, the papreg burr formed when the nail pierced the papreg was found to interfere with the uniformity of pressure exerted. Preboring of the papreg before gluing resulted in good gluing if the assembly time and spread were properly controlled.

Table 1.--Effect of surface treatment of papreg on the strength of the glue joints.

Glue	Surface treatment	Dry shear strength			Papreg failure		
		Min.	Max.	Av.	Min.	Max.	Av.
		Lb. per sq. in.			Percent		
Tests of three-ply specimens[1]							
Plaskon 201-2, hardener 841, hot-setting acid urea	No treatment	0	0	0	0	0	0
	Benzene[2]	0	235	72	0	0	0
	Alkali[3]	0	315	174	0	10	2
	Acid[4]	530	650	581	50	100	94
	Sanded[5]	525	650	584	100	100	100
Bakelite 7381, liquid, hot-setting alkaline phenol	No treatment	520	615	574	30	100	85
	Benzene[2]	505	615	556	20	100	73
	Alkali[3]	515	660	577	50	100	79
	Acid[4]	0	595	249	0	50	12
	Sanded[5]	380	590	534	30	100	87
Plaskon, 250-2, cold-setting acid urea	No treatment	0	0	0	0	0	0
	Benzene[2]	0	0	0	0	0	0
	Alkali[3]	0	345	117	0	10	2
	Acid[4]	270	445	330	0	30	11
	Sanded[5]	560	675	612	95	100	99
Tests of two-ply specimens[6]							
Bakelite 7381, liquid hot-setting alkaline phenol	No treatment	630	845	717	95	100	99
	Sanded[5]	620	715	657	95	100	100
Tego, hot-setting phenol film	No treatment	60	890	442	0	65	20
	Solvent[7]	390	890	786	40	100	90
	Sanded[5]	655	900	707	95	100	99
Durez 12041, low-temperature acid phenol	No treatment	0	360	201	0	0	0
	Sanded[5]	650	775	722	100	100	100
Cascophen LT-67, low-temperature alkaline phenol	No treatment	0	220	45	0	0	0
	Sanded[5]	610	905	773	100	100	100
Penacolite G1124, low-temperature resorcinol	No treatment	0	0	0	0	0	0
	Sanded[5]	625	740	673	100	100	100
Plaskon 201-2, hardener 841	No treatment	0	0	0	0	0	0
	Sanded[5]	560	765	621	100	100	100
Uformite CB-551 cold-setting, acid urea	No treatment	0	0	0	0	0	0
	Sanded[5]	625	725	621	100	100	100
Lauxein 888, casein	No treatment	200	765	471	0	10	2
	Sanded[5]	630	730	685	100	100	100

[1] These data are from 2 panels (14 test specimens) for each treatment

[2] Washed with cold benzene.

[3] Immersed for five minutes in concentrated sodium hydroxide, washed with water.

[4] Immersed for five minutes in concentrated sulfuric acid, washed with water.

[5] Lightly sanded with No. 1/2 garnet sandpaper using a portable belt sander.

[6] These data are from 2 panels (20 to 28 test specimens) for each treatment except the solvent wash on Tego-bonded panels, where specimens were taken from three panels.

[7] Washed with mixture consisting of equal parts by volume of carbon tetrachloride and acetone.

Table 2.--Results of shear tests in comparison of glues for gluing 3-ply, 3/16-inch papreg[1,2]

