ADHESIVES FOR BONDING WOOD TO METAL

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ADHESIVES FOR BONDING WOOD TO METAL

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Introduction

During the past 10 years considerable research and development work has been done on high-strength, durable adhesives for use in bonding wood to metal. The woodworking adhesives such as animal, vegetable, casein, urea-resin, phenol-resin, and resorcinol-resin adhesives have not been found entirely suitable for this purpose, as they usually are not elastic enough to distribute the stresses encountered in service when two dissimilar materials, such as wood and metal, are bonded together, and they generally do not adhere well to the surfaces of metals. Therefore other more elastic materials, such as vinyl resin and natural and synthetic rubbers, have been used in combination with such thermosetting resins as phenol-formaldehyde to result in adhesive formulations that have the proper elasticity and adhere well to both wood and metals.

A number of these adhesives are now commercially available. Many fabricators of wood parts have used them for combining wood and metal so as to utilize the best properties of both materials. In general, the results obtained have been good. Some fabricators, however, have been cautious about designing parts where wood-to-metal bonds are required because of the impression that the use of wood-metal adhesives is difficult or that the results obtained with these adhesives are often erratic. It is the purpose of this report to describe briefly some of the types of wood-metal adhesives that are available, the conditions of bonding that should be used with these adhesives, and the strength and durability of bonds obtained when these adhesives are properly used.

Types of Wood-metal Adhesives

A large number of adhesives have been developed over a period of years for bonding wood to metal. They vary from those types that are formulated for ease of use at room temperature, for quick setting under field conditions, and for low cost, to those types formulated for use where highest strengths

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

are required in the joint and where joints must be resistant to elevated temperatures, high humidities, salt sprays, and general outdoor service conditions. Generally, it has been impossible to incorporate all desirable properties in a single adhesive formulation, and thus each adhesive has its own distinct advantages and limitations.

The work on the bonding of metal to wood at the Forest Products Laboratory has been directed primarily to aircraft applications and has been conducted largely in cooperation with the armed services. For this reason information available at this Laboratory involves mainly those adhesives that have been developed to produce high-strength durable joints, and the information in this report is therefore largely limited to this type of adhesive.

It is difficult to classify adhesives of the kind used for bonding wood to metal into the various chemical types, as has been done for the adhesives used in gluing wood to wood, because the chemical composition of these wood-metal adhesives is more complex. Therefore these high-strength metal-bonding adhesives have been broadly classified according to the curing temperatures and techniques by which they are used rather than by chemical types. At this time, the three main groups of wood-metal adhesives to be discussed are: (1) the direct-bonding, high-temperature-setting, (2) the two-step-bonding with adhesive primer and secondary adhesive, and (3) the direct-bonding, room-temperature-setting groups.

A large group of the metal-bonding adhesives is included in the direct-bonding type that require curing of the bond under pressure at temperatures ranging from 250° to 350° F. Adhesives of this group are usually composed of at least two resins, one being a thermoplastic resin or elastomer, such as polyvinyl formal, polyvinyl butyral, polyvinyl acetate, a polyamide, or a synthetic rubber, and the other being a thermosetting resin, such as phenol formaldehyde, combined in solvents in such proportions as will provide the necessary characteristics of adhesion to metal, elasticity, flow during cure, heat resistance, and durability of the resultant bonds. In some instances, the two resin ingredients may be applied separately. For example, a liquid resin may first be applied to the surfaces and then a powdered resin be sprinkled into the wet adhesive spread; or two liquid resins might be applied to the surfaces in successive coats. In addition to the liquid adhesives for direct bonding to metals, a number of film or tape adhesives are now available.

In bonding wood to metal with the direct-bonding, high-temperature-setting adhesives, high stresses are developed as the bonds are cooled because of the different coefficients of thermal expansion of the two materials. Stresses are also developed when the wood expands as it regains moisture. These high stresses tend to distort the metal-wood construction and may even rupture the bond if the adhesive is not sufficiently elastic and strong. In hot pressing, blistering of the bonds, caused by the tendency of entrapped adhesive solvents to escape, can also occur.

In order to avoid these limitations of the direct-bonding, high-temperature-setting adhesive, as well as to avoid the need for hot-press equipment, a two-step adhesive process was developed. In this process a priming adhesive (many of the high-temperature-setting, direct-bonding adhesives may be used as primers) is applied to the metal in much the same way as a paint finish might be applied. The primer is cured on the metal at elevated temperatures in an oven or on the platens of a hot press without pressure, and the cured primer is bonded to the wood with room- or intermediate-temperature-setting urea-, resorcinol-, or phenol-resin adhesives of the woodworking type.

