NBS CIRCULAR 492

Solders and Soldering

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Solders and Soldering

By R. W. Mebs and Wm. F. Roeser

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This Circular discusses compositions used and procedures followed in soldering. All classes of solders are treated, namely, soft and precious metal solders and common brazing alloys. The procedures include preparation of the parts to be soldered, application of fluxes and solders, and subsequent cleaning. The uses of various solders, and some precautions necessary in applying certain fluxes and solders, are discussed. Also presented are illustrations of several types of soldering equipment and a survey of characteristics of soldered joints. A comprehensive list of references to additional information on solders and soldering is included in the Circular.

I. Introduction

Nearly all common metals can be joined by soldering. Although many of the industrial metals can be bonded with the common lead-tin solders, some metals require special solders and soldering techniques. This circular will discuss both common and special solders, and their methods of application.

A soldered joint generally is employed to obtain a neat, rigid bond between metal parts by simple means, in application where the bonding layer will not be subjected to excessively high stress or temperature. Soldering also is employed to secure a hermetic seal, a low-resistance electrical joint, or a smooth, attractive surface.

There are some applications, however, where the use of solders is not recommended. Many vessels that are subjected to corrosion by their contents, such as water or oil tanks, fail by corrosion pitting. Corrosion in oil tanks is due to water and other impurities that accumulate at the bottom of the tank. Closing the leaks that occur in such vessels, by soldering, will only tend to accelerate the rate of corrosion at adjacent weak points, due to the electrolytic action between the solder and base metal. Also, utensils employed in the processing and storing of foods should not be repaired by soldering, owing to the toxic effect of lead and its salts on the human body. Containers that may be subjected to open flames or other high-temperature heating sources, even though their contents are heated to a fairly low temperature, should not be repaired with soft solders.

Magnesium base alloys can be joined by using special solders and techniques, but the resulting joints are relatively weak. The repair of articles of such alloys should be done by bolting, riveting, welding, or adhesive bonding.

All classes of solders, ranging from the low-melting bismuth solders to the high-melting precious-metal solders and brazing alloys, are discussed in this Circular. The information presented was obtained from a number of sources, including some investigations conducted at this Bureau. More detailed information on the subject can be obtained by referring to the list of books and articles contained in section V of this Circular.

II. General Considerations

1. Definitions

The term "soldering" generally is understood to mean the joining of two metal surfaces by means of another metal or alloy that is applied in the molten condition; the metal or alloy used as a bond is the solder. Pure metals may be used as solders, but practically all solders in common use are alloys.

One of the requisites for a solder is that its melting point must be considerably lower than that of the metals being joined; a distinction between a soldered joint and a welded joint is that the metals to be joined in welding generally are heated locally above their melting points. In a soldered joint most satisfactory adhesion is attained when the solder, or one of its constituents, forms an alloy with the metals it joins. Whether or not alloying occurs, an extremely clean surface must be maintained throughout the soldering operation.

The soldered joint is characterized by a continuous metal bond, possessing a strength, which, though moderate, is often somewhat less than that of the metals being joined. Such a bond possesses many physical properties, for example, electrical and thermal conductivities, which are similar to those of the metals joined.

For any alloy used as a solder, except alloys of eutectic composition, melting occurs over a range of temperatures. The temperature at which the alloy begins to melt is called the solidus, and that at which it becomes completely molten is called the liquidus. A eutectic alloy, like a pure metal, melts completely at a single temperature.

2. Cleaning of Metals

To secure good adherence in soldering or brazing, it is necessary that the surface of the metal and of the solder be free of oxide, dirt, grease, etc. The metal is normally covered with a film or layer of oxide, and the amount of oxide increases as the metal is heated to the soldering temperature.

Most of the grease and dirt can be removed with benzene or other suitable organic solvents. When permissible, oxides and surface stains can best be removed by mechanical abrasion, that is, filing, grinding, or polishing.

3. Necessity for Fluxes

In order to obtain adherence of solder to the metal, the surfaces must be completely free of oxide. As a very thin oxide film forms on most metals at room temperature, following grinding or polishing, a covering material must be employed that will remove the film already present and protect both solder and metal from further oxidation while being heated to soldering temperature. A material performing these functions is known as a soldering flux. Such fluxes react chemically with the oxide at the soldering temperature. The more active fluxes of necessity are strong chemicals, which, if present after the soldering operation is completed, will corrode the solder and the metals being joined. The choice of the proper flux, therefore, is governed by the amount of such corrosion that is permissible and the effectiveness with which the flux can be removed after soldering. The flux compositions used with various solders will be described in conjunction with these alloys.

4. Classes of Solders

The solders in general use may be divided into the following classes: Soft solders, which include lead-tin and other special solders including the aluminum solders; and hard solders, which include the precious metal solders, the common brazing solders or spelters, and the aluminum brazing solders.

The so-called "liquid solders" or "cold solders," which are preparations recommended by their promoters for joining all types of materials, are really cements or glues. Although joints having satisfactory strength for many purposes can be made with such preparations, they generally do not form a metal to metal bond and do not possess low resistance to the flow of an electric current. Disintegration of such joints may occur at temperatures appreciably below the softening point of lead-tin solders. In addition, most such cements are readily soluble in benzene or other organic solvents. However, these preparations are useful for sealing off small holes in metals or other materials, so as to halt or prevent leakage of water. Sealing occurs by the setting or hardening of the liquid solder on exposure to air or mild heat. Such methods are used to repair water jackets, cylinder heads and radiators.

III. Soft Solders

Soft solders have a number of very desirable properties. They can be used for joining metals at relatively low temperatures; they can withstand considerable bending without fracture; they can be applied by simple means and be used with metals having relatively low melting points. One of their chief disadvantages is their low strength as compared to that of the metals usually joined.

1. Lead-tin solders

Soft solders in general use are essentially lead-tin alloys. The eutectic alloy containing 61.9 percent of tin and 38.1 percent of lead melts completely at 360° F (182° C). All other binary lead-tin alloys containing between 20 and 97 percent of tin also have a solidus temperature of 360° F, with the liquidus temperature varying with the relative amounts of lead and tin. The phase diagram for the lead-tin alloys in figure 1 shows the equilibrium temperatures and composition limits of phase fields for the alloys of these two metals.

