

SOLDERING ALUMINUM

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INTRODUCTION

Soldering provides a simple, economical and highly practical means of joining aluminum using production techniques commonly used with other metals although with some modifications. The properties of aluminum require that special attention be paid to certain details of soldering practice such as surface preparation, proper solder composition, soldering temperature and application of heat to the assembly. With the proper attention to these details, a large variety of soldered joints can readily be made in aluminum base materials. The properties of a metal that affect the ease with which it can be soldered are compared for aluminum, copper and iron in Table I on page 11. These properties are discussed briefly below.

The oxide film present on copper or iron is loosely adherent to the surface, and is easily removed by common fluxing agents such as zinc chloride. However, the oxide film which forms on aluminum is tenacious and chemically resistant, which accounts for the excellent resistance of aluminum to corrosion. In order to remove this oxide film it is necessary to use strong fluxing agents.

The difference between the melting point of the parent metal and solder determines the care that must be exercised in heating the assembly to soldering temperature. This is particularly true where heat must be supplied to the exterior surfaces of a complex assembly, and the interior sections brought to soldering temperature by conduction. Since the difference between the melting points of aluminum and some solders is only 470F compared to 1430F for copper assemblies, greater care obviously must be taken to prevent melting of the aluminum during the soldering operation.

Comparison of the values of specific heat for the several metals gives an indication of the amounts of heat needed to bring equal weights of metal to a given temperature. Since, for a given volume of metal, the weight of aluminum is approximately one-third that of copper or iron, it is apparent that less heat is required to raise a piece of sheet of a given thickness in aluminum to a given temperature than the same sheet in either copper or steel.

Values for heat conductivity indicate the relative amount of heat the surrounding metal will carry away from a given joint to be soldered. The data given in Table I show that an aluminum sheet will conduct approximately three and one-half times the amount of heat away from the joint as a sheet of iron, and approximately half as much as a sheet made of copper, providing all are of the same thickness.

The values for the coefficient of linear expansion can be used as a guide, to some extent, to the relative amount of warpage that can be expected with the several metals when similar assemblies are heated to the same temperature. From the data shown in Table I it is apparent that the distortion expected with aluminum assemblies will be greater than that for either copper or iron assemblies. This has been found to be true in production practice.

The melting point of the solder determines the minimum temperature used to solder an assembly, since the solder must be melted before it will flow into a joint. It will be noted that aluminum must be heated to temperatures ranging from 100 to 200F higher than those required for either copper or iron. This stems from the fact that with aluminum, it is generally desirable to use

solders that have higher melting points than the tin-lead solders, in order to provide joints with good resistance to corrosion. This increased soldering temperature required for aluminum (compared to copper or steel) is one of the major reasons why difficulties have been encountered in soldering aluminum.

Recommended practices, flux and solder choice, and a discussion of choice of aluminum alloys for soldering are presented in the following sections.

PREPARING THE SURFACE FOR FILLER METAL FLOW

A thin film of oxide forms on the surface of aluminum when it is exposed to the atmosphere. As previously stated, this film clings tenaciously to the surface and its resistance to chemical attack is responsible for the excellent resistance of aluminum to corrosion. To successfully solder aluminum, then, it is first necessary to remove the oxide film present, so that the filler metal can contact and bond with the parent metal. The oxide film on aluminum can be removed by using one of the following methods of treating the surface:

1. Mechanical abrasion
2. Application of ultrasonic energy
3. Electroplating
4. Use of either "chemical" or "reaction" type fluxes.

Mechanical Abrasion

Mechanical scraping is a simple way of removing the oxide from the surface of aluminum. Unfortunately, the rapid rate at which the oxide reforms makes it impractical to use this method unless the oxide is removed in the presence of molten solder. The molten solder then wets and bonds with the surface of the aluminum as the oxide is removed. A "tinned" surface results. The basic method, described below, has many variations.

- 1) Two sheets of aluminum are heated to the melting temperature of the solder.
- 2) A small amount of solder is then melted on the sheets and rubbed with an abrasion tool until the solder wets the surface.
- 3) The two "tinned" sheets are then placed together and held in contact until the solder solidifies. A strong joint results.

Some of the abrasion tools and methods used to remove the oxide film from aluminum are:

- 1) A steel brush is moved laterally across the surface of aluminum to remove the oxide film. The main disadvantage in using a steel wire brush is the possibility of gouging the heated parent metal. The most effective steel brush is a fine strand, closely-packed brush. Unfortunately bits of the steel brush occasionally become embedded in the aluminum causing corrosion. Stainless steel brushes are often used to avoid this possibility.
- 2) Steel wool is more effective than a steel brush in removing the oxide film and the damage to the parent metal is usually less. However, the amount of fragmented

steel embedded in the metal is greater, and, therefore, stainless steel wool is nearly always used to reduce the corrosion hazard.

