

SOLDERING MANUAL



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Soldering Manual

SOLDERING MANUAL

Second Edition, Revised

Prepared by
AWS Committee on Brazing and Soldering

Under the Direction of
AWS Technical Activities Committee

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INTRODUCTION

Soldering is one of the oldest and most widely practiced methods of joining metals. The art and science of soldering have continuously advanced since the Soldering Manual was first published in 1959. Considerable impetus was provided by the revolutionary changes in the electronics industry where solders were required to join hundreds of components on printed circuits. At the present time, soldering is utilized on microcircuits to provide joints as small as 150 microns. Joint reliability is required for applications ranging from automotive radiators to the most sophisticated computers in environments that range from households to outerspace. As a result of these diverse applications, much new technical information has been generated on solders, their interaction with base metals, and the properties of soldered joints. This second edition of the Soldering Manual incorporates these many advances and new data along with the fundamentals of the soldering process.

The American Welding Society defines soldering as "a group of welding processes which produces coalescence of materials by heating them to a suitable temperature and by using a filler metal having a liquidus not exceeding 450° C (840° F) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces by capillary attraction." The liquidus temperature of 450° C differentiates solders from brazing filler metals.

The data in this manual have been arranged in what the Committee believes to be the proper order for the reader who wishes to study each aspect of the soldering process. However, those

who are familiar with the fundamentals of soldering may proceed directly to chapters on specific metals or applications to obtain information for which they have an immediate need.

While every attempt has been made to provide the most recent and reliable information on soldering, the Committee realizes that all the needs of the specialist will not be filled. However, it is hoped that the manual will provide the necessary information to direct his efforts towards a more complete solution of his problems.

Since the trend in American industry is to convert to the use of metric units, all U.S. customary measurements were converted to metric. The metric units used are those of the *Système Internationale d'Unités* (SI), which is the internationally accepted metric system. Where tolerances are not essential, metric measurements were rounded off to the nearest 0 or 5; for example, 150° C ($\approx$ 300° F)—note that the symbol " $\approx$ " is used to indicate approximation. Where commercial products (which are still available mostly in U.S. customary units) are described, the metric unit is rounded off to the nearest 0 or 5, and the word nominal precedes it. For example, a nominal 1.5 kg (3 lb) solder bar. Throughout the text, U.S. customary units are included parenthetically.

Comments, inquiries, and suggestions for future revisions of this manual are welcome. Address them to Secretary, AWS Committee on Brazing and Soldering, American Welding Society, 2501 N.W. 7th Street, Miami, Florida 33125.

CHAPTER 1

PRINCIPLES OF SOLDERING

GENERAL PROCEDURES

Soldering is a group of welding processes which produces coalescence of materials by heating them to a suitable temperature and by using a filler metal having a liquidus not exceeding 450° C (840° F) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

WETTING, ALLOYING, AND CAPILLARITY

When a molten solder leaves a continuous, permanent film on the base metal surface, it is said to wet that surface. Wetting is frequently incorrectly referred to as *tinning*, which actually means pre-coating the base metal with solder, whether or not the solder contains tin. Without wetting there can be no soldering action. In order for wetting to occur, there must be a stronger attraction between certain atoms of the solder and the base metal than among the atoms of the solder itself. Inter-metallic reactions usually take place at the interface between the base metal and the solder. This wetting action is partly chemical in nature.

Wetting is greatly facilitated by the ability of a solder to alloy with the base metal. For example, pure lead does not readily wet (or adhere to) either copper or steel, whereas a tin-lead solder readily wets both. Lead does not alloy with copper or iron but tin does. Some other metals, such as zinc, increase the wetting properties of lead.

Wetting is often associated with the ease of intermetallic compound formation. Although heat is applied to facilitate wetting, prolonged heating must be avoided when some solders are applied to certain metals. Excessive intermetallic reactions, due to prolonged heating, may cause brittleness or a reduction in joint strength.

The fluidity of molten solder is an important property which influences the spreading of the solder over the metal surfaces. The flowability, or spread, of a solder may be determined by a variety of methods. The simplest method is to melt a given volume of solder by uniform heating on a standard metal plate with a specific flux. The area covered by the solder is a measure of the solder's flow properties on that metal.

The flow of solder into narrow spaces by capillary attraction is important, and a number of tests for determining this property have been devised, for example, measuring the rise of molten solder between standard twisted wires or between plates with a small, measured gap. Such tests are useful for qualification work.

The introduction of automated, high rate soldering operations has added a new dimension to solder testing. In addition to wetting, flow, and capillary, it has become necessary to measure the rate at which wetting occurs. Several fully automated instruments, "Solderability Testers," have been developed to provide these data. The instruments quantitatively record the reaction force between the base metal specimen and the molten solder, as a function of time. The recorded data provide a quantitative evaluation of a solder

system. showing both static and dynamic characteristics. The instruments are used in soldering product and process development and for quality control functions.

BASIC STEPS IN SOLDERING

Joint Fit-Up

Clearances between the parts being joined should be such that the solder can be drawn into the space between them by capillarity, but not so large that the solder cannot fill the gap. A clearance of 0.15 mm (≈ 0.005 in.) is suitable for most work except when precoated metals are used, in which case a clearance of 0.025 mm (≈ 0.001 in.) or less is advisable (see Chapter 4 for further details).

Precleaning

A clean, oxide-free surface is imperative to ensure uniform quality and a sound soldered joint. If all grease, oil, dirt, and oxides have been carefully removed from the base metal before soldering, there is a much better chance of obtaining a sound joint because only then can uniform capillary attraction be obtained. Chapter 5 contains a detailed discussion of cleaning methods.

Application of Flux

The flux that is applied to the surfaces to be soldered should have the following characteristics:

1. It should be fluid and effective in removing oxides and other nonmetallic materials that might be present at soldering temperatures.
2. It should be a barrier to reoxidation of the metal surface that has been previously cleaned.
3. It should permit displacement by the solder.
4. It should promote wetting of the surface by the solder.

The various types of soldering fluxes used are discussed in Chapter 3.

Application of Heat

After the flux is applied, the next step in a soldering operation generally is the application of heat. A number of different heating methods are used; they are described in detail in Chapter 6.

Applying the Solder

Soldering takes place in two steps: wetting the metal surfaces and then filling the gap between them with solder. The two steps can be carried out separately or together, depending upon the conditions dictated by the application. In general, each step is better done separately because the conditions can be more easily controlled. It is frequently desirable to precoat the base metal, especially if it is difficult to solder, with solder or solderable metals.

Cooling the Joint

After the surfaces of the joint have been wetted and the space between them filled with solder, the next step is to cool the joint to room temperature.

Proper jiggling, assembly, or controlled cooling may be employed to prevent excessive deformation of the joint or failure of the joint during solidification of the solder. The solder should be cooled and solidified as rapidly as possible, commensurate with the requirements of the assembly and the solder used, as slow cooling may cause excessive alloying resulting in embrittlement. Fast cooling from too high a temperature may cause warpage and may also cause small fractures in the solder.

Cooling may normally be achieved either by conducting the heat away to the main mass of the assembly or by accelerating it with a water spray or air blast. The cooling method should be varied to suit each individual job.

Flux Residue Treatment

After the soldered joint is completed, there is a flux residue which may or may not be removed, depending upon its degree of corrosiveness. Noncorrosive fluxes, which generally have a rosin base, do not require removal of the residue unless appearance is a prime factor or the joint area is to be painted or otherwise coated. On the other hand, corrosive fluxes, such as those having a zinc chloride or other corrosive base, leave a fused residue which, if not removed, would most likely cause corrosion. The self-neutralizing fluxes vary from slightly to highly corrosive and should be treated accordingly as to the removal of the residue (for more detailed information refer to Chapter 7).

CHAPTER 2

SOLDERS

GENERAL

A better understanding of the nature of solders, and how to select one for a specific application, can be obtained by examining the melting characteristics of metals and alloys. Pure metals transform from the solid to liquid state at one temperature. The melting of alloys is more complicated because they may melt over a temperature range. Any alloy system can best be studied by examining the phase diagram which shows the melting characteristics in relation to chemical composition.

The Tin-Lead Diagram

The tin-lead phase diagram is shown in Fig. 2.1. The terms used are defined as follows:

The *solidus* temperature is the highest temperature at which a metal or solder is completely solid (curve ACEDB of Fig. 2.1).

The *liquidus* temperature is the lowest temperature at which a metal or solder is completely liquid (AEB of Fig. 2.1).

Melting point and flow point are terms which have been in common use, but they have not always been applied with the same meaning. For this reason the terms solidus temperature and liquidus temperature, which can be more clearly defined, will be used.

Eutectic compositions are those specific solder compositions that melt at one temperature and

not over a range. In this respect eutectic solders behave like pure metals. In any binary system having a eutectic, the eutectic is that composition where two descending liquidus curves meet. Thus the eutectic composition (point E in Fig. 2.1) has a lower liquidus temperature than its neighboring compositions.

As shown in Fig. 2.1, 100% lead has a melting point of 327° C (621° F) (point A), whereas 100% tin has a melting point of 232° C (450° F) (point B).

It will be observed that the tin-lead solders containing from 19.5% tin (point C) to 97.5% tin (point D) have the same solidus temperature—183° C (361° F). Figure 2.1 shows that the eutectic composition is approximately 63% tin and 37% lead (point E). When this composition melts, it becomes completely liquid at 183° C (361° F). Any composition other than the eutectic composition will not become completely liquid until a higher temperature is reached. For example: 50% tin-50% lead solder has a solidus temperature of 183° C (361° F) and liquidus temperature of 216° C (421° F). This combination of tin and lead will begin to melt at 183° C (361° F) and will become completely liquid at 216° C (421° F).

At temperatures between the solidus and liquidus lines, the solder is partially melted. The region between the solidus (ACEDB) and liquidus (AEB) lines is called the melting range.

TYPES OF SOLDERS

Tin-Lead Solders

The tin-lead alloys are the most widely used solders and are used for joining most metals.

Joint clearances of 0.1 to 0.15 mm (0.003 to 0.005 in.) are optimum, but variations are allowable in specific instances. Capillary attraction, as a force to fill gaps with solder, does not function with clearances greater than 0.25 mm (0.010 in.). All cleaning and soldering processes may be used with the tin-lead solders. Fluxes of all types are used with these solders. The selection is dependent on the type of metals to be joined. The treatment of the flux residues is dictated by the flux used. These solders have good corrosion resistance to most of the common media. Some characteristics of the tin-lead solders are shown in Table 2.1.

The 2A and 5A solders have relatively high solidus temperatures with a short melting range.* The wetting and flow characteristics are poorer than those of the higher tin content solders, which necessitates extra care in surface preparation. The high lead-containing solders, used for some automotive radiators, have better strength properties at 150° C (≈300° F) than tin-lead solders containing more tin. The high soldering temperature limits the use of organic base fluxes such as rosin or those of the intermediate type (see Chapter 3). The 5A solder is particularly adaptable to torch, dip, induction, or oven soldering. The low tin solders are used for sealing precoated containers, coating and joining metals, and for moderately elevated temperature uses.

The 10B, 15B, and 20B solders have lower liquidus and solidus temperatures but wider melting ranges than the 5A solder. The wetting and flow characteristics are also better. Joint clearances are the same as already described. Extreme care must be taken to avoid movement of the solder joint during solidification to prevent hot tearing. Fluxes of all types and all heating methods are applicable. These solders are used for fabricating automobile radiators and coating and joining of metals where service temperatures are low enough to permit their use.

*The solder classification system used in this document conforms to that given in ASTM B32.

The 25A and 30A solders have lower liquidus temperatures than all previously mentioned alloys but have the same solidus temperature as the 20B solder. Therefore, the melting range is narrower. All standard cleaning, fluxing, and soldering techniques can be used with these solders. Machine and torch soldering are widely used. Many automobile radiators and cans are made with solders of this type.

The 35A, 40A, 45A, and 50A solders have liquidus temperatures low enough to be easily worked. The solidus temperature is the same as that for 20B to 30A solders. The melting ranges, therefore, are relatively narrow. Solders of this group have the best combination of wetting properties, strength, and economy and, as such, are widely used. These tin-lead solders are the general purpose solders and are used for wiping and sweating solders. Soldering automobile radiator cores, electrical connections, roofing seams, and heating units are but a few of the typical applications for these solders. The 40% tin-60% lead solder has become a very popular general purpose solder and is used extensively in sheet metal work. It is used as a rosin cored wire for radio and television applications.

The 60A and 63A solders are generally referred to as fine solders and are used wherever temperature requirements are critical. These solders are most commonly used for wave and dip soldering of electronic assemblies. All methods of cleaning, fluxing, and heating may be used with these solders.

The 70A solder is a special purpose solder used where high tin content is necessary. All soldering techniques are applicable.

Effects of Impurities on the Performance of Tin-Lead Solders

Impurities in tin-lead solders can result not only from carelessness in the refining and alloying operations but can also be added inadvertently during normal usage. Impurity pickup, however, can readily occur during many soldering operations. Because refining of metals requires specialized equipment and close metallurgical control, purification of solders by the user is not generally recommended.

