DURABILITY OF GLUED WOOD TO METAL JOINTS

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DURABILITY OF GLUED WOOD TO METAL JOINT[1]

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This study on the durability of glued wood–to–metal joints subjected to various exposure conditions was conducted at the request of the Army–Navy–Civil Committee on Aircraft Design Criteria. The purpose of the study was to gain information on the comparative durability properties of wood–to–metal joints made with different commercial adhesives, so that they might be more widely and safely used in aircraft construction. Exposure conditions were selected to measure resistance of painted and unpainted aluminum-to–wood and steel–to–wood joints to water, high humidities, high and low temperatures, aircraft fluids, and weather.

Type of Specimen

The type of specimen used for this study consisted of a 1- by 2–inch piece of 0.037–inch (20 gauge) cold–rolled steel or 0.032–inch aluminum–clad aluminum alloy lap–jointed 1/2–inch with a 1-1/4- by 2-inch piece of three–ply, 3/16–inch yellow birch plywood (fig. 1). With one of the adhesives (glue C of table 1), some specimens were prepared by direct bonding of the metal and. birch, and other specimens with a 1/28-inch shim of walnut veneer in the lap area between the metal and the birch plywood. In one–half of the specimens, the metal portion was protected with paint.

Glues and Gluing Processes

Six commercial gluing processes formuated for use in bonding wood to metal were included in this study. With two of these gluing processes, a woodworking resorcinol resin was used as a secondary glue. These gluing processes are designated by numbers and the glues by letters as given in table 1.

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[1] This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

The processes by which the glues were employed differed according to the manufacturer's instructions. Glues A, C, and F were used by themselves in direct bonding. Glues D and E were used together in direct bonding. Glue G was used as the secondary glue with glue B and, in process 6, as a secondary glue for bonding the birch to the walnut shim.

Test Procedures

Preparation of Metal for Gluing

Gluing Process 1.--One- by 2-inch pieces of steel and aluminum-clad aluminum alloy were placed in a jig and 9/64-inch locating holes drilled into them (fig. 2). Burrs formed in drilling were ground off.

The steel pieces were degreased by immersion for 4 to 6 minutes in a hot (160° to 180° F.) trisodium phosphate solution prepared by saturating warm water with trisodium phosphate and adding 0.5 gram of wetting agent per 100 cubic centimeters of solution. The solution was rinsed from the pieces with cold tap water and then with hot distilled water.

After degreasing, the steel pieces were etched for about 5 minutes in an acid solution of the following composition:

	Parts by volume
Concentrated hydrochloric acid	50
30 percent hydrogen peroxide	2
Formalin	10
Distilled water	45

If 5 minutes' immersion was not sufficient time to remove all evidence of rust or mill scale, the etching treatment was continued as long as necessary. Immediately after etching, the metal pieces were rinsed in flowing tap water, immersed in hot distilled water, dipped in acetone, and air dried.

The small aluminum pieces were wiped with a cloth wet with acetone to remove the identification lettering. They were then degreased by immersing in a hot (160° to 180° F.) bath of the following composition:

Sodium metasilicate	36 ounces
Wetting agent	.4 ounce
Distilled water	1.0 gallon

The pieces were immersed until the film of wash tap water showed no "break" as it drained. The period of immersion ranged from 7 to 12 minutes. After degreasing, the pieces were rinsed successively in cold tap water, hot distilled water, and acetone, and finally air dried.

Gluing process 2.--For gluing with this process, 8- by 8-inch metal squares ware degreased and etched preparatory to application of glue and cutting into 1- by 2-inch pieces.

The steel squares were degreased and etched in the same manner as described for the small steel pieces under Gluing Process 1.

The aluminum squares were wiped with an acetone-soaked cloth to remove the identification lettering, degreased in sodium metasilicate solution in the same manner as described under Gluing Process 1, then immersed for about 20 minutes at 140° to 150° F. in an acid bath of the following composition:

	Parts by weight
Sodium dichromate	1
Concentrated sulphuric acid	10
Distilled water	30

After etching, the pieces were rinsed in tap water, immersed in hot distilled water, dipped in acetone, then air dried.

Gluing Process 3.--Steel sheets, 8 by 8 inches in size, were degreased and etched in accordance with the recommendations by the manufacturer of glue C (Process 3). The degreasing was done by immersion for 5 to 7 minutes in a boiling bath of the following composition:

Sodium carbonate	2.0 ounces
Sodium hydroxide	2.0 ounces
Wetting agent	0.5 ounce
Sodium metasilicate	3.0 ounces
Laundry soap	0.6 ounce
Distilled water	1.0 gallon

After rinsing in cold tap water, the sheets were immersed for 2 to 4 minutes at room temperature in a pickling solution of the following composition:

	Parts by volume
Concentrated sulphuric acid	10
Concentrated nitric acid	10
Distilled water	80

The steel sheets were rinsed in tap water and then immersed for approximately 1 minute at room temperature in a "bright" acid bath of the composition:

	Parts by volume
Concentrated hydrochloric mid	60
30 percent hydrogen peroxide	2
Distilled water	38

Afterwards, the sheets were rinsed in running tap water, immersed in hot water, dipped in acetone, and air dried.

The aluminum sheets were degreased in a sodium metasilicate solution and etched in sodium dichromate–sulphuric acid in the same manner as described for Gluing Process 2.

Gluing Process 4.––One by 2–inch pieces of metal were drilled and deburred as described under Process 1. The steel pieces were degreased and etched as in Gluing Process 1. The aluminum was degreased as in Gluing Process 2.

Gluing Process 5.—Thedrilling and deburring of metal pieces was done as described under Gluing Process 1. The steel was degreased and etched as in Gluing Process 1. The aluminum pieces were cleaned as in Gluing Process 2.

Gluing Process 6.—Themetal test pieces were prepared as in Gluing Process 3.

Preparation of Plywood and Veneer

Gluing Processes 1, 2, 3, 4, and 5.––Selected aircraft–grade 1/16–inch yellow birch veneer was bonded with phenol–resin film glue into three–ply, 3/16–inch plywood. The plywood panels were conditioned for at least 1-week at 80° F. and 30 percent relative humidity, then cut into pieces 3 by 8 inches in size, with the grain direction of the face plies parallel to the shorter dimension of the piece. The portion of plywood to which the metal was to be bonded was lightly sanded with No. 00 garnet sandpaper.

Gluing Process 6.––In this process, 1/28-inch sliced walnut veneer was used as a shim between the metal and plywood. The walnut veneer was conditioned to equilibrium at 30 percent relative humidity and 80° F. , then cut into 1/2–inch strips about 9 inches long, with the grain direction in the shorter direction of the ply.

Assembly and Gluing

The glues were used as far as possible in accordance with the manufacturer's directions.

Gluing Process 1; Glue 8.--The glue was thinned to brushing consistency with an equal volume of ethyl acetate. The glue was spread with a brush to both the metal and the plywood in the area of the lap. The first coat was allowed to air–dry at least 1 hour, then a second coat was applied. After the second coat, an open assembly period of 2 to 48 hours was allowed. Groups of 12 specimens were prepared by assembling two panels of six specimens each in a jig, as shown in figure 3. This assembly was set on the

platens of an electric hot press and heated without pressure for 15 minutes at 325° F., after which a pressure of 300 pounds per square inch was applied and the heating continued for an additional 15 minutes. The assembly was removed from the press while hot, but a short cooling period was allowed before the two panels were removed from the jig (fig. 4).

Gluing Process 2; Glues B and G.—The 8- by 8-inch metal pieces were masked with tape (fig. 5) so as to leave exposed slightly more than 1/2 inch of lap-joint area at the end of the 1- by 2-inch pieces into which they were subsequently cut.

Glue B was thinned to a thin spraying consistency with approximately two parts of a special solvent to one of glue. The amount of thinner was varied somewhat, according to the viscosity of different lots of glue. Four coats were applied by spraying to the unmasked areas of each piece, with about one-half hour allowed for air drying between coats. A spray pressure of about 45 pounds per square inch was used, the gun was held 8 to 10 inches from the panel, and the nozzle adjusted to give a fan-shaped, atomized spray.

After the fourth coat was applied, the metal pieces were exposed to room conditions overnight, then baked for 20 to 45 minutes in an electric oven at 310° to 325° F.[2] The cured film was about 0.002 inch thick and greenish-brown in color. It was lightly sanded with No. 1/2 emery cloth.

The 8- by 8-inch squares were next cut into 1- by 2-inch pieces, which were attached to the birch plywood with tape so that the primed surface protruded as shown at the left in figure 6. Glue G was then brush spread to both the cured adhesive primer and a piece of birch plywood in the area of the lap (fig. 6). After an open assembly period of 2 minutes, the metal and plywood were laid together and placed in a book press (fig. 7) between thin yellow-poplar veneer, sheets of rubber, and heavy birch plywood cauls. After the period of 10 to 15 minutes that was required to arrange six layers of 18 specimens each in the press, pressure of 100 to 150 pounds per square inch was applied. The pressure was maintained overnight (approximately 18 hours) at room temperature of 80° to 90° F. The assembly was taken from the press, tapes removed, separated into 18 individual panels, and each panel sawn into six specimens.

Gluing Process 3; .Glue C.—One volume of the glue was thinned to spraying consistency with 0.8 volume of a special solvent. Eight-inch squares were employed as in Gluing Process 2. The adjustment of the spray gun was the same as used in spraying Glue B, but the air pressure was reduced to about 10 pounds per square inch. Six double passes of the spray gun were made to apply enough glue to the metal and plywood to result in a dry film thickness of approximately 0.002 inch. A flash-off period of about 10 minutes was allowed after each double pass of the spray. The final.

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[2] The manufacturer's recommendation was 15 minutes at 300° F. but under these conditions the glue film did not adhere properly to the metal, and longer baking at high temperature was found to give better adhesion,

coating was allowed to air dry overnight, then baked in an oven at 180° F. for 45 minutes. As in Process 2, the 8-inch squares were cut into the 1- by 2–inch metal pieces. The metal and plywood were assembled together in the pressing jig (fig. 3), and the assembly was cured for 20 minutes at 325° F. at a pressure of 300 pounds per square inch.

Gluing Process 4; Glues D and E.—Thelap area of the 1- by 2-inch metal pieces was sprayed with Glue D at 40 pounds of air pressure. 10 double passes being made with the spray gun to build up a dry film thickness of about 0.003 inch. An air–drying period of 24 hours was then allowed for evaporation of solvent from the adhesive.

Two coats of glue E were applied by brush to the plywood, allowing 10 minutes for the first coat and 20 minutes for the second coat to air dry. The metal pieces were then assembled to the plywood, and the assembly was cured for 30 minutes at 325° F. and 100 pounds per square inch pressure.

Gluing Process 5; Glue F.--Two coats of liquid glue F were brushed on the lap area of the 1- by 2–inch metal pieces, allowing approximately 30 minutes between coats. Immediately after the second coat, the metal pieces were dipped into a mound of the powdered component of glue F so that a uniform layer of powder adhered to the liquid resin on the surface of the metal. Following this step, an open assembly period of 1 to 24 hours was allowed, then the 12 metal pieces and two plywood pieces were assembled in the jig (fig. 3) and placed in an electric hot press. The assembly was cured at 320° F. for 15 minutes at a pressure of 150 pounds per square inch and taken from the press without cooling. The panels were removed from the jig (fig. 4) after a short cooling period.

Gluing Process 6; Glues C and G.--The 8-inch metal squares were masked (fig. 5), coated, and cut into small pieces, as described under Gluing Process 2. Glue C was thinned, sprayed, and precured on the metal and the walnut shims, by the same method as used in Process 3. The small metal pieces and walnut shims, 1/2–inch wide, were assembled on a caul of yellow–poplar veneer so that the adhesive coatings on the metal and shims were in contact (fig. 8). The entire assembly was pressed in an electric hot press for 25 minutes at 3250 to 3300 F. at 175 pounds per square inch. After gluing the metal pieces to the walnut shims, the surface of the walnut was lightly sanded to remove any contamination. Glue G was then applied to the walnut shim and birch plywood, which were glued together by the procedure used in bonding the metal to the plywood for Process 2 (figs. 6 and 7).

It was evident during the preparation of the specimens with the walnut shims that some shims were unaccountably weak. All the shim specimens, therefore, were pretested with 500 pounds tension load, and those that failed were replaced to complete the sets.

Number of Panels and Specimens

For each glue and metal, 160 panels of 6 specimens in each were prepared, except for Process 4, glues D & E, for which only 34 panels were prepared with each metal. In all, a total of 11,928 specimens were prepared.