- 3) A fibrous glass brush is one of the most effective abrasion tools, since it does not create a corrosion hazard. Also, the fine close-packed strands remove the oxide with very little damage to the parent metal.
- 4) Some solder rods, called "abrasion solders", have melting characteristics which permit them to perform the dual role of solder source and abrasion tool. The effectiveness of this method depends primarily upon the design of the part and the use of a technique that will ensure that the solder scraping "tool" is brought into contact with a large percentage of the surface.

The primary objection to abrasion soldering in most applications is that the method produces only a "tinned" surface and a second operation is required to complete the joining operation.

Removal of the Oxide Film Using Ultrasonic Energy

The oxide film can be removed from an aluminum surface using ultrasonic energy. In this method, an electronic power oscillator is used to generate electrical impulses (currents) of frequencies from 15 to 50 kilocycles per second. These electrical impulses are converted to mechanical motion by a device known as a magnetostrictive transducer. The present commercial transducers used in soldering tools consist of a nickel core and a coil around the core that is connected to the oscillator. When the nickel core (a laminated nickel core is usually used to reduce eddy currents) is subjected to an electromagnetic impulse resulting from electric current flowing through the coil, it constricts a maximum of 30 1/millionths (30×10^{-6}) of its length.

If the end of the vibrating core is brought into contact with molten solder, the vibrating core will produce numerous holes or voids within the liquid. This phenomenon is known as cavitation. If a piece of aluminum is immersed in the liquid solder, the collapse of the voids will create an abrasive effect known as cavitation erosion on the surface of the metal. This erosive action removes the oxide film from aluminum and permits the molten solder to alloy with the aluminum.

In practice the ultrasonic vibrations are transmitted from the laminated nickel core to the work in the following manner. A sonotrode (a metal rod that connects the transducer to the soldering tip) of suitable length is attached to the core so that maximum disturbance will result at the free end. The free end of the sonotrode forms the soldering tip and is immersed in a small pool of molten solder that contacts the surface to be soldered. As the sonotrode is moved across the surface of the aluminum, the ultrasonic vibrations break up the oxide on the surface exposing the underlying metal to the action of the molten solder. If the end of the sonotrode is used as the bottom of a soldering pot, the ultrasonic vibrations will be transmitted through the bath of molten solder, and the surface of an object immersed in the bath will be subjected to cavitation erosion. Tremendous power is required to initiate cavitation action over large areas; for this reason, commercial ultrasonic soldering baths are quite small. One commercial soldering pot is 7/8" in diameter and 3/8" deep. This small bath is operated at 55 watts electrical input to the transducer and the entire unit has a power consumption of 450 watts. The forces generated by ultrasonic soldering devices also tend to promote liquid metal penetration, and the cavitation action can erode the soldering tip or sidewalls of the container.

In soldering aluminum ultrasonically, the area to be "tinned" is heated to soldering temperature, a suitable quantity of solder is melted on the surface to form a molten puddle and the end of the transducer is swept over this surface. Two such "tinned" areas are then placed together and heated until the solder coat melts and forms a bond. The primary advantages of this process are:

- 1) No flux is required.
- 2) Joint quality is equal to that of joints prepared by any other process using the same solder and parent metal.

The primary disadvantages are:

- 1) High cost of equipment.
- 2) Small capacity of the units.
- 3) Direct soldering of lap or crimp joints is not practical.

Solders usually recommended for joining aluminum by ultrasonic soldering techniques are the low melting solders, and include those having the following composition:

96% Sn - 4% Zn	85% Sn - 15% Cd	35% Sn - 65% Cd
97% Sn - 3% Cu	85% Sn - 15% Zn	80% Sn - 20% Zn

Use of Plated Surfaces for Soldering

It is possible to prepare the surface of aluminum for soldering by electrolytically plating it with a metal such as copper. The deposition of copper is preceded by treatment of the aluminum surface by immersion of the aluminum in a solution of alkaline sodium zincate. This is referred to as a zincating treatment. In this process the aluminum oxide is dissolved by the sodium hydroxide solution, and the zinc is plated out on the oxide-free surface by galvanic displacement. The zincated surface is then electrolytically plated with copper to produce a surface that can be easily soldered with the conventional solders and fluxes used to solder copper.