Glue	Type of glue	Assembly[3]	Time in press	Pressure	Temperature of press	Dry test: Plywood shear[4] Min.	Dry test: Plywood shear[4] Max.	Dry test: Plywood shear[4] Av.	Dry test: Papreg failure Min.	Dry test: Papreg failure Max.	Dry test: Papreg failure Av.	Wet test: Plywood shear[4] Min.	Wet test: Plywood shear[4] Max.	Wet test: Plywood shear[4] Av.	Wet test: Papreg failure Min.	Wet test: Papreg failure Max.	Wet test: Papreg failure Av.	Boil test: Plywood shear[4] Min.	Boil test: Plywood shear[4] Max.	Boil test: Plywood shear[4] Av.	Boil test: Papreg failure Min.	Boil test: Papreg failure Max.	Boil test: Papreg failure Av.
				Lb. per sq.in.	°F.	Lb. per sq.in.			Percent			Lb. per sq.in.			Percent			Lb. per sq.in.			Percent		
Cycleweld C-3	Hot-press, modified rubber	17-19 hr. (open)	25 min.	200	325	520	860	725[5]	40	100	85[5]	515	925	661[5]	30	100	69[5]	320	780	578[5]	0	95	41[5]
Bakelite 7381	Hot-press phenol-formaldehyde, alcohol soluble	17-19 hr.	15 min.	150	315	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
		21 hr. (open)	15 min.	150	315	425	600	512	100	100	100	375	635	485	95	100	99	395	750	504	100	100	100
Bakelite 13268	Hot-press phenol-formaldehyde, water soluble	24 hr. (open)	15 min.	150	315	275	485	396	0	100	94	245	465	357	20	100	88	210	550	402	0	100	47
Tego	Hot-press phenol-formaldehyde film	--	15 min.	150	315	330	730	605	60	100	98	420	870	671	80	100	97	645	1230	799	85	100	99
Impregnated paper	Hot-press phenol-formaldehyde film	--	15 min.	150	315	540	620	569	90	100	99	290	800	602	70	100	96	310	780	613	90	100	98
Worden's Resin	Phenol furfural	4 hr.	15 min	150	315	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
		17-19 hr.	15 min.	150	315	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)	(6)
		17-19 hr. (open)	15 min.	150	315	0	560	250	0	60	16	0	430	123	0	30	2	0	125	23	0	0	0
		22 hr. (open)	25 min.	150	315	0	595	288	0	100	44	0	730	328	0	100	53	0	715	277	0	100	35
Amberlite PR-65	Hot-press phenol-aniline	10-20 min.	15 min.	150	315	480	630	565	80	100	97	445	640	539	80	100	95	410	680	578	80	100	97
Vinylseal MA-28-18	Thermoplastic	24 hr. (open)	15 min.	150 cooled in press	315	290	565	439	0	100	66	45	470	235	0	0	0	30	45	40	0	0	0
Butacite 4639	Thermoplastic	24 hr. (open)	10 min.	150 cooled in press	270	210	495	361	15	95	57	0	550	357	0	100	61	55	320	125	0	0	0
Du Pont 4624	Modified thermo-plastic	4 hr. (open)	20 min.	150	270	0	295	143	0	0	0	0	165	60	0	0	0	0	110	17	0	0	0
Melmac 400	Melamine	4-5 hr.	15 min.	150	260	355	660	522	95	100	99	445	560	495	90	100	97	490	610	539	80	100	96
Bakelite 12772, hardener 14282	Hot-setting, urea	17-19 hr.	15 min.	150	260	410	665	562	50	100	84	355	770	528	70	100	89	310	675	501	0	100	61