Painting the Specimens

The panels of each set were randomly distributed into two groups, one to be painted, the other to be left unpainted. To the specimens requiring painting were applied one brush coat of zinc chromate primer conforming to Federal Specification AN-TT-P-565, thinned with three parts of thinner to four parts of the primer, and two brush coats of aluminized glycerol phthalate spar varnish conforming to Federal Specification AN–TT–A–461. The paint was applied to the metal only and, if any paint overlapped on to the wood, the paint film was cut precisely to the glue joints with a knife.

Cutting the Specimens

After painting and numbering of the specimens, the plywood portion of the panel was cut to specimens of the desired dimensions (fig. 1).

Distribution of Test Specimens

The painted and unpainted specimens for each gluing process were sorted into 11 lots of 40 specimens each to be subjected to 11 exposure conditions, Distribution was such that only one specimen from each pair of panels (12 specimens) made in the same pressing operation would be Included in each exposure condition. Each Lot of 40 specimens was divided into 8 groups of 5 specimens for testing after certain exposure intervals, only one or two specimens from each pair of panels being tested at any test period.

Specimens glued by process 4 were included in only four exposure conditions, and therefore the distribution varied slightly, but the general distribution method was the same as for the other glues.

Exposure Conditions

All specimens were first conditioned for at least 1 week at 80° F. and 30 percent relative humidity. For each gluing process and combination of metal and wood used, 55 specimens were tested dry as controls without exposure. These control specimens were selected about equally from both the painted and unpainted specimens reserved for the first test. The other half of these reserved specimens (55) along with the extra specimens resulting from the distribution method were mounted on a board and exposed continuously to the weather,

The remaining groups of specimens prepared by the different gluing processes (excepting Process 4) were exposed to the following exposure conditions:

1. Continuous exposure to air of 80° F. and 30 percent relative humidity.

2. Continuous soaking in tap water at room temperature.

3. Continuous exposure to air of 80° F. and 97 percent relative humidity.

4. Alternate exposure for 2 weeks at 80° F. and 97 percent relative humidity, and 2 weeks at 80° F. and 30 percent relative humidity.

5. Continuous exposure to air at 158° F. and 20 percent relative humidity. The specimens were tested after conditioning 1 week at 80° F. and 30 percent relative humidity,

6. Alternate exposure for 1 day at 158° F., 20 percent relative humidity, and 1 day at -67° F. in a cabinet cooled with solid carbon dioxide. The specimens were tested after conditioning 1 week at 80° F. and 30 percent relative humidity.

7. Continuous soaking at exterior temperature in 100-octane gasoline.

8. Continuous soaking at exterior temperature in 73-octane gasoline.

9. Continuous soaking at exterior temperature in ethylene glycol.

10. Continuous soaking at exterior temperature in isopropyl alcohol de-icer fluid.

11. Continuous soaking at exterior temperature in aircraft lubricating oil.

In addition to the control and exterior exposure tests, specimens prepared by Gluing Process 4 were exposed to conditions 1, 2, 3, and 4.

It was planned to remove for testing five specimens of each kind from exposure conditions 1, 3, 4, 5, and 6 after 4, 8, 16, 24, 32, 52, and 104 weeks: from conditions 7, 8, 9, 10, and 11 after 2, 4, 6, 8, 12, 24, and 52 weeks; and from cordition 2 after 3, 4, 6, 7, 8, 16, and 24 weeks. Specimens exposed to exterior conditions are to be removed after 12, 24, 52, and 104 weeks.

Testing

All specimens were tested by applying a tension force to the specimen in a standard plywood testing machine at a rate of 600 to 800 pounds per minute.

Results

The average shear-strength values and estimated percentages of wood and glue failure obtained on the unexposed control specimens and on the specimens exposed up to 52 weeks are given in tables 2 through 13. The area of failure was distinguished as to location (a) in the wood, (b) in the primary glue, (c) in the interface between the glue and metal, or (d) in the secondary glue in those processes in which a secondary glue was employed.

There was some difference in the level of the joint strengths shown by the control specimens for the several processes. Gluing Processes 1, 3, and 4 gave the highest average values (936 to 1,000 pounds per one-half square inch), processes 2 and 5 the next (716 to 855 pounds per one-half square inch), and process 6 the least (544 to 652 pounds per one-half square inch). There seemed to be no consistent superiority in strength of the specimens made with one metal over those made with the other metal.

Throughout this study there was little evidence that paint coatings applied to the metal portion of the specimen importantly improved the durability of the joint. In some instances, the effect of the exposure was delayed a few weeks, but even a short delay was not always evident. In analyzing the test data, the results on painted and unpainted specimens were usually so nearly indistinguishable that they were considered together.

Continuous exposure to 80° F. and 30 percent relative humidity (table 2).--Of the specimens glued by Processes 1, 2, and 5, there were no significant changes in joint quality during a year of storage at 80° F. and 30 percent relative humidity. The same was true for the aluminum specimens glued by Process 3, but with the steel specimens made by this process there was a drop in joint strength and wood failure even under these very mild conditions. Of the specimens glued by Process 4, there was a definite indication of decreasing joint quality during the year for both steel and aluminum specimens. The specimens glued by Process 6 showed a slight falling trend in joint quality, but it is not definite enough to be conclusive.

Continuous soaking in water (table a).--The aluminum specimens glued by Process 1 averaged only 59 to 65 percent of the strength of the controls when soaked 3 weeks in water, but there was only a little further loss in strength after soaking for 24 weeks. There was appreciably more failure of the glue to the aluminum in the wet specimens than in the dry controls. The steel specimens glued by Process 1 averaged only 47 to 52 percent of their dry strength when soaked 3 weeks, but there was little change thereafter up to 24 weeks in water.

The aluminum specimens glued by Process 2 averaged 60 to 72 percent of their dry strength when soaked 3 weeks, but there was no apparent further change. There was considerably more failure of the glue at the interface with the aluminum in the wet specimens than in the dry. The steel specimens averaged only 30 to 47 percent of their dry strength after 3 weeks of soaking, but there was little change thereafter. Considerably more failure occurred at the steel interface in the wet specimens than in the dry.

The aluminum specimens glued by Process 3 had 56 to 66 percent of their dry strength when soaked 3 weeks, but no consistent change in the joints was apparent until between 16 and 24 weeks of soaking, when the joint strength dropped sharply to about one-third the dry strength value; considerable increase in the percentage of failure took place at the aluminum interface. The steel specimens glued by Process 3 had only 23 to 31 percent of their dry strengths after soaking 3 weeks and failed almost completely in the bond to the steel, but there was little apparent change thereafter up to 24 weeks.

The aluminum specimens glued by Process 4 had 57 to 63 percent of their dry strength when soaked 3 weeks and there was a considerable increase in the portion of the failure that occurred at the aluminum interface, but little change occurred between 3 and 24 weeks. The steel specimens lost almost all their strength in 3 weeks of soaking and failed entirely in adhesion of the glue to the steel.

The aluminum specimens glued by Process 5 had 78 to 85 percent of their dry strength and showed somewhat greater failure in adhesion to the aluminum after soaking 3 weeks in water, but little change thereafter up to 24 weeks. The steel specimens had only 30 to 40 percent of their dry strength after 3 weeks in water, and failed almost completely in adhesion to the steel.

The aluminum specimens glued by Process 6 had 46-69 percent of their dry strength when soaked 3 weeks in water. and there was appreciably more failure in adhesion of the glue to the metal in the wet specimens than in the dry, but there was little further change between 3 and 24 weeks in water. The steel specimens retained only 10 to 22 percent of their dry strength after 3 weeks in water and failed completely in adhesion to the steel.

Continuous exposure to 97 percent relative humidity (table 4). --The aluminum specimens glued by Process 1 fell to about 65 percent of their dry strength on becoming moist in the air of high relative humidity, but showed only slow or no decline thereafter for several months. Between 32 and 52 weeks, joint strength dropped sharply because of deterioration of the wood, as evidenced by high wood failure. The steel specimens showed similar behavior with less evidence of deterioration of the wood at 52 weeks.

Both aluminum and steel specimens glued by Process 2 lost strength on becoming moist in high relative humidity, but lost little strength thereafter until the wood began to fail.

Both aluminum and steel specimens glued by Process 3 showed progressive loss in shear strength which was undoubtedly influenced, particularly in the latter part of the year, by deterioration of the wood.

The aluminum specimens glued by Process 4 lost strength when they took up moisture in the air of high relative humidity, but showed little change thereafter up to 52 weeks. The steel specimens showed, in general, a progressive loss in strength with time of exposure and increase in the amount of adhesion failure of the glue to the steel.

With both aluminum and steel specimens glued by Process 5, there was relatively little change in joint strength in this exposure, although there was a general increase in adhesion failure to the steel.

Both the aluminum and steel specimens glued by Process 6 lost strength when they took up moisture at the high relative humidity, but showed little change thereafter except for the changes that were probably due to deterioration of the wood. The failure in adhesion was high for the steel specimens after they had been exposed to the high humidity for a few weeks.

Alternate exposure, to 97 and 30 percent relative humidity (table 5).--The aluminum and steel specimens glued by Processes 1 and 2 showed little change during the year of exposure to this cycle.

The aluminum specimens glued by Process 3 showed little change in this exposure over 1 year; the steel specimens showed a moderate decrease in strength of about 22 percent and a gradual increase in failure between the glue and the steel.

The aluminum specimens glued by Process 4 showed a moderate to considerable decrease in the strength of the specimens without a significant change in the nature of the failure. The steel specimens showed a considerable drop in strength, with increase in failure between glue and steel.

The aluminum and steel specimens glued by Process 5 showed no very great change under these cyclic conditions during the year of exposure. The aluminum specimens glued by Process 6 showed little change in 1 year in this cycle. The steel specimens dropped in strength and increased in adhesion failure to the steel.

Continuous exposure to 158° F. and 20 percent relative humidity (table 6).--In this exposure, the wood appeared to be reduced in strength by the high temperature, and the percentage of wood failure, therefore, increased except in those cases where the glues were affected by the exposure.

The aluminum specimens glued by Process 1 showed a moderate drop in strength with an increase in percentage of wood failure. The steel specimens showed little or no significant drop in strength but a slight to moderate increase in failure between glue and steel.

Both the aluminum and the steel specimens glued by Process 2 showed a considerable drop in strength and increase in the percentage of wood failure, but not an increase in the adhesion failure to the metal.

The aluminum specimens glued by Process 3 showed a considerable drop in joint strength and an appreciable increase in adhesion failure in the year at this exposure. The steel specimens, both painted and unpainted, rusted badly and lost practically all their strength in 1 year, failing at the interface between glue and steel.

In the aluminum specimens glued by Process 5, there was a slight drop in strength at the end of the year and an increase in wood failure, but no apparent change in the glue. With the steel specimens, there was a slight increase in the amount of failure in adhesion to the metal, but otherwise little change.

For the aluminum specimens glued by Process 6, there was a large drop in strength and an increase in the failure that occurred in the primary glue (Glue C) and at the interface between Glue C and the metal. The steel specimens rusted badly and failed completely at the metal interface after a year's time, with practically no strength left.

Alternate exposure to 158° F. and –67° F. (table 7).--The specimens exposed to this alternately hot and cold cycle behaved in general like the specimens subjected continuously to the hot, humid exposure, but with less change.

Continuous soaking in 100-octane gasoline (table 8). --Both aluminum and steel specimens glued by Process 1 showed some increase in joint strength during immersion for 2 to 6 weeks, then a sharp drop. At the end of the year, the specimens failed almost entirely in the glue.

Other than a slight increase in tendency to fail in adhesion to the metal, there was practically no change in the specimens glued by Process 2 that were soaked in this high-octane gasoline.

Both aluminum and steel specimens glued by Process 3 were affected by the gasoline, so that there was a large drop in joint strength and wood failure. After a few weeks, the specimens were failing largely in the glue. At the end of the year, the steel specimens failed to a considerable extent in the interface at the steel.

Very little change was caused by the gasoline in, the specimens glued by Process 5.

The specimens glued by Process 6 showed a slight drop in 2 to 4 weeks in the gasoline, with an increase in the failure of the primary glue, but little change thereafter.

Continuous soaking in 73-octane gasoline (table 9).—Gasoline of '73-octane rating had less effect on the specimens glued by Process 1 than the 100-octane gasoline. Both aluminum and steel specimens showed some increase in the percentage of failure that occurred in the glue after soaking 1 year. The gasoline treatment produced an increase in shear strength for 24 weeks, after which there was a sharp decline.

