

GUIDELINE FOR HAND SOLDERING PRACTICES



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Guideline for Hand Soldering Practices

First Edition

by

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Preface

The origins of soldering can be traced back several thousands of years to Middle Eastern cultures that used it to construct a variety of utensils and elaborate jewelry items. Today, it is recognized that soldering extends well beyond the artisan community; in fact, it has become a technology in its own right. Soldering forms the basis for the manufacturing of electronic products ranging from highly functional, Personal Digital Assistants (PDAs) and cell phones to high-reliability military, space, and satellite systems. Such achievements are the result of advances that have been made in understanding the materials science and engineering of solder alloys, wetting-and-spreading behavior of base material surfaces, interface reactions, as well as monotonic and cyclic deformation modes in assembled solder joints. Concurrently, there have been new developments in assembly automation, process control, and inspection that have allowed for the low-cost manufacturing of a wide range of soldered products.

It is important to realize that there are still a large number of applications—many structural in nature—whereby an operator performs the soldering process manually. That person may be an artisan fabricating expensive jewelry; a plumber constructing a critical piping system in a chemical plant; or an operator repairing life-saving medical electronics. As an important manufacturing process in the electronics community, hand soldering has been supported by a large number of instructional resources, certification programs, and standards that are a resource for operators as well as process development engineers.

Unfortunately, there is a gap in the depth of resources such as guidelines, specifications or standards that address, specifically, hand soldering. The third edition of the *Soldering Handbook* (AWS) contains a wealth of fundamental as well as applied materials, processing, and reliability data for soldering as a technology. However, there remains to be a need to provide operators and process engineers with a “jumping-off point” to develop, and subsequently optimize, hand soldering processes for structural applications.

The objective of this *Guideline for Hand Soldering Practices* is to provide an information resource for developing viable, cost-effective hand soldering processes. This book is not intended to provide in-depth treatises on the fundamental principles of soldering; the reader is referred to the *Soldering Handbook* for those detailed discussions. Rather, the guideline’s chapters and sections provide sufficient information that allows the operator and process engineer to develop a hand soldering process that meets the performance and reliability requirements of the final product.

Chapter 1 (Fundamental Understanding) is a brief introduction into the definitions of wettability and solderability. Also, the role of the heating process is described in order to understand its impact on the hand soldering process.

Chapter 2 (Base Materials) discusses the hand soldering of metallic and nonmetallic materials. Supporting information is provided regarding the synergism between base materials and coatings with respect to achieving the desired solderability behavior. Also, given the fact that hand soldering uses electric irons and torches that are very high-temperature heat sources, there are discussions of the need to consider the temperature sensitivity of base materials, especially the effects of heating and cooling rates.

Chapter 3 (Filler Metals) describes filler metals (solder alloys). There are a large number of filler metals available today and the list continues to grow as manufacturers address the need to build ever-more complex parts, as well as changing alloy availability due to environmental regulations in both the United States and abroad (e.g., Pb- and Cd-free solders). The solder can be available in the form of wire, preforms, or paste. The form of the solder will significantly impact the choice of hand soldering technique and process parameters. The final section in this chapter discusses the importance of selecting filler metals that are listed in approved standards and specifications.

Chapter 4 (Fluxes and Controlled Atmospheres) touches on fluxes and their uniqueness to the soldering process. Unfortunately, there remains a great deal of “mystery” behind their role in soldering. The goal of this chapter is to provide an accurate resource describing the selection and utilization of fluxes in a hand soldering process.

The key content of this book resides in Chapter 5 (Process Development). After a brief introductory section, the following two sections address preassembly cleaning and fixture techniques. The next five sections describe specific types of

hand soldering processes as distinguished by the heating technique: (electric) iron, torch (flame), hot gas, resistance, and induction. Within each section, there is an introduction that is then followed by a brief overview of the equipment. Next, there is the detailed description of the soldering procedures (e.g., soldering with filler metal wire, preforms, butt joints, lap joints, etc.). The ninth section considers two less-common hand soldering processes: laser soldering and infrared soldering. The chapter draws to a close with two sections, the first of which, examines post-assembly cleaning steps. The final section provides information related to the use of hand soldering for the rework and repair of solder joints.