The metal bonds formed in this process are quite strong but exhibit only a fair degree of resistance to corrosion. Joints produced by this method find greatest use where aluminum is joined to other metals, and are recommended only for use in protected or interior applications.

FLUXES FOR SOLDERING ALUMINUM

There are two general types of fluxes for soldering aluminum; these are the chemical and reaction fluxes.

Chemical Fluxes

The chemical fluxes are composed of an organic fluoboride such as the addition compound, boron trifluoride-monoethanolamine, a flux vehicle such as methyl alcohol, a heavy metal fluoborate such as cadmium fluoborate ($\text{Cd}(\text{BF}_4)_2$), and a plasticizer such as stearic acid. They may or may not contain other modifiers such as zinc fluoride (ZnF_2), zinc chloride (ZnCl_2) and ammonia compounds. The chemical flux compositions originally proposed did not contain chlorides, but some subsequent commercial formulations have incorporated metallic chlorides to act as accelerators.

Chemical fluxes are usually used where the joint temperature (actual temperature measured at the joint) is less than 525F. However, in some applications the maximum temperature limit can be successfully raised to 620F. At temperatures in excess of 525F the chemical fluxes tend to decompose, and at temperatures in excess of 620F, the rate of decomposition is so rapid that it is usually impractical to use this type of flux.

Since chemical fluxes find the greatest use where low soldering temperatures are desired, they are usually used with the tin-lead-cadmium-zinc solders. For best results the magnesium content of the aluminum alloy being soldered should not exceed 1%, and the silicon content should not exceed 5%.

The flux residue left after soldering by the chemical type of flux is not particularly corrosive, and these fluxes have been used successfully in some commercial applications without subsequent removal of the residue. While the extent of corrosion attributed to the residual flux is not always significant, this feature should be thoroughly investigated before these fluxes are used in production. In general, it is recommended that the residue be removed, especially if large impressed electric potentials are present. In a damp or humid environment, the flux residue may carry the electric current and lead to current leakage and possible destruction of the joint by electrolysis.

Reaction Fluxes

The reaction fluxes usually contain zinc chloride and/or tin chloride in combination with other halides. The metal halides are the primary fluxing agents, and the other chemical compounds are added to modify the characteristics of the flux. For example, ammonium chloride is used in combination with zinc chloride to improve the fluidity of the flux melt, reduce the melting point of the mixture, improve the wetting characteristics and provide a flux cover which effectively prevents re-oxidation in the interval after the oxide is removed from the aluminum surface and before solder flow occurs.

The zinc chloride and tin chloride base fluxes react with aluminum as follows:



It is thought that these fluxes penetrate the oxide until the flux contacts the underlying aluminum. When contact is made, the metal chloride is reduced by the aluminum to form the metal (zinc or tin) and gaseous aluminum chloride. The rapid formation of the gaseous aluminum chloride results in a breakup of the oxide film.

All of the common commercial reaction fluxes deposit zinc and/or tin on the surface of aluminum. These metals alloy with aluminum, and a thin alloy layer is formed in the area near the original surface of the material. With some aluminum alloys, these deposited metals tend to alloy preferentially with the grain boundary material and a condition of intergranular penetration by the liquid metal can result. The electrochemical characteristics of the galvanic couple formed by the deposited metal and aluminum usually determines the corrosion characteristics of soldered systems. The corrosion resistance of soldered joints is discussed more fully in a later section.

SOLDERS FOR ALUMINUM

The commercially important solders for aluminum may be placed into groups. These are the zinc base, zinc-cadmium base, tin-zinc base and the tin-lead base solders - all of which may also contain appreciable quantities of other metals. The compositions of several typical solders for aluminum are listed in Table II.

The zinc base solders develop joints with shear strengths of 15,000 psi and higher, and good corrosion resistance. These solders require soldering temperatures of 700F to 820F. The zinc-cadmium base solders develop joints with shear strengths in excess of 10,000 psi and intermediate corrosion resistance, and require soldering temperatures of 510-750F. The tin-zinc base solders develop joints of intermediate corrosion resistance, with strengths in excess of 7,000 psi shear, and require soldering temperatures of 550F and higher.

Tin-lead base solders which also contain cadmium or zinc give joints with corrosion resistance adequate for interior applications only. These solders produce joint shear strength in excess of 5,000 psi shear and can be applied at soldering temperatures of 450F and higher.