Plaskon 201-2, hardener 841	Fortified, hot-setting urea	40 min.	15 min.	150	260	415	555	486	0	95	52	365	540	453	10	100	58	250	615	479	5	95	38
		4 hr.	15 min.	150	260	430	600	525	100	100	100	440	560	487	90	100	94	410	570	493	90	100	95
Bakelite 16200	Intermediate-temperature alkaline phenol	19 hr. (open)	15 min.	150	260	355	530	438	70	100	84	280	430	359	80	100	93	215	515	428	5	100	62
Durez 11427, hardener 7422	Low-temperature acid-phenol	10-20 min.	16 hr.	150 to 250	140	635	865	763	100	100	100	475	830	661	15	100	85	555	755	664	70	100	96
Durez 12041, hardener 7422	Low-temperature acid-phenol	10-20 min.	16 hr.	150 to 250	90	510	575	539	100	100	100	440	705	571	95	100	99	500	660	590	90	100	99
		10-20 min.	16 hr.	150 to 250	140	535	670	599	100	100	100	670	900	735	100	100	100	665	780	703	90	100	99
Bakelite 11753, hardener 11749	Low-temperature phenol	10 min.	16 hr.	150	75	280	550	375	25	100	75	170	410	242	40	95	70	0	0	0	0	0	0
Cascophen LT-67	Low-temperature alkaline phenol	10-20 min.	16 hr.	150 to 250	90	495	630	575	95	100	99	390	690	591	40	100	83	530	710	621	95	100	99
		10-20 min.	16 hr.	150 to 250	140	540	665	604	100	100	100	540	820	659	100	100	100	660	810	715	100	100	100
Penacolite G1124	Low-temperature resorcinol	10-20 min.	16 hr.	150	75	370	555	437	100	100	100	355	600	478	100	100	100	370	695	494	100	100	100
Du Pont J4600 - X5150[7]	Modified low-temperature phenol	10-20 min.	40 hr.	150	75	0	270	112	0	0	0	0	340	65	0	0	0	0	250	109	0	0	0
Plaskon 250-2	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	525	680	577	100	100	100	615	810	715	100	100	100	675	765	708	100	100	100
Bakelite 12772, hardener 16229	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	490	600	549	95	100	99	575	745	686	100	100	100	610	745	660	90	100	99
Bakelite 16257, hardener 16229	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	375	490	434	100	100	100	330	540	427	100	100	100	90	320	213	0	60	16
Lauxite 77X	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	500	615	542	100	100	100	540	795	669	90	100	99	600	730	688	100	100	100
Cascamite ANS	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	510	640	570	90	100	98	540	760	665	95	100	99	625	750	699	100	100	100
Uformite CB-551	Cold-setting, urea resin	10-20 min.	16 hr.	150	75	440	535	499	100	100	100	570	640	611	80	100	98	520	680	621	95	100	99
Monite Casein	Casein	10-20 min.	16 hr.	150	75	525	660	602	100	100	100	510	705	625	40	100	92	505	860	662	60	100	96

[1] Except as indicated in footnote 7, each average represents 18 or 19 specimens.

[2] The glue was spread after a light sanding of the surface with No. 1/2 garnet sandpaper.

[3] Closed assembly unless otherwise stated.

[4] The fiber direction of all three plies in the test specimen was in the direction of the tension force.

[5] Some of the panels blistered slightly and the specimens in this area were disregarded in computing the average.

[6] Blistered.

[7] Only one-half the usual number of specimens for this glue.

Table 3.--Effect of spread in the gluing of papreg

Glue	Spread of wet glue	Joint strength			Papreg failure
		Min.	Max.	Av.[1]	Av.[1]
	Grams per square foot	Psi.	Psi.	Psi.	Percent
Lauxein 888	12 to 16.0	530	835	658	100
	17.0	465	615	555[2]	100
	20.5 to 25.0	460	595	500[2]	100
	27.0 to 31.0	470	680	548[2]	100
	32.5 to 40.0	460	600	537[2]	100
Durez 12041	10.0 to 12.0	595	835	723	100
	13.1 to 14.5	500	700	553[2]	100
	17.0 to 19.5	510	695	571[2]	100
	23.0 to 24.0	500	600	545[2]	100
	29.0 to 31.0	490	645	559[2]	100
Cascophen LT-67	5.0 to 7.5	610	700	644	100
	12.0 to 17.0	540	685	584[2]	100
	19.5 to 22.0	495	690	577[2]	100
	24.0	495	665	556[2]	100
	29.0 to 36.0	510	630	558[2]	100
Uformite CB-551	7.0 to 9.0	590	745	668	100
	14.5	595	820	676	98
	19.5 to 22.0	515	855	655	100
	24.0 to 26.5	650	875	738	100
	34.0	560	775	646	100
Plaskon 250-2	8.0 to 10.0	590	840	679	100
	15.0 to 15.5	530	810	629	100
	18.0 to 19.5	580	740	644	100
	24.0	565	720	626	100
	29.0 to 30.0	500	660	559[2]	100

[1]Each value is the average of 30 specimens.