The specimens glued by Process 2 showed little or no significant change during the year's immersion in gasoline.

For the specimens glued by Process 3 there was a considerable drop in joint strength in 52 weeks, and increased glue failure.

The specimens glued by Process 5 showed little or no significant change during the year's immersion in gasoline.

The specimens glued by Process 6 lost moderately in joint strength by soaking in gasoline for a year. The gasoline inoreased the failure within the primary glue (Glue C). Toward the end of the year, much of the failure in the steel specimens was at the interface between the glue and the steel.

Continuous soaking in ethylene glycol (table 10).--The specimens glued by Process 1 showed a moderate falling off in joint strength and a slight inorease in the tendency to fail in the glue upon soaking 1 year in glycol.

The specimens glued by Process 2 also showed some falling off in joint strength but no significant change in the nature of the failure.

The specimens glued by Process 3 showed a considerable decrease in joint strength upon soaking 1 year in glycol but no very significant change in the nature of the failure.

The effect of the glycol on the specimens glued by Process 5 appeared to be small and perhaps without significance.

The changes in the aluminum specimens glued by Process 6 appeared to be small and without significance. The steel specimens, however, showed a slight decrease in strength but a considerable increase in the amount of adhesion failure.

Continuous soaking in isopropyl alcohol (table 11).--Glue A was softened by the isopropyl alcohol and the specimens bonded by Process 1 failed at low strengths almost entirely in the glue after 6 to 8 weeks of soaking.

Isopropyl alcohol apparently had no effect on Glues B and G, as there was no significant change in the specimens glued by Process 2.

Glue C may be slightly affected by isopropyl alcohol, for the specimens glued by Process 3 showed in general some decrease in strength towards the end of the year and an appreciable increase in glue failure.

There was apparently no effect by the isopropyl alcohol on the specimens glued with Glue E by Process 5.

The data on specimens glued by Process 6 also indicate slight effect by the alcohol on Glue C. There was a decrease in the amount of failure that occurred in the wood with the soaked specimens, and an appreciable increase in adhesion failure in the steel specimens at the end of the year Of immersion.

Continuous soaking in aircraft lubricating oil (table 12) From the results on the specimens glued by Process 1, the lubricating oil may have a slight effect on Glue A, but it was not revealed until the tests were made at the 52-week period and not consistently at that time.

There was no apparent effect of the lubricating oil on the glues of Process 2.

The results on specimens glued by Process 3 indicate that there may be a slow effect of the oil on Glue C, but the effect in a year of immersion was slight.

The results on specimens glued by Process 5 indicate that there may be a slow effect of the oil on Glue F, for some of the tests made at the end of the year showed an appreciable drop in shear strength and an increase in adhesion failure.

The results on specimens glued by Process 6 again indicate some slow effect of the oil on Glue C, but it was not revealed until tests were made at 52 weeks and not consistently at that time.

Continuous exposure to weather (table 13).--The unpainted aluminum specimens glued by Process 1 showed a moderate drop in strength and a considerable increase in adhesion failure during the year outdoors. The painted aluminum specimen and the steel specimen, painted or unpainted, showed little change that was significant.

The aluminum specimens glued by Process 2 showed little change during the year but the steel specimens showed an appreciable drop in strength and increase in adhesion failure.

The specimens glued by Processes 3 and 4 showed some drop in joint strength during the year's exposure without a consistent change in the nature of the failure.

The specimens glued by Processes 5 and 6 showed no significant changes during the year's exposure outdoors.

Table 1. --Designation of gluing processes and glues

Gluing process	Adhesive designation	Type of adhesive	Manner of use
1	A	Modified thermoplastic resin	Direct bonding
2	B	Thermoplastic resin modified with thermosetting resin and pigment	As metal primer
	G	Room-temperature-setting resorcinol resin	As secondary glue
3	C	Thermosetting resin and synthetic rubber	Direct bonding
4	D	Thermosetting mixture of synthetic rubber and plastics	Direct bonding
	E	Low-pressure thermoplastic resin	Used in combination with adhesive D
5	F	Two components of thermosetting resin solution and thermoplastic powder	Direct bonding
6	C	Thermosetting resin and synthetic rubber	Direct bonding to shim
	G	Room-temperature-setting resorcinol resin	As secondary glue to shim

Table 2.—Averaged results of shear tests on glued wood-to-metal joints exposed continuously to 80° F. and 30 percent relative humidity

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[1]	980	88	12	0	[1]	971	93	7	0	[1]	971	93	7	0	[1]
	4	1014	96	4	0	—	1008	93	7	0	—	1122	97	3	0	—	978	98	2	0	—
	8	1032	95	5	0	—	999	94	6	0	—	787	99	1	0	—	939	96	4	0	—
	16	827	97	3	0	—	842	96	4	0	—	966	96	4	0	—	936	99	1	0	—
	24	1148	84	16	0	—	932	99	1	0	—	888	99	0	1	—	819	98	2	0	—
	32	1023	87	13	0	—	1193	89	11	0	—	1086	100	0	0	—	1093	92	4	4	—
	52	958	100	0	0	—	870	95	5	0	—	701	97	3	0	—	919	89	10	1	—
	104																				
2	0 control	716	52	0	12	36	716	52	0	12	36	866	58	0	4	38	856	58	0	4	38
	4	723	64	0	14	22	797	70	0	9	21	780	68	0	0	32	885	74	0	0	26
	8	679	50	0	9	41	759	64	0	12	24	744	71	0	9	20	715	36	0	11	53
	16	679	73	0	13	14	689	74	0	10	16	870	80	0	5	15	798	66	0	13	21
	24	696	59	0	30	11	758	54	0	14	32	811	65	0	15	19	874	57	0	17	26
	32	697	67	0	24	9	666	71	0	9	20	768	56	0	6	38	772	78	0	6	16
	52	646	37	0	22	41	604	65	0	32	3	694	50	0	0	50	743	67	0	4	29
	104																				
3	0 control	945	53	47	0	[1]	945	53	47	0	[1]	936	34	56	10	[1]	936	34	56	10	[1]
	4	904	50	50	0	—	1056	59	41	0	—	972	22	76	2	—	884	49	40	11	—
	8	991	54	46	0	—	874	55	45	0	—	817	10	80	10	—	848	17	68	15	—
	16	981	44	56	0	—	980	42	58	0	—	746	8	71	21	—	790	15	74	11	—
	24	974	41	59	0	—	928	48	32	20	—	685	1	90	9	—	775	5	75	24	—
	32	874	60	40	0	—	785	32	68	0	—	688	5	77	18	—	646	4	82	14	—
	52	906	51	49	0	—	848	51	49	0	—	739	6	80	14	—	663	2	95	3	—
	104																				
4	0 control	998	50	36	14	[1]	998	50	36	14	[1]	1000	50	26	24	[1]	1000	50	26	24	[1]
	4	981	53	35	12	—	1078	57	22	21	—	1035	53	22	25	—	1028	38	28	34	—
	8	846	36	38	26	—	951	57	11	32	—	936	30	34	36	—	859	34	33	33	—
	16	803	24	24	52	—	917	30	34	36	—	953	64	20	16	—	962	36	32	32	—
	24	772	24	54	22	—	666	13	65	22	—	845	44	32	24	—	755	18	35	47	—
	32	647	3	82	15	—	649	15	64	21	—	829	33	42	25	—	795	12	46	42	—
	52	721	9	89	22	—	690	8	76	16	—	780	11	30	59	—	738	24	45	31	—
	104																				
5	0 control	723	88	12	0	[1]	723	88	12	0	[1]	779	93	7	0	[1]	779	93	7	0	[1]
	4	784	96	4	0	—	708	93	7	0	—	861	100	0	0	—	762	100	0	0	—
	8	816	92	8	0	—	733	100	0	0	—	950	90	8	2	—	839	88	2	10	—
	16	742	100	0	0	—	750	96	4	0	—	844	90	10	0	—	764	100	0	0	—
	24	709	98	2	0	—	726	100	0	0	—	857	100	0	0	—	773	100	0	0	—
	32	805	90	6	4	—	905	90	10	0	—	1045	95	5	0	—	925	98	2	0	—
	52	735	96	4	0	—	810	100	0	0	—	893	94	4	2	—	774	99	1	0	—
	104																				
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	484	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	4	534	66	4	0	30	528	59	0	0	41	560	78	6	8	8	594	66	7	6	21
	8	554	70	0	0	30	565	67	1	0	32	641	68	4	0	28	615	55	4	7	34
	16	593	66	0	0	34	557	66	0	0	34	602	50	8	2	40	546	34	15	4	47
	24	519	47	0	0	53	552	33	0	0	67	572	20	46	4	30	507	34	27	12	26
	32	574	57	0	0	43	567	54	0	0	46	536	47	30	2	21	569	51	20	15	14
	52	464	30	0	0	70	517	71	0	0	29	436	17	65	5	13	507	18	47	14	21
	104																				

[1] Averages are for 55 control specimens and 5 exposed specimens.
[2] Metal bonded directly to wood with primary glue.
[3] Birch and walnut failures combined

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Table 3.—Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in water at room temperature and tested wet

Gluing process	Exposure period	Alclad to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	3	578	85	0	15	--	631	88	0	12	--	475	34	0	66	--	458	43	0	57	--
	4	681	92	6	2	--	698	91	7	2	--	496	52	0	48	--	480	51	1	48	--
	6	601	72	0	28	--	609	60	6	34	--	500	22	0	78	--	524	13	0	87	--
	7	578	65	9	26	--	635	74	22	4	--	479	38	0	62	--	544	18	0	82	--
	8	464	44	20	36	--	580	33	22	45	--	520	24	4	72	--	488	36	2	62	--
	16	613	62	3	35	--	532	52	10	38	--	481	34	0	66	--	492	12	0	88	--
	24	555	54	5	41	--	554	75	5	20	--	554	26	0	74	--	546	40	2	58	--
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	3	485	39	0	53	8	514	72	0	23	5	397	13	0	66	21	377	25	0	73	2
	4	537	60	0	34	6	496	56	0	38	6	196	4	0	84	12	306	17	0	79	4
	6	594	75	0	23	2	524	71	0	26	3	315	16	0	84	0	440	40	0	55	5
	8	521	74	0	19	7	425	66	0	26	8	329	13	0	78	9	230	1	0	99	0
	16	565	81	0	17	2	491	60	0	34	6	281	14	0	86	0	358	19	0	81	0
	24	547	73	0	18	9	569	65	0	21	14	323	1	0	98	1	331	11	0	85	4
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	3	626	78	19	3	--	570	27	47	26	--	290	0	0	100	--	220	0	0	100	--
	4	587	43	33	24	--	603	61	19	0	--	221	0	0	100	--	240	0	0	100	--
	6	607	37	40	23	--	432	50	17	33	--	216	0	0	100	--	194	0	0	100	--
	7	688	47	45	8	--	631	30	48	22	--	207	0	0	100	--	214	0	0	100	--
	8	540	58	42	0	--	532	36	26	38	--	176	0	0	100	--	247	0	0	100	--
	16	640	64	35	1	--	617	58	19	23	--	214	0	7	93	--	200	0	0	100	--
	24	302	25	16	59	--	354	24	9	67	--	216	0	11	89	--	137	0	0	100	--
4	0 control	998	50	36	14	[2]	998	50	36	14	[2]	1000	50	26	24	[2]	1000	50	26	24	[2]
	3	635	54	6	41	--	574	47	9	44	--	18	0	0	100	--	44	0	0	100	--
	4	563	24	16	60	--	570	37	13	50	--	48	0	0	100	--	52	0	0	100	--
	6	585	23	7	70	--	616	54	9	37	--	43	0	0	100	--	47	0	0	100	--
	7	564	38	4	58	--	601	40	7	53	--	10	0	0	100	--	63	0	0	100	--
	8	570	49	7	44	--	642	67	10	23	--	9	0	0	100	--	20	0	0	100	--
	16	592	49	8	43	--	568	37	16	47	--	0	0	0	100	--	0	0	0	100	--
	24	632	51	6	43	--	644	40	23	37	--	91	0	0	100	--	49	0	0	100	--
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]
	3	600	77	23	0	--	600	77	23	0	--	285	0	0	100	--	240	1	0	99	--
	4	583	53	1	46	--	560	77	4	19	--	289	5	0	95	--	440	36	0	64	--
	6	637	72	2	26	--	661	80	1	19	--	395	11	0	89	--	329	16	0	84	--
	7	569	52	0	48	--	590	86	2	12	--	193	2	6	92	--	148	0	0	100	--
	8	575	71	1	28	--	720	70	5	25	--	266	2	0	98	--	246	1	0	99	--
	16	648	50	4	46	--	609	88	4	8	--	322	17	0	83	--	226	2	0	98	--
	24	479	73	7	20	--	577	75	0	25	--	292	0	0	100	--	140	0	0	100	--
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[1]	2	0	31	594	67[1]	2	0	31	652	68[1]	6	0	26	652	68[1]	6	0	26
	3	370	60	7	18	15	555	12	25	63	0	86	0	0	100	0	144	0	0	100	0
	4	371	45	30	23	2	415	48	29	11	12	26	0	0	100	0	92	0	0	100	0
	6	377	57	17	26	0	353	44	16	24	16	73	0	0	100	0	119	0	0	100	0
	7	314	22	27	51	0	437	58	8	14	20	109	0	0	100	0	7	0	0	100	0
	8	434	70	5	10	15	350	38	27	35	0	26	0	0	100	0	15	0	0	100	0
	16	425	30	50	20	0	460	60	33	7	0	67	0	0	100	0	81	0	0	100	0
	24	349	69	1	19	11	395	27	23	50	0	108	0	0	100	0	136	0	0	100	0

[1]Averages are for 55 control specimens and 5 exposed specimens.
[2]Metal bonded directly to wood with primary glue.
[3]Birch and walnut failures combined.