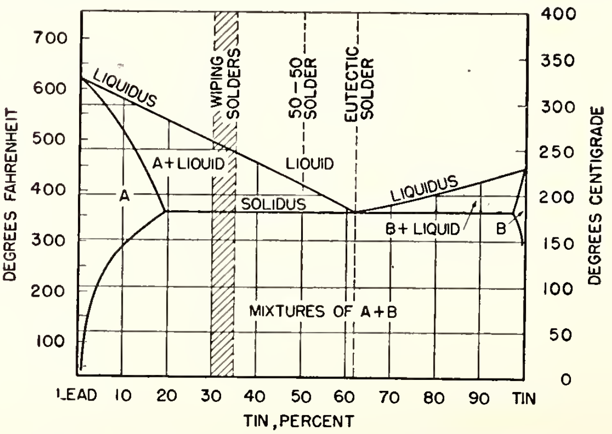

Figure 1. *Phase diagram for the lead-tin alloy system.*

Table 1. *Lead-tin solders*

No.	Designation			Nominal composition				Approximate freezing range [d]	
	Fed. [a]	ASTM [b]	SAE [c]	Tin	Antimony, maximum	Copper, maximum	Bismuth, maximum	Solidus	Liquidus
				Percent	*Percent*	*Percent*	*Percent*	°*F*	°*F*
1	Sn-50	50B		50	0.50	0.08	0.25	360	420
2	Sn-40	40B	2A	40	.50	.08	.25	360	460
3	Sn-35	35C		35	[e] 1.6 to 2.0	.08	.25	360	490
4	Sn-30	30C	3B	30	[e] 1.4 to 1.8	.08	.25	360	500
5		25B	4A	25	0.50	.08	.25	360	510

[a] Solders Sn-50, Sn-40, Sn-35, and Sn-30 are covered by Federal Specification. QQ-S-571b, (1947).
[b] Solders 50B, 40B, 35C, 30C, and 25B are covered by ASTM specification. B32-48T.
[c] Solders 2A, 3B, and 4A are covered by SAE 1948 Standards for Solders.
[d] The values in these columns depend upon the actual composition and are average values taken from references.
[e] Minimum and maximum.

The values for some common types of solders are indicated.

The nominal composition of a series of lead-tin solders with tin contents ranging from 25 to 50 percent are listed in table 1. These are representative of the commercial solders covered by current specifications. The lead content of these solders, although not listed, can be obtained approximately by subtracting the sum of the values given for the various elements from 100 percent. The limiting values of only the more important minor elements are given. Values for other minor elements may be obtained by referring to the original specification listed in the footnotes. Class designations and freezing ranges are also given in the table.

Prior to the year 1941 the most widely used "general purpose" soft solder was the "50-50" or "half-and-half" alloy containing 50 percent of lead and 50 percent of tin. This corresponds to solder 1 in table 1. The liquidus temperature of this alloy is about 420° F (216° C). The alloy containing about 2 parts of lead to 1 part of tin, commonly called plumbers solder, was used in preference to the "half-and-half" alloy for making "wiped" joints, as it remains partially molten over a wider temperature interval and therefore can be molded during solidification. Solders 3 and 4 of table 1 have both been recommended for this use. Because of the limited availability of tin during the recent war, and since one-fifth of the metallic tin used in this country prior to the war entered into the manufacture of solders, it became necessary to restrict the amount of tin that could be used for this purpose. Although the supply of available tin now is gradually increasing, it is still sufficiently scarce to maintain its price at a fairly high level. In many applications, therefore, economy will justify the use of solders containing less tin than employed prior to the past war, so that information on the methods of application and limitations of such solders becomes desirable.

Most commercial soft solders contain small percentages of one or more elements such as antimony, bismuth, or silver, which are deliberately added for specific purposes. Antimony apparently increases the strength of the solder. However, lead-tin solders used for joining zinc, cadmium, or galvanized metals should be practically free of antimony because antimony combines with these metals to form a brittle constituent, which markedly lowers the strength of the joint. Bismuth and silver promote "tinning" or "spreading" of the solder, although the tinning by the latter metal becomes effective only for the higher melting point solders. In general, the added elements may slightly alter both the solidus and liquidus temperatures; the additions of antimony to solders 3 and 4 in table 1, which are made to improve their usefulness in wiping operations, lower their melting points from 6 to 9 deg F below that of comparable antimony-free solders (not listed).

The higher melting temperatures, the slower rates of spreading, and the broader freezing ranges of the solders containing 25 to 40 percent of tin make hand-soldering operations more difficult, but with proper soldering techniques and fluxes, joints can be made with these solders that are in many cases as strong and as satisfactory as those made with "50-50" solder. However, in soldering stainless steel, an operation requiring strict adherence to a definite procedure, the use of "50-50" solder has been found to be advisable. Solders 4 and 5 are also used for filling dents and seams in automobile body repair operations.

There are many modifications of the lead-tin soft solders, the advantages or particular application of which are not discussed here. Information as to the use of these modified alloys can be obtained from some of the references listed in section V of this Circular.

2. Special solders

Lead-silver solders containing 2.25 to 2.5 percent of silver have proved their usefulness as substitutes for lead-tin solders for many purposes. The lead-silver eutectic alloy contains about 2.5 percent of silver, is very fluid when molten, and solidifies completely at a definite temperature. The commercial form of the lead-silver eutectic alloy is described in Federal Specification QQ-S-571b (1947), ASTM Specification B32-48T (1948), and SAE Non-ferrous Metals Emergency Alternate

Specifications, issued January 1944. It contains 2.5 percent of silver, 0.50 percent of antimony, 0.08 percent of copper, and 0.25 percent of bismuth, and has a melting range of only 580 to 585° F (304° to 307° C). When a wider freezing range is required, the silver content is lowered to about 2.25 percent and 3 percent of tin is added. The melting temperatures of these lead-silver alloys are considerably higher than those of ordinary lead-tin alloys; consequently, somewhat different fluxing and soldering techniques are required. Solders of this type have proved satisfactory for copper, copper-base alloys, iron, steel, and tin plate. Although the 2.5-percent-silver alloy was used during the recent war for sealing the side seams of cans, this alloy has been superseded by a 2-percent-tin alloy of lead, as the result of economic considerations and the development of adequate machine soldering methods.

The ordinary lead-tin alloys cannot be used for soldering the alloys classed as pewter. Table 2 lists some alloys that possess sufficiently low melting points to be used as solders on pewter. The solidus temperature for all these solders is approximately 205° F (96° C).

