LEAD INDUSTRIES ASSOCIATION, INC.

292 MADISON AVENUE
NEW YORK 17, N. Y.

October 23, 1963

SUBJECT: "SOLDERING AND SOLDERING ALLOYS"

To Members of the Lead Industries Association, Inc.:

We are attaching a reprint entitled, "Soldering and Soldering Alloys" which is a section appearing in "The Nonferrous Metals Book Issue" of "Machine Design," September 19, 1963.

The article was prepared by L.I.A. and will be used to handle individual inquiries on solder.

If you would like additional copies they are available up to 25 free of charge with larger quantities at 15¢ each.

Very truly yours,

David M. Borcina
Secretary

DMB:HMK

Look Ahead with Lead

Soldering and Soldering Alloys

Reprinted from

DESIGN

THE NONFERROUS METALS BOOK ISSUE

September 19, 1963

LEAD INDUSTRIES ASSOCIATION, INC.

292 MADISON AVENUE

NEW YORK, N. Y. 10017

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Soldering and Soldering Alloys

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SOLDERING ALLOYS encompass a wide range of alloying elements and properties. About the only thing these alloys have in common is the fact that they are used almost entirely for joining various materials and that they have a liquidus (lowest temperature at which they are completely liquid) of below 800 F.

Solders

Tin-Lead: This is the largest single group and the most widely used of the soldering alloys. Most metals can be joined with these alloys. Joint clearances of 0.003 to 0.005 in. are recommended. Tin-lead solders can be used with all types of cleaning of the base metal, fluxing, and heating methods. Some of the characteristics of these alloys are shown in Table 1.

The lower the tin content of these solders, the poorer the wetting and flow characteristics. Thus, when they are used, greater care is required in the surface preparation of the base metals to be joined.

The highest melting-temperature solder in this group is that classified as 5A. This high-lead alloy is particularly suitable for use where operating temperature of the soldered part may approach 300 F.

The most widely used solders of the tin-lead system are the 35A through 50A classifications. They provide optimum wetting and flow properties, good strength at low temperatures, and require less time to prepare and make the joint. These solders are often referred to as general-purpose solders.

The 60A solder, almost the eutectic, is particularly adaptable to delicate work or when soldering temperature may be critical.

The solder with the highest tin content, 70A, is useful for soldering zinc.

Table 1—Tin-Lead Solders

ASTM Classification	Composition (per cent by weight) Tin	Lead	Temperature (deg F) Solidus	Liquidus	Pasty Range
5A	5	95	572	596	24
10A	10	90	514	573	59
15A	15	85	437	553	116
20A	20	80	361	535	174
25A	25	75	361	511	150
30A	30	70	361	491	130
35A	35	65	361	477	116
40A	40	60	361	460	99
45A	45	55	361	441	80
50A	50	50	361	421	60
60A	60	40	361	374	13
70A	70	30	361	378	17

Table 2—Tin-Antimony-Lead Solders

ASTM Classification	Composition (per cent by weight) Tin	Antimony	Lead	Temperature (deg F) Solidus	Liquidus	Pasty Range
20B	20	1.0	79.0	363	517	154
25B	25	1.3	73.7	364	504	140
30B	30	1.6	68.4	364	482	118
35B	35	1.8	63.2	365	470	105
40B	40	2.0	58.0	365	448	83

Tin-Lead-Antimony: These ternary alloys are generally used, with a few exceptions, in the same applications as the tin-lead solders. They are not recommended for use on aluminum, zinc, or galvanized steel. The addition of antimony to the tin-lead solders up to a maximum of 6 per cent of the tin content does not seriously affect the wettability or flow characteristics, but it does increase the mechanical properties. Table 2 lists the melting characteristics and compositions of some of the more important tin-lead-antimony alloys.

As with the tin-lead alloy system, this ternary alloy can be used with all cleaning, fluxing, and heating methods. Joint-clearance recommendations are the same.

