EFFECT OF SURFACE TREATMENT ON THE ADHESIVE BONDING PROPERTIES OF MAGNESIUM

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EFFECT OF SURFACE TREATMENT ON THE ADHESIVE BONDING PROPERTIES OF MAGNESIUM

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Summary

Several types of surface treatments for AZ31-H24 magnesium, including de-oxidizing, chemical sealing, and anodizing methods, were investigated as pretreatments for bonding with commercial metal-bonding adhesives. In addition to original tests of bond quality, tests were also made after the specimens were aged at elevated temperature, high humidity, and salt-water spray conditions.

Highest original joint strength values were usually obtained with rigid-type (high modulus) adhesives applied to the surfaces treated with deoxidizing...
solutions of chromic acid. However, when bonds to magnesium that had been treated by these deoxidizing methods were exposed to high humidity or salt-water spray conditions, corrosion of the magnesium was severe, and usually resulted in deterioration in the quality of bond.

In bonding the AZ31-H24 magnesium surfaces treated by anodize methods, higher joint strength values were usually obtained with the less rigid (low modulus) adhesives than with the rigid adhesives. This was particularly true when metal surface coatings resulting from the anodize treatments, were rather brittle. The best overall bonding performance, both in original dry strength after exposure to high humidity and salt-water spray, was obtained with a low-modulus adhesive, Scotchweld AF-6 Film, applied to AZ31-H24 magnesium treated by an acid anodize method, Dow 17.

Exposure of the adhesive films to a high-humidity condition prior to bonding AZ31-H24 magnesium was generally found to lower the original bond strength and strength after exposure by very significant amounts in some cases. However, use of the moist Scotchweld AF-6 Film resulted in exceptionally good bonds after all exposure conditions on the magnesium treated with the acid anodize treatment, Dow 17. These results confirmed the general results obtained in the initial part of this investigation.

**Introduction**

There has been much work done on the adhesive bonding of aluminum alloys, including extensive investigations by the U. S. Forest Products Laboratory (8, 9) and others on the types of surface treatments to be used in preparing this metal for bonding. As a result of these studies, the sodium dichromate-sulfuric acid or chromic-acid-sulfuric acid solutions are now widely used to prepare aluminum surfaces for bonding. Investigations on surface treatments for preparing magnesium for bonding, however, have been much more limited. Investigations of this type have been reported by Wyandotte Chemical Corp. (16), and the Franklin Institute (15) in cooperation with Wright Air Development Center, and the U. S. Forest Products Laboratory (10, 11). Surface treatments for preparing magnesium for bonding have also been established by Convair (6), Boeing Airplane Co. (2, 3), and by the Chance Vought Aircraft, Inc. (4, 5). Surface treatments for the protection of magnesium sheets have also been investigated or developed by the Dow Chemical Co. (7), Allied Research Products, Inc. (1), the Sherwin-Williams Co. (13), Frankford Arsenal (12), National Bureau of Standards, and Hanson-Van Winkle-Munning Co. (14). Many of these investigations have been limited to use of a single adhesive bonding process, to the investigation of corrosion.
resistance of the metal when adhesive bonding was not included, or to investigations concerned only with the original dry strength of the bonds and not performance after exposure to high moisture conditions or other aging factors.

It is the purpose of this present study to investigate the adhesive bonding properties of some of the more promising surface treatments for magnesium with each of several typical bonding processes. Such tests were to include the original bond strength and strength after exposure to conditions of elevated temperature, high humidity, salt-water spray, and tidewater. These bonding tests were made with five commercial metal-bonding adhesives applied directly to the surface coatings, with no protective paint coatings applied either before or after bonding.

Processes and Procedures

Adhesive Bonding Processes

The adhesive bonding tests of this study were made using the following five adhesive bonding processes.

Metlbond 4021. — A high-temperature-setting formulation of nitrile rubber and phenolic resin in the form of an unsupported film used with a liquid primer of nitrile rubber and phenolic resin. Manufactured by Narmco Resins and Coatings Co., 600 Victoria St., Costa Mesa, Calif.

Bloomingdale FM-47 Film. — High-temperature-setting formulation of the vinyl-phenolic type, supported on woven glass fabric. Supplied by Bloomingdale Rubber Co., Chester, Pa.

Scotchweld Brand AF-6 Bonding Film. — A high-temperature-setting formulation of nitrile rubber and phenolic resin in the form of an unsupported film. Manufactured by Minnesota Mining and Mfg. Co., Adhesives and Coatings Division, 900 Fauquier Ave., St. Paul 6, Minn.

Redux 775 Film. — A high-temperature-setting two-component formulation of phenol-resin and vinyl polymer powder in the form of an unsupported film. Manufactured by CIBA Company, Inc., Plastics Division, 627 Greenwich St., New York 14, N. Y.

Epon Adhesive VIII. — A liquid formulation of epoxy resins. Produced by Shell Chemical Corporation, 380 Madison Ave., New York 17, N. Y.

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The conditions of bonding used with each of these adhesive processes are listed in table 1. These conditions were within the ranges recommended by the adhesive manufacturer at the time the test panels were prepared.

**Type and Number of Test Specimens**

Small 4- by 5-1/2-inch overlap test panels of the type shown in figure 1 were prepared by bonding together two 3- by 4-inch pieces of 0.064-inch magnesium. The overlap in these panels was controlled to be 0.50 ± 0.01 inch. AZ31-H24, formerly designated as FS1-H24, magnesium alloy (Federal Specification QQ-M-44) was used for the regular set of test panels, but some exploratory tests were also made on HK31-H24 magnesium alloy, as indicated later.

The small metal pieces were cut from sheets in such a way that the roll direction of the metal would coincide with the 5-1/2-inch lengthwise direction of the bonded test panels. Any cutting burrs on the edges of the pieces were removed by light hand filing before the surfaces were prepared for bonding.

Fourteen test panels were prepared for each bonding variable investigated, except when otherwise noted.

**Procedures for Treating Surfaces**

**Degreasing procedure.** Prior to application of the surface treatments, the magnesium pieces were degreased, by means of the following treatments, either singly or in combinations, as indicated in each section describing the specific surface treatment:

(A) The metal sheets were wiped with a clean cloth saturated with acetone.