Table 2. *Low melting point solders*

Designating numbers	Nominal composition			Liquidus temperature
	Lead	Tin	Bismuth	
	Percent	*Percent*	*Percent*	*° F*
1	25	25	50	266 (130° C)
2	50	37.5	12.5	374 (190° C)
3	25	50	25	338 (170° C)

An alloy of 95 percent tin with 5 percent of antimony, melting at approximately 450° F (232° C) with a small melting range, has been recommended for use as a soft solder. Joints made with this alloy are claimed to be somewhat higher in strength than those made with lead-tin solders.

For joints required to withstand higher temperatures than can be met by the lead-tin and other soft solders described above, an alloy of 95 percent cadmium with 5 percent silver has been recommended. This alloy has a solidus of approximately 640° F (338° C) and is completely molten at approximately 740° F (393° C).

Much difficulty generally is encountered in soldering zinc-base die-cast metal with ordinary lead-tin solders. The eutectic alloy of cadmium and zinc is recommended for this application. This alloy contains 82.5 percent of cadmium and 17.5 percent of zinc and melts at 508° F (264° C).

3. Aluminum solders

Aluminum solders are unusual in bearing the name of the type of alloys with which they are used rather than being identified according to their constitution or properties. Aluminum of commercial purity or better, and the wrought aluminum alloys containing not more than 1 percent of manganese or 1 percent of magnesium are the only metals of this group for which soldering is considered advisable. Soldering of heat-treated alloys in either plain or clad form is not recommended, inasmuch as the soldering operation will nullify some of the strengthening effects obtained by heat treatment.

Generally it is considered preferable to join aluminum and its alloys by welding, because soldered joints of these metals will corrode rapidly in moist atmospheres.

Most of the soft solders found to be satisfactory for soldering aluminum and aluminum alloys contain 50 to 75 percent of tin, with the remainder usually zinc; the solder containing 60 percent of tin and 40 percent of zinc is frequently used. Proprietary alloys possessing a wide range of melting points are now available for soldering aluminum.

4. Forms of soft solder

Commercial solder is available in several forms, to suit special requirements of application. Solder in bar or stick form is used for solder pots employed in dipping and wiping operations. Solder also is produced in the form of strip, foil, wire, and powder. The wire is sometimes made with a flux core. The powder is also obtainable mixed with powdered or paste flux.

5. Fluxes used with soft solders

The fluxes most commonly used for soft soldering metals other than aluminum are solutions or pastes that contain zinc chloride or a mixture of zinc and ammonium chlorides as the active fluxing agent. These generally are called "acid" fluxes. It is claimed that a flux containing zinc and ammonium chlorides in their eutectic proportions (71 and 29 percent by weight, respectively) is the most satisfactory flux for lead-tin soldering. Fluxes containing only zinc chloride, or with small additions of ammonium or stannous chloride, have been found very satisfactory for lead-silver soldering.

The heat of the soldering operation evaporates the medium containing the chloride flux. The flux then melts and partially decomposes with the liberation of hydrochloric acid, which dissolves the oxides from the metal surfaces. The fused flux also forms a protective film that prevents further oxidation from taking place.

These acid fluxes are available in either liquid or paste forms. The liquid flux is usually prepared by dissolving the chloride salts in water. A small, stiff brush is useful in applying this flux. The paste flux is made by mixing the salts with petrolatum jelly, using a little water as an emulsifying agent. When applying a liquid chloride flux, the soldering operation should follow immediately; a paste chloride flux can remain on the work for a period as long as an hour before soldering, owing to its lesser activity at room temperature. At soldering temperatures, where the liquid and paste chloride fluxes are equally active, the reaction should not be allowed to continue too long, as salt deposits will occur, which make subsequent soldering difficult. After soldering, any excess flux should be removed immediately by using a large swab and hot water; in this operation, liquid flux is more easily removed than the paste flux, leaving a clean, greaseless surface.

Because chloride fluxes have a corrosive action, it is sometimes necessary to employ other fluxes for certain types of work, where the last traces of the flux cannot be removed after soldering is completed. Rosin is the most commonly used flux of this type and is the only flux known to be noncorrosive in all soldering applications. Rosin may be mixed with alcohol in varying proportions to obtain any desired consistency. Paste rosin flux also can be made by using petrolatum as a base.

Because rosin fluxes wet the metal more slowly than do the chloride fluxes, wetting agents are sometimes added. Also a polymerized form of rosin known as a "rosin dimer" has greatly improved wetting qualities over that of ordinary rosin.

"Activated" rosin fluxes are sometimes used in electrical work, even though the activating agent may be slightly corrosive. Such a flux is made by adding 1 or 2 percent of the hydrochloride of an amine, such as aniline, naphthylamine, or hydroxilamine, to a rosin-alcohol mixture. It is claimed by the producers of such fluxes that the residue after soldering is rendered harmless by being enveloped in solidified rosin. Nevertheless, whenever there exists a possibility that the flux later may be dissolved or decomposed, and hence flow over adjacent surfaces, freedom from corrosion would not be assured. A mildly corrosive "activated" rosin flux can also be made by adding a small quantity of either oleic or lactic acid to an ordinary rosin flux.

Stearine is a mild flux useful for soft soldering jobs, but is corrosive towards lead and lead alloys. Palm oil, olive oil, or rosin, or mixtures of these have been recommended as suitable fluxes for soldering pewter. Tallow is frequently used in wiping operations. These mild fluxes are not corrosive, but for the sake of appearance and cleanliness are generally removed with benzene or other organic solvent after soldering.

Until recently, the only satisfactory method of removing the oxide film from aluminum and its alloys was by rubbing or abrading the metal surface beneath the molten solder with a wire brush, file, or steel wool during application of the solder.

Satisfactory fluxes have now been developed for use in soldering these metals that eliminate the necessity for such mechanical removal of the oxide layer. These fluxes are proprietary in nature and may be obtained from any supplier of aluminum solders. As most fluxes used with aluminum solders are somewhat corrosive, they should be removed immediately after soldering with a large swab and warm water.

Soft solder wire with a core of acid, rosin, or certain special fluxes is available commercially.