[2]The papreg used in these tests was from an early lot, and the shear strength was found to be slightly lower than that obtained from subsequent lots.

Table 4.--Effect of assembly period and pressure in the gluing of papreg[1]

Glue	Assembly period (closed)	Pressure 1.5 lb. per sq. in.		Pressure 25 lb. per sq. in.		Pressure 50 lb. per sq. in.		Pressure 150 lb. per sq. in.		Pressure 250 lb. per sq. in.	
		Av. joint strength	Av. papreg failure	Av. joint strength	Av. papreg failure	Av. joint strength	Av. papreg failure	Av. joint strength	Av. papreg failure	Av. joint strength	Av. papreg failure
	Min.	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
Cascophen LT-67	2	661	97	685	99	735	100	652	100	621	100
	10	625	98	779	100	725	100	629	100	648	100
	30	608	99	798	100	711	100	684	100	674	100
	60	600	99	786	100	774	99	691	100	695	100
Uformite CB-551	2	589	97	670	99	670	99	680	100	700	100
	10	579	94	670	98	693	100	686	100	709	100
	30	555	97	688	99	668	99	668	100	620	100
	60	579	94	649	98	705	99	668	100	643	100
Durez 12041	2	698	99	848	100	751	100	636	100	671	100
	10	821	99	775	100	772	100	669	100	626	100
	30	791	99	798	100	796	100	655	100	674	100
	60	737	95	742	100	893	100	668	100	668	100
Lauxein 888	2	643	88	662	99	606	100	737	100	642	100
	10	635	82	575	99	616	99	638	100	693	100
	30	656	66	560	97	604	99	655	100	655	100
	60	688	86	594	98	589	100	639	100	654	100

[1]Each value given is the average from 30 tests.

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Table 5.--Effect of pressing time and temperature in the gluing of papreg[1]

Glue	75°F.			90°F.			140°F.			160°F.			200°F.		
	Pressing time[2]	Average joint shear strength	Average papreg failure	Pressing time[2]	Average joint shear strength	Average papreg failure	Pressing time[2]	Average joint shear strength	Average papreg failure	Pressing time[2]	Average joint shear strength	Average papreg failure	Pressing time[2]	Average joint shear strength	Average papreg failure
	Hours	Pounds per square inch	Percent	Hours	Pounds per square inch	Percent	Hours	Pounds per square inch	Percent	Hours	Pounds per square inch	Percent	Hours	Pounds per square inch	Percent
Durez 12041	8	630	96	4	308	19	1	667	100	1	654	100	1/2	710	100
	16	735	100	8	760	99	2	677	99	2	675	100	1	737	100
	24	695	100	16	737	96				4	649	100	2	644	100
	48	749	100	24	780	100				6	663	100	4	630	100
	96	658	100	48	776	100									
Cascophen LT-67	8	706	100	4	722	96	1	654	99	1	695	99	1/2	719	100
	16	657	100	8	691	96	2	655	99	2	747	100	1	612	99
	24	732	99	16	733	97				4	630	99	2	628	100
	48	671	99	24	692	97				6	674	99	4	668	100
	96	608	100	48	780	99									
Uformite CB-551	1	479	37	1	703	96									
	2	474	66	2	679	99									
	4	689	99	4	710	100									
	8	721	100	8	703	100									
	16	681	100												
Lauxein 888	1	623	70	1	722	96									
	2	719	71	2	688	98									
	4	779	100	4	713	100									
	8	728	100	8	724	100									
	16	671	100												

1 Each average value is an average of 40 tests.

2 One half of the panels glued at each time and temperature were held 24 hours longer than indicated here (at the same temperature but without clamps). Since no significant change in strength resulted from the longer heating, the test values for the two heating periods were averaged together.

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Table 6.--Effect of moisture conditioning, before gluing, on joint strength of papreg bonded with Tego glue (surfaces sanded before gluing).

Relative humidity in conditioning rooms at 80° F.	Dry shear strength[1]	Papreg failure[1]
Percent	Lb. per sq. in.	Percent
30	572	96
65	607	100
80	544	100
90	622	99
97	534	100

[1]Each value is based upon 7 test specimens except the values at 30 percent relative humidity, which were based on 25 specimens.