The third kind of metal-bonding adhesives includes those adhesives capable of forming direct bonds to metals at room temperatures. At the present stage of development, joints of metal to wood made with the available room-temperature-setting adhesives do not have the over-all strength at room and elevated temperatures, and after soaking in water and aircraft fluids, of those made with the hot-setting and two-step adhesives. The casein-rubber-latex adhesives have been used successfully at room temperatures for bonding wood to metal for those applications that are not so critically stressed as aircraft construction, but these adhesives usually have the disadvantage of losing a large part of their strength when the bonds become wet or are exposed to high humidity. Recently, some room-temperature-setting adhesives have been formulated with epichlorohydrin resins, but it is not known if these adhesives will maintain their bond strength when wet or when stressed at elevated temperatures.

In addition to the room-temperature-setting wood-metal adhesives mentioned above, there are a number of mastic and solvent-type adhesives for bonding wood to metal at room temperatures at only a low initial pressure. These adhesives generally produce joints between wood and metal with considerably lower strengths than joints made with the adhesives previously mentioned. For this reason, these mastic and solvent-based adhesives are intended primarily for applications where high strengths are not required.

The mastic and solvent-base adhesives are usually liquid adhesives or pastes consisting of synthetic or reclaimed rubber, asphalt, or certain lower-cost resins that are dispersed either in suitable, inexpensive organic solvents or in water. Whereas most of the high-temperature-setting and two-stage adhesives, previously referred to, develop their joint strength principally by undergoing chemical reactions, these mastic and solvent-base adhesives generally develop their joint strength by a loss of solvent. At present the chemically reactive types of metal-bonding adhesives have been more widely investigated because they were more promising for forming strong and resistant bonds than were the mastic and solvent-type adhesives. For this reason the following discussion will be limited chiefly to the high-temperature-setting and the two-stage adhesive systems.

Bonding Procedures

In bonding wood to metal, as in bonding wood to itself, care must be taken to use the proper conditions of bonding. These conditions include surface preparation, application of the adhesive, assembly period, pressure, and curing time and temperature. While the same general principles apply both in bonding wood to wood and in bonding wood to metal, several of the conditions are more complicated and critical in bonding wood to metal. While the woodworking resin adhesives can generally be mixed and cleaned from equipment with water and are of high solids content (50 to 60 percent), the wood-metal adhesives are usually soluble only in organic solvents and are of low solids content (15 to 25 percent), which fact introduces new problems in spreading, air drying, and curing. The important conditions of bonding that must be adhered to in order to obtain high-strength wood-metal bonds with these structural adhesives have been established by the adhesive manufacturer in his recommendations for use. Whenever specific ranges of these conditions are given by the adhesive manufacturer for use with his adhesive product, conditions within these ranges should be used.

Preparation of Wood

No treatment of wood surfaces is necessary other than that which is normally used when preparing the surfaces for wood-to-wood bonding. The surfaces should be free of all dirt, wax, grease, and oil, and the machining of the surfaces should be such that uniform pressures will be obtained when the joint is assembled and the pressure applied. Surfacing should be done preferably just before bonding in order to minimize any dimensional changes in the surface between surfacing and bonding. The moisture content of the wood, within a normal range of 5 to 15 percent, is not generally considered to be critical so far as adhesion is concerned. When the direct-bonding, high-temperature-setting adhesives are used for bonding metal to large areas of wood at comparatively high moisture content, however, the bonds may blister. As in bonding wood to itself, the moisture content of the wood when glued should be as nearly as possible that which it will reach in use, in order to reduce dimensional changes in service to a minimum.

Preparation of Metal

A review of adhesive manufacturers' recommendations for preparing various metals for bonding shows no general agreement on the best method to be used, except that the surfaces should be free of all loose oxides, grease, wax, and oil, and that the adhesive manufacturer's recommended procedure for cleaning the metals for use with his adhesive should generally be followed. A test frequently used to determine if these waxes and oils have been removed from the surfaces consists of flushing the surfaces with water; if the film of water breaks over certain sections, the presence of oil or wax is indicated, as shown in figure 1. This test procedure obviously requires that the metal be dried again before bonding.

Methods of cleaning metals that have been used and recommended by various industries, primarily for aluminum, include washing the surfaces with solvents such as benzene, carbon tetrachloride, trichloroethylene, acetone, or naphtha; abrading them with steel or aluminum wool, abrasive cloth, sandblast, or wire brushes; immersing them in mild alkaline detergents and soaps; etching them with alkaline and acid solutions; and cleaning them by electrolytic methods. Various combinations of these cleaning procedures have been used.

A study[2] was made for the Military Services interested in aircraft sandwich construction to compare the effectiveness of a number of these cleaning methods in preparing 24S-T3 clad aluminum alloy for adhesive bonding. Conclusions were based on the initial dry shear strengths developed in lap shear specimens of aluminum to aluminum in which the metal was cleaned by various methods before bonding. In general, the most effective methods for preparing aluminum for adhesive bonding were found to be the use of (1) acid etching solutions such as sulfuric acid-sodium dichromate solution (10 minutes at 150° F. in a water solution of 25 percent concentrated sulfuric acid and 2.5 percent sodium dichromate); (2) hydrofluosilicic acid (8 to 10 minutes at 75° F. in a 1 percent solution); (3) phosphoric-chromic acid (5 minutes at 150° F. in a solution containing 6.5 percent of phosphoric acid and 2.5 percent of chromic acid); or (4) commercial alkaline detergent cleaners or sodium metasilicate (5 minutes at 170° F. in a 3 percent solution). Each treatment must be followed by thorough rinsing of the surfaces with water.