(B) The metal sheets were degreased for 3 minutes in a conventional vapor degreaser charged with stabilized trichloroethylene. The sheets were alternately immersed and removed from the degreasing chamber to obtain as much action as possible.

(C) The metal sheets were degreased by immersion for 10 minutes at 160° to 190° F. in a solution consisting of:

- 3.0 ounces of sodium metasilicate
- 1.5 ounces of tetra sodium pyrophosphate
- 1.5 ounces of sodium hydroxide
- 0.5 ounce of Nacconal NR
- 1.0 gallon of distilled water
The pieces were then rinsed in cold distilled water following the above treatments.

(D) The metal sheets were degreased by immersion for 10 minutes at 170°F to 190°F in a solution made up of 13 to 15 ounces of sodium hydroxide dissolved in enough distilled water to make 1 gallon of solution. The pieces were rinsed in cold distilled water following the above treatment.

(E) The metal sheets were degreased electrolytically by immersion for 1 to 3 minutes at 170°F to 190°F in the sodium hydroxide solution used in (D). A 6-volt direct current was applied between the stainless steel metal tank containing the sodium hydroxide solution and the metal sheets, which were made the cathode. The current was adjusted to be 30 to 50 amperes per square foot of cathode surface. The pieces were rinsed in cold distilled water following the treatment. This is a recommended procedure (7) for the degreasing of magnesium metal.

Types of Treatments. -- The following seven surface treatments were used in this investigation for preparing the magnesium surfaces before bonding. These surface treatments represent methods currently being used to provide corrosion resistance of magnesium surfaces or to prepare the magnesium surfaces for protective paint coatings. The methods were selected for investigation in this study on the basis of suggestions made by the cooperator. Treatments were applied to the entire surfaces of the pieces of magnesium. No protective paint coatings were applied to these surfaces either before or after adhesive bonding.

Deoxidization. -- The bright deoxidization treatment (7) used in this study consisted of degreasing treatments (A), (B), and (C) followed by immersion for 5 minutes at 150°F in a solution of:

- 24 ounces of chromic acid
- 4 ounces of sodium nitrate
- 1/8 ounce of calcium fluoride
- Enough distilled water to make 1 gallon of solution

The magnesium pieces were then rinsed in cold distilled water and dried at 110°F in front of a circulating fan. A bright metallic surface was produced by this treatment.

Modified deoxidization. -- The second deoxidize treatment consisted of degreasing the magnesium pieces by methods (A), (B), and (C) followed by immersion of the pieces for 3 minutes at room temperatures in a solution of:

- 26.6 ounces of chromic acid
- 32.0 ounces of sodium nitrate
- 1 gallon of glacial acetic acid
- 1 gallon of distilled water
The magnesium pieces were rinsed in cold distilled water and dried at 110° F. in front of a circulating fan. The resulting surface was not as bright as that obtained in the first deoxidize treatment mentioned.

This type of treatment, which is a combination of conventional acetic acid and chromic acid etch treatments (7) for magnesium, had been found by another investigator (16) to show promise in preparing magnesium surfaces for bonding.

Iridite 15 process. -- This treatment is a commercial chromate conversion protective treatment for magnesium. The magnesium pieces were treated in this study following the procedure recommended by the manufacturer (1). The pieces were first degreased by methods (A), (B), and (D). For method (D) the immersion period was reduced to 3 to 5 minutes at 185° F. The pieces were then etched for 3 minutes at room temperatures in a solution of:

- 24 ounces of chromic acid
- 4 ounces of sodium nitrate
- Enough distilled water to make 1 gallon

This solution was rinsed from the metal in cold distilled water. The magnesium pieces were then treated for 15 to 30 seconds at room temperatures in the Iridite 15 solution prepared from:

- 5 ounces of Iridite 15 Compound
- 7.5 fluid ounces of concentrated hydrochloric acid (20° Be.)
- 1 milliliter of ARP 2 Detergent
- Enough distilled water to make 1 gallon

The Iridite 15 and ARP 2 Detergent are products of Allied Research Products, Inc., 4004 E. Monument Street, Baltimore 5, Md. The surfaces of the pieces were rinsed in cold and then hot distilled water at 140° to 160° F. and force dried at 110° F. in front of a circulating fan. The resultant coating was hard and uniformly dark brown in color. The surface changed to a brownish-black color on heating during the cure of the adhesive bonds.

Dichromate Seal. -- The dichromate seal treatment is a conventional method (2, 12) used as a corrosion-resistant paint-base treatment for magnesium surfaces. Its use is outlined in Specification MIL-A-3171, Type III. It is commonly designated as Dow 7 treatment (7).

The pieces of magnesium were first degreased by methods (A), (B), and (D). The surfaces were then etched by a 1-minute treatment at 70° to 90° F. in a solution of:

- 1 part by volume of 60 percent hydrofluoric acid
- 2 parts by volume of distilled water

After removal from this solution, the pieces were thoroughly rinsed in cold distilled water and then sealed by boiling for 30 minutes in a solution of:

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24 ounces of sodium dichromate  
0.3 ounce of calcium fluoride  
Enough distilled water to make 1 gallon of solution

The pH of this solution was maintained during use in the range of 4.2 to 4.5 by addition of suitable amounts of chromic acid in order to obtain proper coating formation.

After removal from this solution, the pieces were rinsed successively in cold and hot distilled water and then force dried at 110° F. The coating obtained by the above treatment was thin, smooth, and uniformly medium brown in color. This color changed to golden brown on heating during the cure of the adhesive bonds.

Acid anodize treatment. -- The acid anodize treatment used in this study was the low-voltage Dow 17 treatment (3, 7). The pieces of magnesium were first degreased by methods (A), (B), and (D). The pieces were then immersed for 3 minutes at room temperatures in a solution of:

24 ounces of chromic acid  
4 ounces of sodium nitrate  
Enough distilled water to make 1 gallon

The pieces were then rinsed in cold distilled water following the treatment. The sheets were then anodized for 3 minutes at 160° to 180° F. in a solution of:

32 ounces of ammonium acid fluoride  
13.3 ounces of sodium dichromate  
11.5 fluid ounces of 85 percent phosphoric acid  
Enough distilled water to make 1 gallon

Two pieces were anodized in each operation with an alternating current. The two pieces acted as electrodes as the current was applied between them. Forty volts was applied at the start of the test. A current of 15 to 20 amperes per square foot of electrode surface was maintained by gradually increasing the voltage to 50 volts after 1 minute, 60 volts after 2 minutes, and 67 volts after 3 minutes. The pieces were then rinsed in cold and then hot distilled water at 140° to 160° F. and force dried at 110° F. in front of a circulating fan. The resultant coating was smooth, hard, and had a uniformly light-green color.