Table 7.--Results of block-shear tests on joints between papreg and maple lumber glued with Uformite CB-551 at 75° F.

Spread	Block-shear strength[1]			Papreg failure[1]		
	Min.	Max.	Av.	Min.	Max.	Av.
Grams of wet glue per sq. ft. of glue joint	Lb. per sq. in.			Percent		
17.0 to 18.5	792	2225	1572	85	100	98
19.5 to 21.0	1546	2385	1914	100	100	100
23.0 to 24.0	1253	2522	1856	90	100	99
30.0 to 33.0	1069	2202	1608	95	100	99

[1]Each average value based on results of 30 tests.

Table 8.--Results of block shear tests on joints between thick papreg and wood.[1]

Glues	Papreg-to-papreg		Papreg-to-maple		Papreg-to-spruce	
	Shear strength	Papreg failure	Shear strength	Papreg failure	Shear strength	Papreg failure
	p.s.i.	Percent	p.s.i.	Percent	p.s.i.	Percent
Uformite CB-551	1995[2]	100[2]	1332	100	1157	100
	1504[3]	82[3]				
Lauxein 888	1744	100	1385	100	1206	100
Durez 12041	1910	100	1343	100	1037	100
Cascophen LT-67	1619	100	1134	100	1118	99

[1]The papreg used in these tests was 9/16 inch thick.

[2]Each value is the average for 10 specimens.

[3]This set of results was obtained on papreg which had been only sanded before gluing. All other papreg panels were milled before gluing.

Table 9.--Results of shear tests on nail-glued joints between wood cap strips and papreg skins. Papreg not prebored

Species of wood in cap strip	Assembly time	Spread	Average shear strength	Average papreg failure	Average wood failure	Number of specimens tested	Number of specimens that failed before test
	Minutes		P.s.i.	Percent	Percent		
Sitka spruce	1	Heavy	609	21	75	27	0
	2	Light	419	21	38	18	0
	2	Medium	524	24	44	18	0
	10	Light	185	19	6	9	5
	10	Medium	413	31	33	9	0
	30	Light	13	0	0	9	6
	30	Medium	291	29	0	9	0
Yellow birch	1	Heavy	493	45	23	30	2
	2	Light	148	12	0	9	6
	2	Medium	526	63	0	9	0
	10	Light	0	0	0	9	9
	10	Medium	90	25	0	0	5
	30	Light	0	0	0	9	9
	30	Medium	0	0	0	9	9
	60	Light	0	0	0	9	9
	60	Medium	0	0	0	9	9

Table 10.--Results of shear tests on nail-glued joints between wood cap strips and papreg skins with the papreg prebored

Species of wood in cap strip	Assembly time	Spread	Average shear strength	Average papreg failure	Average wood failure	Number of specimens tested	Number of specimens that failed before test
	Minutes		P.s.i.	Percent	Percent		
Sitka spruce	1	Light	573	0	100	3	0
		Medium	573	0	100	3	0
		Heavy	753	0	100	3	0
	2	Light	577	30	70	3	0
		Medium	710	2	98	3	0
		Heavy	523	0	100	3	0
	10	Light	500	25	42	3	0
		Medium	683	0	100	3	0
		Heavy	736	3	97	3	0
	30	Light	383	28	8	3	0
		Medium	610	3	63	3	0
		Heavy	676	0	100	3	0
Yellow birch	1	Light	776	66	33	3	0
		Medium	680	0	100	3	0
		Heavy	856	33	66	3	0
	2	Light	770	43	33	3	0
		Medium	973	3	97	3	0
		Heavy	920	48	18	3	0
	10	Light	443	14	0	3	0
		Medium	680	86	0	3	0
		Heavy	846	66	33	3	0
	30	Light	657	40	33	3	0
		Medium	716	86	0	3	0
		Heavy	753	60	33	3	0