When the aluminum surfaces were merely wiped with a cloth saturated with benzene, moderately high joint strength was obtained with several wood-metal adhesives, but some of these adhesives gave inferior bonding to surfaces prepared in this manner. When solvent cleaning alone resulted in inferior bonding, abrading of the cleaned surfaces with aluminum wool or abrasive cloth was found to result in some improvement in the joint strength, but results were generally not so good as when one of the above acid or detergent methods was used.

One type of cleaning process often gave better results with one adhesive than with another, and the selection of a proper cleaning process thus depended on the adhesive being used. Cleaning by the use of the sulfuric acid-sodium dichromate solution, however, was found to give optimum joint strength with all of the adhesive processes investigated. The differences in effectiveness of cleaning observed in this research are probably of more importance when bonding aluminum to itself than when bonding aluminum to wood.

Additional data[3] on results of tests of similar aluminum-to-aluminum lap specimens made after a 30-day salt-water spray exposure have indicated considerable differences in the corrosion resistance of the metal, with resultant differences in bond strengths, when the aluminum was originally cleaned by different processes. The sulfuric acid-sodium dichromate treatment was found to give the highest-quality results after this salt-water spray exposure. A benzene wash, together with abrasion with aluminum wool was also very effective and definitely superior to benzene wash alone or with no cleaning treatment.

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[2]Eickner, H. W., and Schowalter, W. E. "A Study of Methods for Preparing Clad 24S-T3 Aluminum-alloy Sheet Surfaces for Adhesive Bonding." Forest Products Laboratory Report No. 1813, May 1950.

[3]Eickner, H. W. "A Study of Methods for Preparing Clad 24S-T3 Aluminum-alloy Sheet Surfaces for Adhesive Bonding -- Pt. III, Effect of Cleaning Method on Resistance of Bonded Joints to Salt-water Spray." Forest Products Laboratory Report No. 1813-A, Dec. 1950.

It is probable that the cleaning procedure used may be an important factor in determining joint performance in other types of severe exposures, but data are not available to evaluate such effects. However, aluminum cleaned by the sodium dichromate-sulfuric acid method has usually resulted in good joint performance with a number of adhesives under laboratory exposures to elevated-temperature or high-humidity conditions.

It has been the general experience of fabricators of adhesive bonds to metal that the cleaning procedures required and the strength of bonds obtained will vary for different metals. Cold-rolled steel has been successfully cleaned for bonding by immersing it in a cleaning bath of sodium metasilicate, sodium hydroxide, and sodium carbonate, then immersing it in a pickling solution of sulfuric and nitric acid, and finally rinsing it in a bright dip bath of hydrochloric acid and hydrogen peroxide. A simpler alternative consists of abrading it with steel wool and then washing it with a solvent such as benzene, toluene, or chlorinated hydrocarbons; or degreasing it with a trisodium phosphate solution and then etching it free of oxides with a hydrochloric acid solution. It has been reported by some investigators that other metals, such as cadmium plate, zinc plate, stainless steel, and bronze, have been successfully cleaned for bonding by abrading them with steel wool and then washing them with a suitable solvent. In bonding wood to magnesium, the protective prime coat is usually removed from the metal with a wire brush and the surface is anodized with acid solutions. Some difficulties have been reported in bonding wood to copper, brass, stainless steel, and nickel plate, but joints are obtainable between these metals and wood that are generally as strong as most species of wood.

Care should be taken in cleaning metals that chemical solutions are always thoroughly rinsed from the metal surfaces before they have a chance to dry on the surface. Following the final rinse, and after checking for any breaks in the water film, the water should be quickly dried from the surface of the metal in order to prevent water stains and oxidation of the metal. Cleaned metal surfaces should be protected from further contamination prior to bonding and should probably be bonded as soon after cleaning as possible.

Applying the Adhesives

Adhesives can be applied to the surfaces with any convenient device -- brush, hand roller, conventional glue spreader, gear-type applicator, spray gun, or dip tank -- that will spread the adhesive uniformly. The conditions during adhesive application are more critical with the wood-metal adhesives than with the woodworking adhesives, because many of the wood-metal adhesives have little flow during the bonding cycle, and, therefore, any resultant irregularities in the adhesive film are likely to cause some low-pressure areas in the bonds that, in turn, will result in joints of low strength. Because most of the wood-metal adhesives are of low solids content, a considerable amount of the wet adhesive must be applied to the bonding surfaces to provide sufficient final dry adhesive film. The entire amount of adhesive usually cannot be applied in a single application. Therefore it is necessary to apply the adhesive in several coats, with a drying period between coats, so as to obtain an adhesive film of sufficient thickness and with as little entrapped solvent as possible.