Finally, Chapter 6 (Environmental Safety and Health) offers a brief synopsis of the environmental, safety, and health concerns specific to hand soldering operations. The chapter does not provide a complete listing of federal, state, or local regulations and directives. Besides the ungainly number of such statutes, environmental and safety regulations change on an almost daily basis thereby quickly rendering them obsolete. Rather, the intent of this chapter is to describe “common sense” procedures that should be implemented by the operator or process engineer in order to minimize the likelihood of accidents and/or environmental contamination when using hand soldering procedures.

An important feature of this guideline is the illustrations. The author is all too familiar with the fact that solder joints are not well presented using standard light photography. Shiny surfaces and extraneous shadows cause misleading visual artifacts. Therefore, photographic images are used sparingly. Rather, greater use is made of schematic illustrations to show fixtures as well as solder flow behavior and fillet geometries.

The author would like to express his sincere gratitude to the following individuals who have contributed to this piece. First, I would like to thank Sara Sokolowski, Don Susan, Brian Wroblewski, Edwin Lopez, Mike Hosking, as well as the members of the AWS C3B Subcommittee on Soldering (Chairperson Creed Darling) for their painstaking review of the manuscript. Secondly, I want to acknowledge those folks at Sandia National Laboratories who have worked alongside of me and who have taught me “a-thing-or-two” about soldering materials, processes, and reliability. Jerry (JR) Rejent, together with Mark Grazier and Peter Duran, have performed the experiments and data analysis that is the heart of the research and development successes in Sandia’s soldering technology program. Alice Kilgo, Dick Grant, Gary Zender, and Paul Hlava (ret.) are the metallography and microanalysis “talents” that provided valuable insight into properties of solder alloys and the performance of soldered assemblies.

My extreme gratitude goes to Steve Borrero, AWS Secretary to the C3 Committee on Brazing and Soldering, who assisted the author with the proofing as well as publication logistics of this book from its inception. His diligence and attention to detail were absolutely crucial to the completion of this work.

Lastly, I would like to thank my wife, Karen, and daughters Maria, Sara, and Ana for their patience and love throughout this effort. Without their support and encouragement, this book would not have been possible.

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Sandia National Laboratories *and* the
C3 Committee on Brazing and Soldering,
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Guideline for Hand Soldering Practices

1. Fundamental Understanding

1.1 Hand Soldering. The terms *hand soldering* and *manual soldering* refer to soldering operations performed by an operator. Traditional images associated with hand soldering include the assembly of electronic components [see Figure 1.1(A)], or the joining of pipes for plumbing and similar applications [see Figure 1.1(B)].

The extent to which an operator participates in the soldering process can be to various degrees. In a fully manual process, the operator is responsible for the following steps:

- (1) Positioning the individual parts;
- (2) applying the heat source;
- (3) applying the flux;
- (4) introducing the filler metal;
- (5) cleaning the finished assembly; and
- (6) inspecting the finished joint.