These solders have almost the same properties as equivalent tin-lead solders with about 5 per cent more tin. The physical properties—tensile, creep, and hardness—are greater than the nonantimonial alloys.

Tin-Antimony: The 95 per cent tin-5 per cent antimony solder has the best electrical properties of any of the solder alloys. In addition they have high strength under moderately elevated operating temperatures (up to 300 F), and excellent flow characteristics.

Tin-Silver: The tin-silver alloys exhibit the same characteristics as the tin-antimony solders and are used for delicate instrument work. The characteristics of the solders are given in Table 3.

Tin-Zinc: This group of alloys, Table 4, has recently found widespread application in the soldering of aluminum. The 70 and 80 per cent tin, remainder zinc, is highly recommended. Recently an alloy containing 1 to 2 per

Table 3—Tin-Silver Solders

Composition (per cent by weight) Tin	Silver	Temperature (deg F) Solidus	Liquidus	Pasty Range
96.5	3.5	430	430	0
95	5	430	473	43

Table 6—Cadmium-Zinc Solders

Composition (per cent by weight) Cadmium	Zinc	Temperature (deg F) Solidus	Liquidus	Pasty Range
82.5	17.5	509	509	0
40	60	509	635	126
10	90	509	750	241

Table 4—Tin-Zinc Solders

Composition (per cent by weight) Tin	Zinc	Temperature (deg F) Solidus	Liquidus	Pasty Range
91	9	390	390	0
80	20	390	518	128
70	30	390	592	202
60	40	390	645	255
30	70	390	708	318

Table 5—Lead-Silver Solders

ASTM Classification	Composition (per cent by weight) Lead	Silver	Tin	Temperature (deg F) Solidus	Liquidus	Pasty Range
2.5S	97.5	2.5		579	579	0
5.5S	94.5	5.5		579	689	110
1.5S	97.5	1.5	1.0	588	588	0

cent aluminum, with zinc up to 40 per cent, has been widely used. The addition of aluminum increases resistance to corrosion but also increases the liquidus temperature.

Lead-Silver: The physical properties of these solders—tensile, creep, and shear strengths—are good up to 350 F. Fatigue properties are also better than the non-silver solder alloys. The silver-lead solders, however, have poor wetting characteristics and are subject to humid-atmosphere corrosion in storage. The addition of 1 per cent tin, replacing silver, increases wetting and flow, and reduces susceptibility to corrosion. When tin is added to the lead-silver alloy, the silver content should be limited to 1.5 per cent because above this percentage, segregation occurs. The characteristics of these solders are shown in Table 5.

Cadmium-Zinc: The cadmium-zinc solders, Table 6, are useful in joining aluminum to itself or other metals. It is particularly useful in applications where service temperature is higher than allowed with the lower melting alloys.

Zinc-Aluminum: Designed specifically for soldering aluminum, zinc-aluminum solder provides high joint strength and good corrosion resistance. Its high soldering temperature (720 F) limits its use to those applications where such temperature will not affect other components.

Indium Solders: Indium solders are normally used only in special applications. A representative group of these solders is given in Table 7. These solders generally show good resistance to alkali corrosion. The 50 per cent indium-50 per cent tin alloy is particularly useful for glass-to-glass and glass-to-metal soldering.

Fusible Alloys: These bismuth-containing solders are extremely useful for soldering operations that must be performed at temperatures below 361 F. A representative group of these alloys is shown in Table 8. These solders are generally sensitive to long time loading above room temperatures. The higher bismuth solders in this group are not easily adaptable to high-speed soldering operations nor do they easily wet the base metal.