The adhesive can be brushed on if the bonding surfaces are small. Hand rollers and conventional roll-type glue spreaders are convenient for applying some adhesives, but other adhesives dry excessively on the rollers because they are dissolved in highly volatile organic solvents.

Many structural wood-metal adhesives are most conveniently applied by spraying, as are many paints. Adhesive manufacturers usually supply the adhesive properly thinned for spraying, or furnish suitable thinners for that purpose. The recommended solvents or thinners should always be used for spraying in order to provide desired rates of evaporation from the film.

In general, the spray-gun adjustment should be such that when the gun is moved over the bonding surfaces at a uniform rate of 300 to 400 inches per minute at a distance of 8 to 10 inches from the surface, a uniform film will be obtained that will be free from defects. With certain of the direct-bonding, high-temperature-setting adhesives, which have good flow characteristics, slight surface defects in the resultant film can be tolerated. It is the general practice to apply the direct-bonding adhesive to both the wood and the metal surface. The necessary adhesive film should be applied in a minimum of two spray coats, although with some adhesives as many as 10 coats are needed to obtain sufficient film thickness. Each spray coat usually consists of one pass back and forth across the surface, followed by air drying for 5 minutes to 1 hour. Successive coats should be applied at right angles to each previous one in order to produce a uniform adhesive film.

With practically all high-temperature-setting wood-metal adhesives, satisfactory spraying can be done at temperatures of 55° to 75° F. when the relative humidity does not exceed 55 percent, and at temperatures up to 100° F. when the relative humidity does not exceed 30 percent. When some of these adhesives are sprayed at higher humidities and temperatures, solvent evaporation is so rapid that the surface of the adhesive film will "blush" as the film is cooled below the dew point of the air and moisture condenses on it. The term "blushing," is used in the finishing industry to denote the low-gloss, grey appearance of sprayed films that results from this condensation of moisture from the air on the film as it dries. Inferior strength will often result when blushed films are used. Some adhesives, however, are especially formulated with slow-drying solvents so that they can be sprayed at the higher humidities without danger of blushing, and others can apparently tolerate some blushing with no significant reduction in bond strength.

The amount of adhesive that should be applied is dependent upon a number of factors, such as the type of adhesive used, the strength of the materials being bonded, how well the two faying surfaces fit together, and the type of stress to be applied to the bond. The amount of adhesive required is also dependent on the flow of adhesive during the formation of the bond. In addition to the type of adhesive being used, this flow depends on other bonding conditions such as assembly time, curing temperature, and pressure.

For most applications, the wood-metal adhesive should be applied to each surface to result in a dry-film thickness of 0.002 to 0.005 inch. Adhesive primers used for two-step bonding are also usually applied in that film thickness. When the surfaces being bonded do not fit well, heavier spreads should be used so that good contact will be obtained between the adhesive films when the bonds are cured under pressure. Secondary adhesives of the type used in the two-step method of bonding and room-temperature-setting adhesives are usually applied to both faying surfaces in a total wet spread of approximately 50 pounds per 1,000 square feet of bond line.

Assembly Period

Adhesives of the woodworking type generally require short assembly periods (the length of time between final application of the adhesive and the application of pressure) because they tend to set or harden rapidly before the bonds are made. Usually closed assembly (two wood surfaces are in contact without pressure) are involved in such wood-to-wood bonding. With the high-temperature-setting wood-metal adhesives, however, hardening of the film is rather slow and much longer assembly periods are usually required so that the entrapped volatile solvents can escape, and open assembly (surfaces open to the air) is also required. In bonding wood to metal with the high-temperature-setting wood-metal adhesives, it is common practice to allow an open-assembly period of 8 to 25 hours to elapse between the application of the adhesive to the surfaces and the assembly and cure of the bond. With some adhesives of this type, open-assembly periods as long as several months have been used.

With short assembly periods (1 to 8 hours), it is frequently necessary to precure the adhesive film at elevated temperatures without pressure in order to remove solvents that might otherwise cause excessive flow of the adhesive or blistering of the bond. With some adhesives, precuring is recommended even when the adhesive films have been air dried for periods as long as 24 hours. Some adhesives are also precured to improve the resistance of the bond to high-temperature exposures. Since the conditions of precuring are mainly dependent on the formulation of the adhesive, manufacturers have usually established the proper precuring conditions for their adhesives. These conditions vary from drying in an oven for 30 minutes to 1 hour at 180° to 230° F. to precuring on the platens of a hot press for 5 to 15 minutes at the normal curing temperatures (300° to 335° F.). Film blisters during precure may be due to adhesive coats that are too heavy, air-drying periods that are too short, or precuring temperatures that are too high. Adhesive films should not be precured so much that they will not flow during the final curing.