6. Soft soldering procedures

In soldering, the prime requisite is a constant source of heat that will maintain the surface at the desired temperature with the least amount of oxidation. In soft soldering, this is frequently accomplished either (a) with a preheated soldering "iron" (actually made of copper) of good thermal

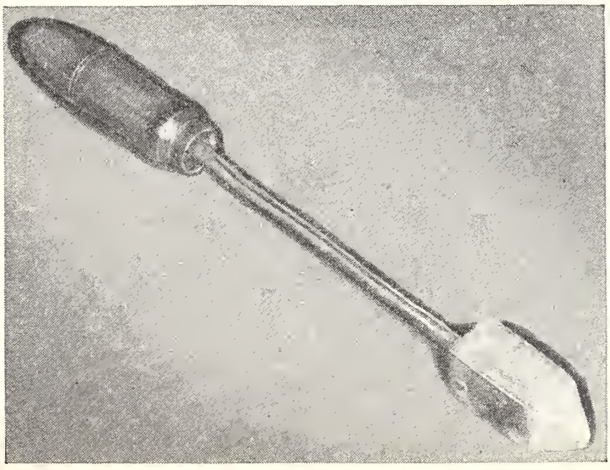

Figure 2. *Common-type externally heated soldering iron.*

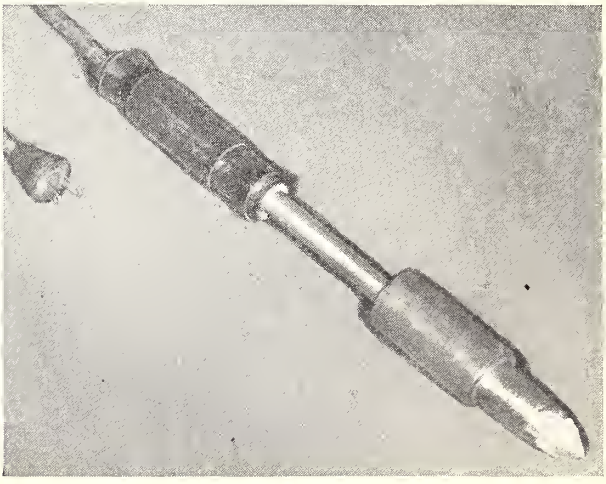

Figure 3. *Common-type electric soldering iron.*

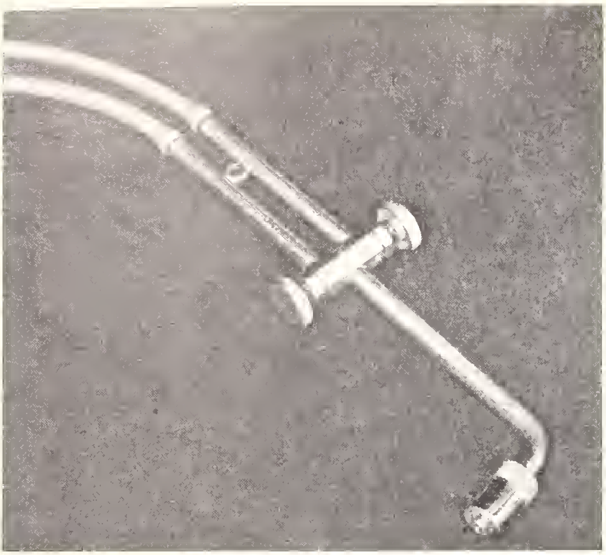

FIGURE 4. *Gas-mixing burner or torch.*

conductivity and large heat capacity (fig. 2), (b) with an electrically heated source (fig. 3), or (c) with a controlled flame as supplied by a gas mixing burner (fig. 4) or a blowtorch (fig. 5). Recently there have been developed various "gun" type electrically heated soldering irons (fig. 6) that can be used conveniently in soldering small objects or wires in somewhat inaccessible regions.

Excessive amounts of flux or solder should be avoided in soldering. An excess of solder can be removed after soldering by wiping it off with a thick cloth while still molten.

The tip of a soldering iron should be cleaned, fluxed, and covered with a thin layer of molten solder before using; this process generally is referred to as "tinning" the iron. Lead-tin solder may be used for tinning the soldering iron employed in aluminum soldering.

When using a torch, it should be directed at a point a short distance away from the junction of the surfaces being joined to avoid oxidation by the flame.

In manufacturing processes, soldering is frequently accomplished by dipping the assembled parts into a solder bath covered with a flux. Carefully machined and fitted surfaces providing proper clearance are required for such operations. As will be discussed later, these surfaces should have the optimum clearance of about 0.002 in. Such a clearance can be obtained by the use of spacers and clamps. Often prefluxing and pretinning of the bonding surface are desirable. Much electrical equipment is produced with the connecting terminals pretinned to assist in installation. A heavy electrical connection that is not amenable to hand, torch, or dip soldering can sometimes be bonded by pouring molten solder from a hand ladle held above the fluxed joint and catching the excess solder in a ladle held below. The ladle positions are reversed and the operation

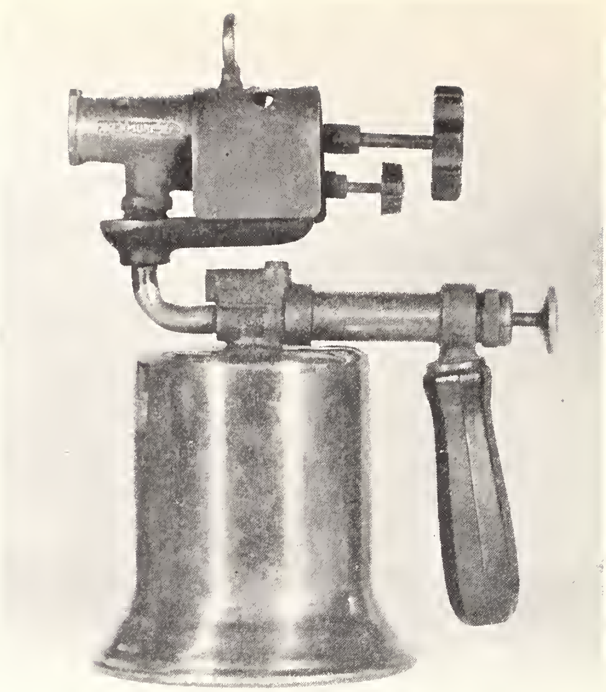

FIGURE 5. *Gasoline blow torch.*

FIGURE 6. *Gun-type electric soldering iron.*

repeated until complete penetration of the solder into the connection is obtained.

When solidification of a solder occurs over a wide range of temperature, as for some solders in table 1, particularly wiping solder, care must be taken to prevent any relative motion of the parts of the joint during solidification, as this would damage the bond. Clamping of the pieces in place during such an operation is advisable.

Satisfactory bonding with one of the lower-tin alloys can be accomplished by employing a sufficiently high temperature to promote proper penetration of the solder, although, under these conditions the operation must be completed as rapidly as possible in order to minimize oxidation of either the solder or the metals being joined. Overheating the parts during any soldering operation should be avoided, as this will promote excessive oxidation and also may affect the flux adversely.