It is generally acknowledged that high zinc solders applied to aluminum form a soldered system that is highly resistant to corrosive attack. Assemblies prepared with pure zinc solder have withstood outdoor corrosive attack for many years and are considered satisfactory for most exterior applications requiring a long service life. The addition of small amounts of aluminum to zinc lowers the melting point of the solder but does not significantly alter the excellent corrosion characteristics of this system. Also, small additions of copper, silver and titanium may improve the properties of pure zinc solder.

Zinc readily alloys with aluminum and forms a eutectic composition containing approximately 5% aluminum. Therefore, the zinc solder forms a thin alloy layer (diffusion zone) with the surface of the parent alloy. In addition, the zinc tends to alloy preferentially with the grain boundaries, and in most instances the rate of penetration along the grain boundaries is greater than the rate of general or intragranular diffusion. In certain alloys, eg, 6061, the rate of intergranular penetration is accelerated if the parent alloy contains internal stresses induced by cold working or by other means. The rate of diffusion and extent of penetration can be minimized by stress relieving the assembly before soldering and by operating at the lowest feasible soldering temperature.

Tin readily wets an aluminum surface from which the oxide film has been removed and forms joints of intermediate strength and corrosion resistance. Hot dip tinned surfaces are also used in special applications to produce readily solderable surfaces. Pretinned aluminum is advantageously used in applications where normal aluminum soldering materials and techniques cannot be used. However, molten tin penetrates aluminum-magnesium alloys along the grain boundaries, and alloys containing more than 0.5% magnesium can be seriously damaged by this penetration.

Cadmium is only slightly soluble in solid aluminum and forms a very limited diffusion zone in aluminum soldered joints. Cadmium is not usually used as a solder by itself but is effectively used to improve the properties of zinc and tin base solders.

Lead is practically insoluble in solid aluminum and by itself is not normally used as a

solder. However, lead in combination with tin, zinc and cadmium forms an important class of solders for aluminum.

JOINT DESIGN

The joint design used in a soldered assembly determines to some extent the strength, corrosion resistance, and fabricating cost of the assembly. The designs used for soldered aluminum assemblies are basically similar to those used with other metals, and the most commonly used designs are lap, crimped and Tee type joints. Capillary spacing will vary with the soldering method, parent alloy composition, solder composition, joint design and flux composition. However, as a guide, joint spacings of from 0.010 to 0.025 inch are maintained when a chemical flux is used, and from 0.002 to 0.010 inch spacing is employed when a reaction flux is used.

SOLDERING TECHNIQUES

The following practices are recommended for soldering aluminum using the designated heat source.

Soldering Irons

Because aluminum rapidly conducts heat away from the joint area, a high capacity heat source is required to raise the joint to soldering temperature. Because of the limited heat capacity of gas or electrically heated soldering irons, they are useful only in joining small assemblies or thin sheet, eg, 0.010 inch.

Aluminum sheet of thickness greater than 0.064 inch is very difficult to solder satisfactorily with a soldering iron even though the area of the assembly is small. When soldering assemblies contain thick sections, an auxiliary heat source, eg, a hot plate, is recommended. The flux is usually applied to the joint by painting, and the solder is manually fed into the joint using a wire of solder.

The best heating technique consists of placing the soldering iron slightly to one side of the assembly to heat the joint by conduction through the aluminum. If the iron is brought into direct contact with the chemical fluxes, the flux will be charred and its fluxing efficiency reduced or destroyed.

Torch Soldering Air-gas or oxygen-gas torches are effectively used to solder aluminum assemblies. The flame temperature (gas mixtures) and heat output (torch size) can be independently adjusted to provide optimum conditions for a specific application. The flux is usually painted on the joint, and the solder is either preplaced or manually fed into the joint using solder wire. The best torch soldering technique involves heating the assembly initially on both sides of the joint area until solder flow can be initiated in the joint area. The flame can then be moved to a position directly over the joint and slightly behind the front of the solder flow. In this way the flame does not come into direct contact with the flux before it has performed its function, and the speed and ease of soldering is at a maximum.

Resistance Soldering When an electric current is passed through a metal the amount

of heat generated is dependent upon the electrical resistance of the metal and the amount of current used. The electrodes are either water-cooled metal or uncooled carbon electrodes. Since the heat is generated in the metal, there is little danger of damaging the flux by excessive heating before solder flow occurs. This method is well suited to joining aluminum to aluminum or joining aluminum to other metals. It is also suitable for spot or tack soldering. The flux is usually applied to the joint area by painting and the solder is either preplaced or manually fed into the joints using a wire of solder.