In two-step bonding of wood to metal, the assembly and precuring conditions for metal-priming adhesives are essentially the same as those for the direct-bonding, high-temperature-setting wood-metal adhesives. The dangers of excessive precure and resultant lack of flow are not so critical with the metal-priming adhesives because these primers are not expected to flow during the final pressing of the bond. The secondary adhesives of the woodworking type used in bonding the primed metal to the wood are usually handled under the same assembly conditions for these adhesives as in gluing wood.

The casein-latex adhesives used for room-temperature bonding of wood to metal give good results with open-assembly periods of 10 to 15 minutes at normal room temperature.

Bonding Time and Temperature

Each adhesive manufacturer usually recommends the bonding time and temperature for use with his adhesive because these depend on the formulation of the adhesive. Most direct-bonding, high-temperature-setting adhesives with a synthetic-rubber base should be cured at temperatures of 325° F. or higher, but some can be cured at 300° F. Some vinyl-modified, high-temperature-setting adhesives can be cured at temperatures as low as 240° F., but in general adhesives of this type are cured at temperatures of 300° to 315° F. Typical curing periods for several of these adhesives at 300° F. or higher vary from 15 to 30 minutes.

When these adhesives are used as metal primers in the two-step bonding process, curing temperatures can be the same as when the adhesives are used for direct bonds. Secondary adhesives used in two-step bonding can be cured under the conditions normally used with these adhesives in woodworking, but in some instances the curing of these adhesives at slightly higher temperatures than normally used for wood bonding has resulted in stronger bonds.

The casein-rubber-latex room-temperature-setting adhesives generally require 10 hours for pressing at normal room temperatures.

A pressing period of 24 hours at normal room temperatures is apparently required before bonds made with the present epichlorohydrin-resin adhesives can be safely handled, and 4 or 5 days of conditioning are required before bonds made with them will reach full strength.

Pressure

The pressure that should be used during the formation of the wood-metal bond is dependent on the flow characteristics of the adhesive at the curing temperature being used and is limited to the maximum pressure that the wood can withstand without crushing. For most wood-metal adhesives, pressures of 150 to 250 pounds per square inch are used with dense species of wood and 100 to 150 pounds per square inch with less dense species. With certain resin-rubber-base adhesives, which have poor flow characteristics during bond formation, slightly higher pressures may be required in order to obtain complete contact between the adhesive films than would otherwise be used on other types of adhesives in the same constructions.

The epichlorohydrin-resin adhesives may be cured under contact pressure if surfaces fit together well. This is a distinct advantage, since most other wood-metal adhesives require bonding pressures of at least 50 pounds per square inch.

Wood-metal adhesives are used for such structural purposes as bonding wood-metal panels for partitions in railroad dining and sleeping cars, for bonding metal fittings to wood in wood glider construction, or for bonding metal-faced balsa sandwich panels that are used in the fuselage, flooring, and partitions of some aircraft structures. In these structural applications it is necessary that the bonds be durable when exposed to high and low temperatures and humidities, and perhaps to soaking in water. For aircraft applications, bonds should also be resistant to soaking in alcohol, gasoline, oil, antifreeze solution, or similar aircraft fluids, and should have good resistance to creep and fatigue. Even in nonstructural applications wood-metal adhesives need to have high bond strength to resist the stresses developed by the wood-metal combinations under the normal daily and seasonal temperature and moisture changes, and for some purposes they may also have to possess good resistance to high temperature and humidity conditions in order to perform satisfactorily.

In any quantitative evaluation of adhesives for bonding wood to metal, it is essential that standard test specimens be used. Several types of test specimens that have been used by the Forest Products Laboratory in evaluation of wood-to-metal and metal-to-metal bonds are shown in figure 2. Much of the evaluation work on wood-metal adhesives has been done on shear specimens. In general, the Laboratory's evaluations of wood-metal adhesives have been limited to the use of a lap-joint specimen of birch plywood and clad aluminum alloy (fig. 2, A) or to a plywood-type specimen of birch veneer core and clad aluminum-alloy faces (fig. 2, B), although other types of test specimens have been used in evaluating these adhesives for special applications. For some additional performance tests of adhesives suitable for wood-metal bonding, lap-joint specimens of clad aluminum alloy to itself have been used (fig. 2, C) so that higher stresses can be applied to the adhesives without causing failure in the material being bonded.

Original Bond Strength

In evaluation tests made with a lap-joint specimen of three-ply, 3/16-inch birch plywood and 0.032-inch clad aluminum alloy (fig. 2, A), and with a three-ply type of specimen of 1/16-inch birch veneer core and 0.032-inch clad aluminum alloy faces (fig. 2, B), failures in the birch of 75 to 100 percent are usually obtained when bonding with the high-temperature-setting adhesives having a base of vinyl resin, and 25 to 65 percent when bonding with the high-temperature-setting rubber-base adhesives or with the two-step bonding processes. When woods of lower density are used, failures with all of these types of wood-metal adhesives are almost completely in the wood.