Table 7—Indium Solder

Composition (per cent by weight) Tin	Indium	Bismuth	Lead	Cadmium	Temperature (deg F) Solidus	Liquidus	Pasty Range
8.3	19.1	44.7	22.6	5.3	117	117	0
12	21	49	18		136	136	0
12.6	4	48	25.6	9.6	142	149	7
50	50				243	260	17
48	52				243	243	0

Table 8—Fusible Alloys

Alloy	Composition (per cent by weight) Lead	Bismuth	Tin	Other	Temperature (deg F) Solidus	Liquidus	Pasty Range
Lipowitz	26.7	50	13.3	10 Cd	158	158	0
Bending (Wood's Metal)	25	50	12.5	12.5 Cd	158	165	7
Eutectic	40	52		8 Cd	197	197	0
Eutectic	32	52.5	15.5		203	203	0
Rose's	28	50	22		204	229	25
Matrix	28.5	48	14.5	9 Sb	217	440	223
Mold and pattern	44.5	55.5			255	255	0

Design Considerations

In designing for the use of the soldering alloys, little, if any, reliance should be placed on the strength of the solder. Instead, the joint should be designed to take advantage of the mechanical properties of the base metal: locking joints, edge reinforcing, or rivets, by the use of such techniques as interlocking.

No matter what type of mechanical method or device is used, there are basically only two types of joints—lap or butt—used in soldering. Lap joints are preferred because of the greater strength they impart to the assembly. Butt joints should be used only where sealing of the assembly is necessary. Fig. 1 illustrates typical designs for soldered joints.

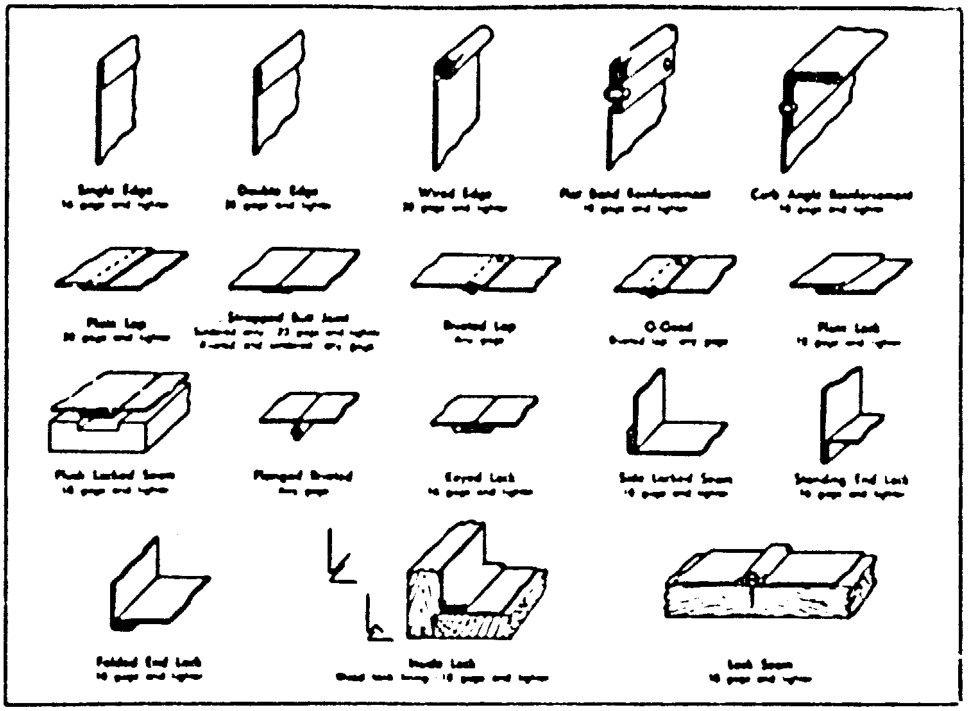

Fig. 1—Typical solder joint designs.