Furnace Soldering Furnace soldering is an efficient, high production method that is well suited to fabricating complete aluminum assemblies. In furnace soldering the entire assembly is raised to soldering temperature and distortion is generally at a minimum. However, the strength of work-hardened or heat-treated alloys is uniformly reduced, and the assembly must, of course, be designed on the basis of the mechanical properties of the as-soldered unit. In addition the strength of the assembly is much lower at the soldering temperature than at room temperature and care must be exercised to prevent collapse of large unsupported spans during the furnace soldering operation.

In this operation the solder is normally preplaced in the joint using wires, shims, washers, etc., of filler metal. The flux is applied by spraying, painting or immersing the part in the flux or by flowing a liquid flux over the assembly. The assembly is then placed in a furnace and brought to soldering temperature. The rate of heating must be adjusted to insure that the flux is not destroyed by charring or volatilization before it has performed its function. Also, the heating characteristics of the furnace and the design of the assembly should be such that all sections of the joint are brought to temperature at the same time in order to prevent excessive alloying and penetration by liquid solder.

Dip Soldering Dip soldering is well suited for joining aluminum assemblies because the solder pot represents an excellent large capacity heat source. The method is ideal for joining assemblies at a high production rate, and the same techniques and production schedules can often be retained when aluminum is used in place of other metals previously used. The solder and flux must, of course, be changed when conversion is made to aluminum.

Any of the solders listed in Table II can be used for a dip soldering operation and selection should be based primarily on the service characteristics required, operating characteristics desired and cost of the solder.

In a dip soldering operation the flux tends to insulate the part from the solder, and a heavy coating of flux will reduce the rate at which a part is brought to soldering temperature. Since the rate of heating will be greatest if a small amount of flux is used, and also because solder will prevent the surface from being re-oxidized, it is desirable to use a dilute liquid flux for dip soldering. Also, the flux should be selected to operate at the optimum temperature of the solder to minimize drossing, dissolution, liquid metal penetration, etc., and to provide the best operating characteristics possible.

CORROSION RESISTANCE OF SOLDERED JOINTS

The corrosion resistance of soldered aluminum joints may be excellent to poor, depending upon the choice of solders and upon the degree of removal of residual soldering fluxes.

When aluminum is soldered a thin interfacial alloy layer is formed between the solder and the aluminum. In many instances the rate of corrosion is greatest in this thin interfacial area, and this is the location where failure by corrosion is most likely to occur.

In general, the corrosion rate of soldered joints is greatest in the presence of good electrolytes, ie, salt solutions formed by water and residual fluxes, or moisture in contaminated industrial atmospheres or in marine atmospheres. The corrosion rate is considerably less in the presence of poor electrolytes, eg, tap water, and is not significant in dry atmospheres, eg, indoor locations. By covering the joint area with a suitable paint, the corrosion rate approaches that which occurs in a dry atmosphere regardless of the environment or the composition of the solder used. However, it must be emphasized that while the corrosion resistance of soldered joints may be improved by suitable coatings, unprotected soldered joints can be satisfactorily used in many applications with excellent results. The most corrosion resistant solders, such as those having a zinc base, are suitable for use in exterior locations with no protective coatings.

As stated before the rate of corrosion attack is generally accelerated if the residual flux is not removed after soldering. The residual products formed by most of the commercial soldering fluxes are readily soluble in water and can be removed by washing the part with warm water. If difficulty is experienced in removing the residue of a particular flux, scrubbing with a brush and/or immersion in a 2% sulfuric acid bath followed by immersion in a 1% nitric acid bath and warm water rinse may be required.

CHOICE OF ALUMINUM ALLOYS FOR SOLDERING

The metals commonly added to aluminum to make aluminum base alloys are manganese, magnesium, silicon, copper and zinc. While aluminum and all the aluminum alloys can be satisfactorily joined by soldering, the alloying elements do influence the ease with which aluminum alloys can be soldered. The general solderability of the commercially important aluminum alloys is shown in Table III and discussed in some detail below. It will be noted that the aluminum alloys commonly used in commercial application are 1100, 1145, 3003, 5005, 6061 and 8112.

Commercially pure aluminum (1100 alloy), aluminum of higher purity (1145) and the aluminum-manganese (3003) alloys can be readily joined using all soldering techniques. These alloys may be joined using any of the solders listed in Table II. Aside from ensuring that the surface is reasonably free of extraneous dirt, corrosion products, etc., no special surface preparation is needed for soldering these alloys. Also these alloys are resistant to intergranular penetration by liquid solder.