Failure loads obtained with these specimens bonded with the better wood-metal adhesives generally ranged from 650 to 900 pounds per square inch for the 1-inch plywood-type aluminum-and-birch specimen and from 1,300 to 1,800 pounds per square inch for the 1/2-inch lap-joint of aluminum and birch plywood. A few of the high-temperature-setting adhesives with high percentages of vinyl resins produced joints having slightly higher strengths. This increase may have been caused by relief of certain stresses in these more elastic joints under the test conditions used.

Durability Characteristics

The performance of adhesive-bonded joints of metal to wood made with several typical adhesive processes have been investigated at the Forest Products Laboratory. Much of the data from these tests are given in one report.[4] The following comments are based on this report and upon other unpublished data.

Water Immersion

Lap-joint specimens and plywood-type specimens of birch and clad aluminum alloy bonded with wood-metal adhesives have generally shown good resistance to continuous soaking in water. In a study started in 1946 at the Forest Products Laboratory,[4] lap-joint specimens of birch plywood and clad aluminum alloy, bonded with each of several processes, were soaked for 16 weeks in tap water, after which time they were found to have retained 63 to 79 percent of their original dry strength, and there was little increase in the amount of failure in the adhesive bond itself, with failure being still largely in the wood. Included in this study were four high-temperature-setting wood-metal adhesives, two of the vinyl-phenol type, and two of the resin-rubber-base type. In addition, one two-step bonding process, with a rubber-base primer and a resorcinol-resin secondary adhesive, was studied. Other investigations have included similar tests on specimens of this type bonded with a casein-latex adhesive. In this work it was noted that a 2-week water soak reduced the wet strength of the wood-metal bonds made with casein-latex adhesive to about 20 percent of the original dry strength.

It has been found, however, that some of the adhesives that give highly water-resistant bonds between clad aluminum alloy and birch plywood do not give equally durable bonds to other metals, such as cold-rolled steel, which are less corrosion-resistant. With most of the adhesives evaluated in the 1946 study,[4] similar bonds in other lap-joint specimens between cold-rolled steel and birch plywood had practically no strength after 16 weeks' immersion in tap water, with pronounced corrosion of the steel being observed. The high-temperature-setting adhesive, which contained a large percentage of vinyl resin, gave the best performance in this immersion of the steel-wood specimens of any of the adhesives, maintaining about 50 percent of its original strength after 16 weeks of soaking, and failures were approximately 30 percent in the birch plywood. The inferior performance of these adhesives on steel is probably caused by greater corrosion of steel than of aluminum.

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[4] Eickner, H. W. "Durability of Glued Wood to Metal Joints." Forest Products Laboratory Report No. 1570, 1947.

Immersion in Other Fluids

Numerous tests have been made on bonded lap-joint specimens of clad aluminum alloy and birch plywood that have been exposed to soaking in such fluids as gasoline, ethylene glycol, isopropyl alcohol, benzene, and lubricating oils, since these fluids are widely used in aircraft.

Birch-plywood-to-aluminum joints bonded with one high-temperature-setting wood-metal adhesive containing a high percentage of vinyl resins were found to have practically no bond strength after 1 week of soaking in benzene or after 8 weeks of soaking in isopropyl alcohol. Specimens soaked for 12 weeks in high-octane gasoline lost about 50 percent of their original strength.

Strength of bonds made between birch plywood and aluminum with high-temperature-setting wood-metal adhesives having a rubber base was decreased as much as 50 percent when soaked for 1 week in benzene, 25 to 35 percent when soaked for 12 weeks in high-octane gasoline, and about 25 percent when soaked for 12 weeks in ethylene glycol.

The high-temperature-setting wood-metal adhesives containing a high percentage of phenol resin and the room-temperature-setting casein-latex adhesives generally performed well when soaked in these aircraft fluids.

Exposure to High Humidity

Lap-joint specimens of steel and birch plywood and of aluminum and birch plywood bonded with a number of the wood-metal adhesives have been exposed for periods up to 1 year at a relative humidity of 97 percent at 80° F., and also to cyclic exposures of 2 weeks at this relative humidity followed by 2 weeks at 30 percent.

At the continuous high-humidity exposure, most adhesive bonds between aluminum and birch were not weakened so much by the exposure as was the birch itself, because the failures in the birch generally increased as the exposure time progressed. Bonds made between steel and birch plywood, however, did show some loss in strength with an increase in the percentage of bond failure during 4 to 32 weeks of exposure, and by then the strength of the birch had decreased so that the failures were again in the wood. The high-temperature-setting adhesives of the vinyl-phenol-resin type usually performed better than did the rubber-base adhesives in these high-humidity exposure tests of bonds between steel and birch plywood.

In a repeating cycle of 2 weeks at 97 percent relative humidity at 80° F. followed by 2 weeks at 30 percent relative humidity at 80° F., only those steel-to-birch joints bonded with the rubber-base adhesives tended to show a decided loss of strength and an increase in the amount of bond failure. Even with these adhesives, the bonds, after 1 year, retained more than 50 percent of their original strength.