Manodyze treatment. -- The Manodyze treatment is an anodize treatment developed and licensed (14) by Convair and is reported (6) to be used in combination with zinc chromate prime coats in preparing magnesium for adhesive bonding. The magnesium pieces for this study were treated following the general procedure of these methods, except that no zinc chromate prime coating was used.
The metal sheets were first degreased by methods (A), (B), and (E). The pieces were then etched for 3 minutes at room temperatures in a solution of:

- 24 ounces of chromic acid
- 4 ounces of sodium nitrate
- Enough distilled water to make 1 gallon of solution

This solution was intended to remove any remaining surface coatings. The solution was then rinsed from the metal in cold distilled water.

Following this treatment, the pieces of magnesium were etched by dipping for 5 to 10 seconds at room temperatures of 70° to 90° F. in a solution of:

- 4.3 ounces of concentrated sulfuric acid (specific gravity 1.84)
- 2.8 ounces of concentrated nitric acid (specific gravity 1.42)
- Enough distilled water to make 1 gallon of solution

Immediately following this acid etch treatment and rinsing in cold distilled water, the pieces were anodized by treatment for 5 minutes at 180° to 200° F. in a solution of:

- 40.0 ounces of sodium hydroxide
- 0.5 ounce of phenol
- 5.2 ounces of sodium silicate (41° Baume)
- Enough distilled water to make 1 gallon of solution

An alternating current of 25 amperes per square foot of magnesium surface at 4 to 6 volts was applied between the magnesium pieces and the sides of the stainless steel tank while the pieces were in the solution. Magnesium clips were used to attach the leads to the magnesium pieces.

After removal from the electrolytic solution, the metal pieces were rinsed in cold distilled water and then immersed for 5 minutes in hot distilled water at 180° to 200° F. A final rinse treatment of 1 to 1-1/2 minutes was given at 135° to 145° F. in a solution of 0.08 ounce of chromic acid in 1.0 gallon of distilled water. This rinse was followed by forced drying at 110° F. in front of a circulating fan. The resultant coating was light gray-green in color, and darkened to gray and gray-black when heated during the cure of the adhesive bond.

HAE treatment. -- The HAE treatment is an alkaline anodizing process (12) for applying protective coatings to magnesium. This treatment was developed at the Frankford Arsenal. All pieces used in this study were treated at the Frankford Arsenal. All conditions of treatment cited were as reported by the Arsenal staff. Several variations of this process were used in the surface treatment of magnesium for this study. The principal work was done with a tan "oatmeal" coating, which, although reported by the Frankford Arsenal to have less corrosion resistance than heavy coatings, is less brittle.
The general procedure used in preparing these magnesium pieces with the tan treatment was to degrease by method (D) in which hot sodium hydroxide solution was used, and then anodize for 6 to 10 minutes, depending on the current density used, in a solution of:

- 1 ounce of aluminum (2S) dissolved in
- 20 to 22 ounces of potassium hydroxide, to which was added
- 4.5 ounces of potassium fluoride
- 4.5 ounces of trisodium phosphate
- 2.5 ounces of potassium manganate
- Enough distilled water to make 1 gallon of solution

An alternating current was applied between two sets of the metal pieces immersed in the solution. The automatic current regulator was set at the required amperage. Starting at zero, the voltage was automatically raised to between 40 to 45 volts within 1 second. Thereafter the voltage was automatically adjusted to maintain a current density of about 20 amperes per square foot of total metal surface immersed in the bath during the anodizing operation. The final operating voltage was 60 to 62 volts. The temperature of the solution was 0° to 5° F. No cooling was necessary since the length of treatment was about 8 minutes, and the rise in temperature was very slight.

After a rinse in cold water, the pieces were given a 1-minute dip in a solution of 20 grams of sodium dichromate and 100 grams of ammonium bifluoride per liter of solution. The pieces were then dried without rinsing and were subjected to a humid atmosphere for 7 hours at 170° to 175° F. The resultant coating was tan in color.

Investigations limited to original dry strength tests were also made using hard-type and low-voltage HAE treatments. The hard-type, deep-brown coating was produced under similar conditions to the tan coating, except that the treating time was 45 to 60 minutes. The olive-drab coating produced at low voltage was obtained by increasing the temperature of the anodizing solution to between 132° and 140° F., and using an alternating current density of 40 amperes per square foot of metal surface at 9 volts for 20 to 25 minutes.

**Exposure and Testing**

From the 14 test panels prepared with each surface treatment and adhesive process, 2 panels were selected for original room-temperature control tests at 72° to 76° F., and the remaining 12 panels were subjected to the following exposure conditions:
<table>
<thead>
<tr>
<th>No. of panels</th>
<th>Exposure conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>150 hours in oven at 250° ±2° F.</td>
</tr>
<tr>
<td>2</td>
<td>6 months at 120° F. and 97 percent relative humidity. Panels were exposed vertically with the overlap edge in a horizontal position. The panels were exposed over water in a closed steel container maintained at 120° ±2° F. The test panels were spaced so that they did not touch each other or the container.</td>
</tr>
<tr>
<td>2</td>
<td>30 days' exposure in a commercial salt-water spray chamber in accordance with Military Specification MIL-A-5090B. Panels were exposed vertically with the overlap edge at an angle of approximately 35° from the horizontal position. The principal path of salt-water spray was parallel to the face of the panels. The temperature of the chamber was maintained at 95° ±2° F.</td>
</tr>
<tr>
<td>6</td>
<td>Exposure at Navy Bureau of Aeronautics' Fisher Island, Miami, Fla., tidewater site. Test panels were mounted on creosote-treated wood frames using ceramic insulators and stainless steel screws as shown in figure 2. This procedure was one recommended by personnel experienced in the exposure of magnesium metal. No stress was applied to the test panels by this mounting procedure. These frames were exposed on the racks at an angle of 45° and facing south. These frames were so mounted that the overlap edge of the exposed face of all panels faced downward. Inspections were made by Navy personnel after 3 months of exposure. Many of the test panels were lost by being washed away during this period, presumably because of corroding away of metal around the insulators (fig. 2) and a loss of adequate fastening. The remaining panels were then removed for test after this 3 months of exposure.</td>
</tr>
</tbody>
</table>