Cast iron, and alloys containing large proportions of chromium, nickel, or zinc, can be soldered only when acid fluxes are used and certain other precautions taken. For cast iron, the oxide skin must be removed by machining or shot blasting, the surface degreased, and then immersed in a bath of molten flux of the mixed chloride type, immediately before soldering.

When soldering stainless steel, hydrochloric acid diluted with an equal volume of water is applied first to the area to be soldered, and after an interval of 5 minutes, without washing off the acid, zinc-chloride flux is applied. The 50–50 solder is then applied in the normal manner. This class of steels does not solder as readily as do most other metals.

In soldering galvanized iron or alloys containing zinc with a lead-tin solder, a mixture of ammonium and zinc chlorides is the most widely used flux. It should be applied sparingly before soldering, and the excess removed immediately after joining, as this flux attacks zinc very rapidly. Inasmuch as many commercial lead-tin solders may inadvertently contain one or more percent of antimony when manufactured from secondary metals, the following procedure is advised in joining zinc-coated metals, or alloys containing zinc, by solders whose minor constituents are not known. After applying the mixed chloride flux and solder, the soldering iron should be moved slowly in one direction over the work, as repeated movement may cause the zinc to combine with any antimony present in the solder, making the solder layer gritty and brittle.

In the soldering of zinc-base die castings with the cadmium-zinc eutectic alloy, no flux is used. A soldering iron is employed to apply the solder by vigorously rubbing it into the work surface. A preferred method of joining zinc or zinc alloy parts is to nickel-plate the surface and then solder with an ordinary lead-tin solder.

The copper alloys containing aluminum, silicon, or beryllium have very refractory oxides on their surfaces, which must be removed by grinding before fluxing. A mixture of equal volumes of concentrated hydrochloric acid and a 25-percent solution of zinc chloride in water is used as a flux. A high-tin solder is then applied in the usual manner.

7. Characteristics of soft-soldered joints

The best test of a solder is, of course, a practical soldering test. However, very useful information can be obtained by a relatively simple qualitative test, namely, observing the spreading of a drop of solder on a properly fluxed surface of the metal to be soldered, while maintained at a temperature somewhat above that at which the solder becomes molten. The amount that the solder spreads over the surface, and the degree of alloying occurring between solder and basis metal, are useful indications of the relative merits of the solder.

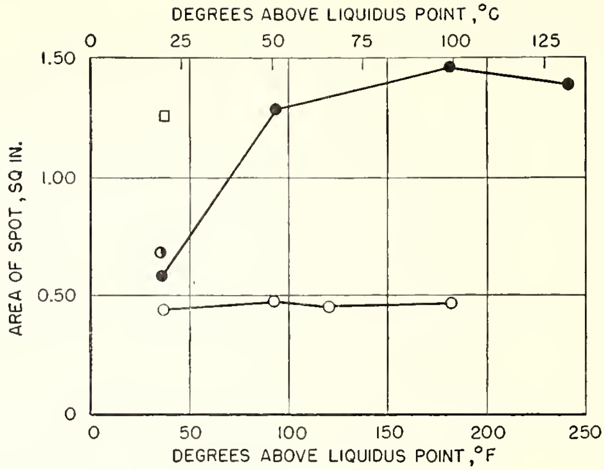

FIGURE 7. *Comparative spreading tests for 50–50 and 80–20 lead-tin solders.*

Tests were made with 0.05 cubic centimeter of solder on a copper sheet cleaned with HCl and coated with eutectic zinc-ammonium chloride flux before heating. The two points not on the curves were obtained on sheets roughened with a coarse file before fluxing.

□, ●, 50–50 solder; ◑, ○, 80–20 solder. Liquidus point, 50–50 solder = 423° F; liquidus point, 80–20 solder = 540° F.

Figure 7 shows the relative spreading ability of 50–50 and 80–20 lead-tin solders on copper at various temperatures above their respective liquidus points [15].[1] A decrease in tin content evidently lowers the rate of spreading of these solders. The curves were obtained for smoothly polished surfaces. As indicated by the two points lying above these curves, the use of a slightly roughened surface apparently increases the spreading rates of these solders on copper. A 1½-percent addition of silver to the 80–20 solder was found to have little effect on its spreading characteristics. On black iron, the spreading of the 80–20 solder was found to exceed that of the 50–50 solder.

Metal surfaces electroplated to adequate thickness generally bond more readily than do the same metals in ordinary form, owing to the matte surface formed during plating.

In certain corrosive environments, galvanic corrosion will occur at a soldered joint, owing to the presence of dissimilar metals. Such corrosion is not severe in most joints soldered with the lead-base alloys, with silver solders or with the brazing spelters, but, as indicated earlier, rapid galvanic corrosion will occur in soldered joints of aluminum or aluminum alloys, if not adequately protected in moist atmospheres. Where such joints are exposed to humid or marine atmospheres, it is desirable to make long lap or scarf joints. Soldered joints of aluminum or its alloys in salt water or spray can be cathodically protected by attaching strips of zinc or cadmium very close to the joint. In an ordinary humid atmosphere, or in plain water where an electrolyte is not present, it is considered good practice to use a moisture-proof lacquer or paint coating over the joint. When

[1] Figures in brackets indicate the literature references at the end of this paper.

feasible, welding is preferred to soldering for aluminum and its alloys.

Because of the comparatively low melting temperature of the soft solders, joints made with lead-tin alloys should not be used at temperatures higher than about 350° F (177° C); those soldered with tin-antimony solder would melt apart at about 450° F (232° C) and those made with cadmium-silver solder at about 640° F (338° C). Under prolonged loading, the limiting temperatures would be somewhat below these values. The influence of test temperature on the shear strength of various types of solders, as conducted in long time tests at this Bureau on sleeve joints made of copper tubing, is shown in figure 8 [13]. A solder film thickness of about 0.002 in. was employed. The indicated stresses were sustained for a period of at least 5,000 hours; hence they are somewhat lower than those for a short-time tensile test (see fig. 10). Although a high value was obtained with the tin-antimony solder at 325° F, examination of the solder layer after test indicated the presence of a brittle constituent as caused by diffusion of the copper into the solder. Hence, joints in copper tubing made with this solder should not be considered dependable for temperatures exceeding 250° F (121° C). The solder layers in joints made with lead-tin solders also acquired a brittle constituent after long time loading at 325° F. Joints made with lead-silver and lead-cadmium-zinc solders, however, were found to be satisfactory up to 325° F (163° C).