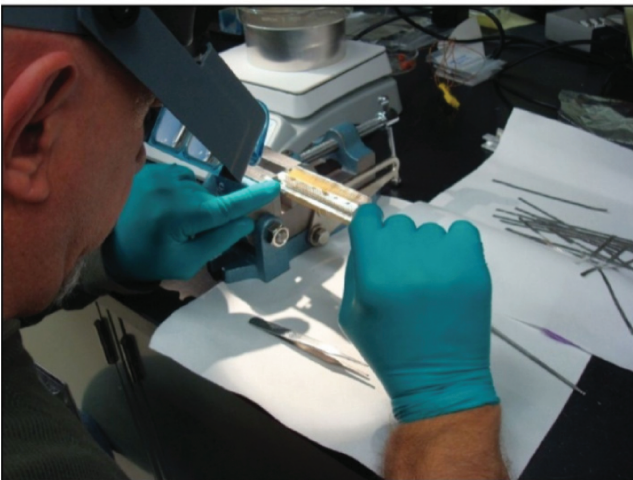


Image courtesy of Sandia National Laboratories

(A) ASSEMBLY OF A CONNECTOR

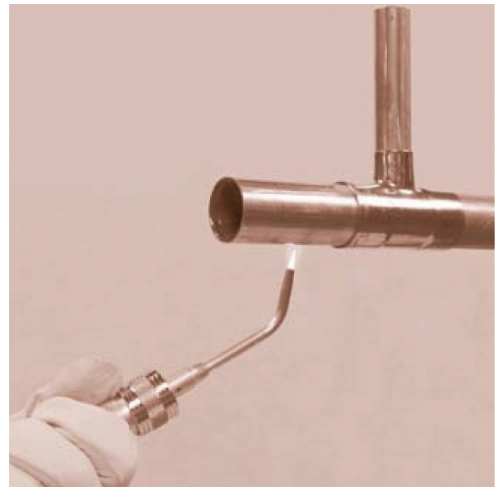


Image courtesy of the
Copper Development Association

(B) JOINING OF PIPES AND FITTINGS

Figure 1.1—Hand Soldering Processes

Semiautomated soldering processes allow machines to perform one or several of the above steps. For example, the positioning of parts can be performed by a robot prior to the soldering step. In the case of (fully) *automated soldering* processes, the operator is typically responsible only for loading the individual parts into the “front” of the assembly line and for removing the finished assemblies from the “back” of the line. The electronics industry uses automated furnace or wave soldering processes to maximize production volumes, thereby minimizing the costs of manufacturing printed wiring assemblies.

At first glance, the hand soldering of a single joint at a time appears to contradict the precepts for cost-effective manufacturing: high volume (many joints made at a time) and statistical process controls that are optimized through automation. Yet, hand soldering *is* cost effective for a number of applications. There are companies that concentrate on low-volume, short production runs where the capital and maintenance costs of machines simply are *not* justifiable. In other applications, an operator provides a flexibility that is required to address “unusual” part configurations that would otherwise require elaborate fixturing and/or equipment modifications if performed by a machine. Lastly, hand soldering is the only method to perform field repairs where equipment and operator portability are essential.

It is not the case that the quality or “workmanship” of hand-soldered joints is nominally below par of that produced by machine soldering. Rather, the quality of hand soldered joints tends to be more variable than of automated processes; it depends on the operator’s training and skill. In terms of solder joint quality, an important advantage of hand soldering is that the operator inspects each joint as it is being completed, thereby providing the opportunity to identify defects (e.g., poor solderability) before a large number of parts have been processed. This attribute minimizes costly rework activities or scrapped material, particularly during the assembly of high-value, high-reliability products in which a single solder joint defect would have unacceptable consequences.

It is important that design and process engineers, as well as operators, understand the fundamental materials engineering that underscore soldering technology. Foremost, there are the *wettability* and *solderability* properties that are basic to the creation of a solder joint. Secondly, the successful hand soldering operation (or any soldering operation) is dependent upon a *heating process*. It will be observed that these factors—wettability, solderability, and heating process—are integral to the development of a successful hand soldering operation.

1.2 Wettability and Solderability. Soldering, as one of the two filler metal joining technologies (the other is brazing), is used in a wide range of structural and electronics assembly applications. It is distinguished from brazing by the liquidus temperature of the filler metal; solder filler metals have liquidus temperatures that are less than 450 °C [842 °F].¹ Brazing filler metals have liquidus temperatures that exceed 450 °C [842 °F].

The fabrication of a solder joint requires the molten filler metal to *wet* the base material(s). *Wettability* refers to the process by which a metallurgical reaction (layer), typically an intermetallic compound (IMC), bonds the solder alloy to the base material alloy upon solidification. An optical micrograph of the reaction layer that formed between 63Sn-37Pb (wt.%) solder and copper (Cu) is shown in Figure 1.2.

The layer is 1 micron to 2 microns (μm) [39 microinches to 78 microinches (μin)] thick and has the stoichiometry, Cu₆Sn₅. It is important to recognize that the base material does not melt during the soldering process. Instead, the base material dissolves into the molten solder in addition to forming the IMC reaction layer noted above. The extent of dissolution depends upon the base material composition, the solder composition, the molten solder temperature, and the exposure time. The effects of time and temperature are illustrated in Figure 1.3, which shows the different extents of silver (Ag) dissolution caused by molten Sn-Ag-Cu solder under processing conditions (A) and (B).

Only a limited area of the base material surface is actually required to be wetted by the solder to complete the joint. That area is referred to as the *faying surface*. The faying surfaces not only include the base material surfaces within the joint gap, but also a portion of the exposed surfaces that are wetted to develop the fillet.

The *solderability* of a joint refers to the capacity for the molten filler metal to wet *and* spread spontaneously over the faying surfaces. In the absence of a gap, solderability refers to the wetting and spreading of molten solder on a horizontal surface or the “meniscus rise” up a vertical surface as indicated by cases (A) and (B) in Figure 1.4.