After exposure, each of the 4- by 5-1/2-inch test panels was cut into three 1-inch-wide overlap specimens (fig. 1) with a metal-cutting bandsaw. The edges of the exposed panels were discarded. These lap-joint specimens were then tested, as in the original control tests by loading them in tension to failure at a rate of 600 pounds per minute. The ends of the specimens were held during the testing in 1-inch-wide, Templin-type grips that extended down to within 1 inch of the edge of the overlap. Testing was done at a temperature of 72° to 76° F.
Additional Tests

In addition to the regular evaluation program as outlined, the following additional treating and adhesive bonding tests were also made using 3- by 4-inch pieces of 0.064-inch magnesium alloy.

(1) Pieces of the AZ31-H24 magnesium alloy were treated for bonding using a treating method that had been found to give good results in tests by the Franklin Institute (15). The treatment consisted of degreasing the pieces by methods (A), (B), and (C), as described in the section on degreasing treatments, and then immersing them for 15 minutes at 150° F. in a 20 percent solution by weight of chromic acid. The pieces were rinsed in cold distilled water and force dried at 110° F. in front of a circulating fan. Six test panels were bonded with each of the five adhesives included in this program. These panels were exposed as follows: 2 panels were exposed for 6 months at 120° F. and 97 percent relative humidity, 2 panels were used for the 30-day salt-water spray exposure, and 2 panels were cut into specimens and tested at normal room-temperature conditions. After exposure, test specimens were cut and tested as previously described.

(2) Pieces of AZ31-H24 magnesium alloy were prepared for bonding with the acid anodize (Dow 17) treatment using 2, 4, and 6 minute total anodizing periods. For each of these periods, 2 test panels were bonded with Scotchweld AF-6 Film and 2 with Bloomingdale FM-47 Film. Tests on 1-inch-wide specimens cut from these panels were made under standard room-temperature conditions only.

(3) Pieces of HK31-H24 magnesium alloy which contain 3 percent thorium and 7.3 percent zirconium, were used in an attempt to obtain effective surface treatments by use of the following methods: deoxidation, modified deoxidation, Iridite 15 process, dichromate seal, acid anodize, and HAE treatment. The pieces taking satisfactory treatment as judged by color uniformity were then bonded with Metlbond 4021 and with Epon VIII adhesive to furnish six test panels with each adhesive and treatment. These panels were exposed, as in the regular study; namely, 2 panels were exposed for 6 months at 120° F. and 97 percent relative humidity, 2 panels were used for the 30-day salt-water spray exposure, and 2 panels were cut into specimens and tested at normal room-temperature conditions.

(4) Pieces of AZ31-H24 magnesium were bonded using each of the film adhesives, Metlbond 4021, FM-47 Film, Redux 775 Film, and Scotchweld AF-6, after these films had been exposed for 5 weeks at 80° F. and 90 percent relative humidity. The films were unrolled and protective plastic liners were removed prior to being hung up as sheets in this atmospheric condition. This
work was done to simulate an extreme condition when films might be improperly stored under conditions that result in a high percentage of moisture being retained within the film.

Pretreatment of the magnesium pieces was done using the modified deoxidize, Iridite 15, and acid anodize (Dow 17) treatments. Six panels were prepared with each adhesive-surface treatment combination, and 2 panels were exposed for 6 months at 120° F. and 97 percent relative humidity, 2 panels were exposed for 30 days to a salt-water spray condition, and 2 panels were cut into specimens and tested at normal room-temperature conditions.

Results

The results of the bonding tests of the AZ31-H24 magnesium sheets prepared with the various surface treatments are given in tables 2, regular deoxidize; 3, modified deoxidize; 4, Iridite 15; 5, dichromate seal Dow 7; 6, acid anodize Dow 17; 7, Manodyze; and 8, HAE.

Original Tests

The original bonding properties of the various surface treatments on the magnesium depended in many instances on the type of adhesive being used. Good bonding with lap shear strength values of 2,000 to 3,000 pounds per square inch was obtained with Bloomingdale FM-47 Film, Redux 775 Film, and Epon VIII Adhesive to the surfaces given the deoxidize treatment (chromic-nitric-fluoride). The less rigid adhesives, Metlbond 4021 and Scotchwel AF-6, gave bonds of lower strength to this surface. This same general trend occurred when using the modified deoxidize treatment (chromic-acetic), except that the bonding with the Metlbond 4021 improved so as to attain a joint strength of 2,203 pounds per square inch. The highest average strength of 3,056 pounds per square inch was obtained in this study with FM-47 Film bonds to magnesium treated by this modified deoxidize method.

The trends, however, were reversed on magnesium treated by dichromate seal, acid anodize, and Manodyze treatments in that the less rigid adhesives, Metlbond 4021, and Scotchwel AF-6, generally gave better results than the three rigid adhesives. With many of these rigid adhesives, failures at the lower loads were within the coatings produced by treatments on the magnesium surfaces. This indicates that the more flexible adhesive bonds are probably desirable in order to distribute stresses more uniformly over these brittle surface coatings. An exception was in the bonding to surfaces treated by the
Manodyze process, in which bonds with Epon VIII adhesive were stronger than those made with Metlbond 4021. Strength values of more than 2,000 pounds per square inch were obtained with either Scotchweld AF-6 or Metlbond 4021 applied to the surfaces treated by dichromate seal, acid anodize, or Manodyze methods, whereas none of the other three adhesives ever reached this level on any of these treated surfaces.

All adhesive processes gave similar results on the surfaces treated by the Iridite process. Average strength values in the range of 1,371 to 1,995 pounds per square inch were obtained on such surfaces.