Table 4.—Average[1] results of shear tests on glued wood-to-metal joints exposed continuously to 80° F. and 97 percent relative humidity

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 178 sq. in.	Percent	Percent	Percent	Percent	Lb. per 178 sq. in.	Percent	Percent	Percent	Percent	Lb. per 178 sq. in.	Percent	Percent	Percent	Percent	Lb. per 178 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	4	653	67	0	33	—	903	86	0	14	—	868	88	0	12	—	665	82	0	18	—
	8	692	53	0	47	—	713	67	2	31	—	684	64	0	36	—	636	59	0	41	—
	16	641	57	2	21	—	458	95	0	5	—	639	61	0	39	—	418	31	0	69	—
	24	661	48	5	47	—	940	65	0	35	—	614	38	0	68	—	616	52	0	48	—
	32	676	60	8	32	—	332	70	7	83	—	486	27	0	73	—	694	53	7	40	—
	52	85	100	0	0	—	59	100	0	0	—	467	70	0	30	—	231	90	0	10	—
	104																				
F	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	4	581	47	0	45	38	531	46	0	49	5	640	25	0	42	33	622	38	0	45	17
	8	649	43	0	55	2	631	50	0	34	16	642	25	0	68	7	597	51	0	46	3
	16	591	57	0	36	7	529	29	0	47	24	390	15	0	73	12	584	44	0	44	12
	24	598	47	0	51	2	568	34	0	45	21	459	25	0	68	7	667	53	0	33	14
	32	528	42	0	38	20	549	65	0	25	10	413	35	0	59	6	470	34	0	57	9
	52	297	85	0	4	11	81	99	0	0	1	520	45	0	28	27	192	60	0	40	0
	104																				
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	4	814	62	38	0	—	802	45	55	0	—	594	7	8	85	—	662	20	14	66	—
	8	706	48	52	0	—	673	39	61	0	—	549	7	25	68	—	614	5	11	84	—
	16	703	55	36	9	—	691	54	46	0	—	558	0	1	99	—	853	80	34	86	—
	24	565	44	56	0	—	700	52	48	0	—	422	2	3	95	—	516	16	1	83	—
	32	532	72	28	2	—	610	61	39	0	—	443	51	24	25	—	496	27	0	73	—
	52	336	85	15	10	—	322	69	31	0	—	268	75	3	22	—	137	82	13	5	—
	104																				
4	0 control	998	50	36	14	[2]	998	50	36	14	[2]	1000	50	26	24	[2]	1000	50	26	24	[2]
	4	777	47	18	35	—	739	41	46	13	—	665	24	6	70	—	538	14	7	79	—
	8	661	24	50	26	—	709	53	22	25	—	497	3	0	97	—	464	13	27	60	—
	16	807	59	17	24	—	590	43	23	34	—	432	14	6	80	—	448	0	5	95	—
	24	644	25	34	41	—	652	41	18	41	—	533	16	5	79	—	371	0	0	100	—
	32	681	50	16	34	—	590	25	30	45	—	366	0	9	91	—	283	8	12	80	—
	52	696	64	7	29	—	615	52	24	24	—	363	0	0	100	—	480	0	0	100	—
	104																				
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]
	4	764	88	0	12	—	682	86	1	13	—	847	98	2	0	—	774	97	0	3	—
	8	590	58	0	42	—	719	89	0	11	—	746	90	0	10	—	743	90	0	10	—
	16	626	75	0	25	—	681	64	6	30	—	723	51	0	49	—	764	92	0	8	—
	24	771	90	4	6	—	794	86	14	0	—	739	65	0	35	—	697	78	0	22	—
	32	770	83	3	14	—	794	91	5	4	—	720	48	4	48	—	778	68	0	32	—
	52	619	84	0	16	—	537	76	0	24	—	514	25	0	75	—	646	27	0	73	—
	104																				
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	4	466	46	25	1	28	478	55	36	0	9	382	8	61	5	25	479	14	23	37	26
	8	513	66	3	0	31	539	52	6	6	36	313	6	16	70	8	372	33	21	33	13
	16	488	31	30	7	22	527	73	6	2	19	326	2	12	86	0	360	3	31	57	9
	24	471	55	23	5	17	511	43	20	0	37	342	2	22	70	6	292	15	2	63	20
	32	525	21	67	2	10	546	57	5	0	38	225	40	0	60	0	278	22	0	78	0
	52	341	59	5	4	32	472	38	49	8	5	208	27	10	55	8	203	55	5	34	6
	104																				

[1] Averages are for 55 control specimens and 5 exposed specimens.

[2] Metal bonded directly to wood with primary glue.

[3] Birch and walnut failures combined.

Table 5.—Average[1] results of shear tests on glued wood-to-metal joints exposed alternately to 97 and 30 percent relative humidity at 80° F

Gluing process	Exposure period	Aluminum to Birch plywood										Steel to Birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	972	93	7	0	[2]	972	93	7	0	[2]
	4	856	93	0	7	—	790	83	0	17	—	746	96	2	2	—	893	84	0	16	—
	8	1048	86	2	12	—	987	83	5	12	—	1051	98	0	2	—	981	98	0	2	—
	16	980	100	0	0	—	916	80	0	20	—	1071	96	2	2	—	961	88	0	12	—
	24	1002	91	0	9	—	950	93	0	7	—	1081	94	0	6	—	911	96	4	0	—
	32	1120	70	6	24	—	1012	69	6	25	—	974	92	4	4	—	958	86	0	14	—
	52	928	96	4	0	—	900	93	7	0	—	1000	80	1	19	—	1011	91	0	9	—
	104																				
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	4	767	52	0	16	32	664	42	0	29	29	801	34	0	41	25	780	38	0	39	23
	8	681	51	0	39	10	760	58	0	33	9	850	59	0	14	27	869	78	0	17	5
	16	814	72	0	13	15	694	50	0	25	25	837	73	0	11	16	712	42	0	38	20
	24	760	78	0	9	13	803	47	0	27	26	802	52	0	35	13	898	73	0	19	8
	32	772	43	0	18	39	716	53	0	31	16	741	59	0	37	4	755	70	0	21	7
	52	636	34	0	53	13	592	46	0	28	26	682	45	0	40	15	674	30	0	49	21
	104																				
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	4	1094	63	37	0	—	1008	61	39	0	—	976	38	47	15	—	984	28	55	17	—
	8	987	73	27	0	—	977	59	41	0	—	924	27	52	21	—	818	16	55	29	—
	16	968	61	39	0	—	881	68	32	0	—	849	13	44	43	—	788	22	43	35	—
	24	1001	70	30	0	—	1093	59	11	0	—	707	4	59	37	—	780	3	37	60	—
	32	904	84	16	0	—	910	39	28	0	—	822	13	37	50	—	739	9	52	39	—
	52	796	65	35	0	—	876	68	32	0	—	726	12	27	61	—	731	18	33	49	—
	104																				
4	0 control	998	50	36	14	[2]	998	50	36	14	[2]	1000	50	26	24	[2]	1000	50	26	24	[2]
	4	1051	51	34	15	—	955	45	39	16	—	928	37	34	29	—	1050	56	25	19	—
	8	1065	74	13	13	—	891	16	69	15	—	693	5	21	74	—	651	4	21	75	—
	16	957	66	23	11	—	935	68	16	16	—	820	34	27	39	—	855	38	35	27	—
	24	849	66	25	9	—	778	57	29	14	—	679	23	20	57	—	580	12	17	71	—
	32	738	10	80	10	—	728	31	59	10	—	672	8	41	51	—	507	6	14	80	—
	52	834	48	47	5	—	643	23	63	14	—	538	0	17	83	—	478	0	11	89	—
	104																				
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]
	4	814	100	0	0	—	783	99	0	1	—	853	95	0	5	—	769	85	1	14	—
	8	828	94	6	0	—	801	97	1	2	—	917	98	2	0	—	884	98	2	0	—
	16	802	86	2	12	—	787	83	1	16	—	932	97	2	1	—	816	89	0	11	—
	24	830	74	9	17	—	842	80	3	17	—	902	96	0	4	—	861	96	4	0	—
	32	830	64	5	31	—	850	87	4	9	—	1038	94	0	6	—	932	74	2	24	—
	52	711	90	0	10	—	752	80	5	15	—	651	83	0	17	—	728	90	0	10	—
	104																				
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	4	514	83	0	0	17	558	80	0	0	20	584	65	16	19	0	605	46	33	10	11
	8	567	70	0	0	30	633	79	0	0	21	535	29	46	23	2	627	80	6	11	3
	16	520	78	0	0	22	576	69	4	0	27	567	42	29	29	0	602	48	14	11	27
	24	608	56	0	0	44	556	93	0	0	47	591	24	13	25	38	595	34	10	11	45
	32	589	72	0	0	28	559	69	0	0	31	518	60	15	21	4	586	40	9	18	33
	52	510	36	2	1	61	524	65	0	0	35	388	3	8	70	19	517	6	16	66	12
	104																				

[1] Averages are for 55 control specimens and 5 exposed specimens.

[2] Metal bonded directly to wood with primary glue.

[3] Birch and walnut failures combined.

Z M 72932 F

Table 6—Average[1] results of shear tests on glued wood-to-metal joints exposed continuously to 145° F. and 20 percent relative humidity