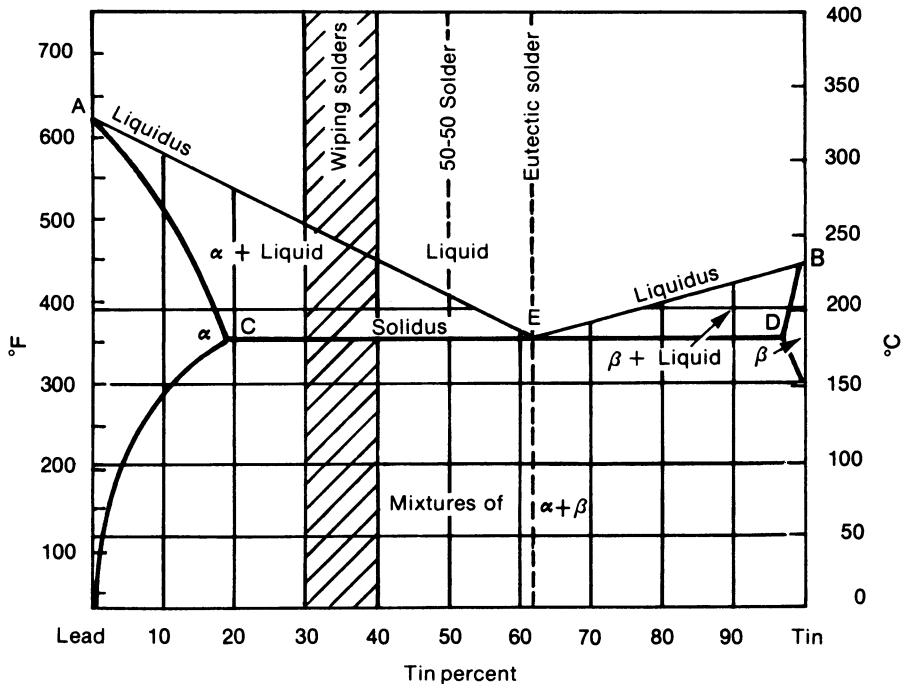


Fig. 2.1 — Phase diagram for the tin-lead alloy system

Zinc and Aluminum. The soldering properties of tin-lead solders are acutely affected by small traces of aluminum or zinc. More than 0.005% of either metal may cause lack of adhesion, grittiness, or susceptibility to failure during solidification. Both ASTM and federal specifications limit the maximum amount of either of these metals to 0.005%.

Iron. The presence of iron-tin compounds makes tin-lead solders hard and gritty, although harmful effects are not ordinarily detectable below 0.1%. ASTM and federal specifications limit iron content to 0.02%.

Copper. There is considerable discrepancy between British and American standards on copper limits in tin-lead solders. The British Standard Specification has a value of 0.5% maximum compared to a limit of 0.08% for both ASTM and federal specifications. Copper amounts above 0.3% may adversely affect the appearance of soldered joints.

Antimony. Antimony can play a dual role in tin-lead solders. Depending on the purpose for

which the solder is to be used, it can be considered as either an impurity or as a substitute for some of the tin in the solder. Federal Specification QQ-S-571 requires antimony content of 0.2 to 0.5% maximum for compositions Sn 70, Sn 63, Sn 62, Sn 60, Sn 50, Sn 40, Sn 30, and Sn 20. However, grades Sn 35, Sn 30, and Sn 20 require antimony contents up to approximately 6% of the tin content. ASTM B32, Class A, specifies a maximum of 0.12% antimony for solders containing more than 35% tin, and Class B requires 0.2 to 0.50% antimony content. Class C covers solders containing 20 to 40% tin and specifies that the antimony content is not to exceed 6% of the tin content.

Arsenic. Contamination well in excess (2 to 4 times) of the specified 0.02-0.03% arsenic may cause dewetting on brass or copper. Spots may occur on bar solder, but soldered joints will not be frosty.

Excessive Contamination in Dip Soldering. Excessive contamination in dip soldering is usually indicated when, after operating for some

Table 2.1 – Tin lead solders

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Tin % Desired	Lead % Nominal	Antimony %		Silver % Desired	Melting Range	
				Minimum	Desired		Solidus °C °F	Liquidus °C °F
70A		70	30	—	—	—	183 361	192 378
70B	Sn 70	70	30	0.20	—	—	—	—
63A		63	37	—	—	—	183 361	183 361
63B	Sn 63	63	37	0.20	—	—	—	—
	Sn 62	62	36	0.20	—	2	—	—
60A		60	40	—	—	—	183 361	190 374
60B	Sn 60	60	40	0.20	—	—	—	—
50A		50	50	—	—	—	183 361	216 421
50B	Sn 50	50	50	0.20	—	—	—	—
45A		45	55	—	—	—	183 361	227 441
45B		45	55	0.20	—	—	—	—
40A		40	60	—	—	—	183 361	238 460
40B		40	60	0.20	—	—	—	—
40C	Sn 40	40	58	1.8	2.0	—	185 365	231 448
35A		35	65	—	—	—	183 361	247 477
35B	Pb 35	35	65	0.20	—	—	—	—
35C	Sn 35	35	63.2	1.6	1.8	—	185 365	243 470
30A		30	70	—	—	—	183 361	255 491
30B	Pb 30	30	70	0.20	—	—	—	—
30C	Sn 30	30	68.4	1.4	1.6	—	185 364	250 482
25A		25	75	—	—	—	183 361	266 511
25B		25	75	0.20	—	—	—	—
25C		25	73.7	1.1	1.3	—	184 364	263 504
20B	Pb20	20	80	0.20	—	—	183 361	277 531
20C	Sn 20	20	79	0.80	1.0	—	184 363	270 517

Table 2.1—Tin lead solders continued

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Tin % • Desired	Lead % Nominal	Antimony %		Silver %		Melting Range	
				Minimum	Desired	Desired	Maximum	Solidus °C °F	Liquidus °C °F
15B		15	85	0.20	—	—	0.50	227 440	288 550
10B	Sn 10	10	90	0.20	—	—	0.50	268 514	299 570
5A		5	95		—	—	0.12	270 518	312 594
5B	Sn 5	5	95	0.20	—	—	0.50		
2A		2	98	—	—	—	0.12		

NOTE: Bismuth content allowed for all the above alloys is 0.25% maximum. The allowable copper content is 0.08% maximum, the iron content is 0.02% maximum, the aluminum content is 0.005% maximum, and the zinc content is 0.005%. The arsenic content of solders containing 60 to 70% tin is 0.03%, for 45 to 50% tin the arsenic allowed is 0.025%, and for all solders from 20 to 40% tin the arsenic limit is 0.02%. Analyses shall be made regularly for the elements described in Table 2.1 and this note.

Table 2.2—Tin-antimony solder

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Composition (weight %)		Temperature	
		Tin	Antimony	Solidus °C °F	Liquidus °C °F
95TA	Sb5	95	5	233 452	240 464

Table 2.3—Tin-silver solder

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Composition (weight %)		Temperature	
		Tin	Silver	Solidus °C °F	Liquidus °C °F
96.5TS	Sn 96	96.5	3.5	221 430	221 430

time at a reasonable solder pot temperature, it becomes necessary to increase the pot temperature substantially to overcome what appears to be sluggishness in the solder. Excessive contamination is also characterized by a rough and gritty solder bond. The increase of the pot temperature to overcome sluggishness is only a temporary expedient since the increased temperature will further accelerate contamination.

ASTM and federal solder specifications which specify maximum allowable concentrations of impurities for different grades of solders are intended only as a basis for purchasing solder. Their use as a guide for determining when solder is contaminated could result in discarding solder that is still very satisfactory for the purpose intended. Thus, although the federal specifications require that the iron content be less than 0.02%, bad effects, such as grittiness, are usually not detectable below 0.1%.

Some iron and copper can be removed from the contaminated solder by taking advantage of the lower solubility of copper-tin and iron-tin compounds at the liquidus temperatures. For best results the temperature of the solder should be lowered to just above the liquidus temperature of the uncontaminated solder, at which point the copper-tin and iron-tin compounds will crystallize. These crystals (dross) can be removed with a perforated ladle.

Tin-Antimony-Lead Solders

Antimony may be present as an impurity in solder, or deliberately added. The solders for which 0.2 to 0.5% antimony is the specified range are generally classed as B solders, i.e., 20B, 30B, 40B, etc. Federal Specification QQ-S-571 requires the presence of antimony to prevent the possible phase change from beta tin to alpha tin (called the tin pest), with the accompanying change in volume and drastic loss of solder strength. These solders may normally be used, except in very special cases, for the same applications as the A solders. Antimony may be added to a tin-lead solder as a substitute for some of the tin. The addition of antimony up to 6% of the tin content increases the mechanical properties of the solder with but slight impairment of the soldering characteristics.

Joint clearances for the tin-antimony-lead solders should be from 0.1 to 0.15 mm (≈ 0.003 to 0.005 in.), whereas 0.25 mm (0.010 in.) is a practical maximum to obtain capillary flow. All standard methods of cleaning, fluxing, and heating may be used with these solders. Their use is not recommended on aluminum, zinc, or zinc coated metals, such as galvanized iron. Solders containing antimony, when used on zinc or zinc alloys, form an intermetallic compound of zinc and antimony which causes the solder joint to become brittle.

The 20C to 40C solders have melting properties closely approximating those of equivalent A solders containing 5% more tin (see Table 2.1). The tensile strength, creep strength, and hardness of the soldered joints are higher than those obtained with nonantimonial solders, but solder flow and capillarity are somewhat lower. The use of these solders is limited to soldering non-zinc-containing metals or coatings.

Tin-Antimony Solder

The tin-antimony solder shown in Table 2.2 has excellent soldering and strength characteristics. It is useful for application where moderately elevated temperature is a factor. It has a higher electrical conductivity than the tin-lead solders and is also recommended in applications such as in food handling vessels where lead contamination must be avoided. This solder may be easily applied with rosin fluxes.

Tin-Silver Solders

The characteristic of the tin-silver solder, listed in Table 2.3, is similar to those of the tin-antimony solder. The tin-silver solders are usually used for fine instrument work and some specialty tube joining because the cost is prohibitive for general purpose soldering. They are easy to apply with rosin flux.

Tin-Zinc Solders

A large number of tin-zinc solders, some of which are listed in Table 2.4, have come into use for the joining of aluminum. Galvanic corrosion of soldered joints in aluminum is minimized if the metals in the joint are close to each other in the electrochemical series. Thus, alloys containing

70 to 80% tin, balance zinc, have been highly recommended. These alloys have liquidus temperatures between 260° and 310° C (500° and 590° F). In recent years the tendency has been to add 1 to 2% aluminum or to raise the zinc content to as high as 40%. These solders are more corrosion resistant but they have higher liquidus temperatures and are therefore a little more difficult to apply (see Chapter 15 on aluminum).

Lead-Silver Solders

Lead-silver solders listed in Table 2.5 have solidus temperatures high enough to make them useful where strength at moderately elevated temperatures is required. Although pure lead melts at 327° C (621° F), a comparatively high temperature for solder, it is not used because lead normally does not wet steel, cast iron, or copper and its alloys. The addition of silver to lead results in alloys which will more readily wet steel and copper. Flow characteristics, however, are very poor. The lead-silver solders are susceptible to humid atmospheric corrosion in storage and may become unusable as solders. The addition of 1% tin to a lead-silver solder increases its wetting and flow characteristics and, in addition, reduces its susceptibility to humid atmospheric corrosion.

Table 2.4—Tin-zinc solders

Composition (weight %)		Temperature			
Sn	Zn	Solidus		Liquidus	
		°C	°F	°C	°F
91	9	199	390	199	390
80	20	199	390	270	518
70	30	199	390	311	592
60	40	199	390	341	645
30	70	199	390	376	708

The addition of tin to a lead-silver solder containing more than 1.75% silver causes the segregation of tin-silver intermetallic crystals. Therefore, silver content is generally limited to 1.5% when tin is to be added.

The tensile, creep, and shear strengths of these solders at temperatures up to 175° C ($\approx$ 350° F) are good. Their fatigue properties are considerably better than those of the solders that do not contain silver. The lead-silver solders require higher soldering temperatures and special fluxing techniques. The use of a zinc chloride base flux to produce a good joint on uncoated metals is recommended. Rosin fluxes are readily decomposed at the higher soldering temperatures and can be used only when the soldering time is relatively short (see Chapter 3).

Cadmium-Silver Solder

The 95% cadmium-5% silver solder has melting characteristics shown in Table 2.6. The primary use of this solder is in applications where service temperatures will be higher than permissible with lower melting solders. At room temperature butt joints in copper can be made to produce tensile strengths of 170 MPa (25 000 psi). At 220° C ($\approx$ 425° F) a tensile strength of 18 MPa (2600 psi) can be obtained.

Joining of aluminum to itself or dissimilar metals is possible with cadmium-silver solder. However, as is generally true in joining aluminum with dissimilar metals, electrolytic corrosion must be considered. Improper use of this solder may lead to health hazards (see Chapter 21 for safety precautions).