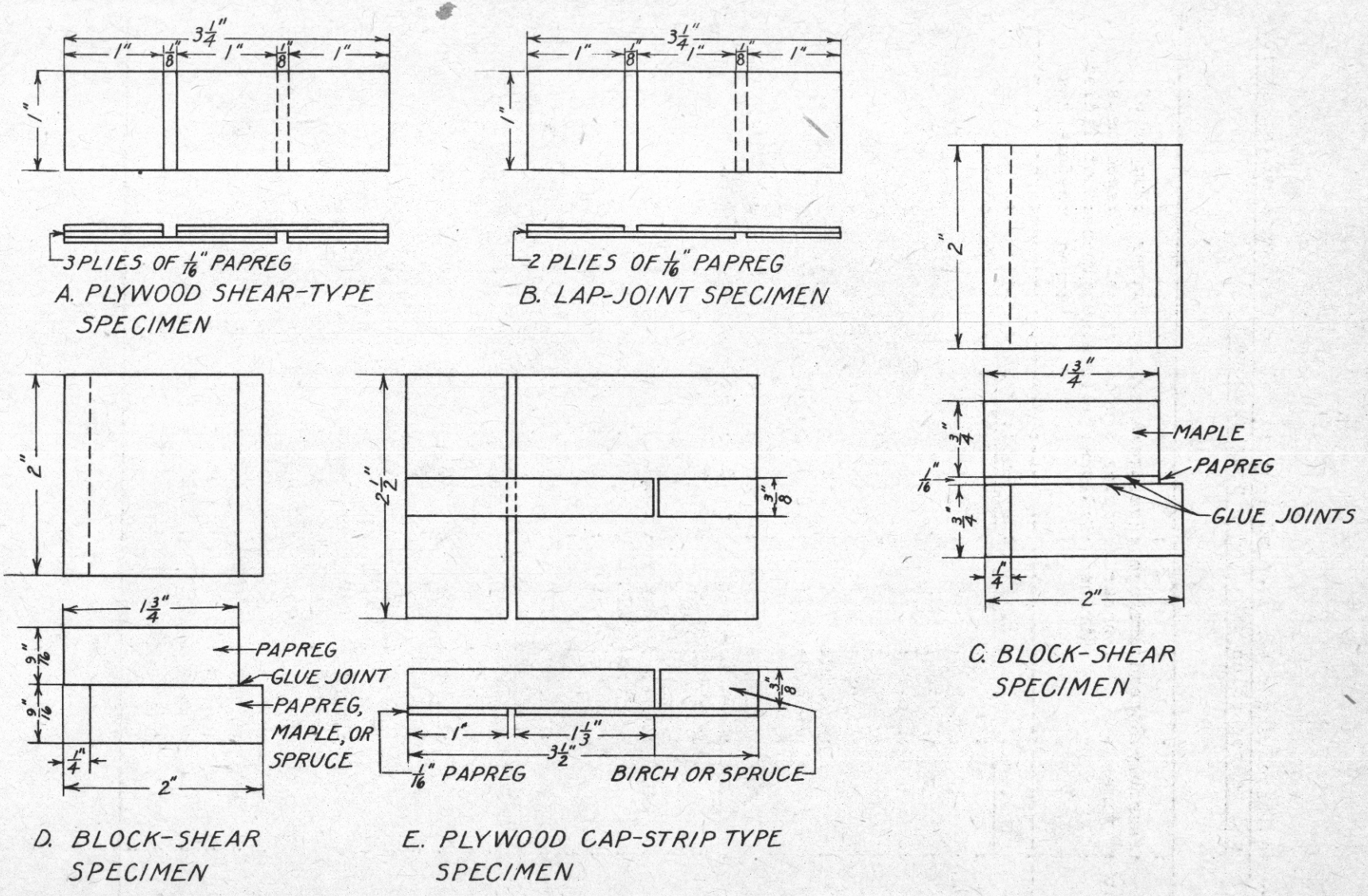

Figure 1.--Types of specimens used to test glue joints between papreg panels and those between papreg and wood.