**Heat-Aging Test**

The exposure of the bonds for 150 hours to a temperature of 250° F., before testing at normal room temperatures, significantly effected only those bonds made with Redux 775 Film. With this adhesive there was a decrease in bond strength values of 30 to 50 percent, particularly for those bonds that had original strength values of more than 1,300 pounds per square inch. These bonds with Redux 775 Film were cured at 300° F.; a condition that is no longer recommended by the manufacturer for optimum results. The use of a higher curing temperature with this adhesive might have reduced deterioration at this condition.

**High Humidity and Salt-Water Spray Aging**

The exposure of the bonded panels to 120° F. and 97 percent relative humidity for 6 months and to a salt-water spray condition for 30 days in a spray of a solution of 20 percent salt caused a decrease in the strength of many of the adhesive bonds. The decrease in strength was generally greatest in those panels exposed to high humidity, except for the bonds of Metlbond 4021 and Scotchweld AF-6 to the surfaces that were treated with deoxidize or modified deoxidize treatments (tables 2 and 3). These latter bonds showed only moderate decreases in strength when exposed to the high humidity conditions, but had low strength values after exposure to salt-water spray conditions. The panels treated by the deoxidize methods generally showed the greater amount of corrosion of the facings in both exposures, and the bond strength values after exposure were generally low, with a complete failure of panels bonded with Epon VIII and exposed to the high humidity aging.

The decrease in bond strength values in panels prepared with magnesium treated with Iridite 15 (table 4) was not great for those exposed to the salt-water spray but strength values with all adhesives were less than 1,000
pounds per square inch after exposure to the high humidity condition. The bonds to the Manodyze-treated surfaces (table 7) generally had low strength values after aging at these two conditions, with only bonds made with Scotch-weld AF-6 showing strength values of more than 1,000 pounds per square inch.

The best general performance in these aging tests was obtained on those surfaces treated by the acid anodize Dow 17 process (table 6), as used in this study, with only Epon VIII bonds exposed to the high-humidity test failing to have a strength of at least 1,000 pounds per square inch after exposure. The best overall performance for any adhesive was obtained when bonding the magnesium surfaces treated by the acid anodize Dow 17 process with Scotch-weld AF-6 Film. These bonds had strength values of more than 2,500 pounds per square inch after exposure to high humidity and to salt-water spray aging conditions, as well as in the original test, and after exposure for 150 hours to a temperature of 250° F.

The faces of most of the test panels exposed to the salt-water spray showed evidence of extreme corrosion, especially those panels prepared with the deoxidize treatments. A typical group of test panels after exposure to the salt-water spray is shown in figure 3. Panels treated with the Iridite 15 and with acid anodize Dow 17 showed the best corrosion resistance based on visual examination of panels after exposure. The HAE treatment also gave good protection, particularly in later tests with HK31-H24 magnesium. Corrosion was so complete in some of the panels treated with the deoxidize methods that often there were holes completely through the 0.064-inch-thick sheets. The corrosion on the faces of the panels exposed to the high-humidity condition was less severe than that from the salt-water spray exposure, but again it was the panels with the deoxidize treatments that had the greater amount of corrosion.

There was evidence of appreciable corrosion within the bond line of some of the panels prepared with magnesium treated by the deoxidize methods. The only other instance in which appreciable corrosion was noted within the bond line was in one group of panels treated with the Manodyze process. There was a decided change in the appearance of some of the Scotchweld AF-6, Metlbond 4021, Redux 775, and FM-47 Adhesive Films in the bond line of the deoxidize-treated panels exposed to the high humidity and salt-water spray conditions, in that the films changed to a deep-red color.

Tidewater Immersion

Most of the panels exposed in the Florida tidewater site were lost during exposure, presumably because of corroding away of metal (fig. 4) around...
the mounting insulators. One set of panels in which the magnesium surfaces had been treated with Iridite 15 were saved, however, and tested after 3 months of exposure. The results of these tests are included in table 4. The reduction in joint strength from the original strength values was generally less than 20 percent, except for the Epon VIII bonds that had only about 50 percent of their original strength. Typical appearance of these exposed panels are shown in figure 4. In general the results of the 3 months' tide-water exposure more closely approximated the results obtained in the 30-day salt-water spray exposure than they did the results of the 6 months' high-humidity exposure.

**Additional Tests**

**Franklin Institute Method of Surface Treatment.** -- The results of tests made of the bonds to magnesium surfaces treated by the Franklin Institute Method (15), which included immersion of the magnesium panels for 15 minutes at 150° F. in a 20 percent by weight chromic acid solution, are given in table 9. These results indicate from original dry tests and tests made after 6 months of high humidity or 30 days' salt-water spray exposure that the bonding is generally similar to that obtained on surfaces treated by the regular deoxidize method (table 2). An exception was in the bonding with Redux 775 Film, in which exceptionally high strength values of more than 3,100 pounds per square inch were obtained in the original test and after high humidity and salt-water spray exposure when the Franklin Institute treating method was used. There was considerable corrosion of the metal faces in the salt-water spray exposure to the same extent as was noted for panels treated by the deoxidize and modified deoxidize methods. Because of the pitting of the faces of these panels in the salt-water spray and the lowering of the tensile strength of the sheets, the Redux-bonded specimens, exposed at this condition, failed during test at a high stress in the metal sheet instead of in the adhesive bond. Exposure of bonds made to the Franklin Institute treated magnesium with Metlbond 4021 and Epon VIII again confirmed the result obtained in the tests on the deoxidized magnesium (table 2); namely, that the high humidity exposure had an extremely deleterious effect on bonds with Epon VIII, but on bonds with Metlbond 4021 it was the salt-water spray exposure that caused the severe deterioration.

**Treating Time with Acid Anodize Dow 17 Process.** -- The results of tests of bonds made with FM-47 Film and with Scotchweld AF-6 Film to the AZ31-H24 magnesium treated by the acid anodize Dow 17 process for 2-, 4-, and 6-minute total anodizing periods are shown in table 10.
These results indicated that the quality of original bonding to magnesium is lowered by the use of longer treating periods with methods such as the acid anodize (Dow 17) process. These results also confirmed the results obtained in the earlier tests (table 6) which showed better bonding to this type of surface with Scotchweld AF-6 Film than with Bloomingdale FM-47 Film.