Aluminum alloys containing 0.5% or more magnesium suffer intergranular penetration by molten tin solders. Zinc will also penetrate the aluminum-magnesium alloys intergranularly but the extent of penetration is usually not significant until the magnesium content of the parent alloy exceeds 0.7%. The intergranular penetration by liquid solder of aluminum-magnesium alloys is aggravated if the part is prestressed by cold working, but this can be significantly reduced if the assembly is stress-relieved by heating the part to 700F before soldering. If the solder being used, eg, 95% zinc-5% aluminum, has a solidus temperature of 700F or greater, the part will be stress relieved before the liquid solder will actually contact the surface of the aluminum. Therefore, a stress relieving treatment will not be required in this case. The addition of 4% or more

aluminum to the solder also tends to reduce the extent of intergranular penetration or general dissolution of all aluminum alloys.

The addition of up to 1% magnesium to aluminum does not significantly reduce the effectiveness of the flux in preparing the surface of the aluminum alloy for soldering. However, in general, the surface of alloys containing greater than 1% magnesium cannot be satisfactorily soldered using chemical fluxes, and alloys containing greater than 1.5% magnesium are difficult to solder using reaction fluxes.

The addition of silicon to aluminum seriously reduces the effectiveness of most commercially available fluxes in preparing the surface of aluminum alloys for soldering. The aluminum alloys containing greater than 5% silicon are not usually soldered by procedures requiring the use of a soldering flux. Therefore, abrasion or ultrasonic soldering techniques are usually used when it is necessary to solder the aluminum-silicon alloys.

The addition of zinc or copper to aluminum does not materially reduce the solderability of aluminum. However, these metals are usually used in combination with other elements forming complex, high-strength, heat-treatable alloys. The films formed on the surface of these complex alloys during heat treatment tend to reduce the ease with which these alloys are soldered, and a chemical surface pretreatment is usually recommended to remove the film before soldering is attempted. In some instances alloys such as 2024 and 7075 have been satisfactorily soldered using reaction fluxes without using chemical pretreatment. If chemical fluxes are used, a chemical pretreatment is usually required.

Additions of small amounts of magnesium and silicon to aluminum produce an alloy system commonly referred to as the aluminum-magnesium silicide alloys. These alloys (6061-6063) are easily soldered and are not as susceptible to intergranular penetration by liquid solder as are the binary aluminum-magnesium alloys of a similar magnesium content. The general soldering characteristics of these alloys are intermediate to those described for commercially pure aluminum and the binary aluminum-magnesium alloys.

TABLE I

PHYSICAL AND CHEMICAL PROPERTIES OF ALUMINUM, COPPER AND IRON WHICH AFFECT THE EASE WITH WHICH THESE METALS ARE SOLDERED

Metal	Chemical Resistance of Oxide Film to Flux Action	Melting Point °F	Sp Ht cal/°C	Heat to Raise Unit Vol 1°C cal/cm ³	Heat Conductivity cal/cm ² /cm/°C/sec	Coefficient of Linear Expansion per °C	*Melting Range of Solders Used °F
Aluminum	Very resistant	1220	0.23	0.62	0.46	24×10^{-6}	450 - 750
Copper	Reduced easily	1980	0.09	0.80	0.93	17×10^{-6}	361 - 550
Iron	Reduced with moderate ease	2802	0.13	1.03	0.14	14×10^{-6}	361 - 550

* This melting range applies, with but few exceptions, to the solders commonly used to join these metals.
 Note: The above values are approximate and should be used for comparison only.

TABLE II
COMPOSITION OF TYPICAL SOLDERS FOR USE WITH ALUMINUM

Solder Type	Composition, %						*Approximate Melting Range F
	<u>Sn</u>	<u>Zn</u>	<u>Al</u>	<u>Cd</u>	<u>Pb</u>	<u>Cu</u>	
Zn base		94	4			2	720 - 740
Zn base		95	5				710
Zn base	2	79.6	10	0.4	3	5	420 - 750
Zn-Cd base		90		10			509 - 760
Zn-Cd base		17.5		82.5			509
Sn-Zn	20	15	0.8	64.2			230 - 530
Sn-Zn	30	70					390 - 710
Sn-Zn	60	39.4			.1	0.5	390 - 645
Sn-Zn	69.3	28	0.7		2.0		385 - 635
Sn-Zn	80	20					390 - 530
Sn-Pb	36.9			3.8	59.3		290 - 450
Sn-Pb	31.6	9		8	51	0.4	282 - 485
Sn-Pb	40	15	0.8		44.2		335 - 675
Sn-Cd	20	15	0.8	64.2			230 - 530

* Solidus - Liquidus Range.