Within the confined geometry of a gap or hole, capillary forces assist the spreading action of the molten solder in either the horizontal direction (see Figure 1.5) or in the vertical direction. There are two gap thickness ranges that are considered when hand soldering a gap or hole:

¹ Vianco, P., 1999, *AWS Soldering Handbook*, 3rd Edition, Miami, Florida: American Welding Society.

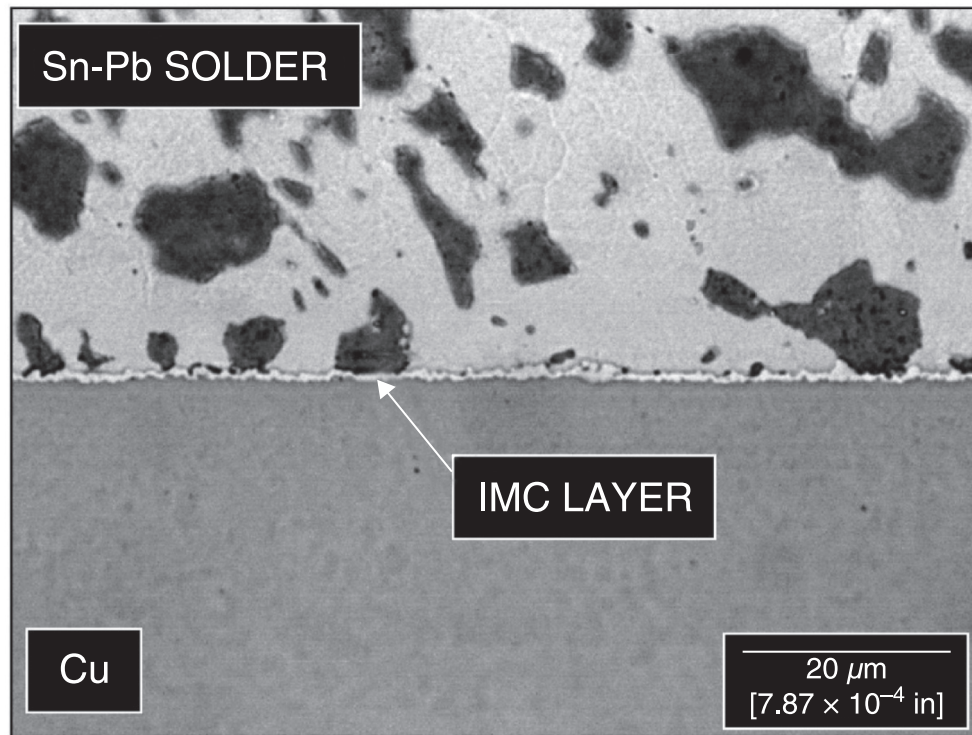


Image courtesy of Sandia National Laboratories

Figure 1.2—An Optical Micrograph of the Intermetallic Compound (IMC) Layer Formed Between the 63Sn-37Pb Solder and Copper (Cu) Base Material

- (1) There is the nominal gap that refers to the widest thickness range capable of supporting a hand soldering process:

Nominal gap thickness: 0.025 mm to 0.38 mm [0.0010 in to 0.015 in]

It is *not* to say that solder joints cannot be made having gaps smaller than 0.025 mm [0.0010 in] or wider than 0.38 mm [0.015 in]. Rather, such applications are going to require extraordinary techniques (e.g., fixtures, base material tolerances, etc.) to successfully make the joint by hand soldering.

- (2) There is the preferred gap that refers to the thickness range that is most likely to optimize the capillary action of the molten solder during hand soldering:

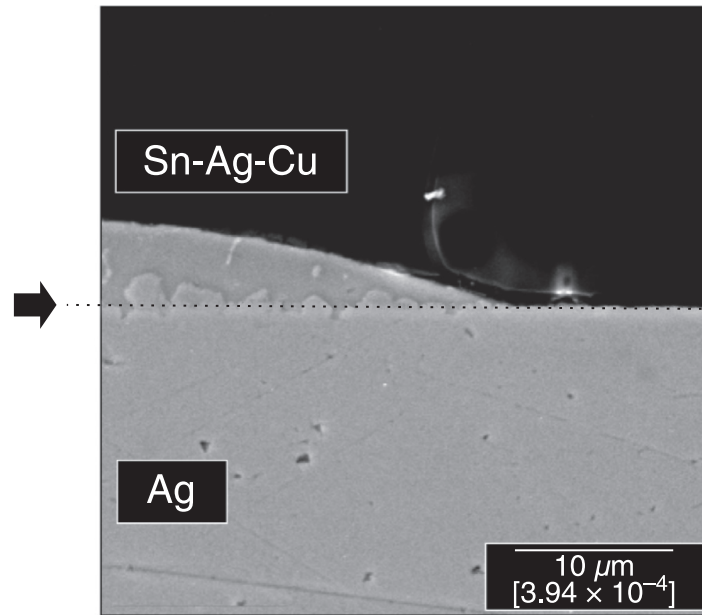
Preferred gap thickness: 0.076 mm to 0.18 mm [0.0030 in to 0.0070 in]