Table 2.5—Lead-silver solders

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Composition (weight %)			Temperature			
		Pb	Ag	Sn	Solidus		Liquidus	
					°C	°F	°C	°F
2.5 S	Ag 2.5	97.5	2.5	—	304	579	304	579
5.5 S	Ag 5.5	94.5	5.5	—	304	579	365	689
1.5 S	Ag 1.5	97.5	1.5	1.0	309	588	309	588

Cadmium-Zinc Solders

The cadmium-zinc solders, listed in Table 2.7, are useful for soldering aluminum. These solders develop joints with intermediate strength and corrosion resistance when used with the proper flux. The 40% cadmium-60% zinc solder has found considerable use in the spot soldering of aluminum lamp bases. Improper use of these solders may lead to health hazards (see Chapter 21 for safety precautions).

Zinc-Aluminum Solder

The zinc base solder, shown in Table 2.8, is specifically for use on aluminum and develops joints with high strength and good corrosion resistance. The solidus temperature of the solder is high, which limits its use to applications where soldering temperatures in excess of 370° C (≈700° F) can be tolerated. This solder is extensively used in ultrasonic soldering of aluminum heat exchanger return bends.

Fusible Alloys

Bismuth-containing solders, the so-called fusible alloys, are useful for soldering operations where a soldering temperature below 183° C (361° F) (lower than that available with the tin-lead solders) is required. The melting characteristics and compositions of a representative group of fusible alloys are shown in Table 2.9.

Fusible alloys have applications in cases such as the following:

- 1. Soldering heat treated surfaces where higher soldering temperatures would result in a softening of the part.
- 2. Soldering joints where adjacent material is very temperature sensitive and would deteriorate if a higher soldering temperature were necessary.

3. Step soldering operations where a low soldering temperature is necessary in order to avoid destroying a nearby joint that has been made with a higher melting temperature solder.

4. On temperature sensing devices where the failure of a soldered joint is required at a relatively low temperature, which is known as the yield temperature.

Table 2.6—Cadmium-silver solder

Composition (weight %)		Temperature			
Cd	Ag	Solidus		Liquidus	
		°C	°F	°C	°F
95	5	338	640	393	740

Table 2.7—Cadmium-zinc solders

Composition (weight %)		Temperature			
Cd	Zn	Solidus		Liquidus	
		°C	°F	°C	°F
82.5	17.5	265	509	265	509
40	60	265	509	335	635
10	90	265	509	399	750

Table 2.8—Zinc-aluminum solder

Composition (weight %)		Temperature			
Zn	Al	Solidus		Liquidus	
		°C	°F	°C	°F
95	5	382	720	382	720

Table 2.9—Typical fusible alloys

Sn	Composition (weight %)				Solidus		Liquidus		Yield temperature	
	Bi	Pb	Cd	Others						
					°C	°F	°C	°F	°C	°F
13.3	50.5	26.7	10	—	70	158	70	158	70	158
15.5	52.5	32.0	—	—	90	203	90	203	90	203
14.5	48.0	28.5	—	antimony 9.0	103	217	227	440	116	241
—	55.5	44.5	—	—	124	255	124	255	124	255
43	57.0	—	—	—	138	281	138	281	138	281

Many of these solders, particularly those containing a high percentage of bismuth, are very difficult to use successfully in high speed soldering operations. Particular attention must be paid to clean metal surfaces and the use of strong fluxes to obtain satisfactory joints on uncoated metal surfaces such as copper or steel. On uncoated surfaces it is very unlikely that satisfactory soldering can be obtained with a noncorrosive type flux. If a plated surface, such as tin, silver, or cadmium, can be provided for soldering, then there is the possibility of using a noncorrosive flux. Joints produced with these solders exhibit very low creep strengths, particularly above room temperature (see Chapter 4 for recommended joint designs).

Indium Solders

Indium solders possess certain properties which make them valuable for some special applications. Their usefulness for any particular application should be checked with the supplier. The melting characteristics and compositions of a representative group of indium solders are shown in Table 2.10.

The standard 97.5% lead-2.5% silver solder does not wet most metals well. Adding 1 to 2% indium to this solder improves its wetting properties. Thus, a higher melting solder can be used without precoating the parts to be soldered. The lead-silver-indium solders are especially applicable where alkaline corrosion is a problem.

Solders containing tin, lead, and indium having more than 25% indium also show very good resistance to corrosion by alkaline solutions. However, they start melting at a much lower temperature and have a wider pasty range than the lead-silver-indium solder. A 50% indium-50% tin solder adheres to glass readily and may be used for glass-to-metal and glass-to-glass soldering. The low vapor pressure of this alloy makes it useful for seals in vacuum systems.

Indium solders generally do not require special techniques during use. The low melting indium solders containing bismuth do require the use of acid fluxes or precoating. All of the heating methods, fluxes and techniques which are used with the common tin-lead solders are applicable with indium solders.

COMMERCIAL FORMS OF SOLDERS

Typical commercial forms of solder are given in Table 2.11.

The tables in this chapter pertaining to solder specification are excerpts. Copies of the latest complete specification should be secured from the following organizations:

- ASTM American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103
- QQ Federal Specifications, Naval Publication and Forms Center, 5801 Tabor Avenue, Philadelphia, Pa. 19120

Table 2.10—Indium solders

Composition (weight %)					Temperature			
Tin	Indium	Bismuth	Lead	Cadmium	Solidus		Liquidus	
					°C	°F	°C	°F
8.3	19.1	44.7	22.6	5.3	47	117	47	117
12	21	49	18	—	58	136	58	136
12.8	4.0	48.0	25.6	9.6	61	142	65	149
50	50	—	—	—	117	243	127	260
48	52	—	—	—	117	243	117	243

Table 2.11—Commercial forms of solders

Solders are commercially available in various sizes and shapes which can be grouped into about a dozen classifications. These major groups are listed below. This listing is by no means complete, inasmuch as any desired size, weight, or shape is available on special order.

<i>Pig</i>	Available in nominal 22.5 and 45 kg (50 and 100 lb.) pigs.	<i>Segment or drop</i>	Triangular bar or wire cut into any desired number of pieces or lengths.
<i>Cakes or ingots</i>	Rectangular or circular in shape, weighing nominal 1.5, 2.5, and 4.5 kg (3, 5 and 10 lb.).	<i>Wire, Solid</i>	Diameters of nominal 0.25 to 6.5 mm (0.010 to 0.250 in.) on spools.
<i>Bars</i>	Available in numerous cross sections, weights and lengths.	<i>Wire, Flux Cored</i>	Solder cored with rosin, organic, or inorganic fluxes. Diameters of nominal 0.25 to 6.5 mm (0.010 to 0.250 in.).
<i>Paste</i>	Available as a mixture of powdered solder and suitable flux in paste.	<i>Preforms</i>	Unlimited range of sizes and shapes to meet special requirements.
<i>Foil, Sheet or Ribbon</i>	Available in various thicknesses and widths.		

CHAPTER 3

FLUXES

DEFINITION

A soldering flux is a liquid, solid, or gaseous material which, when heated, is capable of promoting or accelerating the wetting of metals by solder. The purpose of a soldering flux is to remove and exclude oxides and other impurities from the joint being soldered. Anything that interferes with the attainment of uniform contact between the surface of the base metal and the molten solder will prevent the formation of a sound joint. An efficient flux removes films and oxides from the metal and solder and prevents reoxidation of the surfaces when heated. It is designed to lower the surface tension of the molten solder so that the solder will flow readily and adhere to the metal. The flux should be readily displaced from the metal by the molten solder.

THE NATURE OF SURFACE CONTAMINANTS

Surfaces to be soldered are often covered with films of oil, grease, paint, heavy oxides or atmospheric grime which must be removed. Cleaning methods are outlined in Chapter 5.

Chemical reactions occur on clean metal surfaces at room temperature and deposit fresh surface films. Although nitrides, sulfides, and carbides are formed in some instances, the prevalent reaction is oxidation. The rate of oxide formation, its structure, tenacity and resistance to re-

moval with a flux varies with each base metal. Aluminum, magnesium, stainless and high alloy steels, aluminum and silicon bronzes, when exposed to air, form hard adherent oxide films. Highly active and corrosive fluxes must be used to remove and prevent the reformation of the tenacious films during soldering. Copper and silver, on the other hand, when exposed to air, form less tenacious films, and at a slower rate, so that mild fluxes remove them easily and prevent them from reforming.

THEORIES OF FLUX ACTION

Many theories have been proposed to explain flux action, and some of these theories have been useful in the development of new fluxes. The most widely held view is that the flux removes the oxide film from the base metal and solder by reacting with and loosening the film and floating it off into the main body of the flux. Because of the refractory nature of many oxide films, it has been suggested that the flux wets, coagulates, and suspends the oxide which has been loosened by a penetrating and reducing action. The molten flux then forms a protective blanket over the bare metal, which prevents the film from reforming. Molten solder displaces the flux and reacts with the base metal to form an intermolecular bond. The solder layer builds up in thickness and when the heat is removed, it solidifies (see Fig. 3.1).

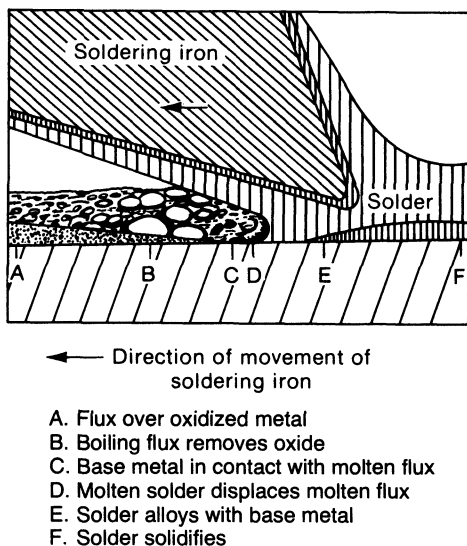


Fig. 3.1 — Mechanism of flux action

TYPES OF FLUX

Fluxes are frequently classified on the basis of their residues. They are divided into three main groups: corrosive, intermediate, and noncorrosive fluxes. The mildest flux that will perform satisfactorily in a specific application should always be selected.

Corrosive Fluxes

The corrosive fluxes, consisting of inorganic acids and salts, are used to best advantage where conditions require rapid and highly activated fluxing. They can be applied as solutions, pastes, or as dry salts and function equally well with all heating methods, since they do not char or burn.

Corrosive fluxes can be formulated to be stable over various temperature ranges. They are more versatile in this respect than the less corrosive fluxes. Corrosive fluxes are almost always required when the higher melting temperature solders are used.

Corrosive fluxes can be formulated to penetrate the most tenacious of the oxide films. Commercial fluxes are available for specific applications in the form of dilute and concentrated solu-

tions, as pastes, or as fillers for acid core solder wire.

The corrosive fluxes have one distinct disadvantage: The residue remains chemically active after soldering. The residue, if not removed, may cause severe corrosion at the joint. Adjoining areas may also be attacked by residues from the spray or flux vapors. For this reason corrosive fluxes are not used to solder closed containers such as thermostats or bellows nor to solder assembled electrical equipment. Removal of flux residues is covered in Chapter 7.

The inorganic salts and acids listed in Table 3.1 all have a fluxing action on metals when heated. If a water solution is used, the water rapidly evaporates on heating, and the molten salt reacts with the base metal to produce a protective environment which insulates the metal from contact with the air.

Corrosive Flux Ingredients

Zinc Chloride. The main ingredient in most corrosive fluxes is zinc chloride. It can be prepared by adding an excess of zinc to concentrated hydrochloric acid or can be purchased as fused zinc chloride, which is more convenient to use. Zinc chloride has a melting temperature well above the solidus temperature of most commercial tin-lead solders, which means that if it is used alone, unmelted salt particles may be entrapped in the joint. These inclusions will corrode and weaken the joint. It is good practice, therefore, to mix other inorganic chlorides with zinc chloride to lower the melting temperature of the flux.

Ammonium Chloride. A water solution of ammonium chloride may be used as a flux. When the water evaporates, the ammonium chloride sublimes as a white fume. It is less effective than zinc chloride because the protective action of a molten salt is not present and the base metal may reoxidize before it reaches soldering temperature. A combination of one part ammonium chloride to three parts zinc chloride forms a eutectic flux mixture which melts at 175° C (≈350° F). This mixture takes advantage of the excellent oxide reducing properties of the ammonium chloride and the excellent protective action of the zinc chloride to form a flux which is considerably more effective than either constituent when used alone. A one to nine ratio of

Table 3.1—Inorganic salts and acids

(a) Zinc chloride	(g) Sodium or potassium fluoride
(b) Ammonium chloride	(h) Boron trifluoride
(c) Stannous chloride	(i) Hydrochloric acid
(d) Sodium or potassium chloride	(j) Hydrofluoric acid
(e) Lithium chloride	(k) Orthophosphoric acid
(f) Aluminum chloride	(l) Fluoboric acid

the salts (1 part ammonium chloride to 9 parts zinc chloride) is commonly used without fear of flux inclusions in the soldered joint.