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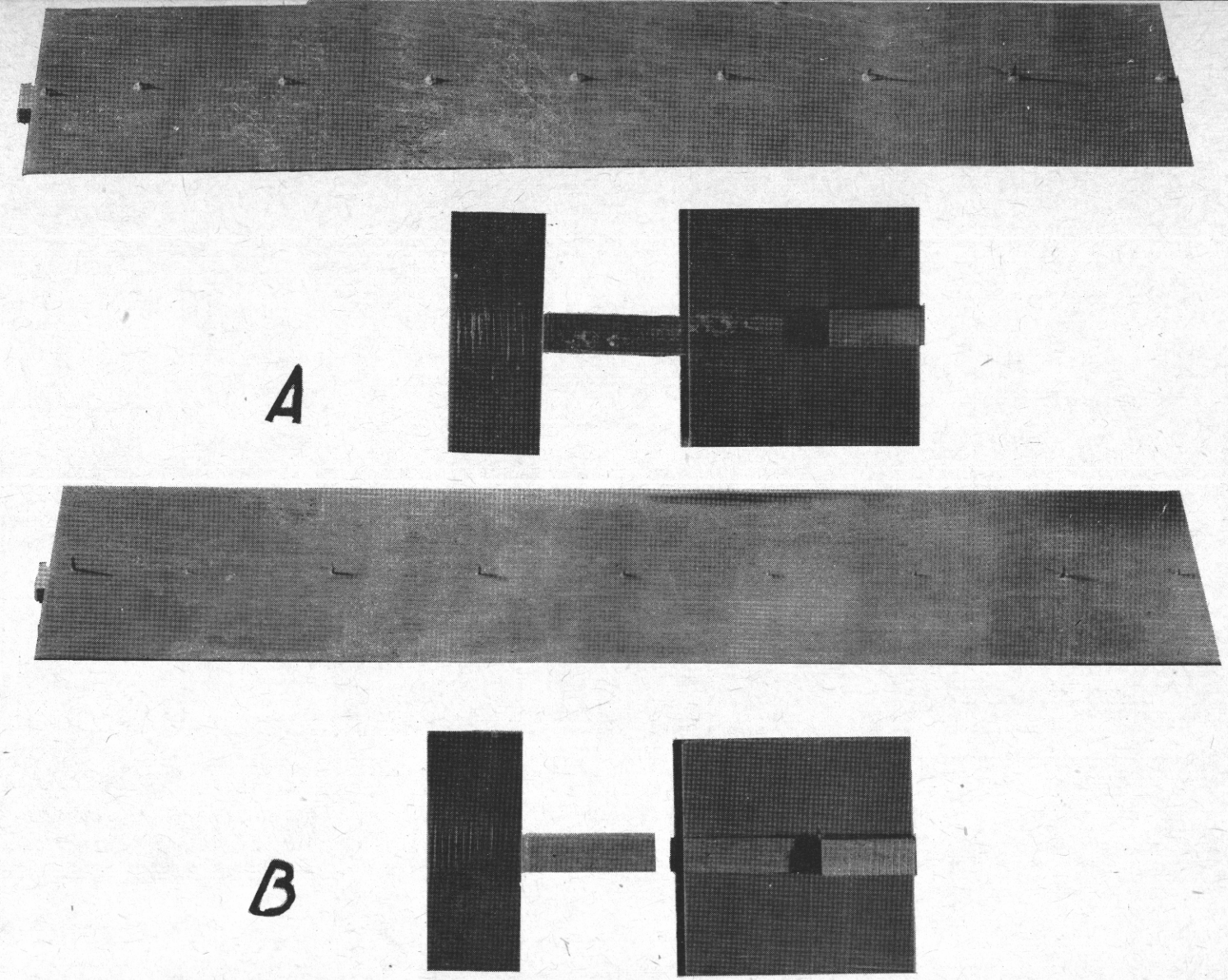

Figure 2.--Nail gluing of papreg. A, normal nail gluing produces burrs on the under side of the papreg sheet which interfere with formation of good joints. B, prebored holes eliminate burrs and allow strong joints.

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