Whatever gap is selected for the joint, having a uniform thickness over the faying surfaces will assure consistent solderability of the gap or hole.

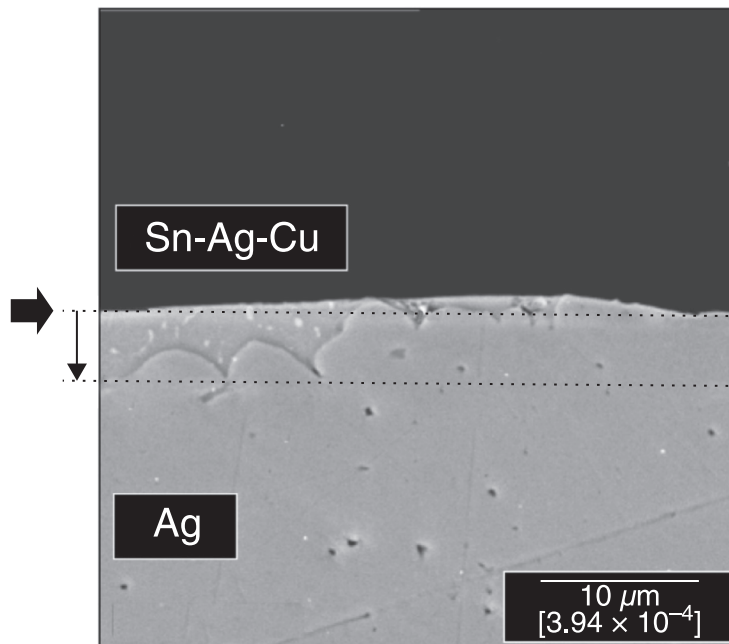
In the vertical direction, the capillary rise of molten solder is also affected by gravity. In order for the capillary action to take place at all, it is necessary that the faying surfaces first be wettable by the molten solder.

Solderability is a function of the filler metal and base material compositions. It is also dependent upon the geometries of the parts to be joined together, including the manner in which those geometries determine the solder joint length and gap thickness dimensions. The assembly process affects solderability. Critical parameters include flux composition, the process time-temperature profile, atmosphere, and operator technique.

It is important to identify acceptable versus unacceptable solderability performance. Unacceptable solderability is often represented by *nonwetting* or *dewetting* defects. Schematic diagrams and associated photographs describing satisfactory wetting, nonwetting, and dewetting are provided in Figure 1.6.



(A) TEST CONDITIONS: 260°C [403°F], 30 s



(B) TEST CONDITIONS: 290°C [554°F], 60 s

Images courtesy of Sandia National Laboratories

Notes:

1. Scanning Electron Microscope (SEM), Secondary Emission (SE) Mode.
2. Dotted lines indicate the movement of the solder/base material interface.

Figure 1.3—Images of the Edge of the Sn-Ag-Cu Solder Layer on Silver (Ag) Showing Different Degrees of Base Metal (Ag) Dissolution