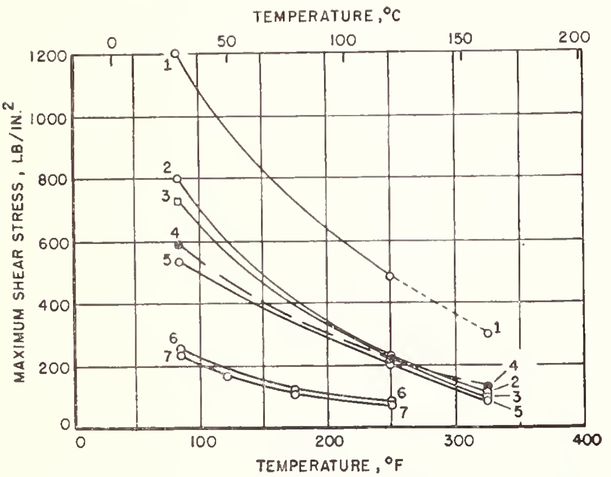

FIGURE 8. *Effect of composition and temperature on shear strength of soldered sleeve joints in copper-tube lines.*

1, (95-5) tin-antimony; 2, (95.3-4.7) lead-silver; 3, (85.4-14.3-0.3) lead-cadmium-zinc; 4, (95-5) lead-tin; 5, (99.98) lead (high purity); 6, (60-39-1) lead-tin-antimony; 7, (50-50) lead-tin.

The form of the joint used in soldering will be an important factor in determining the maximum load it can support without failure due to fracture or deformation. Figure 9 shows a number of common types of joints used in soldering. Butt joints are the weakest, that is, they only support loads corresponding to the tensile strength of the solder. However, as the solder exists only as a thin film, its strength will exceed that of the solder in wire or strip form.

Lap or scarf joints, when properly made, will withstand loads corresponding to tensile stresses several times the strength of the solder. A lap joint often cannot be used where there are strict limitations as to the thickness of the joint. Bending of a lap joint may also occur under heavy tensile loads. A combination of a lap and butt joint is obtained in the strap butt joint.

A scarf joint eliminates many of the objections as to thickness and bending, as found in lap joints. However, the scarf joint is difficult to make and to fit properly during joining.

In the wiped joint, the parts are fitted together as shown in figure 9, and the wiping solder molded, while pasty, into a smooth mass about the joint.

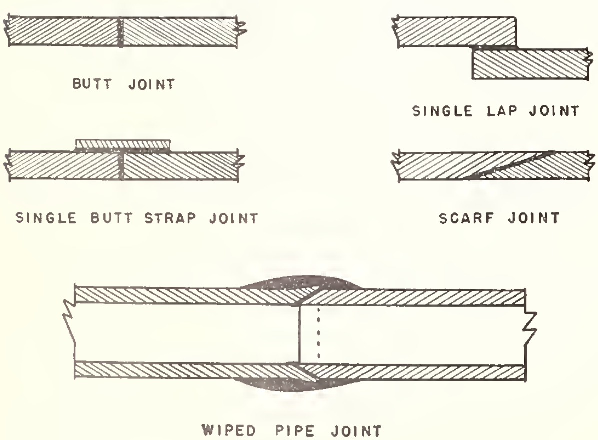

FIGURE 9. *Some types of joints used in soldering.*

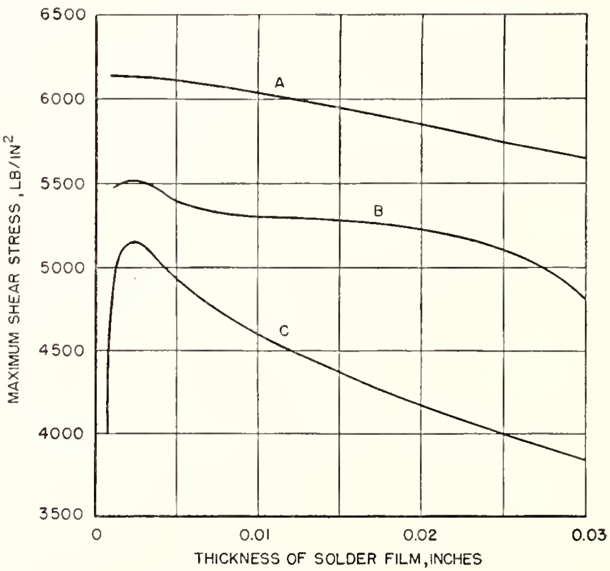

FIGURE 10. *Effect of composition and solder-film thickness on the shear strength of soldered joints.*

A, 95–5 tin-antimony solder; copper-sleeve joint. *B*, 50–50 lead-tin-solder; copper-sleeve joint. *C*, 80–20 lead-tin solder; brass-lap joint.

Further instructions as to the preparation of a wiped joint are given in the references listed in section V [1, 2, 20].

The soldered sleeve joint has widely supplanted the wiped or threaded joint in plumbing installations containing copper and brass tubing. When properly designed and made, such joints will withstand loads up to the point of failure of the tubing itself.

The effect of film thickness on the tensile strength of sleeve joints employing several types of soft solders is illustrated in figure 10 [10, 15]. It is evident that the strength of the joint decreases with increase in film thickness above an optimum value of about 0.002 in. The strength values were obtained from short-time tensile tests and are somewhat greater than those found for long-time tests (see fig. 8).

In some soft-solder applications, the principal role of the solder is that of a hermetic seal, a low-resistance electrical joint, or a smooth, attractive surface. For such applications, mechanical strength may be provided prior to soldering by bolting, interlocking, twisting together of wires, or by other suitable joining methods.

IV. Hard solders

Hard solders are distinguished from soft solders in that they have much higher melting points and form joints of much higher strength.

There are three typical hard solders, namely, precious-metal alloy solders, ordinary brazing solders, and aluminum brazing solders. In trade practice, joining with hard solders is generally referred to as "brazing," as distinguished from the term "soldering" applied in joining with soft solders.

1. Silver solders

The most widely used precious-metal alloy solders are the silver solders, which are principally alloys of silver, copper, and zinc. Silver solders are malleable and ductile, and silver-soldered joints in many metals may be as strong as the metals themselves.

There are many variations in the proportions of silver, copper, and zinc used in commercial silver solders. It is believed that a solder satisfactory for most purposes can be selected from the compositions listed in table 3.

Alloy 13 of table 3 is widely used and is claimed to be "self fluxing" (not requiring the use of flux). It is recommended for copper and its alloys but not for steel, iron, or the alloys of nickel. A recently developed, general-purpose silver solder, suitable also for joining a wide variety of metals including nickel alloys and stainless steels, is alloy 14. Tungsten can be soldered to copper with alloy 8.