Tests with HK31-H24 Magnesium. -- In attempts to apply surface treatments to HK31-H24 magnesium, the deoxidize and modified deoxidize methods gave surfaces that were brighter than were obtained on AZ31-H24 magnesium. The Iridite treatment produced brown-colored coatings that appeared to be powdery and loose from the surface. The dichromate seal (Dow 7) and acid anodize (Dow 17) processes produced thin and erratic coatings. No attempts were made to modify the methods from those regularly used in order to obtain successful treatments by these surface treating methods. The HAE coatings were applied by the Frankford Arsenal, and appeared to be of similar characteristics to those obtained with this treatment on AZ31-H24 magnesium.

Sufficient panels for bonding tests were prepared with only the deoxidize and modified deoxidize, the Iridite, and the HAE methods. The results of these bonding tests are given in table 11. With the two adhesives used, Metlbond 4021 and Epon VIII, the original dry test gave strength values of 1,500 to 2,000 pounds per square inch, except strength values below this range were obtained with Metlbond 4021 applied to surfaces treated by the deoxidize method and with Epon VIII applied to the surfaces treated with HAE method. These exceptions agree with results obtained in the original phase of the study. There was usually a slight reduction in strength of practically all of the bonded panels after a 30-day exposure in the salt-water spray chamber, the greatest effect being on Metlbond 4021 bonds with the deoxidize treatment. Exposure of the bonded panels to high humidity caused complete failure of the Epon VIII bonds to the magnesium surfaces treated by the deoxidize and modified deoxidize methods and considerable loss in strength of the Epon VIII bonds to the surfaces treated with the Iridite treatment.

Films Exposed to High Humidity. -- The results of the bond tests made to AZ31-H24 magnesium, using adhesive films which had been exposed for 5 weeks at 80°F. and 90 percent relative humidity prior to use, are summarized in table 12. The Redux 775 Film and FM-47 Film, themselves, did not appear to be physically affected by the prior high-humidity exposure. The Metlbond 4021 Film changed from a tan to a deep-red color, and AF-6 Film stretched and changed to a milky tan color.

When moist adhesive films were used, the original dry strength values with Metlbond 4021 in bonding to the deoxidized and Iridite-treated surfaces (table 12) were much lower than in the original tests with properly stored films.
(tables 3 and 4). Bloomingdale FM-47 and Redux 775 Films, when exposed to the high-humidity condition, also showed lower dry strength values in the bonds to the Iridite-treated and acid anodize (Dow 17) treated surfaces, (table 12).

The bond strength values obtained after salt-water spray or high-humidity exposure were in several instances lower when humidified films were used than those obtained with the original films. This was particularly true in cases where FM-47 and Redux 775 Films were applied to the Iridite-treated surfaces. However, good strength values, much better than the original values obtained with properly stored film, were obtained after salt-water spray exposure of the bonds made with humidified Scotchweld AF-6 Film to the surfaces treated with the modified deoxidize method. This latter result may indicate abnormally low results in the original salt-water spray exposure tests (table 3) made to this surface with the properly stored Scotchweld film. Generally, humidification of the films before bonding to magnesium was undesirable, regardless of the surface treatment used.

These tests again confirmed the earlier performance of Scotchweld AF-6 on magnesium surfaces treated with acid anodize (Dow 17) in that strength values of more than 2,500 pounds per square inch were obtained in both original dry-strength tests and after high-humidity and salt-water spray exposure.
References

(1) Allied Research Products, Inc.

(2) Boeing Airplane Co.

(3)

(4) Chance Vought Aircraft, Inc.

(5)

(6) Convair

(7) Dow Chemical Co.

(8) Eickner, H. W. and Schowalter, W. E.

(9)
Eickner, H. W. and Schowalter, W. E.


Frankfort Arsenal
1954. Recommended Practice for the Operation of the HAE Process for Magnesium.

Hay, T. K., Bechtle, G. F., Schurr, G. G., and Van Loo, M.

Hanson-Van Winkle-Munning Co.

Munchnick, S. M.

Shane, R. S., Eriksson, T. L., Korczak, A., and Conklin, D. B.

U. S. Military Specification MIL-M-3171
Table 1.--Bonding conditions used in preparation of test panels

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Spread</th>
<th>Assembly time</th>
<th>Pressure</th>
<th>Cure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metlbond 4021 (2021)</td>
<td>0.0005-inch spray coat</td>
<td>16 to 20 hours air dry</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>(402)</td>
<td>1 layer film</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bloomingdale FM-47 Film</td>
<td>1 spray coat and 1 layer film</td>
<td>16 to 20 hours air dry, 1 hour at 220° F.</td>
<td>200</td>
<td>1/39</td>
</tr>
<tr>
<td>Scotchwel AF-6 Film</td>
<td>1 layer film</td>
<td></td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Redux 775 Film</td>
<td>1 layer film</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Epon Adhesive VIII</td>
<td>1 medium coat</td>
<td>Immediate</td>
<td></td>
<td>10 to 15</td>
</tr>
</tbody>
</table>

1\(^\text{First 9 minutes without pressure.}\)  
2\(^\text{Cooled under pressure.}\)
### Table 2: Results of tests of bonding AZ31-BP magnesium given dezoxidize (chronic-nitrate-fluoride) treatment

| Test or exposure condition | Test results for 1<sup>st</sup>  
|---------------------------|---------------------------------
|                           | Metalbond 4021  
|                           | Bloomingdale FM-47 Film  
|                           | Redux 775 Film  
|                           | Epoxy Adhesive VIII  
|                           | Scotchwell AF-6  
|                           | shear  
|                           | Average: Adhesive failure  
|                           | peak shear  
|                           | Cohesion: Adhesion  

<table>
<thead>
<tr>
<th>Controls, 72° to 76° F.</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,100</td>
<td>0</td>
<td>2,200</td>
<td>0</td>
<td>1,000</td>
<td>0</td>
<td>2,100</td>
<td>0</td>
<td>1,900</td>
<td>0</td>
<td>1,800</td>
<td>0</td>
</tr>
</tbody>
</table>

1<sup>st</sup> Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.