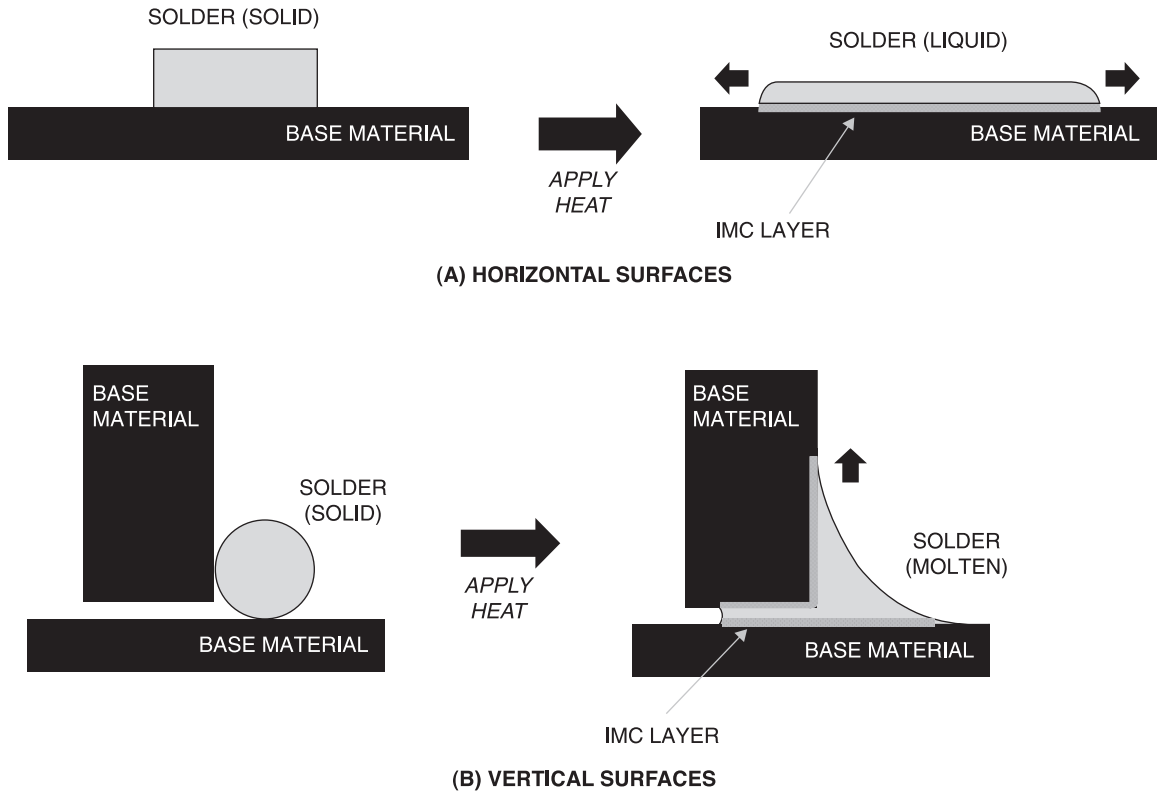


Figure 1.4—Wetting and Spreading of a Molten Solder

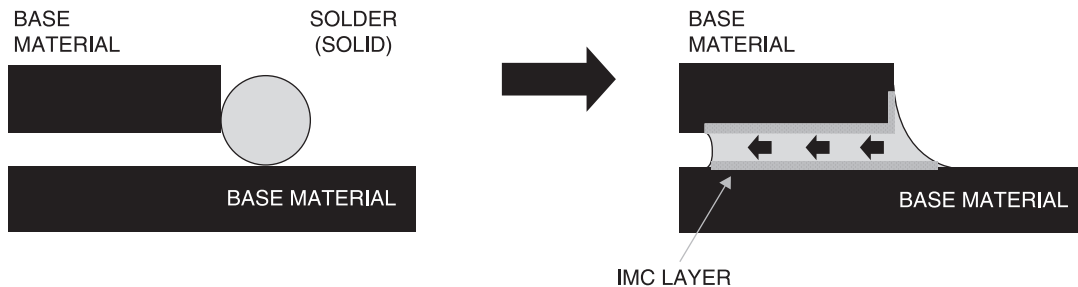
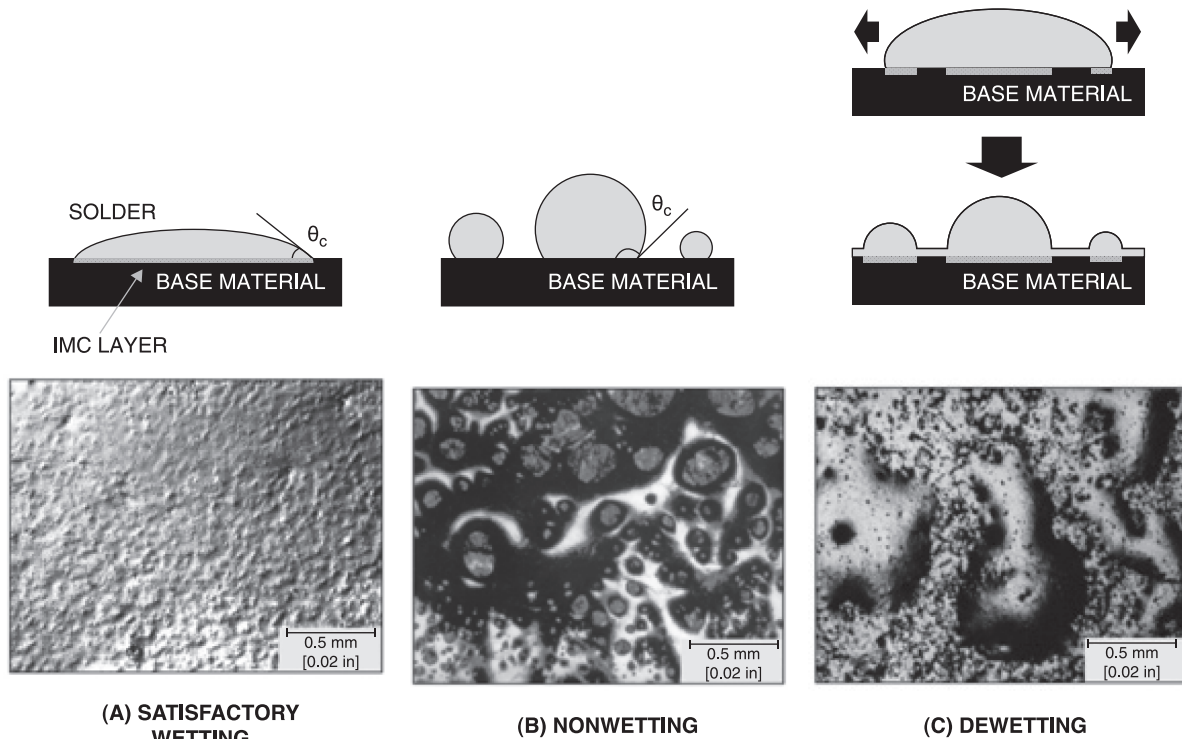