Exposure at High Temperatures

Bonded lap joints of steel to birch plywood and of aluminum to birch plywood made with several typical bonding processes were exposed for periods up to 1 year at a temperature of 158° F. and 20 percent relative humidity and then tested at 80° F. Under these conditions most of the structural wood-metal adhesives were found to maintain their initial joint quality. Most of the decrease in strength that did occur can be attributed to the weakening of the wood, since the joint failures were mainly in the wood. The one exception noted was in bonds to steel made with a high-temperature-setting adhesive having a rubber base. With this adhesive, the joints decreased decidedly in strength after 32 weeks of exposure, and the failure was mainly in adhesion to the steel. The loss of strength in this case appeared to be caused more by a corrosion of the steel than by the effect of the temperature on the adhesive.

Similar exposure tests were also made on bonded lap-joint specimens of birch and metal that had been exposed for periods up to 1 year to repeating cycles of 1 day at a temperature of -67° F. followed by 1 day at 158° F. and at 20 percent relative humidity. The results obtained were similar to those obtained in continuous exposure to 158° F.

Lap-joint specimens of birch plywood and aluminum heated to 200° F. and tested at once at this temperature maintained 50 to 90 percent of their room-temperature strength. The bonds that lost most strength were those made of adhesives having a high percentage of thermoplastic vinyl resins.

Fatigue Resistance

Fatigue resistance of some bonded wood-to-metal joints has been determined[5] by stressing in cantilever bending a 1/2-inch lap-joint specimen of 5/32-inch yellow birch plywood and 3/16-inch clad aluminum alloy (fig. 2, D). The fatigue resistance of wood-metal adhesives in these tests was generally considered to be good. Those bonds made with structural rubber-base adhesives or with vinyl-phenol adhesives having a high percentage of phenol resin generally gave better results than bonds made with high-temperature-setting adhesives having a high percentage of vinyl resin or adhesive bonds made by a two-step bonding process.

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[5] Eickner, H. W., Mraz, E. A., and Bruce, H. D. "Resistance to Fatigue Stressing of Wood-to-metal Joints Glued with Several Types of Adhesives." Forest Products Laboratory Report No. 1545, 1946.

Selected Articles on

Wood-to-metal and Metal-to-metal Bonding

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Figure 1.--Illustrating the water-break test for cleanliness of aluminum sheets. The sheet on the left is clean, the one on the right has not been properly cleaned for bonding.

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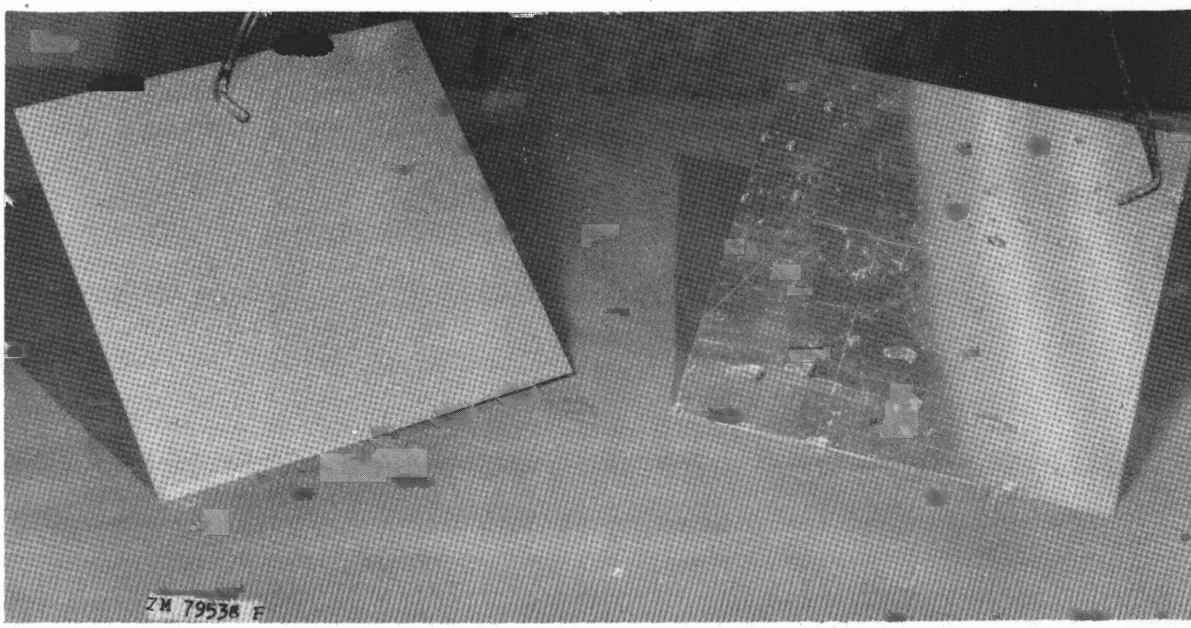
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Figure 2.--Three typical shear test specimens and one fatigue test specimen of metal to wood.