2<sup>nd</sup> The values in parentheses represent the percent of the bond area in which corrosion was observed.

### Table 3: Results of tests of bonding AZ31-BP magnesium given modified dezoxidize (chronic-acetic) treatment

| Test or exposure condition | Test results for 1<sup>st</sup>  
|---------------------------|---------------------------------
|                           | Metalbond 4021  
|                           | Bloomingdale FM-47 Film  
|                           | Redux 775 Film  
|                           | Epoxy Adhesive VIII  
|                           | Scotchwell AF-6  
|                           | shear  
|                           | Average: Adhesive failure  
|                           | peak shear  
|                           | Cohesion: Adhesion  

<table>
<thead>
<tr>
<th>Controls, 72° to 76° F.</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
<th>P.s.i.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,100</td>
<td>0</td>
<td>2,200</td>
<td>0</td>
<td>1,000</td>
<td>0</td>
<td>2,100</td>
<td>0</td>
<td>1,900</td>
<td>0</td>
<td>1,800</td>
<td>0</td>
</tr>
</tbody>
</table>

1<sup>st</sup> Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.

2<sup>nd</sup> The values in parentheses represent the percent of the bond area in which corrosion was observed.
Table 4.--Results of tests of bonding AZ31-M24 magnesium given Tritone 15 treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Metbond 4021</th>
<th>Bloomingdale FM-47 Film</th>
<th>Redux 775 Film</th>
<th>Epon VIII Adhesive</th>
<th>Scotchwell AF-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.S.I.</td>
<td>Percent</td>
<td>P.S.I.</td>
<td>Percent</td>
<td>P.S.I.</td>
</tr>
<tr>
<td>Controls, 72° to 78° F.</td>
<td>1,540</td>
<td>100</td>
<td>0</td>
<td>1,520</td>
<td>0</td>
</tr>
<tr>
<td>Exposed for 150 hours at 200° F.</td>
<td>1,799</td>
<td>100</td>
<td>0</td>
<td>1,173</td>
<td>0</td>
</tr>
<tr>
<td>Exposed for 6 months at 150° F. and 67% relative humidity</td>
<td>338</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>777</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>1,680</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>1,240</td>
</tr>
<tr>
<td>1 month at Florida</td>
<td>1,569</td>
<td>0</td>
<td>0</td>
<td>167</td>
<td>0</td>
</tr>
</tbody>
</table>

*Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.*

Table 5.--Results of tests of bonding AZ31-M24 magnesium given WIL-421 type III (Low T) treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Metbond 4021</th>
<th>Bloomingdale FM-47 Film</th>
<th>Redux 775 Film</th>
<th>Epon VIII Adhesive</th>
<th>Scotchwell AF-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.S.I.</td>
<td>Percent</td>
<td>P.S.I.</td>
<td>Percent</td>
<td>P.S.I.</td>
</tr>
<tr>
<td>Controls, 72° to 78° F.</td>
<td>2,155</td>
<td>0</td>
<td>12</td>
<td>1,583</td>
<td>0</td>
</tr>
<tr>
<td>Exposed for 150 hours at 200° F.</td>
<td>2,285</td>
<td>0</td>
<td>0</td>
<td>1,946</td>
<td>0</td>
</tr>
<tr>
<td>Exposed for 6 months at 150° F. and 67% relative humidity</td>
<td>1,535</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>1,043</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>1,690</td>
<td>0</td>
<td>0</td>
<td>160(1/2)</td>
<td>0</td>
</tr>
</tbody>
</table>

*Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.*

*The values in parentheses represent the percent of the bond area in which corrosion was observed.*
### Table 6. Results of tests of bonding 631-S magnesium given alkaline anodize (Dev 17) treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Method 4001</th>
<th>Bloomingdale PM-47 Film</th>
<th>Redux 775 Film</th>
<th>Epon VIII Adhesive</th>
<th>Scotchwell AF-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls, 72° to 76° F.</td>
<td>1,115</td>
<td>2,556</td>
<td>69</td>
<td>1,638</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 150 hours at 295° F.</td>
<td>1,412</td>
<td>1,478</td>
<td>78</td>
<td>1,172</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 6 months at 120° F. and 97 percent relative humidity</td>
<td>1,197</td>
<td>1,333</td>
<td>86</td>
<td>1,259</td>
<td>75</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>1,660</td>
<td>1,460</td>
<td>81</td>
<td>1,660</td>
<td>75</td>
</tr>
</tbody>
</table>

Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.004-inch-thick magnesium sheets overlapped for 1/2 inch.

### Table 7. Results of tests of bonding 631-S magnesium given Macoris treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Method 4001</th>
<th>Bloomingdale PM-47 Film</th>
<th>Redux 775 Film</th>
<th>Epon VIII Adhesive</th>
<th>Scotchwell AF-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls, 72° to 76° F.</td>
<td>1,328</td>
<td>100</td>
<td>100</td>
<td>1,844</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 150 hours at 295° F.</td>
<td>1,412</td>
<td>100</td>
<td>90</td>
<td>1,146</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 6 months at 120° F. and 97 percent relative humidity</td>
<td>783</td>
<td>100</td>
<td>100</td>
<td>1,435</td>
<td>17</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>990</td>
<td>100</td>
<td>100</td>
<td>1,380</td>
<td>93</td>
</tr>
</tbody>
</table>

Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.004-inch-thick magnesium sheets overlapped for 1/2 inch.

1. Test panels failed during sawing into individual specimens.
2. The values in parentheses represent the percent of the bond area in which corrosion was observed.
Table 8.—Results of tests of bonding A531-B34 magnesium given Epo (tan octane) treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Test results for 1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>Test results for 2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>Test results for Epo Adhesive VII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National 4021</td>
<td>Bloomingdale 94-47 Film</td>
<td>Redox 775 Film</td>
</tr>
<tr>
<td>Controls, 72° to 76° F.</td>
<td>1,218</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>(Low-voltage)</td>
<td>593</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Exposed for 150 hours at 200° F.</td>
<td>1,642</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 6 months at 120° F. and 97 percent relative humidity</td>
<td>1,468</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>1,468</td>
<td>0</td>
<td>44</td>
</tr>
</tbody>
</table>

1Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/4 inch.