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	2	980	88	12	0	2	971	93	7	0	2	971	93	7	0	2
	4	990	84	16	0	--	937	92	8	0	--	1015	92	3	5	--	965	88	7	5	--
	8	971	94	6	0	--	921	81	5	14	--	944	97	3	0	--	838	94	4	2	--
	16	910	89	3	8	--	836	88	0	12	--	1041	95	5	0	--	971	82	5	13	--
	24	925	80	0	20	--	1051	94	6	0	--	860	95	2	3	--	938	97	0	3	--
	32	1056	88	12	0	--	1079	84	10	6	--	1064	86	7	7	--	891	91	8	1	--
	52	764	100	0	0	--	765	99	1	0	--	942	68	0	32	--	936	93	0	7	--
	104																				
2	0 control	716	52	0	12	36	716	52	0	12	36	855	56	0	4	38	859	58	0	4	38
	4	705	54	0	8	38	782	69	0	10	21	838	77	0	7	16	939	81	0	1	18
	8	719	77	0	15	8	670	55	0	27	18	753	82	0	8	10	837	85	0	8	7
	16	708	73	0	20	7	768	80	0	11	9	783	83	0	5	12	805	64	0	33	10
	24	626	73	0	6	21	646	63	0	10	27	699	70	0	12	18	734	76	0	17	7
	32	623	62	0	1	37	672	72	0	4	24	726	82	0	8	10	583	77	0	7	16
	52	496	95	0	0	5	502	72	0	0	28	661	90	0	0	10	624	85	0	0	15
	104																				
3	0 control	945	53	47	0	2	945	53	47	0	2	936	34	56	10	2	936	34	56	10	2
	4	977	69	27	4	--	1024	63	37	0	--	846	30	66	4	--	926	24	66	10	--
	8	927	52	48	0	--	990	64	36	0	--	885	26	61	13	--	854	30	52	13	--
	16	753	41	45	14	--	996	70	26	4	--	578	63	24	13	--	528	62	28	13	--
	24	660	91	8	1	--	710	90	10	0	--	233	57	4	39	--	366	90	0	10	--
	32	523	84	9	7	--	480	86	14	0	--	25	0	0	100	--	127	7	0	93	--
	52	459	57	28	15	--	407	55	19	26	--	0	0	0	100	--	0	0	0	100	--
	104																				
5	0 control	723	88	12	0	2	723	88	12	0	2	779	93	7	0	2	779	93	7	0	2
	4	795	88	12	0	--	765	80	8	12	--	837	99	1	0	--	742	98	5	0	--
	8	854	95	5	0	--	676	95	5	0	--	886	93	7	0	--	870	96	4	0	--
	16	822	90	10	0	--	749	90	6	4	--	760	76	2	22	--	856	93	4	3	--
	24	760	96	4	0	--	753	90	10	0	--	774	75	1	24	--	733	80	3	17	--
	32	738	89	11	0	--	815	84	9	7	--	803	73	4	23	--	774	73	0	27	--
	52	672	93	5	2	--	588	95	5	0	--	702	89	4	7	--	789	89	0	11	--
	104																				
		Aluminum to Walnut Skin to Birch										Steel to Walnut Skin to Birch									
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	4	513	83	0	0	17	492	70	0	0	30	524	80	2	0	18	537	73	18	2	7
	8	518	57	0	0	43	503	59	0	0	41	478	49	36	3	12	496	38	23	2	37
	16	463	40	36	0	24	419	70	0	0	30	163	15	0	81	4	272	22	2	76	0
	24	441	64	7	0	29	441	44	6	0	50	117	8	0	92	0	203	12	0	84	4
	32	306	33	47	20	0	323	29	34	37	0	37	4	2	94	0	56	0	0	100	0
	52	242	9	61	30	0	226	72	9	19	0	0	0	0	100	0	0	0	0	100	0
	104																				

[1]Averages are for 55 control specimens and 5 exposed specimens.

[2]Metal bonded directly to wood with primary glue.

[3]Birch and walnut failures combined.

Table 7.—Average[1] results of shear tests on glued wood-to-metal joints exposed alternately to 158° F. and -67° F.

Gluing process	Exposure period	Aluminum to birch plywood												Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted						
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure		
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent		
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]		
	4	990	91	9	0	—	990	96	4	0	—	982	94	6	0	—	1087	88	12	0	—		
	8	920	97	3	0	—	979	93	7	0	—	1054	94	3	3	—	883	96	4	0	—		
	16	947	92	8	0	—	955	95	5	0	—	957	97	0	3	—	831	99	1	0	—		
	24	1001	94	6	0	—	1092	93	4	3	—	1019	77	4	19	—	870	97	0	3	—		
	32	916	95	5	0	—	1003	99	1	0	—	932	98	2	0	—	943	91	5	4	—		
	52	847	100	0	0	—	905	99	1	0	—	903	99	1	0	—	852	91	1	8	—		
	104																						
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38		
	4	672	75	0	15	10	714	56	0	30	14	762	75	0	3	22	734	61	0	12	27		
	8	688	72	0	4	24	685	73	0	8	19	825	80	0	6	14	710	61	0	7	32		
	16	690	79	0	18	1	766	87	0	3	10	746	90	0	1	9	779	79	0	3	18		
	24	658	67	0	17	16	713	53	0	2	45	691	80	0	14	26	732	66	0	21	13		
	32	655	79	0	2	19	669	68	0	5	27	746	82	0	2	16	714	80	0	7	13		
	52	575	60	0	22	18	560	60	0	25	15	664	84	0	5	11	651	72	0	10	18		
	104																						
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]		
	4	962	71	29	0	—	889	52	48	0	—	948	40	48	12	—	891	39	53	8	—		
	8	982	76	24	0	—	979	54	46	0	—	870	45	53	2	—	912	20	67	13	—		
	16	869	61	39	0	—	880	50	50	0	—	757	18	72	10	—	811	23	57	20	—		
	24	814	58	40	2	—	1013	66	32	2	—	658	9	80	11	—	721	25	62	13	—		
	32	846	65	34	1	—	628	46	54	0	—	608	9	76	15	—	614	11	79	10	—		
	52	652	42	37	21	—	883	47	50	3	—	491	14	23	63	—	493	7	47	46	—		
	104																						
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]		
	4	697	94	6	0	—	698	98	2	0	—	835	94	6	0	—	698	97	3	0	—		
	8	821	91	9	0	—	829	93	7	0	—	936	93	7	0	—	882	98	2	0	—		
	16	816	92	8	0	—	757	95	5	0	—	709	90	0	10	—	793	98	2	0	—		
	24	746	95	5	0	—	635	96	4	0	—	915	94	6	0	—	772	95	5	0	—		
	32	708	97	3	0	—	680	99	1	0	—	809	91	3	6	—	699	80	2	18	—		
	52	712	89	10	1	—	719	94	4	2	—	747	98	0	2	—	857	94	3	3	—		
	104																						
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch											
	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26		
	4	524	94	0	0	6	489	68	0	0	32	570	67	14	1	18	602	86	0	0	14		
	8	478	34	0	0	66	465	47	0	0	53	474	45	38	9	8	581	53	34	1	12		
	16	469	66	0	0	34	536	65	0	0	35	406	10	65	25	0	547	50	38	6	6		
	24	465	47	4	0	49	457	52	0	0	48	399	31	49	6	23	499	41	30	6	23		
	32	478	77	0	0	23	475	67	1	0	32	361	62	6	32	0	399	26	30	26	18		
	52	476	26	20	0	54	463	51	13	8	28	0	0	0	100	0	60	3	0	97	0		
	104																						

[1] Averages are for 55 control specimens and 5 exposed specimens.

[2] Metal bonded directly to wood with primary glue.

[3] Birch and walnut failures combined.

Z M 72934 F

Table 8.—Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in 100-octane gasoline

Gluing process	Exposure period	Aluminum to birch plywood									Steel to birch plywood								
		Unpainted					Painted				Unpainted					Painted			
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 1/8 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/8 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/8 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/8 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	2	1285	97	3	0	--	1085	90	10	0	--	1103	94	6	0	--	1183	91	9	0	--
	4	1234	55	45	0	--	1322	91	9	0	--	1111	96	4	0	--	1084	95	5	0	--
	6	1105	85	15	0	--	1086	78	22	0	--	1088	86	12	2	--	835	80	18	2	--
	8	806	29	71	0	--	978	33	67	0	--	737	46	54	0	--	684	28	72	0	--
	12	530	6	94	0	--	468	2	98	0	--	687	29	71	0	--	427	18	82	0	--
	24	356	1	92	7	--	373	4	96	0	--	391	18	82	0	--	387	2	98	0	--
	52	407	0	100	0	--	305	0	100	0	--	386	6	94	0	--	357	6	94	0	--
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	2	644	42	0	2	46	642	64	0	2	34	744	39	0	6	55	744	39	0	6	55
	4	742	62	0	14	24	696	29	0	22	49	833	76	0	10	14	851	39	0	3	58
	6	697	60	0	37	3	661	50	0	4	46	787	58	0	4	38	880	63	0	18	19
	8	701	72	0	3	25	761	64	0	6	30	741	75	0	2	23	775	66	0	3	31
	12	789	56	0	24	20	748	71	0	3	26	800	56	0	16	28	889	83	0	5	12
	24	760	60	0	21	19	798	82	0	14	4	830	53	0	24	23	902	84	0	0	16
	52	683	67	0	25	8	717	58	0	25	17	830	71	0	13	16	766	65	0	13	22
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	2	779	13	87	0	--	790	18	82	0	--	784	0	87	13	--	634	3	87	10	--
	4	798	20	80	0	--	717	0	100	0	--	695	0	100	0	--	612	0	96	4	--
	6	734	14	86	0	--	743	5	95	0	--	737	3	95	2	--	637	0	99	1	--
	8	744	11	89	0	--	746	5	95	0	--	577	1	96	3	--	601	0	96	4	--
	12	789	10	90	0	--	748	0	100	0	--	621	0	98	2	--	655	8	89	3	--
	24	665	3	96	1	--	654	3	97	0	--	701	0	90	10	--	493	0	59	41	--
	52	615	1	99	0	--	549	1	99	0	--	429	0	69	31	--	301	0	48	52	--
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]
	2	719	92	8	0	--	626	95	5	0	--	872	98	2	0	--	752	96	4	0	--
	4	753	94	6	0	--	669	96	4	0	--	836	91	9	0	--	721	98	2	0	--
	6	670	80	2	18	--	768	93	7	0	--	827	94	6	0	--	817	96	4	0	--
	8	787	96	4	0	--	759	96	4	0	--	756	98	2	0	--	715	93	7	0	--
	12	718	98	2	0	--	844	98	2	0	--	801	97	3	0	--	839	96	4	0	--
	24	795	100	0	0	--	719	98	2	0	--	769	97	3	0	--	818	98	2	0	--
	52	779	90	10	0	--	638	93	7	0	--	867	98	2	0	--	785	100	0	0	--
		Aluminum to Walnut Shim to Birch									Steel to Walnut Shim to Birch										
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	2	435	53	40	0	7	438	52	15	0	33	491	33	51	0	16	582	40	40	0	20
	4	475	53	14	6	27	461	78	0	0	22	563	6	68	16	10	457	31	35	3	31
	6	447	59	5	1	35	499	48	19	1	32	469	39	20	34	7	471	30	48	7	15
	8	439	37	43	0	20	459	79	0	0	21	560	29	31	4	36	558	25	52	7	16
	12	466	13	57	0	30	524	77	0	0	23	466	17	67	7	9	397	22	48	14	16
	24	539	62	6	0	32	558	42	16	1	41	415	16	60	18	6	489	5	59	19	17
	52	494	39	38	0	23	453	17	58	2	23	418	10	75	11	4	410	15	66	14	5

[1] Averages are for 55 control specimens and 5 exposed specimens.
[2] Metal bonded directly to wood with primary glue.
[3] Birch and walnut failures combined.

24 72935 F

Table 9.—Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in 73 octane gasoline

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	2	1175	97	3	0	—	1290	97	3	0	—	1117	96	4	0	—	845	97	3	0	—
	4	1304	90	10	0	—	1117	98	2	0	—	1288	94	6	0	—	1178	95	5	0	—
	6	1356	95	5	0	—	1094	96	4	0	—	901	98	2	0	—	1217	89	8	5	—
	8	1440	93	7	0	—	1158	92	8	0	—	1152	92	3	5	—	1082	83	15	2	—
	12	1309	90	10	0	—	1177	88	12	0	—	1070	92	8	0	—	1011	95	5	0	—
	24	1136	62	38	0	—	1164	87	13	0	—	1189	92	6	2	—	989	93	6	1	—
	52	851	75	25	0	—	891	60	40	0	—	872	42	56	2	—	793	64	36	0	—
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	2	726	72	0	16	12	725	62	0	7	31	748	76	0	9	15	812	65	0	17	18
	4	598	49	0	36	15	711	66	0	25	9	797	74	0	0	26	761	55	0	4	41
	6	637	54	0	26	20	762	68	0	17	15	692	59	0	7	34	898	66	0	4	30
	8	769	87	0	8	5	726	73	0	22	5	765	79	0	1	20	747	60	0	10	30
	12	749	84	0	7	9	708	67	0	6	27	739	78	0	7	15	827	79	0	7	14
	24	753	66	0	21	13	780	54	0	19	27	874	93	0	4	3	877	94	0	1	5
	52	678	50	0	17	33	661	59	0	16	25	775	71	0	17	12	785	61	0	6	33
3	0 control	949	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	2	693	11	89	0	—	762	4	96	0	—	753	17	78	5	—	710	0	96	4	—
	4	834	4	96	0	—	823	18	81	1	—	768	0	97	3	—	768	3	89	8	—
	6	867	2	98	0	—	842	13	87	0	—	716	0	96	4	—	601	0	100	0	—
	8	846	5	95	0	—	737	4	96	0	—	664	0	100	0	—	682	0	91	9	—
	12	885	9	91	0	—	857	9	91	0	—	685	2	96	2	—	691	6	85	9	—
	24	757	9	91	0	—	801	2	98	0	—	581	0	100	0	—	629	1	99	0	—
	52	566	5	95	0	—	642	1	99	0	—	604	0	91	9	—	578	0	96	4	—
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	779	93	7	0	[2]
	2	771	90	10	0	—	744	84	16	0	—	702	92	8	0	—	789	100	0	0	—
	4	801	95	5	0	—	717	94	6	0	—	817	94	6	0	—	723	100	0	0	—
	6	771	84	16	0	—	761	90	10	0	—	851	97	3	0	—	798	100	0	0	—
	8	617	97	3	0	—	795	98	2	0	—	888	90	0	10	—	694	99	1	0	—
	12	720	100	0	0	—	732	94	6	0	—	839	99	1	0	—	826	100	0	0	—
	24	727	88	4	8	—	745	96	4	0	—	782	98	2	0	—	848	96	4	0	—
	52	706	98	2	0	—	758	92	6	2	—	777	92	6	2	—	825	100	0	0	—
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	2	526	61	14	0	25	532	76	7	0	17	566	58	8	0	92	538	58	30	0	12
	4	487	70	4	0	26	508	59	6	0	35	547	50	31	2	17	506	71	1	6	22
	6	497	68	0	0	31	455	57	28	0	15	511	46	38	2	14	499	35	14	0	51
	8	542	71	6	3	20	525	88	0	0	12	504	27	29	27	17	461	34	24	6	36
	12	539	58	9	3	30	556	57	0	0	43	472	22	67	10	1	454	11	73	1	15
	24	515	36	34	0	30	528	60	4	0	40	468	49	19	20	16	507	25	55	12	28
	52	390	29	61	2	8	419	18	63	0	19	254	1	20	79	0	381	11	46	31	12

[1] Averages are for 55 control specimens and 5 exposed specimens.
[2] Metal bonded directly to wood with primary glue.
[3] Birch and walnut failures combined.