Stannous Chloride. Stannous chloride is formed by dissolving metallic tin in hydrochloric acid. It is commercially available in the anhydrous and hydrated forms. Stannous chloride is a highly effective flux when used alone in powder, paste or molten form. It is also effective when mixed with zinc and ammonium chlorides.

Sodium or Potassium Chloride. Sodium chloride is not effective as a flux when used alone, but is effective in diluting zinc chloride and lowers its melting point. A low melting flux can be obtained by mixing nine parts of zinc chloride with two parts of sodium chloride. A ternary eutectic mixture, melting at 203° C (397° F) is obtained by mixing 75 parts zinc chloride, 11 parts sodium chloride, and 14 parts potassium chloride.

Other Chlorides and Fluorides. Lithium and aluminum chlorides and fluorides are seldom used alone, but they are used effectively as fluxes when mixed with other compounds.

Hydrochloric Acid. Hydrochloric acid has limited use when used alone as a flux. When hydrochloric acid is applied to galvanized iron, the zinc coating is dissolved to form zinc chloride, which acts as the flux. Hydrochloric acid is used to activate the zinc chloride type fluxes. Mixtures of inorganic salts and hydrochloric acid are the basis of stainless steel fluxes.

Hydrofluoric Acid: Hydrofluoric acid is extremely corrosive. It is added to zinc chloride base fluxes for the purpose of dissolving silicon inclusions on the surface of cast iron (see Chapter 21 for safety in handling).

Orthophosphoric Acid. Orthophosphoric acid is an effective flux for steel, copper, and brass. It leaves a glassy residue which serves as a protective coating. A diluted solution is espe-

cially effective on high tensile manganese bronze.

Intermediate Fluxes

The intermediate fluxes, as a class, are weaker fluxes than the inorganic salt types. They consist mainly of mild organic acids and bases and certain of their derivatives such as the hydrohalides (see Table 3.2). These fluxes are active at soldering temperatures, but the period of activity is short because of their susceptibility to thermal decomposition. Their tendency to volatilize, char, or burn when heated limits their use with torch or flame heating. They are useful, however, in quick spot soldering operations and, when properly used, their residue is relatively inert and easily removed with water.

Table 3.2—Typical intermediate flux constituents

Organic acids

- (a) Lactic acid
- (b) Citric acid
- (c) Oleic acid
- (d) Stearic acid
- (e) Glutamic acid
- (f) Benzoic acid
- (g) Oxalic acid
- (h) Phthalic acid
- (i) Abietic acid

Organic hydrohalides

- (a) Glutamic acid hydrochloride
- (b) Aniline hydrochloride or phosphate
- (c) Hydrazine hydrobromide or hydrochloride
- (d) Cetyl trimethyl ammonium bromide
- (e) Ethyl dimethyl cetyl ammonium bromide
- (f) Cetyl pyridinium bromide

Amines and others

- (a) Urea
- (b) Diethylene di- or triamine
- (c) Glycerol



Intermediate fluxes are particularly useful in applications where small quantities of flux can be applied and where sufficient heat can be applied to fully decompose or volatilize the corrosive constituents. Caution is necessary where undecomposed flux may spread to insulating sleeving or in soldering closed systems where corrosive fumes may be deposited on critical parts of the assembly. When stranded wire is soldered, caution is necessary to avoid entrapment of the corrosive constituents.

Noncorrosive Fluxes

Noncorrosive fluxes all have rosin as a common ingredient. Rosin has unique physical and chemical properties which make it ideal as a flux. It melts at 127° C (260° F) and remains active in the molten state up to 315° C (≈600° F). The active constituent of rosin (abietic acid) is inert in the solid state, active when molten, and returns to an inactive state when cooled. Thus it is widely used in the electrical and electronics industries because the flux residue is noncorrosive and nonconductive.

Three types of rosin fluxes are in common use — nonactivated, mildly activated, and activated rosin.

Nonactivated Rosin. Nonactivated rosin consists of rosin plasticized with an inert plasticizer for core solder or dissolved in an inert solvent as a liquid flux. No additives for the purpose of increasing flux activity are used. This is the mildest of the rosin fluxes, and only extremely clean and solderable metals can be soldered reliably with nonactivated rosin. Federal Specifications MIL-F-14256 and QQ-S-571 designate this type as R.

Mildly Activated Rosin. Because of the slow fluxing action of nonactivated rosin, mildly activated rosin is also used. It contains additives which improve the fluxing action of the rosin but leave residues which are noncorrosive and nonconducting. Mildly activated rosin is used in high reliability electronic assemblies, and removal of the flux residue is optional. Mildly activated rosin can be plasticized for core solder or dissolved in an organic solvent to provide a liquid flux. Federal Specifications MIL-F-14256 and QQ-S-571 designate this type as RMA.

Activated Rosin. The activated rosin fluxes are the most active of all and depend on the

addition of small amounts of complex organic compounds for their increased activity. Hydrohalides of amines such as hydrazine hydrohalide, glutamic acid hydrochloride, cetyl pyridinium bromide, aniline hydrochloride and organic acids such as benzoic and succinic have been disclosed in patent literature as additives for activated rosin fluxes to be used in liquid form or as a core material. Additive amounts varying from 0.2 to 5% have been suggested. Fluxes of this type are designated RA.

The use of activated rosin as a noncorrosive flux is based on the theory that the activator is decomposed by heat and that the residue is not electrically conductive or corrosive. High production-line speeds have demanded more highly active fluxes, but the question of harmful flux residues is still a matter of debate in critical applications where corrosion resistance is the foremost consideration.

Paste Fluxes

It is sometimes convenient to have the flux in paste form. Paste fluxes can be more easily localized at the joint and have the advantage of not draining off the surface or spreading to other parts of the work where the flux would be harmful. The paste-forming ingredients may be water, petroleum jelly, tallow, or lanolin, with glycerine or other moisture-retaining substances. If the pastes contain inorganic salts, such as zinc or ammonium chloride, they are classed as corrosive fluxes.

Solder and Flux Pastes

A true paste solder is a stable blend of finely divided metallic solder with inorganic or organic chemicals acting as the flux in a neutral vehicle or carrier. These paste solders are not merely mechanical mixtures of flux and metal. The blending agents prevent a drying action and settling of heavy metallic particles. The size and shape of the particle of the metal ingredient have a definite bearing on the stability of the pastes.

Paste solders are well suited for preplacement in oven, radiant heat, resistance and induction heating applications. Automatic preplacement methods have been developed for the paste solders and include dipping, brushing or rolling, point feeding, and line feeding. Corrosive and noncorrosive paste solders are available.

mercially. The solder composition may vary from 25% to 60% tin, balance lead.

Reaction Fluxes

Reaction fluxes are a special group of corrosive fluxes developed for soldering aluminum. Their action depends on the decomposition of the flux to form a metallic film on the aluminum (see Chapter 15).

SELECTING THE FLUX

The following factors influence the choice of flux:

1. The assembly being soldered
2. Accessibility of the part for cleaning after soldering
3. Solderability of the base metals
4. Rate of soldering required
5. Heating method.

It is good practice to use the mildest flux that will do the job. (see Table 3.3). The soldering of complicated electrical equipment requires the choice of a noncorrosive flux, since corrosive residues cannot be tolerated and postcleaning is virtually impossible. Corrosive fluxes can be used when the parts can be thoroughly washed after soldering as, for example, in the assembly of radiators.

Where a small degree of corrosion can be tolerated and removal of the flux residue is impractical, the intermediate fluxes, properly used, are sufficiently active and fast for soldering the more difficult-to-solder metals. The more corrosive fluxes are often demanded, however, because of increased speed in soldering.

Although the base metal is a big factor in flux selection, the converse is also sometimes the case. Thus, in the electrical industry, difficult-to-solder metals are precoated with metals such as silver, tin, cadmium and copper to permit the use of rosin fluxes.

Methods of heating may govern the choice of flux and, conversely, the flux may determine the choice of heating method. The inorganic salt type fluxes can be effectively used with any heating method, since they do not char or decompose readily. The intermediate fluxes and rosin base

fluxes, however, are sensitive to the heating method. Since they are of essentially organic origin, they will decompose and become ineffective when overheated. Torch or flame heating methods, unless carefully controlled, are not generally recommended for intermediate and rosin base fluxes.

TYPICAL FLUX COMPOSITIONS

Proprietary flux formulations are available from solder and flux manufacturers for every soldering application. The following flux compositions will show some of the formulations which are used. More detailed information is available from most manufacturers.

Corrosive General Purpose Fluxes

These fluxes are effective on low-carbon steel, copper, brass, and bronze. Applications are in the production of auto radiators, air conditioning and refrigerating equipment, body soldering, and sheet metal assembly.

1. Zinc chloride	1130 g	40 oz.
Ammonium chloride	110 g	4 oz.
Water to make	4 L	1 gal
2. Zinc chloride	1020 g	36 oz.
Sodium chloride	280 g	10 oz.
Ammonium chloride	15 g	1/2 oz.
Hydrochloric acid	30 g	1 oz.
Water to make	4 L	1 gal
3. Zinc chloride	600 g	21 oz.
Sodium chloride	170 g	6 oz.
<i>(Dry flux for molten solder cover in dip soldering)</i>		
4. Zinc chloride	710 g	25 oz.
Ammonium chloride	100 g	3-1/2 oz.
Petroleum jelly	1840 g	65 oz.
Water	180 g	6-1/2 oz.

Corrosive Special Purpose Fluxes

These fluxes can be used for soldering stainless steel, alloy steel, nickel alloys, silicon and aluminum bronzes, zinc coated sheet, cast iron and aluminum.



Table 3.3—Flux selection

Type	Composition	Carrier	Uses	Temperature stability	Ability to remove tarnish	Corrosiveness	Recommended cleaning after soldering
Inorganic Acids							
	Hydrochloric hydrofluoric orthophosphoric	Water, petroleum paste,	Structural	Good	Very Good	High	Hot water rinse and neutralize; organic solvents
Salts	Zinc chloride, ammonium chloride, tin chloride	Water, petroleum paste, polyethylene glycol	Structural	Excellent	Very Good	High	Hot water rinse and neutralize; 2% HCl solution; hot water rinse and neutralize; organic solvents
Organic Acids							
	Lactic, oleic, stearic glutamic, phthalic	Water, organic solvents, petroleum paste, polyethylene glycol	Structural, Fairly Good Electrical	Fairly Good	Fairly Good	Moderate	Hot water rinse and neutralize; organic solvents
Halogens	Aniline hydrochloride, glutamic hydrochloride, bromide derivatives of palmitic acid, hydrazine hydrochloride (or hydrobromide)	Same as organic acids	Structural, Fairly Good Electrical	Fairly Good	Fairly Good	Moderate	Same as organic acids
Amines and amides	Urea, ethylene diamine	Water, organic solvents, petroleum paste, polyethylene glycol	Structural, Electrical	Fair	Fair	Noncorrosive normally	Hot water rinse and neutralize; organic solvents
Activated rosin	Water white rosin	Isopropyl alcohol, organic solvents, polyethylene glycol	Electrical	Poor	Fair	Noncorrosive normally	Water base detergents; isopropyl alcohol; organic solvents
Water white rosin	Rosin only	Same as activated	Electrical	Poor	Poor	None	Same as activated water white rosin but does not normally require post cleaning