A method commonly used in metal-working shops to prepare silver solder for miscellaneous uses is to melt together silver and yellow brass (copper 60 percent, zinc 40 percent) in the proportion of one part of silver to two parts of brass. This is somewhat similar to alloy 4 listed in table 3.

An alloy containing 85 percent of silver and 15 percent of manganese, not listed in table 3, has good soldering characteristics and melts at a relatively high temperature (1,780° F). Satisfactory joints in stainless steel can be made with this alloy, which was developed for the purpose of bonding parts in equipment having very high service temperatures.

TABLE 3. *Silver solders*

No.	Designation				Nominal composition				Freezing range		Color
	AWS [a]	Fed. [b]	ASTM [c]	SAE [d]	Silver	Copper	Zinc	Other	Solidus	Liquidus	
					Percent	*Percent*	*Percent*	*Percent*	°*F*	°*F*	
1	1		No. 1	A	10.0	52.0	38.0		1,510	1,600	Yellow.
2		0	No. 2	B	20.0	45.0	35.0		1,430	1,500	Do.
3	2		No. 3		20.0	45.0	30.0	5.0 cadmium	1,430	1,500	Do.
4	3			C	30.0	38.0	32.0		1,370	1,410	Do.
5	4			D	40.0	36.0	24.0		1,330	1,445	
6	5	1	No. 4	E	45.0	30.0	25.0		1,250	1,370	Nearly white.
7	6		No. 5	F	50.0	34.0	16.0		1,280	1,425	Do.
8	7			G	60.0	25.0	15.0		1,260	1,325	Do.
9		2	No. 6		65.0	20.0	15.0		1,200	1,325	White.
10	8		No. 7		70.0	20.0	10.0		1,335	1,390	Do.
[e] 11	9				72.0	28.0			1,435	1,435	
12	10		No. 8		80.0	16.0	4.0		1,360	1,460	White.
[f] 13	11	3		H	15.0	80.0		5.0 phosphorus	1,200	1,300	Gray-white.
[f] 14	12	4		I	50.0	15.5	16.5	18.0 cadmium	1,160	1,175	Yellow-white.
15		5			50.0	15.5	15.5	16.0 cadmium, 3.0 nickel	1,195	1,270	Do.

[a] As designated in Welding Handbook, 1942 edition, American Welding Society.
[b] Federal Specification No. QQ-S-561d (1944).
[c] American Society for Testing Materials Specification B73-29.
[d] As designated in SAE Handbook, 1948 edition, Society of Automotive Engineers, Inc.
[e] Silver-copper eutectic alloy.
[f] Proprietary alloy.

2. Gold and platinum solders

Other precious-metal alloys used as solders are the gold and platinum solders. Gold solders are used primarily for joining gold and gold alloys, and usually are alloys of gold with copper, silver, and zinc. Gold solders generally are designated by karat numbers to indicate the fineness, or karat number of the alloy with which they should be used.

Soldered joints in platinum or platinum metal alloys may be made with fine gold or the higher karat gold alloys.

3. Brazing solders

The common brazing solders, which contain no precious metals, cover a rather wide range of melting points, from 1,300° F to the melting point of copper (1980° F). The lower melting point alloys, termed brazing "spelters," contain more zinc, phosphorus, or tin than the commercial bronzes; the composition most frequently used consists of equal parts of copper and zinc.

Brazing alloys are generally brittle. Hence, joints made with such alloys, although superior in strength to those made with soft solders, will not withstand bending and impact as well as those made with the silver solders.

The composition ranges and approximate melting ranges of a number of common brazing solders in the order of decreasing copper content are listed in table 4. There are also indicated the classes by which these alloys are designated in Federal Specifications and by various technical societies. As only the major chemical constituents are given in the table, more specific information as to composition can be obtained by referring to the original specifications. Brazing solders useful for joining nearly all common ferrous and nonferrous alloys are included in this table.

Alloy 1 is used for hydrogen brazing of ferrous parts. Joints made with pure copper are classed as brazed joints, although they are often termed "coppered" joints in trade practice. Copper makes a strong ductile joint that will withstand relatively high temperatures. Alloys 2 and 4 are phosphorus and silicon bronzes, respectively, and are useful in brazing thin sheet steel, in hard facing steel, and in joining copper to steel. Alloy 3 is a low-melting phosphorus-copper alloy, which is self-fluxing on copper, and is useful only on copper alloys. Alloys 5, 6, and 7 are general-purpose alloys useful for joining copper, nickel, and ferrous materials, and are distinguished in their applicability only by their differences in melting temperatures. Alloy 8 is somewhat similar in characteristics to alloy 7 except for a lighter yellowish appearance and for being somewhat harder. Alloy 9 is white in color and is used to match the color of nickel-silver and cupro-nickel alloys. Alloy 10 is an inexpensive dark gray alloy useful in most applications where a moderate melting range is desirable or permissible.

4. Aluminum brazing alloys

Brazing is employed in joining aluminum and its alloys when economy or neatness of the product dictate its use in preference to welding. For thin sections brazing is preferred to welding, but complex assemblies or castings containing heavy sections are not amenable to aluminum brazing. In designing parts for aluminum brazing, lap joints are preferred to scarf or butt joints.

Of the wrought nonheat-treatable alloys, only commercially pure aluminum and the aluminum-manganese alloys can be readily brazed with present technique. With care, the popular aluminum-magnesium-chromium alloy can be torch-brazed. After brazing, these alloys will be in the annealed condition. The heat-treatable aluminum alloys containing manganese, chromium, and silicon, referred to as the aluminum-silicide alloys, also can be brazed. Parts made of such alloys can be quenched directly from the brazing operation, or the heat treatment can be performed separately at a later time.