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Table 10.—Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in ethylene glycol anti-freeze fluid

Gluing process	Exposure period	Aluminum to birch plywood												Steel to birch plywood									
		Unpainted					Painted							Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure			Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent			Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	
	0 control	980	88	12	0	[2] —	980	88	12	0	[2] —			971	93	7	0	[2] —	971	93	7	0	[2] —	
	2	874	95	5	0	—	943	90	10	0	—			958	88	12	0	—	890	94	6	0	—	
	4	924	92	5	3	—	793	96	4	0	—			789	96	4	0	—	727	92	8	0	—	
1	6	866	91	9	0	—	829	87	13	0	—			820	90	8	2	—	877	95	5	0	—	
	8	802	86	14	0	—	788	84	16	0	—			755	82	18	0	—	717	90	10	0	—	
	12	759	93	7	0	—	829	92	8	0	—			731	93	7	0	—	855	92	8	0	—	
	24	742	75	25	0	—	696	73	20	7	—			653	82	18	0	—	714	82	18	0	—	
	52	754	77	23	0	—	857	82	18	0	—			825	78	22	0	—	779	86	14	0	—	
	0 control	716	52	0	12	36	716	52	0	12	36			855	58	0	4	38	855	58	0	4	38	
	2	732	76	0	0	24	755	44	0	26	23			795	68	0	6	26	839	74	0	4	22	
	4	651	74	0	12	14	753	68	0	10	22			790	76	0	0	24	823	71	0	6	23	
2	6	742	84	0	19	17	697	59	0	15	26			717	77	0	0	23	892	85	0	6	9	
	8	564	67	0	0	33	619	65	0	5	30			685	64	0	6	30	690	68	0	1	31	
	12	679	74	0	3	23	647	71	0	6	23			701	74	0	0	26	789	79	0	7	14	
	24	701	48	0	8	44	675	47	0	16	37			683	54	0	14	32	806	51	0	7	42	
	52	661	52	0	16	32	616	60	0	2	38			645	52	0	4	44	680	69	0	2	29	
	0 control	945	53	47	0	[2] —	945	53	47	0	[2] —			936	34	56	10	[2] —	936	34	56	10	[2] —	
	2	911	54	46	0	—	838	16	83	1	—			917	38	61	1	—	911	58	51	11	—	
	4	844	74	26	0	—	808	40	60	0	—			884	32	60	8	—	942	34	58	8	—	
3	6	790	70	30	0	—	868	26	74	0	—			877	18	63	19	—	771	29	62	9	—	
	8	753	54	46	0	—	763	42	58	0	—			752	41	57	2	—	906	34	61	5	—	
	12	663	78	22	0	—	704	73	27	0	—			833	44	49	7	—	768	22	77	1	—	
	24	812	63	37	0	—	794	39	61	0	—			791	12	72	16	—	765	19	80	1	—	
	52	617	54	46	0	—	611	13	87	0	—			812	10	82	8	—	715	28	65	7	—	
	0 control	723	88	12	0	[2] —	723	88	12	0	[2] —			779	93	7	0	[2] —	779	93	7	0	[2] —	
	2	757	89	11	0	—	798	98	2	0	—			858	100	0	0	—	882	86	15	0	—	
	4	714	96	4	0	—	753	94	6	0	—			779	86	14	0	—	773	98	2	0	—	
5	6	776	98	0	2	—	752	99	0	1	—			946	100	0	0	—	959	96	0	4	—	
	8	612	70	20	10	—	759	82	18	0	—			838	92	8	0	—	783	93	7	0	—	
	12	675	85	1	14	—	780	98	2	0	—			749	99	0	1	—	758	95	0	5	—	
	24	621	90	9	1	—	665	75	25	0	—			721	84	16	0	—	723	97	3	0	—	
	52	614	91	9	0	—	655	87	9	4	—			753	88	10	2	—	702	96	4	0	—	
		Aluminum to Walnut Shim to Birch												Steel to Walnut Shim to Birch									
	0 control	554	[2] 67	2	0	31	554	[2] 67	2	0	31			682	[2] 68	6	0	26	652	[2] 68	6	0	26	
	2	550	81	5	0	14	548	74	2	0	24			684	74	11	0	15	595	61	35	0	4	
	4	540	38	19	0	43	568	74	0	0	26			510	42	39	17	4	605	53	35	5	7	
6	6	536	62	0	0	38	577	51	23	5	21			606	48	3	5	44	577	47	0	5	48	
	8	518	50	8	0	42	593	60	0	0	40			588	46	26	9	9	496	29	29	10	32	
	12	504	40	18	0	42	482	40	4	4	52			536	17	0	32	41	515	42	15	26	17	
	24	543	44	19	0	37	483	65	0	0	35			526	41	17	7	35	592	27	23	12	38	
	52	494	60	0	0	40	485	47	20	0	33			488	36	13	34	17	426	25	34	41	0	

[1] Averages are for 55 control specimens and 5 exposed specimens.
[2] Metal bonded directly to wood with primary glue.
[3] Birch and walnut failures combined.

Table 11.—Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in isopropyl alcohol de-icer fluids

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent	Lb. per 1/2 sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	2	893	88	12	0	—	974	90	10	0	—	875	88	12	0	—	815	86	14	0	—
	4	516	39	61	0	—	562	36	64	0	—	507	51	49	0	—	922	86	14	0	—
	6	391	32	68	0	—	95	0	100	0	—	430	32	68	0	—	250	8	92	0	—
	8	77	0	99	1	—	63	0	95	5	—	63	0	100	0	—	103	0	100	0	—
	12	62	0	100	0	—	59	0	90	10	—	67	0	100	0	—	66	0	100	0	—
	24	61	0	100	0	—	39	0	100	0	—	39	0	100	0	—	42	0	100	0	—
	52	59	0	82	18	—	74	0	100	0	—	60	0	100	0	—	82	0	100	0	—
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	2	770	88	0	6	6	743	60	0	20	20	768	55	0	19	26	782	70	0	5	25
	4	683	60	0	11	29	715	60	0	8	32	744	69	0	8	23	767	60	0	14	26
	6	782	57	0	15	28	718	65	0	4	31	788	69	0	2	29	764	65	0	0	35
	8	721	80	0	13	7	740	86	0	6	8	830	70	0	3	27	733	79	0	0	21
	12	842	86	0	7	7	789	62	0	2	36	803	54	0	16	30	838	73	0	4	23
	24	821	55	0	11	34	763	46	0	34	20	942	89	0	1	10	920	67	0	8	25
	52	611	59	0	3	38	747	70	0	1	29	812	80	0	9	11	917	92	0	2	6
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	2	896	72	28	0	—	975	66	33	1	—	899	18	80	2	—	933	36	52	12	—
	4	960	44	56	0	—	1018	31	69	0	—	967	31	62	7	—	894	19	72	9	—
	6	865	36	64	0	—	857	14	86	0	—	826	20	64	16	—	871	20	69	11	—
	8	925	31	69	0	—	856	22	78	0	—	828	28	72	0	—	773	12	80	8	—
	12	771	32	68	0	—	766	20	80	0	—	840	6	78	16	—	816	4	82	14	—
	24	849	50	50	0	—	830	23	77	0	—	633	9	82	9	—	765	1	92	7	—
	52	709	24	76	0	—	760	31	69	0	—	822	1	82	17	—	744	1	90	9	—
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	93	7	0	[2]	719	93	7	0	[2]
	2	877	94	6	0	—	752	94	6	0	—	931	96	4	0	—	899	90	10	0	—
	4	809	71	29	0	—	744	92	8	0	—	854	89	11	0	—	688	96	4	0	—
	6	792	100	0	0	—	831	73	27	0	—	928	95	5	0	—	807	96	4	0	—
	8	817	96	4	0	—	774	88	12	0	—	860	98	2	0	—	715	97	3	0	—
	12	890	96	0	4	—	854	100	0	0	—	1012	94	5	1	—	848	100	0	0	—
	24	772	95	2	3	—	856	95	5	0	—	804	96	2	2	—	724	100	0	0	—
	52	890	79	21	0	—	953	96	4	0	—	943	96	4	0	—	880	88	12	0	—
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	594	67[3]	2	0	31	584	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	2	531	83	3	0	14	519	57	12	0	31	905	45	39	0	16	542	33	47	0	20
	4	462	66	0	0	34	466	58	0	0	42	565	62	15	2	21	536	58	15	7	20
	6	534	69	0	0	32	526	68	0	0	32	570	52	22	5	21	552	47	10	0	43
	8	561	64	1	0	35	515	48	2	0	50	548	55	9	7	29	545	38	19	24	19
	12	537	38	22	3	37	474	47	5	3	45	563	33	50	16	1	583	50	17	5	28
	24	548	36	0	0	64	557	56	0	0	44	527	56	4	5	35	545	51	13	6	30
	52	476	46	28	0	26	447	38	14	2	46	398	13	19	46	22	362	2	5	93	0

[1] Averages are for 55 control specimens and 5 exposed specimens.
[2] Metal bonded directly to wood with primary glue.
[3] Birch and walnut failures combined.