- | | | | | | |
|--|--------|-----------|---|--------|--------|
| 1. Zinc chloride | 2410 g | 85 oz. | Diethanol diamine | 110 g | 4 oz. |
| Ammonium Chloride | 180 g | 6-1/2 oz. | Diethanol triamine | 285 g | 10 oz. |
| Stannous Chloride | 260 g | 9 oz. | <i>(For soldering aluminum)</i> | | |
| Hydrochloric acid | 60 g | 2 oz. | | | |
| Water to make | 4 L | 1 gal | 9. Potassium chloride | 1280 g | 45 oz. |
| Wetting agent (optional) — 0.1% by weight | | | Sodium chloride | 850 g | 30 oz. |
| <i>(For stainless steel and galvanized iron)</i> | | | Lithium chloride | 425 g | 15 oz. |
| | | | Potassium fluoride | 200 g | 7 oz. |
| 2. Zinc chloride | 1360 g | 48 oz. | Sodium | | |
| Ammonium chloride | 140 g | 5 oz. | pyrophosphate | 85 g | 3 oz. |
| Hydrochloric acid | 85 g | 3 oz. | <i>(For soldering aluminum)</i> | | |
| Water to make | 4 L | 1 gal | 10. Triethanolamine | 710 g | 25 oz. |
| Wetting agent (optional) — 0.1% by weight | | | Fluoboric acid | 85 g | 3 oz. |
| <i>(For stainless steel)</i> | | | Cadmium fluoborate | 55 g | 2 oz. |
| 3. Zinc chloride | 455 g | 16 oz. | (Chloride-free organic flux for soldering | | |
| Ammonium chloride | 455 g | 16 oz. | aluminium. Fluxing range 175° to 275° C [≈350° | | |
| Glycerin | 455 g | 16 oz. | to 525° F]. The viscous liquid can be dissolved | | |
| Water | 0.5 L | 1 pint | with water or alcohol to any desired concentra- | | |
| <i>(For Monel)</i> | | | tion.) | | |
| 4. Orthophosphoric | | | 11. Stannous chloride | 1250 g | 44 oz. |
| acid (85%) | 960 g | 34 oz. | Ammonium chloride | 140 g | 5 oz. |
| Water | 455 g | 16 oz. | Sodium fluoride | 30 g | 1 oz. |
| <i>(For high tensile manganese, bronze,</i> | | | (Reaction type flux for soldering aluminum. | | |
| <i>copper, brass)</i> | | | Fluxing range 280° to 380° C [≈540° to 720° F] | | |
| 5. Zinc chloride | 910 g | 32 oz. | or higher. It may be used as a dry powder mixture | | |
| Ammonium chloride | 110 g | 4 oz. | or it may be suspended in alcohol.) | | |
| Sodium chloride | 225 g | 8 oz. | 12. Zinc chloride | 1250 g | 44 oz. |
| Hydrochloric acid | 225 g | 8 oz. | Ammonium chloride | 140 g | 5 oz. |
| Water to make | 4 L | 1 gal | Sodium fluoride | 30 g | 1 oz. |
| <i>(For cast iron)</i> | | | (Reaction flux for soldering aluminum. It may be | | |
| 6. Zinc chloride | 1130 g | 40 oz. | used as a dry powder or mixed with water or | | |
| Ammonium chloride | 110 g | 4 oz. | alcohol.) | | |
| Hydrofluoric acid | 35 g | 1-1/4 oz. | Intermediate Fluxes | | |
| Water to make | 4 L | 1 gal | These fluxes contain organic compounds which | | |
| <i>(For cast iron)</i> | | | decompose at soldering temperatures. When | | |
| 7. Stannous chloride | 2350 g | 83 oz. | properly used, the mildly corrosive elements in | | |
| Zinc dihydrazinium | | | the flux volatilize, leaving a residue relatively | | |
| chloride* | 200 g | 7 oz. | inert and easily removed with water. They are | | |
| Hydrazine | | | effective on all materials which are solderable | | |
| hydrobromide* | 285 g | 10 oz. | with mild fluxes. Typical compositions are as | | |
| Water | 285 g | 10 oz. | follows: | | |
| <i>(Paste flux for soldering aluminum)</i> | | | 1. Glutamic acid | | |
| 8. Cadmium fluoboride | 140 g | 5 oz. | hydrochloride | 540 g | 19 oz. |
| Zinc fluoboride | 140 g | 5 oz. | Urea | 310 g | 11 oz. |
| Fluoboric acid | 170 g | 6 oz. | Water | 4 l | 1 gal |
| Diethanol amine | 570 g | 20 oz. | Wetting agent — 0.2% by weight | | |

- | | | |
|------------------------|--------|----------|
| 2. Hydrazine | | |
| monohydrobromide* | 280 g | 10 oz. |
| Water | 2550 g | 90 oz. |
| Nonionic wetting agent | 1.5 g | 1/20 oz. |
| 3. Lactic acid (85%) | 260 g | 9 oz. |
| Water | 1190 g | 42 oz. |
| Wetting agent | 3 g | 1/10 oz. |
| (For beryllium copper) | | |

Noncorrosive Fluxes

The rosin base fluxes — nonactivated, mildly activated and activated — belong in this class. For all electronic and critical soldering applications, water white rosin dissolved in an organic solvent (item 1 below) is the safest known flux. Activators added to the rosin increase the activity, but the flux residue from these fluxes should pass tests for noncorrosivity and nonconductance when used on electronic applications. These fluxes are effective on clean copper, brass, bronze, tinplate, terneplate, electrodeposited tin and in alloy coatings, cadmium, nickel, and silver.

1. Water white rosin: 10-25% by weight
Alcohol, turpentine or petroleum: balance
2. Water white rosin: 40% by weight
Glutamic acid hydrochloride: 2% by weight
Alcohol: balance
3. Water white rosin: 40% by weight
Cetyl pyridinium bromide: 4% by weight
Alcohol: balance
4. Water white rosin: 40% by weight
Stearine: 4% by weight
Alcohol: balance
5. Water white rosin: 40% by weight
Hydrazine hydrobromide 2% by weight
Alcohol: balance

TESTING OF FLUXES

Laboratory tests on fluxes are of questionable value as a final indication of the effectiveness of the flux. However, the following tests are used to classify fluxes according to their efficiency and corrosivity.

Flux Efficiency

The test varies from one laboratory to another, but the details may be generalized. A circular strand of solder of known weight is placed in the center of a one-inch square piece of clean copper sheet and a few drops of the flux applied. The copper sheet is placed on a thermostatically controlled hot plate at 260° C (500° F) for 60 seconds and then carefully removed. The spread of the solder is measured with a planimeter. The apparatus can be improved by eliminating air currents which may affect the spread or by raising or lowering the sheet onto the hot plate mechanically to avoid disturbing the solder. A control test with a standard flux is made along with each test as a comparison of flux efficiency. Although this test procedure is fairly standard, it must be appropriately modified for use with base metals other than copper.

Flux Corrosivity

One method for measuring potential corrosivity of the flux is the measurement of the resistivity of a water extract. The water extract test is a means by which the chemical character of flux residues is determined. As the test is outlined in the Federal Specification QQ-S-571, much care is required to obtain correct and reproducible results. The specification requires that the specific resistivity of a water extract of the flux be at least 100 000 Ω cm for R and RMA and 45 000 Ω cm for RA types. Details of the test procedure appear in Federal Specification QQ-S-571. Other corrosion tests for rosin base fluxes are given in MIL-F-14256, QQ-S-571, and ASTM B284.

*Stock solution to be used in concentration of 2-15% in alcohol. Hydrazine salts and compounds are highly toxic, and fluxes containing these should be used with caution.

CHAPTER 4

JOINT DESIGN

INTRODUCTION

In general, solders have lower strength properties than the materials to which they are joined. Structurally loaded joints must therefore be carefully evaluated so that they will be capable of sustaining the applied stresses for an adequate lifetime. Long-term joint properties are more important than short-time tensile or shear tests in the determination of an appropriate joint cross-sectional area once the design has been selected. Bulk solder alloy properties must not be utilized in design, since they are not reflected in actual joint strengths.

Electrical conductivity of soldered connections is also an important factor. Solder resistivity values vary widely and must be considered in selecting a suitable joint design or connection. The soldered joint should relate to the maximum expected capacity of the electrical circuit and be designed to prevent localized heating or resistance changes that would influence overall circuit performance.

BASE METAL

The base metal's properties will have a strong influence on joint selection. The designer must have a thorough knowledge of the part or assembly and its intended functions in order to arrive at the best joint design, material, and solder for the job. The initial design criteria will eliminate

many materials and solders from consideration. However, it is very likely that several solder-base metal combinations will remain after the engineering assessments. The next most important criterion to consider is cost effectiveness, including relative processing and material costs.

Physical and mechanical properties of the soldered joint are discussed in Chapter 23. As already explained, however, the range of possibilities in configuration variations is such that some test work is mandatory on a proposed joint design and soldering procedure if a specific performance requirement is to be met. When joint designs are compared, the soldering operations must be performed under carefully controlled and similar conditions so that the joint itself is under test and not the method of joining.

Relative thermal expansion of the solder and the base metal are important in processing as well as in service. In processing, joint overstressing can lead to solder joint fracture on solidification. In service, differential thermal expansion or residual stresses from processing can accelerate joint failure by creep or corrosion mechanisms. As service stresses increase, attention should be given to the joint by (1) placing the joint in a relatively low stress area, (2) supporting the joint mechanically, say, by a lock-seam, and (3) resorting to a higher strength solder with suitable strength or creep resistance.

Lap joints are the most widely used and are usually preferable. Butt joints can be made but have limited value. Many variations in joint de-

sign are feasible, a good number of which are presented in Figs. 4.1 and 4.2. Dimensions of the lap joint may be varied so that the joint can adequately sustain service loading or produce failure in the base metal to which it is attached. Most reported test data on joint strengths are not useful to the designer, since in solder joints the ability to withstand load to failure in a short-time room-temperature test generally does not bear much relationship to what that joint can sustain in service. Often the data are meaningless for the designer because sufficient details of the actual test performed are lacking. The shear strength of a solder joint can apparently be doubled or halved depending on the speed of test in tension. Therefore, engineering design must proceed on the basis of test comparisons, using book

values as an initial guide to solder and base metal selection. Joint design with a simple lap joint is more complex than relating a unit cross-section stress or shear value to a developed configuration. Rarely can a solder joint be designed to take a pure shear load. The length and quality of the exposed joint edge is just as important as joint area in strength determination under shear load. Perhaps the most definite work on shear loading of soldered joints was performed by Maupin and Swanger, who fully characterized the load-carrying capabilities of copper tube with sleeve-type joints or fittings. Their results can be effectively interpreted, since overall dimensions are known in addition to the loads applied. Typical copper tube and fitting sizes are found in Chapter 22.

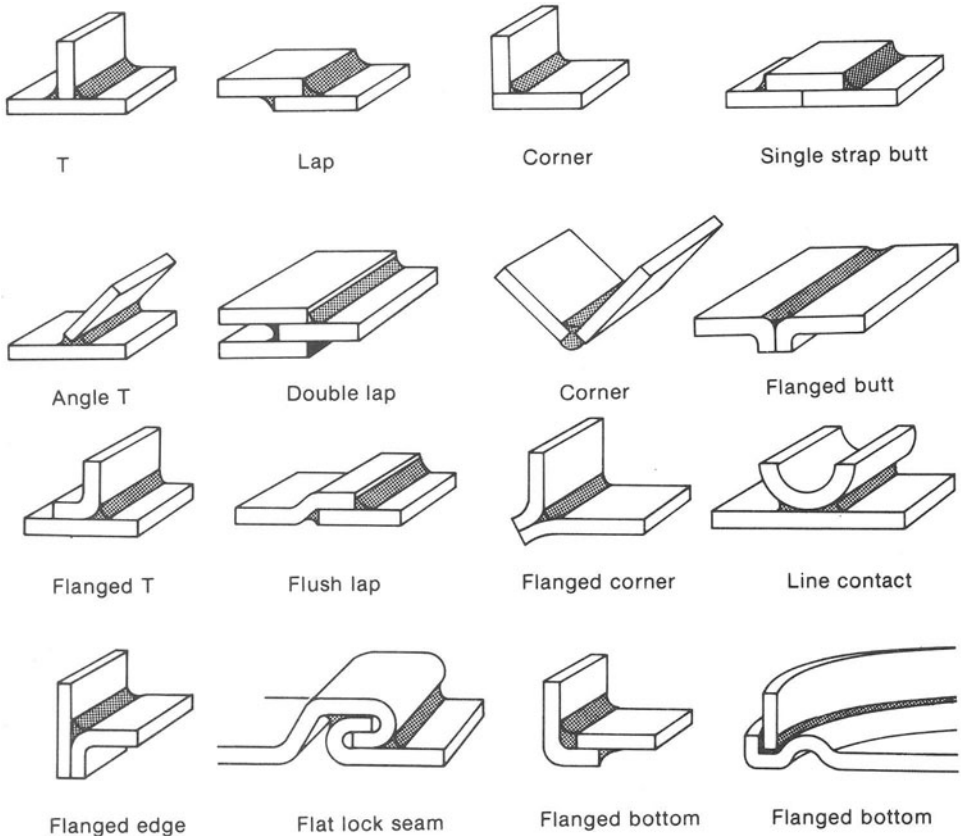


Fig. 4.1a — Joint designs frequently used in soldering. Solder joints terminology has not been standardized

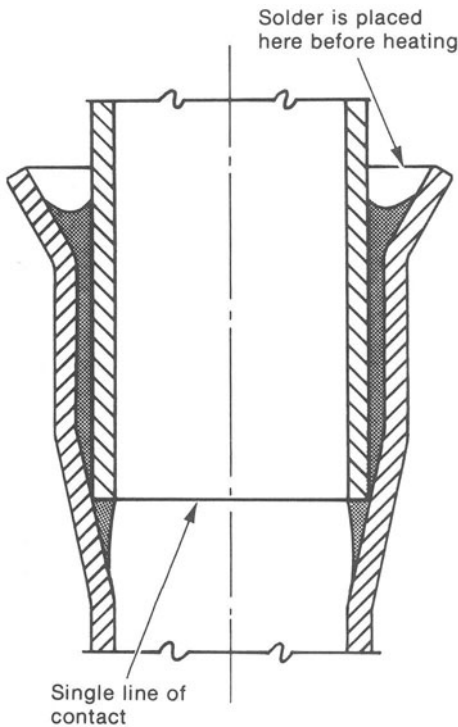


Fig. 4.1b — Typical socket joint design. Note flange which holds solder preform and the single line of contact between inner member and inner wall. The molten solder flows easily beneath the contact line to form a fillet on the other (lower) side