TABLE 4. *Brazing solders*

No.	Designation			Nominal composition				Approximate freezing range	
	Fed.[a]	AWS[b]	SAE[c]	Copper	Zinc	Tin	Other	Solidus	Liquidus
				Percent	*Percent*	*Percent*	*Percent*	°*F*	°*F*
[d] 1		Group 7	A	99.9 min				1,980	1,980
2			D	94.8 min		0.75 max	2.75 to 3.5 silicon	1,850	1,980
[d] 3		Group 1	B	Remainder		0 to 1.0	4.0 to 8.0 phosphorus	1,300	1,750
4		Group 6	C	do	0.2 max	9.0 to 11.0	0.03 to 2.5 phosphorus	1,550	1,830
5	D			78 to 82	Remainder			1,725	1,875
[d] 6	C	Group 4	E, F, G	59 to 72	do	0 to 1.5		1,625	1,760
[e] 7	A			45 to 55	do			1,570	1,620
[d] 8	B			50	do	3.0 to 5.0		1,575	1,620
[d] 9				Remainder	55 to 59		7.0 to 9.0 nickel	1,520	1,600
[d] 10				do	57 to 65	5.0 to 9.0		1,385	1,440

[a] Federal Specification QQ-S-551 (1932) and Amendment 1 (1942).
[b] As designated in Welding Handbook, 1942 edition, page 561, American Welding Society.
[c] As designated in SAE Handbook, 1948 edition, page 413, Society of Automotive Engineers, Inc.
[d] Listed in Metals Handbook, 1948 edition, page 80, American Society for Metals.
[e] Includes ASTM Specification for Copper Brazing Alloy, B64-43.

The hard solders or filler metals used in brazing aluminum and its alloys are proprietary in nature and can be obtained from a manufacturer of aluminum alloys. They consist of special alloys of aluminum.

5. Forms of hard solders or brazing alloys

The silver solders generally are supplied as powder, wire, strip, or sheet. The wire and powder forms are widely used in torch brazing, and the powder and sheet forms in furnace brazing. The precious-metal solders are supplied in the form of strip, wire, or pellets.

The ordinary brazing solders generally are supplied in granular, lump, rod, or wire form. The aluminum brazing alloys are supplied in wire or sheet form.

The base metal sometimes is supplied in sheet form, with the hard solder already bonded to one or both sides. This is called "brazing sheet." The use of such a product enables simplification of the process of joining, by eliminating much of the labor of precleaning, fluxing, and tinning.

6. Fluxes used with precious metal and brazing solders

For ordinary purposes, borax, or mixtures of borax and boric acid (75- to 25-percent borax with the balance boric acid) will meet most requirements as a flux for the precious metal and ordinary brazing solders. Many satisfactory prepared fluxes of the borax-boric acid types are available commercially; some contain phosphorus and halogen salt additions. The chloride fluxes used in soft soldering will not remain on the work at brazing temperatures; hence they cannot be employed in hard soldering.

For brazing metals such as stainless steels, silicon bronze, beryllium copper, or aluminum, certain additions to the borax-boric acid flux mixture may be needed to provide the best results. Many such fluxes are of a proprietary nature. Commonly used additions are the alkali bifluorides. The user should avoid breathing fumes from a flux containing a bifluoride salt.

When brazing tungsten to copper with silver solder 8 of table 3, sodium cyanide satisfactorily performs the function of a flux. Considerable care should be taken when using a cyanide salt that it does not enter the body orally or in skin abrasions. Also, every precaution should be taken that the sodium cyanide be kept dry, does not come in contact with acids, nor become mixed with nitrates, nitrites, or other oxidizing agents.

7. Silver Soldering and Brazing Procedures

Since silver solder and other brazing alloys melt at much higher temperatures than do the soft solders, soldering irons cannot be used. The common methods of application are by dipping the work in the molten alloy, by heating with torches, or in furnaces, by electrical resistance heating methods, by heating with a carbon arc, or by induction heating devices. Oxidizing atmospheres should be avoided.

In dip brazing, either a flux-covered bath of the molten alloy is employed, or the parts are assembled after the flux and solder have been applied to the joining surfaces, and the assembly is dipped in a salt bath maintained at an appropriate temperature.

Blow torches or oxyacetylene torches can be used for heating when the lower melting point hard solders are used. At higher temperatures, where oxidation should be minimized, an oxyhydrogen torch with an excess of hydrogen may be employed; this flame should have a bright yellowish appearance.

In furnace brazing, a controlled atmosphere of hydrogen or other suitable nonoxidizing gas is preferred. The joining surfaces are coated with the flux, and the hard solder, usually in the form of a thin sheet, is placed between these surfaces while the assembly is being clamped in position preparatory to placing in the furnace. This sheet need not cover the whole surface, only sufficient material being inserted to insure flow of the hard solder by capillary action throughout the joining area. The heat treatment of a steel part is often incorporated in the dip or furnace brazing operation provided that a hard solder of proper melting temperature is employed.

Aluminum alloys can be brazed by torch, dip, or furnace brazing. In addition to the cleaning methods ordinarily used preparatory to soldering, as previously described, the surfaces to be joined by aluminum brazing should be etched by immersing 20 to 60 seconds in a 5-percent sodium-hydroxide solution held at 150° F. This is followed by a water rinse, a dip in a 10-percent or stronger solution of nitric acid and a final hot water rinse. The brazing alloy should receive a similar etching treatment. The flux and the brazing alloy are placed in the joint before heating. In dip brazing aluminum alloys, the brazing alloy is set in the joint and the assembly dipped in a pot containing the molten flux. Careful temperature control is required in all of these operations so that the brazing alloy is melted without melting the parts to be joined. Aluminum brazing temperatures will range from 1,060° to 1,185° F, depending on the brazing alloy and flux used. Preheating the parts to be dip brazed is advantageous in order to avoid such difficulties as local freezing and inconsistent joining.

After brazing, it is desirable to clean the assembly of residual flux. This can be done in the brazing of most metals by dipping in boiling water or swabbing with warm water. Aluminum alloys should be cleaned after brazing by dipping in boiling water, followed by dipping 5 to 15 minutes in concentrated nitric acid or in a solution of 10-percent nitric and 25-percent hydrofluoric acids. This is followed by a second boiling water rinse. If resistance of the aluminum product to corrosion is important, a 10-percent nitric acid plus 10-percent sodium dichromate solution may be substituted for the nitric-hydrofluoric acid solution.

Whereas adequate strength is obtained in many cases of soft soldering only by using broad lap or scarf joints, in hard soldering simple butt joints often are adequate. This is possible because of the high strength of the hard solder or brazing alloy in the joint.

V. References

No attempt has been made in this Circular to discuss in detail the metallurgical principles and theories involved in the use of solders. For more detailed information on the subject, reference should be made to the original papers or books listed below.

General

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The publications listed above usually are available for consultation in the technical division of most large libraries. Books may be ordered directly from the publishers. Photostatic copying provides a convenient means for obtaining articles from technical journals. Such copies are supplied by many libraries for a moderate fee. Two such sources are the Library of the United Engineering Societies, 29 West Thirty-Ninth Street, New York 18, N. Y., and the Carnegie Library, Pittsburgh, Pa.