TABLE III

COMPOSITION AND SOLDERABILITY OF COMMERCIAL ALUMINUM ALLOYS

Alloy	Chemical Composition Limits, % (max unless shown as a range)											Flux Recommended	Metallurgical Problem Encountered		
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al Min.	Chemical & Reaction				
Excellent Solderability															
1030	—	—	—	—	—	—	—	—	—	—	—	—	99.30	—	—
1050	—	—	—	—	—	—	—	—	—	—	—	—	99.50	—	—
1060	—	—	—	—	—	—	—	—	—	—	—	—	99.60	—	—
1070	—	—	—	—	—	—	—	—	—	—	—	—	99.70	—	—
1075	—	—	—	—	—	—	—	—	—	—	—	—	99.75	—	—
1080	—	—	—	—	—	—	—	—	—	—	—	—	99.80	—	—
1085	—	—	—	—	—	—	—	—	—	—	—	—	99.85	—	—
1090	—	—	—	—	—	—	—	—	—	—	—	—	99.90	—	—
1095	—	—	—	—	—	—	—	—	—	—	—	—	99.95	—	—
1099	—	—	—	—	—	—	—	—	—	—	—	—	99.99	—	—
1100*	1.0 Si + Fe	—	0.20	0.05	—	—	—	—	—	—	—	0.10	99.00	—	—
1130	0.7 Si + Fe	—	0.20	—	—	—	—	—	—	—	—	—	99.30	—	—
1145*	0.55 Si + Fe	—	0.05	0.05	—	—	—	—	—	—	—	—	99.45	—	—
1160	0.40 Si + Fe	—	0.05	—	—	—	—	—	—	—	—	—	99.60	—	—
1175	0.15 Si + Fe	—	0.10	—	—	—	—	—	—	—	—	—	99.75	—	—
1180	0.09	0.10	0.03	—	—	—	—	—	—	—	—	—	99.80	—	—
1187	0.06	0.06	—	—	—	—	—	—	—	—	—	—	99.87	—	—
1197	0.006	0.006	0.006	—	0.006	—	—	—	—	—	—	—	99.97	—	—
1230	0.7 Si + Fe	—	0.10	0.05	—	—	—	—	—	—	—	—	99.30	—	—
1235	0.65 Si + Fe	—	0.05	—	—	—	—	—	—	—	—	—	99.35	—	—
3003*	0.6	0.7	0.20	1.0-1.5	—	—	—	—	—	—	—	—	Rem ^{††}	—	—
Good Solderability															
3004	0.30	0.7	0.20	1.0-1.5	0.8-1.3	—	—	—	—	—	—	0.10	Rem	—	—
5005*	0.40	0.7	0.20	0.20	0.50-1.1	0.10	—	—	—	—	—	0.25	Rem	—	—
5357	0.12	0.17	0.07	0.15-0.45	0.8-1.2	—	—	—	—	—	—	—	Rem	Reaction	—
6003	0.35-1.0	0.6	0.10	0.8	0.8-1.5	0.35	—	—	—	—	—	0.20	Rem	Reaction	—
6053	(4)	0.35	0.10	—	1.1-1.4	0.15-0.35	—	—	—	—	—	0.10	Rem	—	—
6061*	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.15-0.35	—	—	—	—	—	0.25	Rem	—	—
6062	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.14	—	—	—	—	—	0.25	Rem	—	—
6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	—	—	—	—	—	0.10	Rem	—	—
6151	0.6-1.2	1.0	0.35	0.20	0.45-0.8	0.15-0.35	—	—	—	—	—	0.25	Rem	—	—
6253	(4)	0.50	0.10	—	1.0-1.5	0.15-0.35	—	—	—	—	—	1.6-2.4	Rem	—	—
6951	0.20-0.50	0.8	0.15-0.40	0.10	0.40-0.8	—	—	—	—	—	—	0.20	Rem	—	—
7072	0.7 Si + Fe	—	0.10	0.10	0.10	—	—	—	—	—	—	0.8-1.3	Rem	—	—
8112*	1.0	1.0	0.40	0.6	0.7	0.20	—	—	—	—	—	1.0	Rem	—	—
Fair Solderability															
2011	0.40	0.7	5.0-6.0	—	—	—	—	—	—	—	—	0.30	Rem	—	—
2014	0.50-1.2	1.0	3.9-5.0	0.40-1.2	0.20-0.8	0.10	—	—	—	—	—	0.25	Rem	—	—
2017	0.8	1.0	3.5-4.5	0.40-1.0	0.20-0.8	0.10	—	—	—	—	—	0.25	Rem	—	—