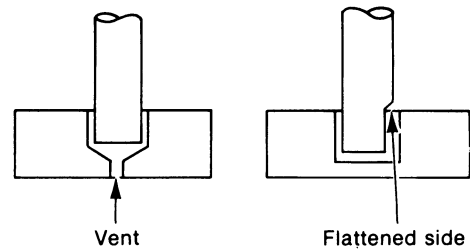


Fig. 4.1c — Venting of closed-end joints can be done by drilling a hole, as at left, or by crimping or flattening one member, as at right

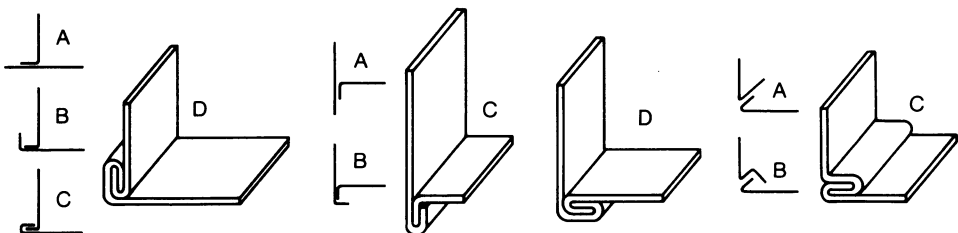


Fig. 4.1d — Several lock seam designs used in soldering sheet. Sequence of formation is shown by the sketches

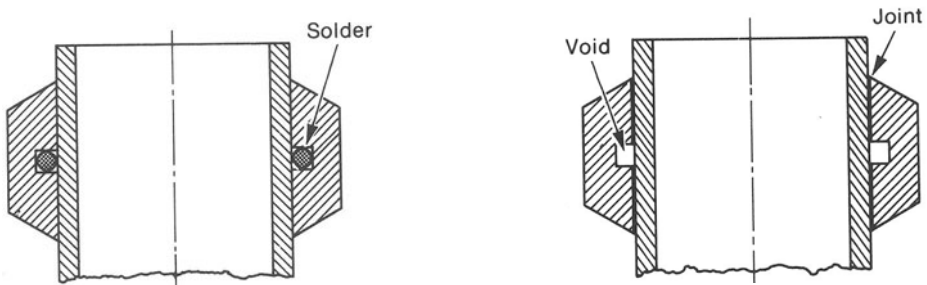


Fig. 4.1e — Joint showing (*left*) solder preplacement before soldering and (*right*) after soldering

Radiators and heat exchangers are among the commonest applications of soldering. Tubes are joined by a lock seam and then joined to tank headers by a lap joint; the remaining joint between the header plate and tank is a trough joint, shown in Fig. 4.4. These joints are required to be structurally capable of operating at elevated temperature and pressure under cyclic conditions. Test work has demonstrated that lap joint strength data are not applicable to the trough system, but a peel test provides a quantitative measure of the comparative merits of solder fillers for header tank use. Joint design in the radiator is controlled by the need for rapid assembly, and solder selection is necessarily progressive because the joints have to be made in sequence. Success depends on the total concept in which joint design has an important place but cannot be separately considered.

Process selection, details of which can be found in Chapter 6, can dictate the appropriate joint design or, conversely, a particular joint design may be limited to a particular process or heating method. For example, in sheet metal work the lock seam has the obvious advantage of being self-jigging, and parts can be roughly handled and still be joined satisfactorily. The ideal use of the lap joint is in tubing where a sleeve fit is easy to assemble for subsequent joining. Both can be hand-soldered or automatically handled with liquid solder or solid wire feed material application. The trough system is particularly useful for rapid automatic production; it does not

require close fit-up, but it uses large quantities of solder. Quantity production of small parts or small joints can best be handled with wire or strip preforms. Joints are designed for solder retention, for example, widening a gap or indenting a part for precise joint configuration. Parts are made for automatic sorting and placement.

Capillary action of liquid solder is necessary for good joint formation in lapped or locked seams in tube sleeves and in some wire type connections. The maximum capillary rise achievable is directly related to joint gap (see Fig. 4.5) and is given by the equation

$$h = \frac{2 \sigma \cos \Theta}{d \rho g}$$

where h = capillary height,
 σ = surface tension, dynes
 Θ = contact angle,
 d = capillary gap,
 ρ = solder density,
 g = gravity.

Joint tolerances are critical to proper capillary action and to the displacement of flux from the joint by the molten solder. These two requirements are conflicting and result in the known optimum lap joint gap of 0.1 to 0.15 mm (≈ 0.003 to 0.005 in.). A smaller gap may produce flux inclusions; a larger gap reduces capillary flow and may also produce voids.

Joint design must be adequate for liquid solder flow. Several factors affect joint design and must

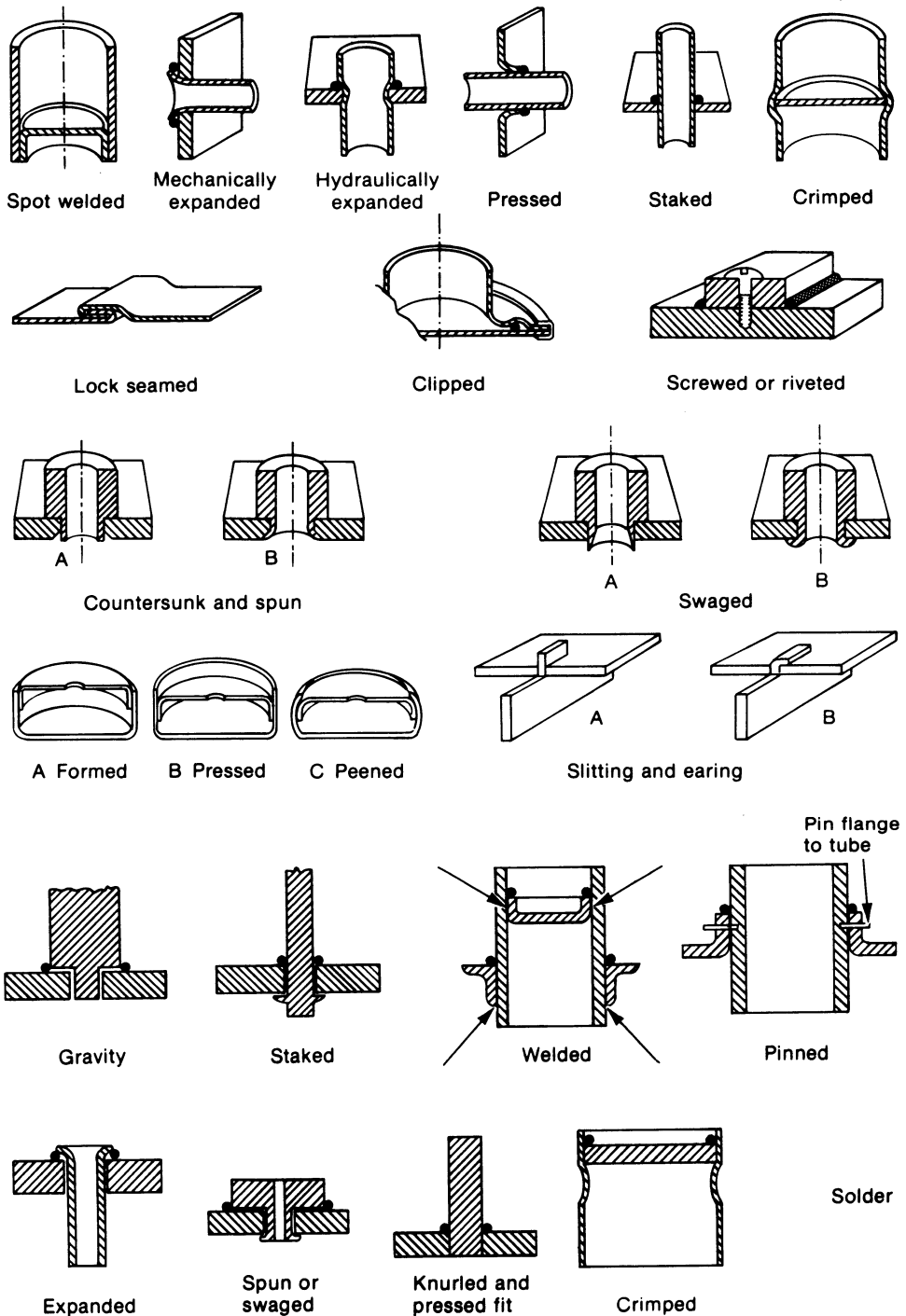


Fig. 4.2 — Twenty-one methods that can be used to make solder joints self-jigging

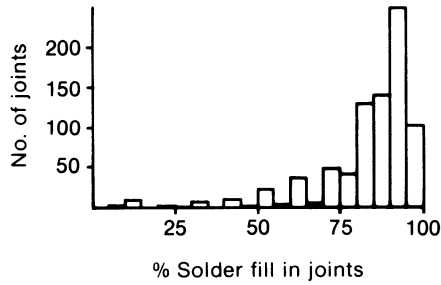


Fig. 4.3 — Histogram of joint areas filled with soft solder. From collection of 812 fitting joints considered to have been giving satisfactory service prior to their removal from service due to building demolition

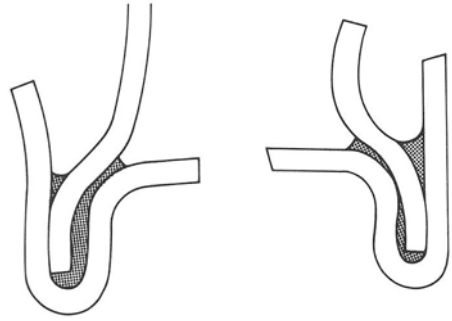


Fig. 4.4 — Section of tank-to-tube plate joint

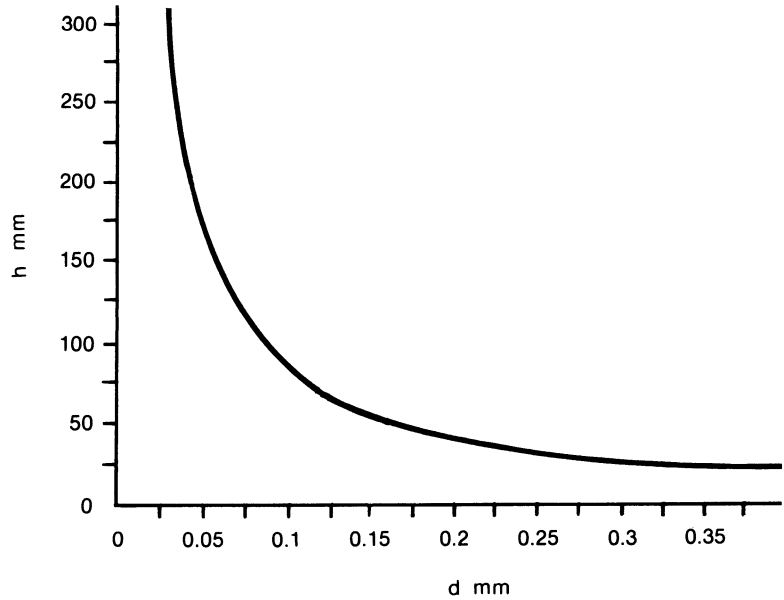


Fig. 4.5 — Maximum head height versus capillary gap dimension between parallel plates for 50% tin-50% lead solder with flux present

be considered if a sound joint is to be produced:

1. A reservoir of molten solder
2. A feed path to the capillary
3. A suitable capillary entrance and exit
4. Controlled gap to provide capillary driving force
5. A balanced mass for even heating and controlled liquid solder flow
6. A joint suitable for the proposed method of heating
7. Enough joint freedom to prevent flux entrapment.

A conscious effort is necessary in joint detailing to provide highly reliable optimum joints.

A widely used practical joint is the interlock or locked seam. From a joint design and ease-of-soldering standpoint, the joint is also one of the most difficult. Usually the heating system has at least three thicknesses to penetrate, and the inner part of the joint may not be hot enough to provide the free solder flow. Sometimes interlocked joints are provided with perforations to assist in observing solder flow.

Soldered joints are widely used in the electronics industry (see Tables 4.1 and 4.2). Joint design for electrical applications has the dual function of providing satisfactory electrical continuity in addition to permanently affixing components and leads for reliable service. Electrical joints for wires and more recently joints in the printed circuit and integrated circuit industries have increasingly been required to be capable of withstanding a variety of service conditions.

The three basic types of joint for the wire-to-tab connection are shown in Fig. 4.6. The lap joint is useful for many electrical applications. The through-lead with or without plated through-holes is widely used but generally not suitable for vibrating or high acceleration service because of soldered joint creep problems. A wrapped or clinched joint is preferable. Several variations are possible here from the wire-to-wire wrap joint to a clinched wire onto a printed circuit board (see Table 4.3). Some advantages can be gained by the use of larger pad areas and longer leads to increase solder mass. Thinner boards help in reducing thermal expansion, and a thick plated

through-hole with solder fill will provide a larger crack propagation path as demonstrated in Fig. 4.7. Component placement is instrumental in restraining movement. Some electrical designs allow a strain-relieved lead but, conversely, an offset component can lead to mechanical or thermal fatigue of the joint if not carefully designed as in Fig. 4.8. See Fig. 4.9 for some helpful tips on component mountings. Swaged terminals should not be soldered to both sides of the joint. A lead wire should be used if a second joint is necessary.