Table 9.—Results of tests of bonding A531-B34 magnesium given chromic acid etch (Franklin Institute) treatment

<table>
<thead>
<tr>
<th>Test or exposure condition</th>
<th>Test results for 1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>Test results for 2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>Test results for Epo Adhesive VII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National 4021</td>
<td>Bloomingdale 94-47 Film</td>
<td>Redox 775 Film</td>
</tr>
<tr>
<td>Controls, 72° to 76° F.</td>
<td>1,218</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>Exposed for 6 months at 120° F. and 97 percent relative humidity</td>
<td>1,468</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Exposed for 30 days in salt-water spray</td>
<td>1,468</td>
<td>0</td>
<td>44</td>
</tr>
</tbody>
</table>

1Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.
2The values in parentheses represent the percent of the bond area in which corrosion was observed.
3Failure in tension of the badly corroded metal.
Table 10.—Results of tests of bonds made with FM-47 Film and with Scotch weld AF-6 Film to AZ31-E24 magnesium treated by the acid anodize (Dow 17) process

<table>
<thead>
<tr>
<th>Treating time</th>
<th>Bloomingdale FM-47 Film</th>
<th>Scotch weld AF-6 Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Dow 17) method</td>
<td>Average</td>
<td>Failure</td>
</tr>
<tr>
<td></td>
<td>shear</td>
<td>strength</td>
</tr>
<tr>
<td>Minutes</td>
<td>P.s.i.</td>
<td>Percent</td>
</tr>
<tr>
<td>2</td>
<td>1,480</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1,208</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1,028</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 11.—Results of tests of bonding HK31-H24 magnesium given various surface treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Test condition</th>
<th>Test results for 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deoxidize</td>
<td>Original dry test</td>
<td>Metlbond 4021</td>
</tr>
<tr>
<td></td>
<td>:6 months at 120° F., 97</td>
<td>:Average: Adhesive failure</td>
</tr>
<tr>
<td></td>
<td>1,482</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>887</td>
<td>0</td>
</tr>
<tr>
<td>Modified</td>
<td>Original dry test</td>
<td>1,716</td>
</tr>
<tr>
<td>deoxidize</td>
<td>:6 months at 120° F., 97</td>
<td>:percent relative humidity:</td>
</tr>
<tr>
<td></td>
<td>:30-day salt-water spray</td>
<td>1,281</td>
</tr>
<tr>
<td>Iridite</td>
<td>Original dry test</td>
<td>1,802</td>
</tr>
<tr>
<td>No. 15</td>
<td>:6 months at 120° F., 97</td>
<td>:percent relative humidity:</td>
</tr>
<tr>
<td></td>
<td>:30-day salt-water spray</td>
<td>1,638</td>
</tr>
<tr>
<td>HAE</td>
<td>Original dry test</td>
<td>2,001</td>
</tr>
<tr>
<td></td>
<td>:6 months at 120° F., 97</td>
<td>:percent relative humidity:</td>
</tr>
<tr>
<td></td>
<td>:30-day salt-water spray</td>
<td>1,758</td>
</tr>
</tbody>
</table>

1 Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3- by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.

2 The values in parentheses represent the percent of the bond area in which corrosion was observed.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Exposure condition</th>
<th>Test results for 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Methbond 4021 : Bloomingdale FM-47 Film : Redux 77 Film : Scotchweild AF-6</td>
</tr>
<tr>
<td>Modified dezodize</td>
<td>Original dry strength : 1,500 : 58 : 42 : 3,203 : 0 : 100 : 0 : 2,156 : 0 : 100 : 0 : 1,731 : 100 : 6 : 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>56 months at 120° F, 97 % humidity : 1,270 : 0 : 100(100) : 362 : 0 : 100(100) : 0 : 260 : 0 : 100(100) : 0 : 1,378 : 8 : 92(83) : 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-day salt-water spray : 689 : 0 : 100(30) : 1,777 : 0 : 100(56) : 0 : 1,620 : 0 : 100(89) : 0 : 2,072 : 35 : 65(65) : 0</td>
<td></td>
</tr>
<tr>
<td>Iridite No. 15</td>
<td>Original dry strength : 1,095 : 100 : 0 : 611 : 0 : 100 : 0 : 597 : 0 : 100 : 0 : 2,359 : 25 : 77 : 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>56 months at 120° F, 97 % humidity : 824 : 69 : 31 : 178 : 0 : 0 : 100 : 214 : 0 : 0 : 100 : 357 : 0 : 100 : 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-day salt-water spray : 899 : 100 : 0 : 533 : 0 : 100 : 0 : 633 : 0 : 100 : 0 : 1,750 : 27 : 26 : 47</td>
<td></td>
</tr>
<tr>
<td>Acid rodize</td>
<td>Original dry strength : 1,276 : 9 : 91 : 458 : 0 : 100 : 0 : 1,022 : 0 : 100 : 0 : 2,525 : 0 : 100 : 0</td>
<td></td>
</tr>
<tr>
<td>Bow 17</td>
<td>56 months at 120° F, 97 % humidity : 1,517 : 0 : 100 : 602 : 0 : 100 : 0 : 630 : 0 : 100(8) : 0 : 2,635 : 0 : 100 : 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-day salt-water spray : 2,826 : 0 : 100 : 508 : 0 : 100 : 0 : 1,245 : 0 : 100 : 0 : 2,529 : 0 : 100 : 0</td>
<td></td>
</tr>
</tbody>
</table>

1 Values given are the average results for tests on 6 specimens, 3 from each of 2 bonded panels. Panels consist of 3-inch by 4-inch 0.064-inch-thick magnesium sheets overlapped for 1/2 inch.

2 The values in parentheses represent the percent of the bond area in which corrosion was observed.
Figure 1. -- Type of overlap test panel prepared with 0.064-inch AZ31-H24 or HK31-H24 magnesium for evaluation of bonding properties.
Figure 2. -- Magnesium test panels as mounted with ceramic insulators on treated-wood panel for tidewater exposure.
Figure 3.—Typical appearance of treated magnesium lap-joint panels after exposure to 30-day salt-water spray condition.
Figure 4. -- Appearance of test panels removed after 3 months of tidewater (Florida) exposure.