Solder Forms and Shapes

Soldering alloys are commercially available in many sizes and shapes. Typical examples are shown in the following listing. However, practically any desired shape, weight, or size can be obtained:

1. Pig. Available in 50 and 100 lb sizes.
2. Slabs. Weight 15 to 35 lb. Common sizes are 36 x 3 x 1 in., 24 x 3 x ¾ in., and 18 x 3 x ½ in.
3. Cakes or ingots. Rectangular or circular in shape, weighing 3, 5, and 10 lb.
4. Bars. Available in numerous cross-sections, weights, and lengths. Some of the more common sizes and shapes are shown in Table 9.
5. Paste. As-"able as a mixture of powdered solder and suitable flux in paste form in quantities of 1 lb or more.
6. Ribbon or tape. Thickness of 1/16 to 3/16 in., ½ to 1 in. in width, on reels or spools and 12 in. lengths.
7. Segment or drop. Triangular bar or wire cut into pieces or lengths of any desired number up to 200 pieces per lb.
8. Pulverized or powdered. Screen sizes from 50 to 200 mesh.
9. Foil. Thickness from 0.00125 in. up, on rolls 5 to 18 in. wide, weighing 20 to 30 lb.
10. Sheet. Thickness from 0.010 to 0.100 in. in sizes not larger than 24 x 36 in.
11. Wire, solid. Diameters of 0.010 to 0.30 in. on spools weighing 1, 5, 10, 20, 25, 50, or 65 lb.
12. Wire, flux cored. Either acid or rosin core, 1/64, 1/16, 3/64, 3/32, and ⅛ in. in diameter on spools weighing 1, 5, 10, 15, 20, 25, and 50 lb. The flux may be incorporated with the solder in single or multiple hollows or in external parallel grooves.
13. Preforms. Unlimited range of sizes and shapes to meet special requirements.

Table 9—Common Forms of Solder Bars

Trade Designation	Weight (lb)	Length (in.)	Cross Section
Regular	[illegible]	[illegible]	Rectangular
Capping	[illegible]	[illegible]	Square [illegible]
Motor	[illegible]	[illegible]	[illegible]
Triangular	....	[illegible]	[illegible]
Tinner's	....	[illegible]	[illegible]
Auto body	[illegible]	[illegible]	Rectangular, round or [illegible] in. square
Spray gun	.	[illegible]	[illegible] and [illegible] in., round

Materials

Most of the nonferrous metals and alloys can be soldered, Table 10. Solderability depends upon the alloy, the solders available, surface preparation, and soldering techniques. Some alloys require very special solders and/or fluxes, and carefully controlled production methods.

Aluminum and Aluminum Alloys. The soldering of aluminum differs from the soldering of copper, brass, steel, and most other common metals in several ways. The most important difference is that aluminum forms a more tenacious and refractory oxide, which in most cases necessitates the use of active fluxes that are specifically designed for aluminum. Noncorrosive fluxes cannot be used. A second difference is that soldering requires special techniques to produce flow into certain types of joints. A third important difference is that finally the resistance of soldered aluminum joints to corrosion is much more dependent upon the composition of the solder than it is for similar joints in copper, brass, or steel.

Because of these differences, the soldering of aluminum is not as well understood or as extensively used as is the soldering of other common metals. With proper attention to the details, however, a large variety of soldered joints can be made in aluminum base materials, Table 11. The commonly soldered wrought-aluminum alloys are 1060, 1100, 1145, 3003, 3005, 6061, 7072, and 8112. Aluminum castings are generally made of alloys containing substantial amounts of copper, silicon, magnesium, or zinc. As a group, they have poor solderability by virtue of their composition, and are likely to exhibit surface conditions that are detrimental to soldering.

Problems: The difference between the melting point of aluminum alloys and the liquidus temperature of some solders is approximately 470 F. This is substantially less than the 1400 F differential

Table 10—Relative Solderability of Some Nonferrous Metals

Metal or Alloy	Flux Requirements: Non-Corrosive	Corrosive	Special Flux and/or Solder	Soldering Not Recommended
Aluminum			X	
Aluminum Bronze			X	
Beryllium				X
Beryllium Copper		X		
Brass	X	X		
Copper	X	X		
Copper Chromium		X		
Copper Nickel		X		
Copper Silicon		X		
Gold	X			
Lead	X	X		
Magnesium			X	
Manganese Bronze				X
Nickel		X		
Platinum	X			
Silver	X	X		
Tin	X	X		
Titanium				X
Zinc		X		