Wire-to-hole ratio and land spacing are two other important factors. Again, selection of both is bound to lead to compromise. A satisfactory minimum radial clearance in a hole for a wire is 0.1 mm (≈ 0.003 in.). Adequate soldering in the hole is more important in the plated through-hole where this area is probably included in the electrical design. Component densities tend to increase, reducing space between conductors and allowing less room for adequate land spacing. Land shape should be related to the conductor shape and size to allow the best fillet formation at the joint area. Some configurations are presented in Table 4.4. Safety factors in joint design are subjective; there are no clear rules because of the numerous variables and compromises that have been made during the designing process. The final test must be a verification trial for manufacturing and a test and inspection program for service. Review and modification of new designs must be included in the cost and time accounting and should not necessarily be regarded as a "mistake." Much remains to be learned, and many pitfalls can be avoided by proper attention.

High density electronic packaging requires close attention to joint design to suit the process. Lead bend angle has profound effects on reported mechanical strengths. Lead mass can affect optimum time-temperature profiles in joint production. A flat length or lead pad of 1.5 mm (≈ 0.050 in.) is needed for conductor attachment, and path widths should preferably be 0.15 mm (≈ 0.005 in.) minimum each side of the lead. Overlapping the conductor produces lower quality joints. Two joints are illustrated in Fig. 4.10.

Table 4.1—Linear thermal expansions of metals and alloys

	Temperature		Coefficient of expansion (in./in./° F × 10 ⁻⁶)	
	°C	°F		
ALUMINUM ALLOYS				
1100	0 to 100	32 to 212	23.6	13.1
3003	0 to 100	32 to 212	23.2	12.9
3004	0 to 100	32 to 212	23.9	13.3
5052	0 to 100	32 to 212	23.8	13.2
6062	0 to 100	32 to 212	22.2	12.4
COPPER AND COPPER ALLOYS				
Electrolytic (ETP)				
Deoxidized (DLP)	0 to 100	32 to 212	17.6	9.8
Oxygen-free (OF)				
Commercial bronze, 90 Cu-10 Zn	0 to 100	32 to 212	18.4	10.2
Red brass, 85 Cu-15 Zn	0 to 100	32 to 212	18.7	10.4
Low brass, 80 Cu-20 Zn	0 to 100	32 to 212	19.1	10.6
Cartridge brass, 70 Cu-30 Zn	0 to 100	32 to 212	20.0	11.1
Muntz metal, 60 Cu-40 Zn	0 to 100	32 to 212	20.9	11.6
Leaded brass; low, medium and high ...	0 to 100	32 to 212	20.3	11.3
Naval brass	0 to 100	32 to 212	21.2	11.8
Phosphor bronze, 8 (Grade C)	0 to 100	32 to 212	18.2	10.1
Cupro-nickel, 70 Cu-30 Ni	0 to 100	32 to 212	16.2	9.0
Cupro-nickel, 90 Cu-10 Ni	0 to 100	32 to 212	16.7	9.3
Nickel silver, 65 Cu-15 Ni	0 to 100	32 to 212	16.2	9.0
Aluminum bronze, 92 Cu-8 Al	0 to 100	32 to 212	16.2	9.0
IRONS AND STEELS				
Ingot iron	0 to 100	32 to 212	11.7	6.5
Wrought iron	0 to 100	32 to 212	12.1	6.7
Gray cast iron	0 to 100	32 to 212	10.8	6.0
“Ni-Hard,” low-or high-carbon	0 to 100	32 to 212	8.6	4.8
Carbon steel, SAE 1020	0 to 100	32 to 212	11.7	6.5
Cast alloy steel	0 to 100	32 to 212	12.1	6.7
Iron-silicon alloy	0 to 100	32 to 212	6.5	3.6
“Durichlor”	0 to 100	32 to 212	6.5	3.6
STAINLESS STEELS				
301, 302, 304, 309, 310	20 to 100	68 to 212	14.4	8.0
321, 347	20 to 100	68 to 212	14.9	8.3
316, 317	20 to 100	68 to 212	15.8	8.8
410, 430	20 to 100	68 to 212	9.2	5.1
414, 420	20 to 100	68 to 212	9.9	5.5
431	20 to 100	68 to 212	11.7	6.5
446	20 to 100	68 to 212	10.3	5.7

Table 4.1 – Linear thermal expansions of metals and alloys *continued*

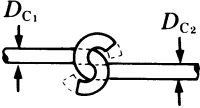
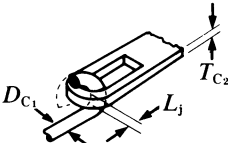
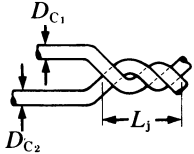
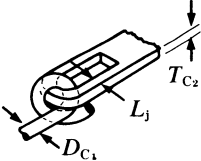
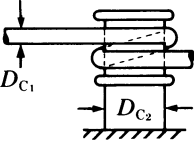
	Temperature		Coefficient of expansion (in./in./° F × 10 ⁻⁶)	
	°C	°F		
NICKEL AND NICKEL ALLOYS				
Nickel (pure)	0 to 100	32 to 212	13.3	7.4
Nickel (wrought or cast)	0 to 100	32 to 212	13.0	7.2
Low-carbon nickel	0 to 100	32 to 212	13.0	7.2
Monel (wrought)	0 to 100	32 to 212	14.0	7.8
Monel (cast)	0 to 100	32 to 212	12.2	6.8
Inconel (wrought or cast)	0 to 100	32 to 212	11.5	6.4
“Hastelloy” Alloy A	0 to 100	32 to 212	11.0	6.1
“Hastelloy” Alloy B	0 to 100	32 to 212	10.0	5.6
“Hastelloy” Alloy C	0 to 100	32 to 212	11.3	6.3
“Hastelloy” Alloy D	0 to 100	32 to 212	11.0	6.1
TIN, LEAD, AND LEAD ALLOYS				
Corroding lead	17 to 100	63 to 212	29.3	16.3
Hard lead (4 Sb)	20 to 100	68 to 212	24.6	15.4
8% antimonial lead (8 Sb)	20 to 100	68 to 212	26.6	14.8
20-80 Solder (20 Sn)	15 to 110	59 to 230	26.5	14.7
Lead base babbitt (80 Pb, 15 Sb, 5 Sn)	20 to 100	68 to 212	23.9	13.3
Lead base babbitt (75 Pb, 15 Sb, 10 Sn)	20 to 100	68 to 212	19.6	10.9
Pure tin	0 to 100	32 to 212	23.0	12.8
MISCELLANEOUS PURE METALS				
Tungsten	near 20	near 68	4.3	2.4
Molybdenum	25 to 100	77 to 212	4.9	2.7
Silver	0 to 100	32 to 212	19.6	10.9
Gold	20	68	14.2	7.9
Platinum	20	68	8.8	4.9
Palladium	20	68	11.9	6.6
Tantalum	near 20	near 68	6.5	3.6
Zinc	20 to 250	68 to 482	29.8	22.1
Titanium	20	68	8.5	4.7
Magnesium	20 to 100	68 to 212	25.9	14.4
Chromium	20	68	6.1	3.4
Cadmium	Room Temperature		29.9	16.6

Table 4.2—Data for electrical-connections design¹

Group I—No mechanical security prior to soldering						
Butt connections						
No.	Type	Diagram	Controlling formula	Conditions	Fixtures	Current
1	Round to round		$D_S = \sqrt{\delta D_{C1}}$	$\rho_{C1} \geq \rho_{C2}$ $D_{C1} \leq D_{C2}$	Yes	Small
2	Square to square		$D_S = \sqrt{\frac{4}{\pi} \delta T_{C1}}$	$\rho_{C1} \geq \rho_{C2}$ $T_{C1} \leq T_{C2}$	Yes	Small
3	Rectangle to rectangle		$T_S = \delta T_{C1}$	$\rho_{C1} \geq \rho_{C2}$ $W_1 = W_2 = W_S$ $T_{C1} \leq T_{C2} \neq T_S$	Yes	Small
Lap connections						
1	Round* to round		$L_j = \frac{\pi}{2} \delta D_{C1}$	$\rho_{C1} \geq \rho_{C2}$ $D_{C1} \leq D_{C2}$ $W_S \geq \frac{D_{C1}}{2}$	Yes	Large
2	Round to flat		$L_j = \frac{\pi}{4} \delta D_{C1}$	$\rho_{C1} \geq \rho_{C2}$ $A_{C1} \leq A_{C2}$	Optional	Large
3	Flat to flat		$L_j = \delta T_{C1}$	$\rho_{C1} \geq \rho_{C2}$ $W_1 = W_2 = W_S$ $T_{C1} \leq T_{C2}$	Optional	Large
4	Wire to post		$L_j = \frac{1}{2} \delta D_{C1}$	$\rho_{C1} \geq \rho_{C2}$ Solder fillet $\geq \frac{D_{C1}}{2}$	No	Medium
5	Wire to cup		$L_j = \frac{1}{4} (\delta - 1) D_{C1}$	$\rho_{C1} \geq \rho_{C2}$	No	Large
6	Wire to hole		$L_j = \frac{1}{4} \delta D_{C1}$	$\rho_{C1} \geq \rho_{C2}$	Optional	Medium

¹H. H. Manko, How to Design the Soldered Electrical Connection, *Prod. Eng.*, June 12, 1961, p. 57.

Table 4.3—Data for electrical-connections design

Group II—Partial mechanical security prior to soldering						
Hook connections						
No	Type	Diagram	Controlling formula	Conditions	Fixtures	Current
1	Round to round		$D_{C1} = \frac{2}{\delta} D_{C2}$	$\rho_{C1} \geq \rho_{C2}$ $D_{C1} \leq D_{C2}$ Hook $\geq 180^\circ$	No	Large
2	Round to flat		$D_{C1} = \frac{1}{\pi \delta} (8L_j + 4T_{C2})$	$\rho_{C1} \geq \rho_{C2}$ $A_{C1} \leq A_{C2}$ Hook $\geq 180^\circ$	No	Medium
Group III—Full mechanical security prior to soldering**						
Wrap connections						
No	Type	Diagram	Controlling formula	Conditions	Fixtures	Current
1	Round to round		$L_j = \frac{\pi}{2} \delta D_{C1}$	$\rho_{C1} \geq \rho_{C2}$ $D_{C1} \leq D_{C2}$ $N > 1$	No	Large
2	Round to flat		$D_{C1} = \frac{8}{\pi \delta} (L_j + T_{C2})$	$\rho_{C1} \geq \rho_{C2}$ $A_{C1} \leq A_{C2}$ $N = 1$	No	Medium
3	Round to post		$D_{C1} = \frac{4N}{\delta} D_{C2}$	$\rho_{C1} \geq \rho_{C2}$ $D_{C1} < D_{C2}$ $N \geq 1$	No	Large

 D_{C1} — Diameter of smaller conductor A_{C1} — Area of smaller conductor S — Solder W — Width L_j — Length of joint T — Thickness N — Number of Turns δ — Resistivity Ratio $\frac{\rho_S}{\rho_{C1}}$ ρ — Resistivity (Microhm—cm)

*Use only when large conductor diameter is 3 to 4 times larger than small diameter; otherwise use round-to-flat lap-joint formula.

**In cases where loosening or breaking of the joint would result in a hazardous condition, mechanical security should be specified.

Table 4.4 — Configurations of printed- circuit lands

Type	Preferred direction for component lead	Solder fillet contour will be	Remarks
 Tear-drop	Toward long end	Even, and almost round	Good design. Enlarged contact area
 Round	Any	Even and round	The universal pattern
 “D”	Toward tip	Uneven	Not widely used
 Rect.	Toward a corner or long end	Uneven	Not widely used
 Delta	Toward base	Uneven	Used if space very limited

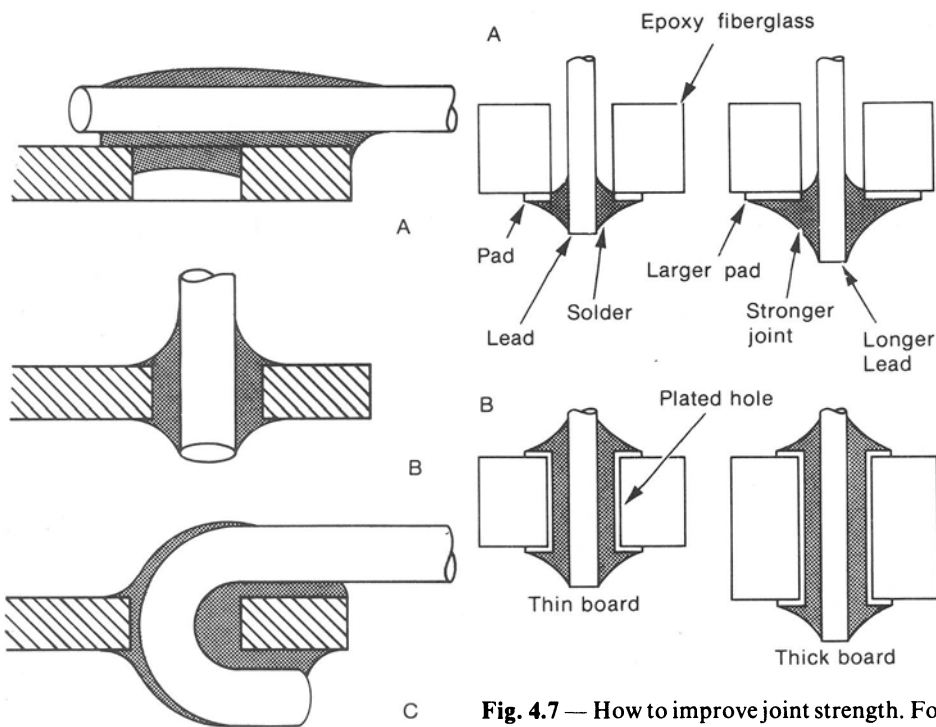


Fig. 4.6 — Methods of making wire-to-tag joints

Fig. 4.7 — How to improve joint strength. For single-sided boards, *A*, larger pads and longer leads increase solder mass; a thinner double-sided board, *B*, is better because it provides a longer path for crack propagation.