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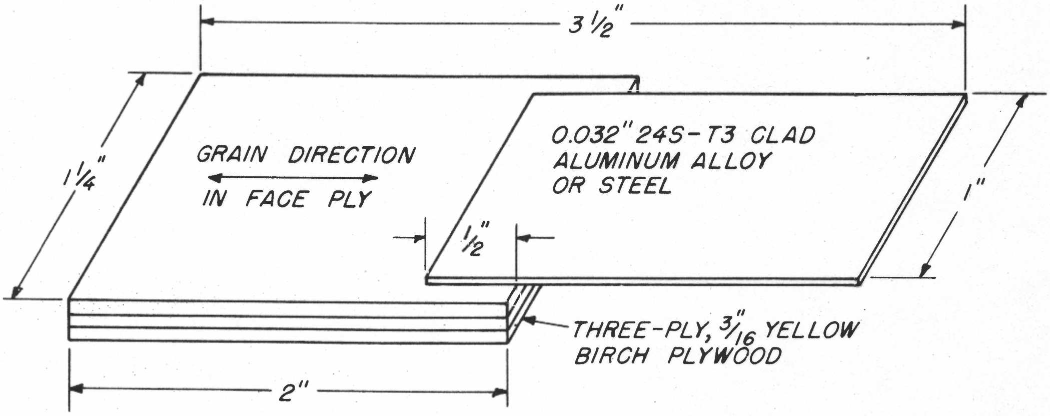

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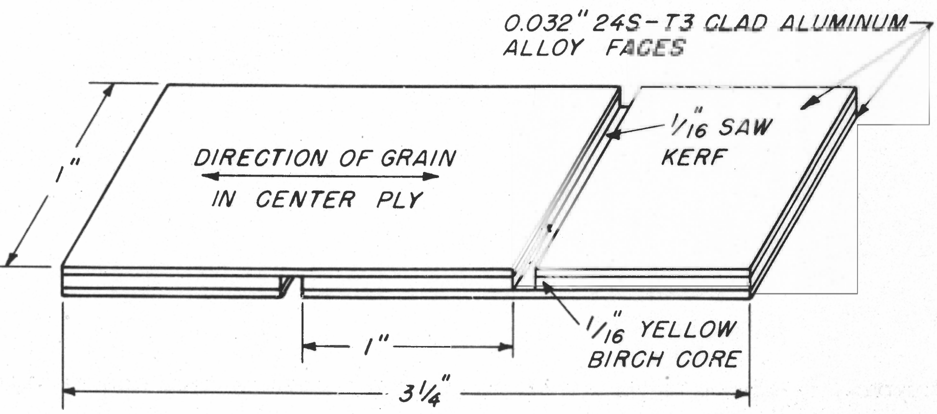

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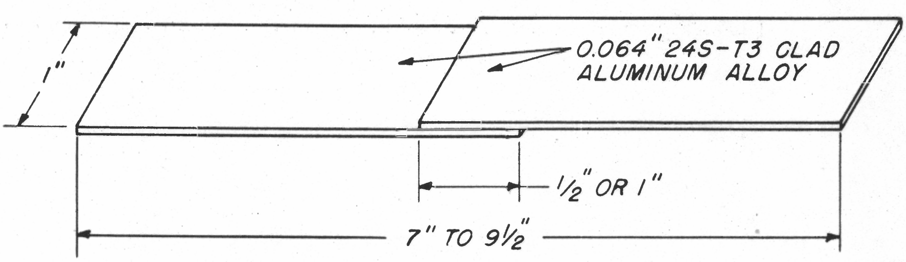

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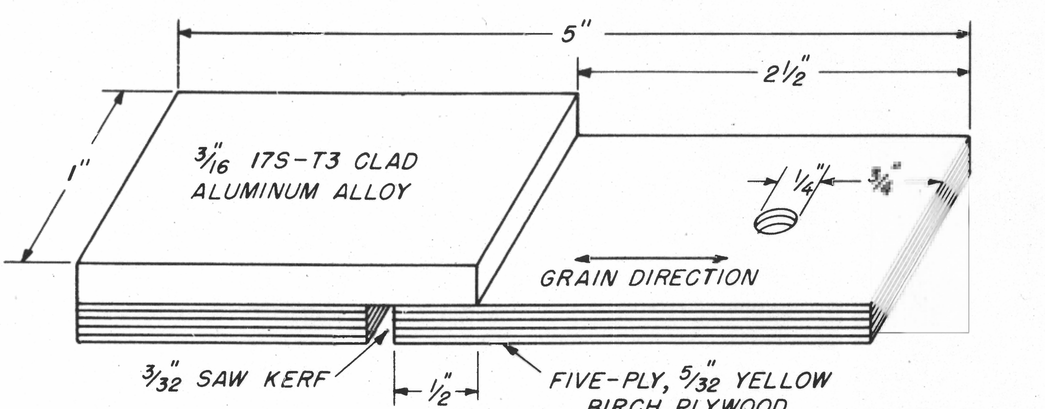

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