Table 11—Solderability of Aluminum Alloys

Alloy Group	Typical Alloy	Solderability	Recommended Flux
1XXX	1060	Good	Chemical or reaction
(Commercial purity or higher)	1100	Good	Chemical or reaction
2XXX (Al-Cu)	2014	Poor*	Reaction
3XXX (Al-Mn)	3003	Good	Chemical or reaction
4XXX (Al-Si)	4043	Poor†	None
5XXX‡	5005	Good	Chemical or reaction
(Al-Mg) or	5050, 5154	Fair*	Reaction
(Al-Mg-Mn)	5454, 5083	Poor*	Reaction
6XXX (Al-Mg-Si)	6061	Good*	Reaction
7XXX‡	7072	Good	Reaction
(Al-Zn)	7075	Poor	Reaction
8XXX‡	8112	Good	Reaction
(Al-others)			

*Susceptible to intergranular penetration by solder
†Solderable only with abrasion or ultrasonic techniques
‡Solderability greatly affected by composition

Table 12—Typical Solders for Aluminum

Composition (per cent)	Temperature (F) Solidus	Liquidus	Density (lb per cu in.)	Wetting Ability on Aluminum	Flux Type Commonly Used	Relative Corrosion Resistance
100 Zn	787	787	0.26	Good	Reaction	Very good
95 Zn 5 Al	720	720	0.24	Good	Reaction	Very good
91 Sn 9 Zn	390	390	0.28	Fair	Chemical & reaction	Fair
70 Sn 30 Zn	390	592	0.26	Fair	Reaction	Fair
60 Sn 40 Zn	390	645	0.28	Good	Reaction	Good
30 Sn 70 Zn	390	705	0.26	Good	Reaction	Good
10 Cd 90 Zn	509	750	0.26	Good	Reaction	Fair
40 Cd 60 Zn	509	635	0.28	Very good	Reaction	Fair
34 Sn 63 Pb 3 Zn	350	490	0.34	Poor	Chemical & reaction	Poor

be soldered copper and, therefore, greater care must be taken in heating, especially in the case of complicated assemblies, to prevent melting of the aluminum during soldering. Since the coefficient of linear thermal expansion is greater for aluminum than for most other common metals, greater distortion can be expected in aluminum assemblies than in comparable configurations of copper or steel.

The oxide film that forms on aluminum and aluminum alloys is tenacious and chemically resistant, making the use of corrosive fluxes mandatory in soldering. Since most of the fluxes used on aluminum contain fluorides, the usual precautions should be taken. Scrupulous flux residue removal is also mandatory for most applications.

The use of solders containing high percentages of zinc or tin is usually recommended. The tin-lead solders are not recommended because the joint has poor corrosion resistance and because of a loss of strength due to aging.

The resistance of soldered aluminum joints to corrosion may depend upon the choice of solder, degree of flux residue removal, and the environment to which the joint is exposed. Soldered joints made with tin-lead or other low melting temperature solders must be protected by a suitable paint in any but dry indoor exposure. Unprotected assemblies made using zinc base solders, on the other hand, exhibit long service life even in marine exposure. In most cases, corrosion is accelerated by the presence of electrolytes. It is important, therefore, that the residues of salt-type fluxes be completely removed after soldering.

Solders. Aluminum solders can be grouped into low temperature, intermediate temperature, and high temperature solders. Low temperature solders for aluminum, which melt below about 500 F, are composed primarily of metals such as tin, lead, and cadmium. They also contain higher melting temperature metals such as zinc, aluminum, copper, nickel, and silver. Intermediate temperature solders, which melt between 500 and 725 F, contain appreciable amounts of both lower melting and higher melting temperature metals. High temperature solders, which melt between 725 and 800 F, have zinc as the major constituent, along with small amounts of aluminum, copper, nickel, and silver. The properties of a number of typical solders for aluminum are shown in Table 12.