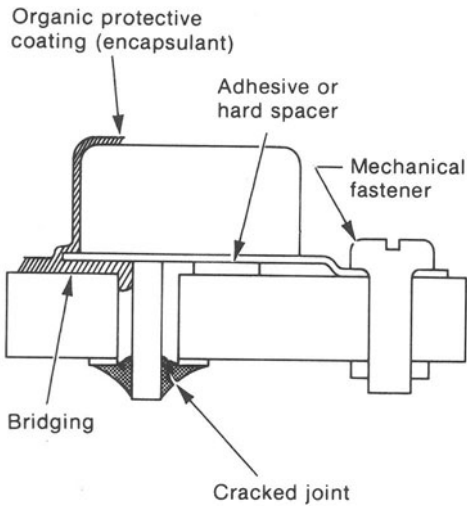


Fig. 4.8 — Restraint of the expanding lead by protective-coating bridging, mechanical fastening, adhesive bonding, or a hard spacer will all reduce the thermal fatigue life

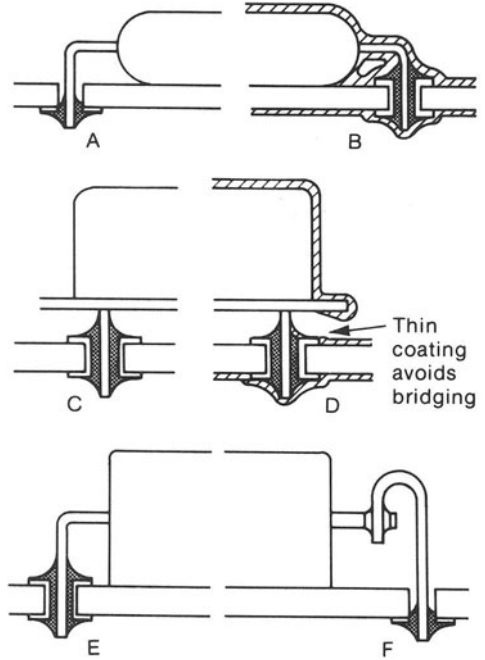


Fig. 4.9—For small parts (resistors and diodes) on uncoated boards, use single-sided boards, *A*; on coated boards, use plated through-holes, *B*. For moderate-size parts (TO-5 cans) on uncoated boards, provide clearance, *C*; when coated, *D*, use a very thin coating to avoid bridging. For heavy, side-mounted parts with moderate size leads, *E*, use plated through-holes; with heavy leads, *F*, weld, braze, or solder on a flexible lead

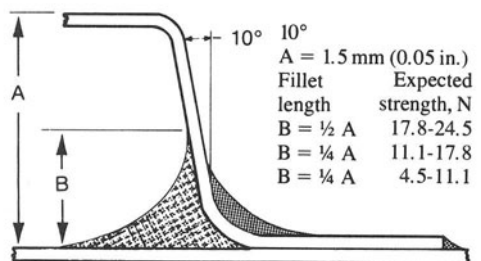
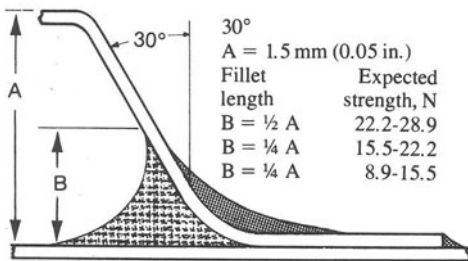


Fig. 4.10 — 60° and 80° preformed leads

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CHAPTER 5

PRECLEANING AND SURFACE PREPARATION

Proper surface preparation is essential to successful soldering. The more frequent precleaning methods are degreasing, acid cleaning, mechanical abrasion, and etching.

DEGREASING

Organic films such as oils and greases are frequently encountered on the surface of metals to be soldered. Such oils and greases must be removed because they prevent wetting action by the flux and solder. Degreasing may be accomplished by immersion of the parts in a liquid or suspension of the parts in vapors of a suitable solvent.

The halogenated hydrocarbons are the most widely used solvents because of their range of solvency power and lack of flash point. Constant boiling (azeotropic) blends of several solvents are sometimes employed to remove both non-ionic and ionic soils.

Impingement of the solvent upon the surface significantly improves the efficiency of the cleaning process. Considerable mechanical removal of the soil can be obtained by agitation, ultrasonics, brushing, or in any manner impinging the solvent upon the surface to be cleaned.

With liquid cleaning, there is always some soil in solution in the cleaning solvent. It is impractical to remove all the liquid cleaner from the

surface. Any cleaner remaining after cleaning will evaporate from the surface cleaned. Being nonvolatile, the soil that was in solution will remain on the object cleaned. To prevent this condition and obtain a higher level of cleanliness, vapor degreasing is used. The parts to be cleaned are suspended in vapors of a boiling cleaning solvent. Because the parts are colder than the vapors, the vapors condense to a liquid, dissolve the soil, and drip off the parts. When the parts have reached vapor temperature, condensation ceases and dry parts may be removed from the vapor degreaser. If a large enough quantity of cleaner of sufficient solvency strength condenses on the parts, the result is clean, dry parts.

The effectiveness of the degreasing can be easily determined by dipping the part in a liquid; if the liquid uniformly adheres to the surface, the part is clean.

ACID CLEANING

The purpose of pickling or acid cleaning is to remove rust, scale, and oxides or sulfides from the metal to provide a chemically clean surface for soldering. The inorganic acids—hydrochloric, sulfuric, orthophosphoric, nitric, and hydrofluoric—singly and mixed, all fulfill this function, although hydrochloric and sulfuric acid are the most widely used.

Hydrochloric Acid

The commercial form of hydrochloric acid has a specific gravity of 1.14 and contains approximately 25% by weight hydrogen chloride. For pickling iron and steel in cold solutions, the commercial acid is diluted in the range of 1 part commercial acid to 2 parts water (10% HCl), to 3 parts of acid to 1 part water (21% HCl).

Hydrochloric acid is an effective pickling solution at ordinary shop temperatures, and in most cases no provision is made for heating it. The acid increases its temperature due to the heat of reaction or by introducing heated work. The recommended acid temperature, however, is between 30° C and 38° C (≈85° and 100° F) but never over 50° C (≈120° F). Scale-free, bright, annealed stock can be pickled in three minutes at 30° C (≈85° F) or in ten minutes at 18° C (65° F). Lightly scaled work may require 15 to 30 minutes, whereas heavily scaled work may require 45 minutes or more. During use, the acid content will fall and the solution, if not replenished with fresh acid, will become less effective. When the iron content reaches 12%, the pickling solution should be replaced. An inhibitor is sometimes added to prevent pitting of the metal after the scale is removed. A solution of 10% HCl is used in some instances to prepare aluminum surfaces for soldering.

Sulfuric Acid

Sulfuric acid is commercially available in various concentrations. The 96-98% acid has a specific gravity of 1.84, whereas the 77% acid has a specific gravity of 1.70. Sulfuric acid pickling solutions vary from 5 to 10% by volume of the commercial acid (77%) added to the water. Sulfuric acid does not work efficiently unless it is heated to temperatures above 70° C (≈160° F), and best results are obtained at 82° C (180° F). Bright, annealed or relatively clean work normally requires only 30 seconds to 2 minutes immersion, whereas heavily scaled work normally requires no longer than 15 minutes. A black smut which forms may be rinsed off with water. Inhibitors, added to sulfuric acid, will help prevent pitting. The acidity of the solution is maintained with periodic additions of fresh acid. When the free acid content falls below 1% or the iron con-

tent rises to 8%, the pickling solution should be discarded.

Sulfuric acid is a suitable medium for pickling steel and copper alloys. For the latter, it is customary to add either 1% by weight of sodium dichromate or 2% by volume of nitric acid.

Orthophosphoric Acid

A dilute solution of orthophosphoric acid (specific gravity 1.87 for 100% acid) is used occasionally for pickling such metals as stainless steel and manganese bronze. Solutions of 10% to 40% by volume are used.

Hydrofluoric Acid

Hydrofluoric acid is extremely corrosive, and contact with the skin should be carefully avoided. A mixture of 5% hydrofluoric acid and 5% sulfuric acid by volume is sometimes used on cast iron, high silicon alloys, and aluminum (see Chapter 21 for safety in handling).

Nitric Acid

Concentrated nitric acid (70% HNO₃) is seldom used without dilution or mixing with other acids. A simple and effective pickling solution for copper contains 15% to 20% by volume of commercial concentrated nitric acid in water. The solution is used cold, and the time required is normally from 2 to 5 minutes.

Mixture of Acids

Some mixtures of acids give a bright, etched finish on metals that do not respond to single acids. Some typical acid mixtures are listed here:*

Copper Alloys

Brass

Sulfuric Acid	8 L**	2 gal.
Nitric Acid	4 L	1 gal.
Water	1 L	1 qt.
Hydrochloric acid	0.015 L	1/2 fl oz.

Nickel-Silver

Sulfuric acid	8 L	2 gal.
Sodium dichromate	0.25 kg	1/2 lb
Water	20 L	5 gal.

* See Chapter 21 for safe handling of these materials.

** Metric conversions are approximate for easy measurement.



Nickel Alloys

Inconel		
Nitric acid	4 L	1 gal.
Hydrofluoric acid	0.5 L	1 pt.
Water	8 L	2 gal.

Stainless Steel

1. Sulfuric acid	4 L	1 gal.
Hydrochloric acid	4 L	1 gal.
Water	32 L	8 gal.
2. Nitric acid	4 L	1 gal.
Hydrofluoric acid	6 L	1-1/2 gal.
Water	10 L	2-1/2 gal.

After pickling, if droplets of water show on the metal surfaces, there may still be traces of grease or other contaminants on the surface which should be removed before proceeding. The articles should be thoroughly washed in hot water after pickling and dried as quickly as possible.

MECHANICAL PREPARATION

Various abrasive techniques are frequently employed to clean metallic surfaces before soldering. They are effective and economical methods but have one definite limitation: particles of the abrasive may become embedded in the surface being cleaned (see Fig. 5.1). These abrasive materials — sand, grit, ceramic, steel wool, etc. — are generally not solderable. Although the surface may appear to be clean, if sufficient abrasive particles to significantly reduce the anchorage area have been embedded in the surface, the result is reduced solderability (see Fig. 5.2). A simple solderability test should be performed following abrasive cleaning. An etch treatment following abrasive cleaning may be required to remove sufficient surface material to eliminate the embedded abrasive.

ETCHING

The removal of a small amount of material from the surface to be soldered is a common cleaning and repair technique. A nonplated copper surface particularly lends itself to this technique. Copper etchants such as ferric chloride, copper chloride, and ammonium persulfate are used.

As mentioned above, a repair of an abraded surface to remove embedded particles may be necessary. A surface may appear clean and indeed be platable (will accept electrodeposited metals), yet not be solderable. Copper surfaces that are solder plated, such as printed circuit boards, sometimes exhibit this defect. Repair of the surface after plating is difficult and costly. The plating must be stripped and the surface etched.

PRECOATING

The coating of the base metal surfaces with a more solderable metal or alloy prior to the soldering operation is sometimes desirable. Coatings of tin, copper, silver, cadmium, iron, nickel, and alloys of tin-lead, tin-zinc, and tin-copper are used for this purpose. The advantages of precoating are twofold: Soldering is more rapid and uniform, and strong acidic fluxes are avoided at the assembly. The precoating of metals which have tenacious oxide films, such as aluminum, aluminum bronzes, highly alloyed steels, and cast iron, is almost mandatory. Precoating of steel, brass, and copper, although not absolutely essential, is of great value in some applications.



Fig. 5.1 — Intermetallic compound crystals with inclusions at surface which have formed during soldering of copper cleaned with fine abrasive