Intergranular Penetration
Corrosion Resistance

TABLE III (Cont'd)

COMPOSITION AND SOLDERABILITY OF COMMERCIAL ALUMINUM ALLOYS

Alloy	Chemical Composition Limits, % (max unless shown as a range)											Al	Flux Recommended	Metallurgical Problem Encountered
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Tl	Min.	Rem			
2018	0.9	1.0	3.5-4.5	0.20	0.45-0.9	0.10	1.7-2.3	0.25	--	Rem	Reaction (1)	Intergranular Penetration (3)		
2024	0.50	0.50	3.8-4.9	0.30-0.9	1.2-1.8	0.10	--	0.25	--	Rem	Reaction (2)	"		
2025	0.50-1.2	1.0	3.9-5.0	0.40-1.2	0.05	0.10	--	0.25	0.15	Rem	Reaction (1,2)	Corrosion Resistance Reduced		
2117	0.8	1.0	2.2-3.0	0.20	0.20-0.50	0.10	--	0.25	--	Rem	"	"		
2118	0.50-1.2	0.25	3.9-5.0	0.40-1.2	0.20-0.8	0.10	--	0.25	0.15	Rem	Reaction	Intergranular Penetration (3)		
2218	0.9	1.0	3.5-4.5	0.20	1.2-1.8	0.10	1.7-2.3	0.25	--	Rem	"	Corrosion Resistance Reduced		
2225	0.50-1.2	0.30	3.9-5.0	0.40-1.2	0.05	0.10	--	0.25	0.15	Rem	"	Intergranular Penetration		
5050	0.40	0.7	0.20	0.10	1.0-1.8	0.10	--	0.25	--	Rem	"	Intergranular Penetration		
Poor Solderability														
5052	0.45 Si + Fe	--	0.10	0.10	2.2-2.8	0.15-0.35	--	0.20	--	Rem	Reaction (2)	"		
5652	0.40 Si + Fe	--	0.05	0.01	2.2-2.8	0.15-0.35	--	0.10	--	Rem	"	"		
7075	0.50	0.7	1.2-2.0	0.30	2.1-2.9	0.18-0.40	--	5.1-6.1	0.20	Rem	Reaction	"		
7178	0.50	0.7	1.6-2.4	0.30	2.4-3.1	0.18-0.40	--	6.3-7.3	0.20	Rem	"	"		
7277	0.50	0.7	0.8-1.7	--	1.7-2.3	0.18-0.35	--	3.7-4.3	0.10	Rem	"	"		
4032	11.0-13.5	1.0	0.50-1.3	--	0.8-1.3	0.10	0.50-1.3	0.25	--	Rem	None Recommended	"		
4043	4.5-6.0	0.8	0.30	0.05	0.05	--	--	0.10	0.20	Rem	"	"		
4045	9.0-11.0	0.8	0.30	0.05	0.05	--	--	0.10	0.20	Rem	"	"		
4343	6.8-8.2	0.8	0.25	0.10	--	--	--	0.20	--	Rem	"	"		
5055	0.30	0.7	0.25	0.30-0.80	4.0-5.0	0.25	--	0.25	--	Rem	"	"		
5056	0.30	0.40	0.10	0.05-0.20	4.5-5.6	0.05-0.20	--	0.10	--	Rem	"	"		
5083	0.40	0.40	0.10	0.50-1.0	4.0-4.9	0.25	--	0.25	0.15	Rem	"	"		
5086	0.40	0.50	0.10	0.20-0.7	3.5-4.5	0.25	--	0.25	--	Rem	"	"		
5154	0.45 Si + Fe	--	0.10	0.10	3.1-3.9	0.15-0.35	--	0.20	0.20	Rem	"	"		
5254	0.45 Si + Fe	--	0.05	0.01	3.1-3.9	0.15-0.35	--	0.20	0.05	Rem	"	"		
5356	0.50 Si + Fe	--	0.10	0.05-0.20	4.5-5.5	0.05-0.20	--	0.10	0.06-0.20	Rem	"	"		

* Alloys that are generally used to make assemblies where soldering is used.

Rem^{int} = Remainder.

Reaction (1): The chemical fluxes can also be used to solder some but not all types of assemblies made using this alloy.

Reaction (2): Reaction fluxes can be used to solder some but not all types of assemblies made using this alloy.

Intergranular Penetration (3): The corrosion resistance of the parent aluminum alloy can be reduced by the soldering operation.

(4) 45 to 65 per cent of Mg content.