Table 12 --Average[1] results of shear tests on glued wood-to-metal joints soaked continuously in aircraft lubricating oil

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2]	980	88	12	0	[2]	971	93	7	0	[2]	971	93	7	0	[2]
	2	1044	97	3	0	--	884	86	14	0	--	915	98	2	0	--	1086	92	8	0	--
	4	995	94	6	0	--	898	100	0	0	--	940	89	0	11	--	1052	87	5	8	--
	6	904	86	13	1	--	902	98	2	0	--	1002	86	14	0	--	855	92	8	0	--
	8	914	90	10	0	--	929	47	33	20	--	949	97	3	0	--	998	88	12	0	--
	12	829	81	11	8	--	941	90	10	0	--	1006	92	8	0	--	1055	80	20	0	--
	24	1056	81	19	0	--	1067	79	21	0	--	1099	94	6	0	--	898	100	0	0	--
	52	812	58	24	18	--	1092	76	24	0	--	1067	74	21	5	--	914	72	6	22	--
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	2	698	40	0	26	34	715	48	0	6	46	843	87	0	2	11	693	37	0	9	54
	4	706	51	0	8	41	711	36	0	48	16	768	35	0	1	64	738	43	0	5	52
	6	690	58	0	8	34	711	58	0	18	26	756	74	0	3	23	898	72	0	12	16
	8	674	60	0	21	19	692	47	0	35	18	719	52	0	3	45	648	28	0	0	72
	12	720	78	0	6	16	800	72	0	5	23	806	49	0	8	43	758	47	0	1	52
	24	759	35	0	40	25	797	58	0	22	20	875	59	0	13	28	914	67	0	13	20
	52	634	45	0	1	54	711	54	0	18	28	723	74	0	0	26	830	78	0	2	20
3	0 control	945	53	47	0	[2]	945	53	47	0	[2]	936	34	56	10	[2]	936	34	56	10	[2]
	2	993	69	31	0	--	835	39	61	0	--	859	17	69	14	--	926	17	77	6	--
	4	1091	49	51	0	--	1067	54	46	0	--	1036	35	53	12	--	904	29	68	3	--
	6	1024	58	42	0	--	866	48	52	0	--	963	30	43	27	--	928	28	59	13	--
	8	997	31	69	0	--	809	34	66	0	--	931	24	73	3	--	950	15	56	29	--
	12	1037	57	43	0	--	904	49	51	0	--	995	29	51	20	--	935	36	47	17	--
	24	951	47	53	0	--	981	39	61	0	--	884	11	77	12	--	885	2	81	17	--
	52	841	41	59	0	--	856	28	72	0	--	820	10	75	15	--	764	1	67	32	--
5	0 control	723	88	12	0	[2]	723	88	12	0	[2]	779	97	3	0	[2]	779	97	3	0	[2]
	2	762	91	9	0	--	715	97	3	0	--	800	84	16	0	--	821	96	4	0	--
	4	706	95	5	0	--	796	90	10	0	--	897	100	0	0	--	809	96	4	0	--
	6	726	96	4	0	--	636	83	2	15	--	916	95	3	2	--	767	100	0	0	--
	8	848	96	4	0	--	667	95	5	0	--	776	96	4	0	--	750	100	0	0	--
	12	756	82	18	0	--	750	91	9	0	--	791	83	17	0	--	773	98	0	2	--
	24	795	93	7	0	--	748	79	21	0	--	797	95	4	1	--	819	100	0	0	--
	52	608	66	0	34	--	676	78	0	22	--	493	18	0	82	--	654	85	0	15	--
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[3]	2	0	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	5	0	26
	2	518	72	3	0	25	555	60	0	0	40	624	50	2	0	48	534	61	11	0	28
	4	530	58	0	0	42	557	50	0	0	50	560	43	28	1	28	570	50	1	2	47
	6	499	64	0	0	36	534	70	0	0	30	592	62	13	7	18	657	44	19	7	30
	8	414	45	0	0	55	542	66	0	0	34	604	45	37	3	15	594	60	0	0	40
	12	549	51	0	0	49	549	42	0	0	58	620	50	18	3	29	610	48	20	2	30
	24	596	49	9	0	42	552	24	0	0	76	654	63	0	0	37	626	55	23	4	18
	52	479	46	30	10	14	312	5	1	51	36	555	27	17	48	8	444	30	19	4	47

[1]Averages are for 55 control specimens and 5 exposed specimens.

[2]Metal bonded directly to wood with primary glue.

[3]Birch and walnut failures combined.

Table 13.—Average[1] results of shear tests on glued wood-to-metal joints exposed to weather outdoors

Gluing process	Exposure period	Aluminum to birch plywood										Steel to birch plywood									
		Unpainted					Painted					Unpainted					Painted				
		Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure	Average shear strength	Average wood failure	Average glue failure	Average metal adhesion failure	Average secondary glue failure
	Weeks	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent	Lb. per sq. in.	Percent	Percent	Percent	Percent
1	0 control	980	88	12	0	[2] —	980	88	12	0	[2] —	971	93	7	0	[2] —	972	93	7	0	[2] —
	12	1054	95	5	0	—	863	92	2	6	—	961	98	2	0	—	1030	91	8	1	—
	24	731	57	8	35	—	919	86	6	8	—	903	80	1	19	—	741	53	3	44	—
	52	684	65	2	33	—	841	100	0	0	—	863	90	0	10	—	855	97	0	3	—
	104																				
2	0 control	716	52	0	12	36	716	52	0	12	36	855	58	0	4	38	855	58	0	4	38
	12	613	37	0	53	10	855	53	0	40	7	883	70	0	20	10	793	50	0	37	13
	24	792	58	0	24	18	750	66	0	28	6	861	57	0	29	14	828	53	0	39	8
	52	596	51	0	31	18	531	46	0	54	0	615	56	0	30	14	640	21	0	43	36
	104																				
3	0 control	965	53	47	0	[2] —	965	53	47	0	[2] —	936	34	56	10	[2] —	936	34	56	10	[2] —
	12	879	45	54	1	—	873	58	42	0	—	804	10	52	38	—	745	2	31	67	—
	24	850	43	56	1	—	894	39	61	0	—	779	10	72	18	—	652	4	59	37	—
	52																				
	104																				
4	0 control	998	50	36	14	[2] —	998	50	36	14	[2] —	1000	50	26	24	[2] —	1000	50	26	24	[2] —
	12	824	61	20	19	—	950	75	6	19	—	814	17	33	50	—	744	23	21	56	—
	24																				
	52																				
	104																				
5	0 control	723	88	12	0	[2] —	723	88	12	0	[2] —	779	93	7	0	[2] —	779	93	7	0	[2] —
	12	933	98	1	1	—	768	91	3	6	—	823	99	0	1	—	680	97	0	3	—
	24	757	86	0	14	—	881	94	0	6	—	748	87	0	13	—	691	98	1	0	—
	52	774	95	0	5	—	840	53	0	47	—	852	93	0	7	—	792	80	0	20	—
	104																				
		Aluminum to Walnut Shim to Birch										Steel to Walnut Shim to Birch									
6	0 control	554	67[3]	2	6	31	554	67[3]	2	0	31	652	68[3]	6	0	26	652	68[3]	6	0	26
	12	531	57	9	1	33	570	53	0	0	47	596	56	22	8	14	551	26	54	12	8
	24	575	60	0	0	40	631	43	0	0	57	567	28	28	15	35	586	47	29	1	23
	52																				
	104																				

[1] Averages are for 55 control specimens and 5 exposed specimens.

[2] Metal bonded directly to wood with primary glue.

[3] Birch and walnut failures combined.

Z M 72940 F

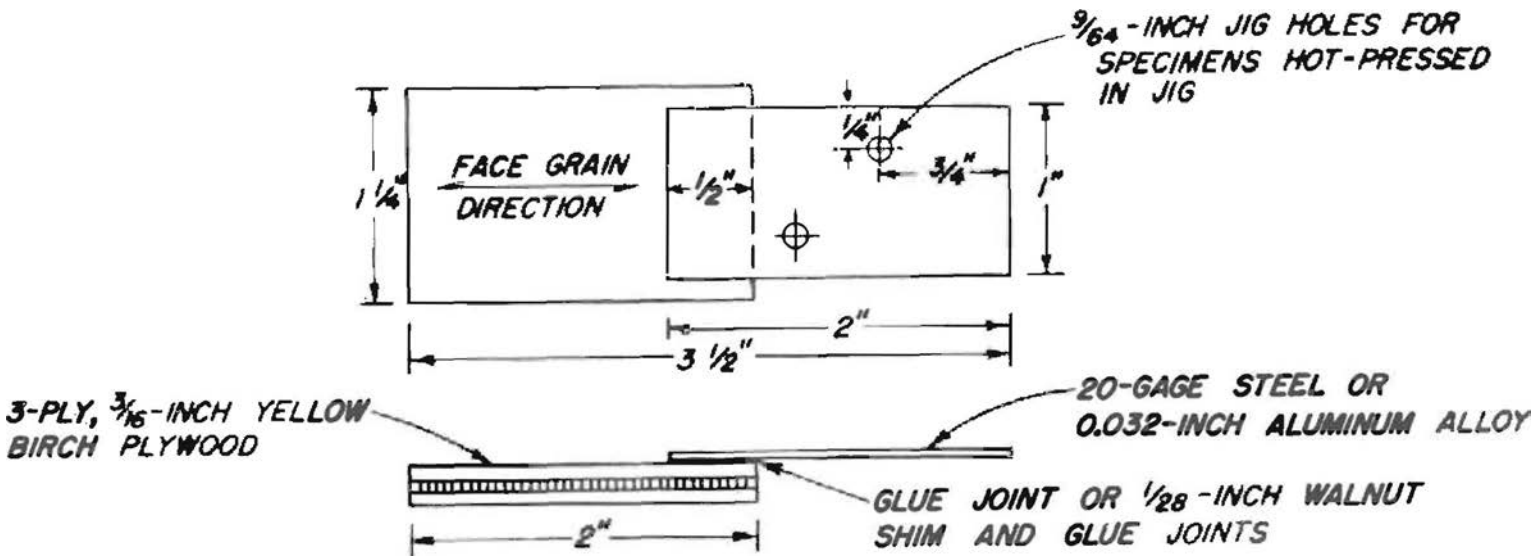

Figure l.--Plywood-to-metal glue-joint test specimen with and without walnut shim.

ZM 92928 F

Figure 2.--Jig for locating alinement holes in metal pieces.

Z M 23507 F

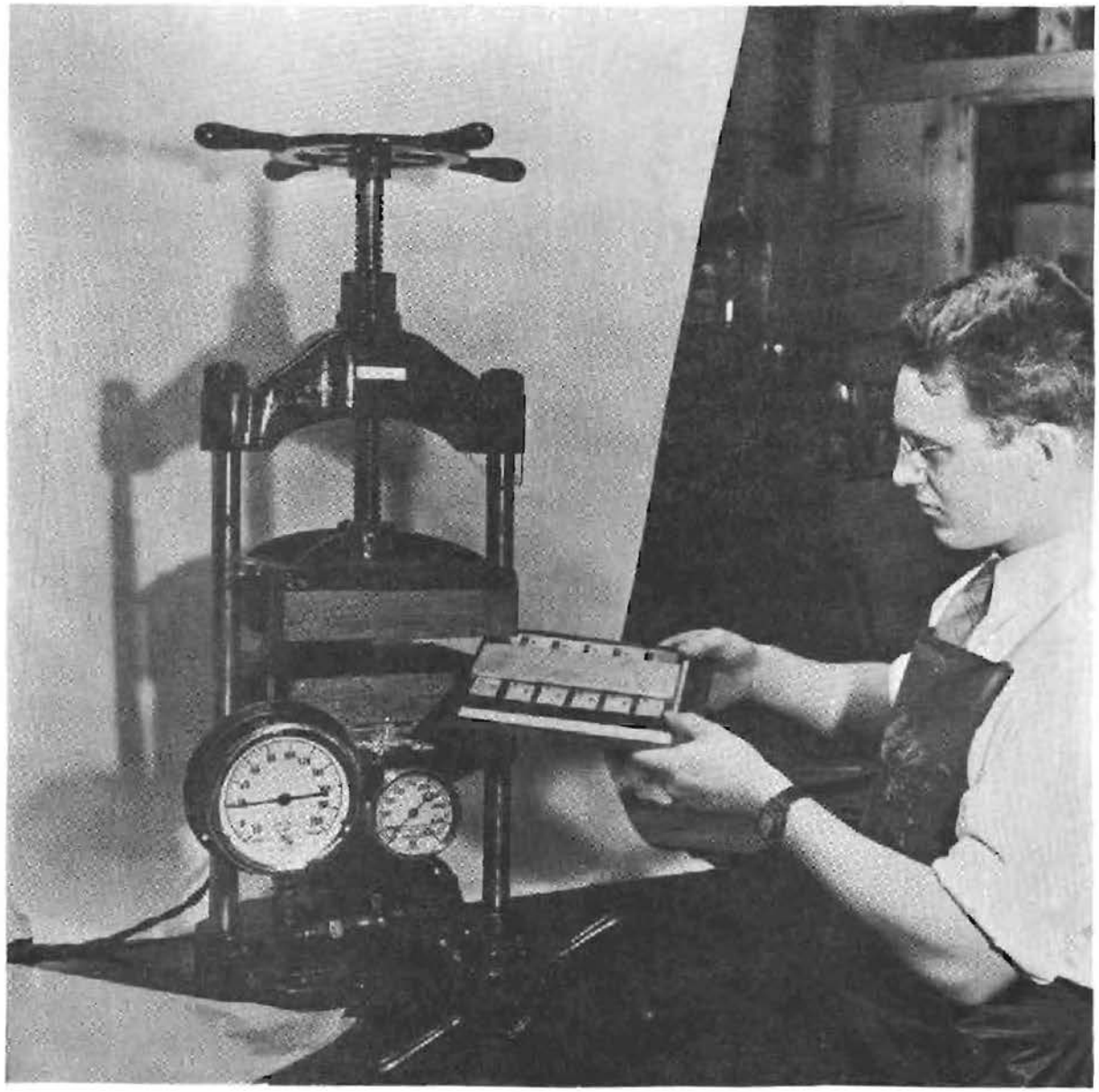

Figure 3.--Hot-press gluing of wood-to-metal joint specimens showing electric hot press, pressing jig, and specimens.