Copper and Copper Alloys: Copper is one of the easier metals to solder. Nearly all types of solders and fluxes can be used to solder it. The relatively low soldering temperatures required permit joints to be made with a minimum of distortion, softening, and scaling of the work, with minimum damage to electrical insulation and protective coatings.

Table 13—Solderability of Copper and Copper Alloys

Metal	Solderability
Copper (electrolytic tough pitch, oxygen-free, phosphorus-deoxidized, silver-bearing, leaded, tellurium and selenium copper)	Excellent. Need only mild or other noncorrosive flux
Copper-tin alloys	Good. Easily soldered with activated rosin and intermediate fluxes
Copper-zinc alloys	Good. Easily soldered with activated rosin and intermediate fluxes
Copper-nickel alloys	Good. Easily soldered with intermediate and corrosive type fluxes
Copper-chromium and beryllium copper	Good. Require intermediate and corrosive type fluxes
Copper-silicon alloys	Fair. Silicon produces refractory oxides that require use of corrosive fluxes
Copper-aluminum alloys	Difficult. May be soldered with help of very corrosive fluxes
High tensile manganese bronze	Not recommended. Should be plated to insure adequate solderability

Table 14—Characteristics of Commonly Used Solders for Copper and Copper Alloys

Composition (per cent)	Temperature (F) Solidus	Liquidus	Type and Uses
60 tin, 40 lead	361	374	Quick setting solder for fine electrical and instrument work
50 tin, 50 lead	361	421	General purpose solder
95 tin, 5 antimony	452	464	Quick setting solder where creep strength at elevated temperatures is higher than that of the usual tin-lead solders. Especially useful for refrigeration joints and hot water copper tube lines that operate at temperatures up to 250 F

Table 15—Solders for Magnesium

Composition (per cent)	Temperature (F) Solidus	Liquidus	Use
[illegible]	315	[illegible]	Low temperature below 300 F
[illegible]	[illegible]	[illegible]	High temperature above 300 F
[illegible]	[illegible]	[illegible]	Medium temperature below 300 F
[illegible]	[illegible]	[illegible]	High temperature above 300 F
[illegible]	[illegible]	[illegible]	High temperature above 300 F
[illegible]	[illegible]	[illegible]	Precoating solder
[illegible]	[illegible]	[illegible]	Filler solder on precoated surfaces
[illegible]	[illegible]	[illegible]	Precoating solder
[illegible]			Filler solder

The solderability of copper base alloys, as shown in Table 13, ranges from excellent to poor.

Problems. There are no serious problems in soldering most of the copper base metals. However, those alloys with beryllium, silicon, and aluminum require special fluxing. Also, copper-zinc alloys (brasses) should not be soldered with any tin-antimony or tin-lead-antimony solders containing more than 1 per cent of antimony or 0.02 per cent of arsenic. The excess antimony contributes to the brittleness of the joint and the arsenic causes dewetting of the solder from the base metal.

The high thermal conductivity of copper and some of its alloys requires that a high rate of heat input be used if localized heating is necessary.

Solders. Except for the restriction against the use of antimony—or arsenic-bearing solders on brass, all grades of solder can be used on the copper base metals. Possible limitations on the use of any particular solder are generally imposed by production controls and final application. Factors to be considered include maximum allowable soldering temperature, the cost of solder, the joint strength, and other physical properties. The characteristics of some commonly used solders for copper-based metals are shown in Table 14.

Nickel and High-Nickel Alloys. Solder can be employed to join nickel and high-nickel alloys either to themselves or to any other metals that are solderable. Good solderability is displayed by pure nickel and such alloys as Monel, K Monel, Permanickel, and Duranickel. Alloys such as Inconel, Inconel X, and Nimonic 75 have fair solderability. In designing a solder joint in any high-nickel alloy, however, it is advisable to take into consideration some of the special characteristics of the base metal.