Z M 73508 F

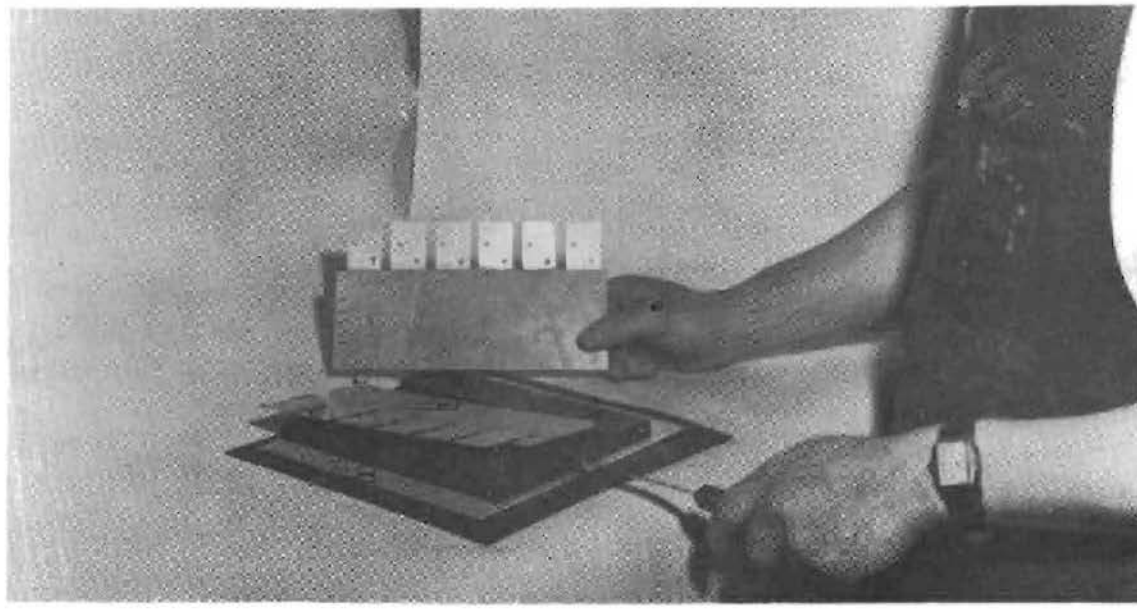

Figure 4.--Removing two panels of wood-to-metal joints from jig after gluing in a hot press.

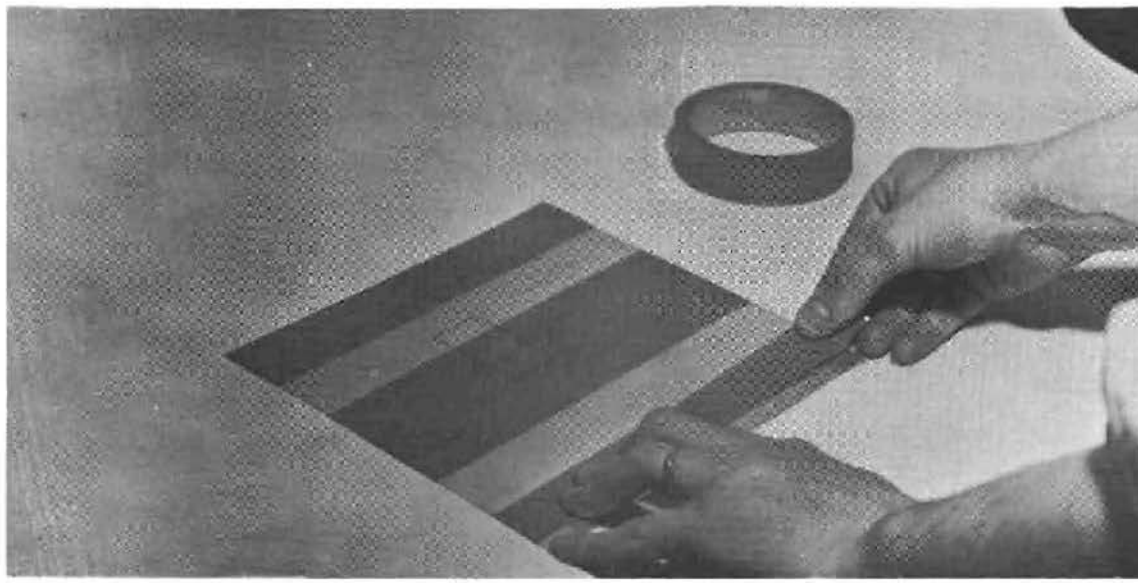

Figure 5.--Masking of the 8- by 8-inch metal sheets before applying the glue. (Outlined area marks the position of the metal portion of one specimen).

Z M 73509 F

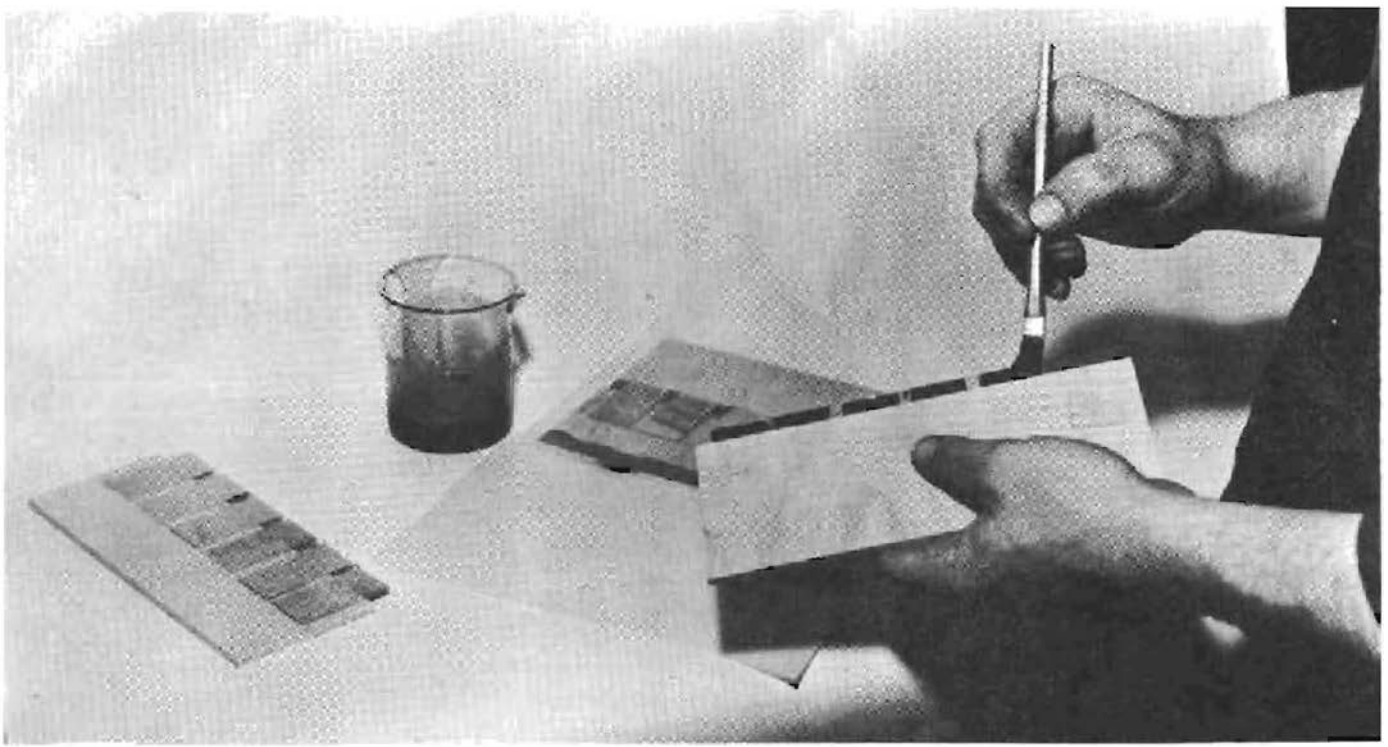

Figure 6.—Applying the secondary glue to the primed metal surface in the preparation of the wood-to-metal glued joint specimens.

ZM 73510 F

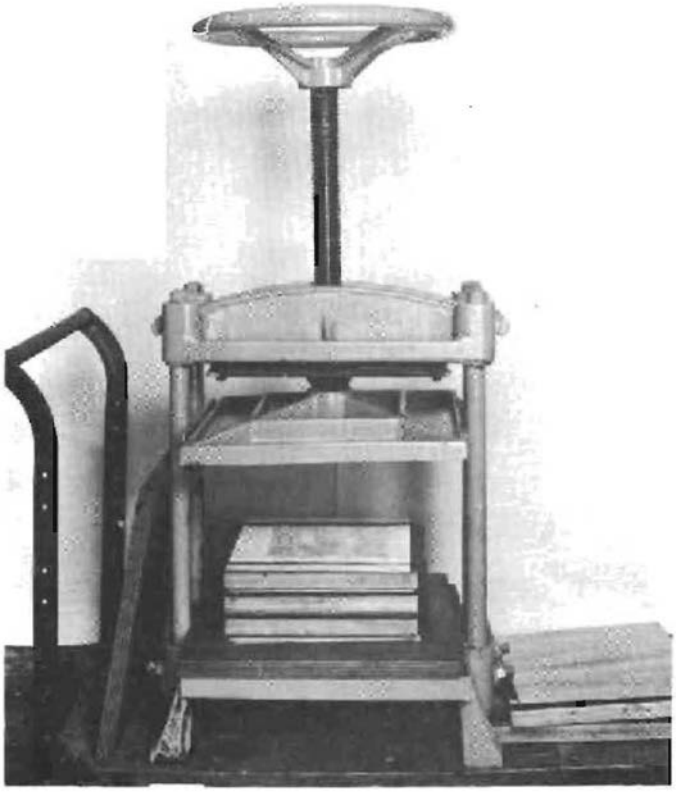

Figure 7.--Press used for the secondary gluing of the wood-to-metal joint specimens.

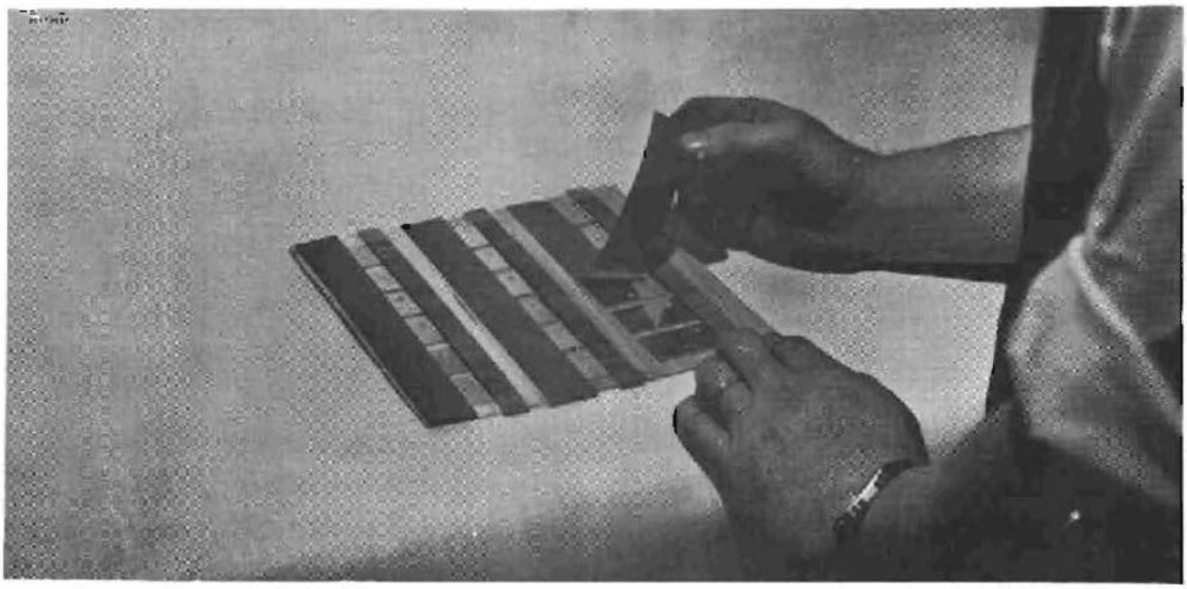

Figure 8.--Taping walnut shims and metal pieces to yellow-poplar cauls.

Z M 73511 F