Many times, the high-nickel alloys are used for a given application because of their resistance to corrosive attack. When corrosion is a factor, the corrosion resistance of the solder alloy must also be considered. In some cases, it is necessary to locate the joint so that the solder alloy will not be exposed to the corrosive environment. The higher tin content solders, such as 95 tin-5 antimony, may result in a better color match if appearance is important. However, the solder may oxidize in a different manner from the base metal and the joint may become noticeable after exposure.

Problems. If soldering is to be done on any of the age-hardenable materials, the soldering should be done after aging. The temperature involved in soldering will not soften such metals as Duranickel, "K" Monel, and Inconel "X," which have been fully age hardened.

The high-nickel alloys are subject to embrittlement at high temperature when in the presence of lead and many other low melting metals. This embrittlement will not occur at normal soldering temperatures, however, overheating should be avoided. If welding, brazing, or other heating is to be done on an assembly, it is imperative that these operations be done prior to soldering.

Solders. Any of the common types of solders may be used for joining the high-nickel alloys. It is usually desirable, however, to choose a relatively high tin solder such as the 60 tin-40 lead or 50 tin-50 lead composition.

Magnesium and Magnesium Alloys. Magnesium, in common with aluminum and some other metals, tends to form a highly refractory oxide film when heated. This oxide film must either be removed chemically with a flux or broken up mechanically to permit the solder to alloy with the magnesium. Since no satisfactory flux has yet been developed for magnesium, soldering is accomplished chiefly by friction or mechanical abrasion of the oxide film.

All magnesium alloys can be soldered by the above technique but the soldering is used chiefly for filling surface defects in castings, dents in sheets, and repair of magnesium printing plates. Electroplated magnesium alloys are solderable by the usual techniques applicable to the coating metal.

Problems. Since only the friction or fluxless soldering method is used on magnesium, careful cleaning and preliminary surface coating or pretinning with a solder composition having good wetting characteristics toward magnesium is a prime necessity. Surface coating is obtained by rubbing with a stick solder, soldering iron, or some other tool to abrade and break up the oxide film under the solder. Either pure tin or tin-zinc alloys of 90 to 70 per cent tin possess the best wetting characteristics on magnesium. Once the surface is precoated, any other solder composition can be used. The latest development in the friction method is the use of a soldering tool with a vibrating wire or glass-fiber brush. The brush attachment permits abrasion of the oxide coating through the layer of molten solder. This produces uniform precoated joint areas of high quality and low cost.

Another development that shows a great deal of promise for soldering magnesium is the ultrasonic method.

The difficulties associated with fluxless soldering are being overcome by application of plated metallic coatings of easily soldered metals such as copper, tin, zinc, silver, or cadmium. Soldering is then performed by techniques normally used on the coating metal.

Because of its high position in the electrochemical series, galvanic corrosion between magnesium and most solders can be expected to be severe. However, by suitable protective coatings and in the absence of moisture, satisfactory service has been obtained in many applications.

Solders. Solders based on tin, zinc, and cadmium, Table 15, are used the most on magnesium. Lead-containing solders, such as the standard 50 tin-50 lead, can be used but give rise to severe galvanic attack in the presence of moisture. Tin-zinc solders generally have lower melting points and better wetting characteristics than tin-zinc-cadmium but form brittle bonds. The high cadmium solders, especially the 60 cadmium-30 zinc-10 tin, result in the strongest and most ductile joints.

The most widely used current practice consists of pretinning with 70 tin-30 zinc followed by the 60 cadmium-30 zinc-10 tin solder for high strength. In photoengraving repairs, the standard 50 tin-50 lead instead of the cadmium base solder is applied over the pretinned surface in spite of its higher susceptibility to corrosion. In this application, the workability of the solder outweighs other considerations. Also, the normal use and storage of engraved plates is under low or controlled humidity conditions so that corrosion is not a problem.

Reference

Soldering Manual, American Welding Society, 1959, New York, N. Y.