Figure 1.5—Capillary Action of Molten Solder within Confined Geometry of a (Horizontal) Gap Between Base Materials

As shown in Figure 1.6(A), satisfactory solderability occurs when the molten solder wets the base material surface as indicated by the IMC layer, producing a thin, uniform film on the faying surface. The contact angle at the edge of the solder film is $\leq 90^\circ$, preferably $\leq 35^\circ$.

Nonwetting is depicted in Figure 1.6(B); the solder balls up on the surface. More importantly, there is no metallurgical bond (e.g., an IMC layer) between the solder and base materials. The most frequent cause of nonwetting on an otherwise wettable base *metal* surface is contamination by either organic residues, or inorganic layers of oxides or corrosion products. Ceramic and glass base materials are inherently nonwetting. The one exception is molten indium (In), or In-based filler metals on some glasses. In these cases, there can be an interface reaction that supports satisfactory wetting. In general, coatings of a wettable metal are deposited on ceramic and glass surfaces to provide adequate solderability.



Images courtesy of Sandia National Laboratories

Figure 1.6—Stereo Images Showing Three Solderability Behaviors

Dewetting is caused by a dynamic change to the base material solderability *during* the soldering process [see Figure 1.6(C)]. Initially, the molten solder wets and spreads over a base material surface with an ample supply to cover those local areas of marginal solderability as indicated by an absence of an IMC layer. However, upon removal of the solder source, the molten solder continues to wet and spread over the surface, causing the molten solder film to become thinner. The local, marginally solderable surface areas cause the thin molten solder to spontaneously retract, resulting in large mounds over wettable surface (note the IMC layer). Between the mounds are areas of very thin solder film that cover the nonwettable areas (note the absence of an IMC layer). Although a solder coating is present over the dewetted surface, this phenomenon is considered a defect because it signifies a marginally wettable base material surface. The mechanical strength of the joint is also developed fully, only where the IMC layer is present; thus, the joint strength is compromised as well.

The marginal solderability, which is the source of dewetting, can be caused by the base material surface condition as illustrated in Figure 1.7.

For example, there are metal alloys that have particles of oxide, carbide, etc. contained in them to improve their strength; those particles are nonsolderable. At first, a relatively thick molten solder coating is capable of spreading over the particles. However, when the source of filler metal is removed and the molten solder coating becomes thinner, dewetting takes place. Similarly, dewetting can occur when the (nonwettable) media from grit blasting, grinding, and polishing processes become inadvertently embedded into the base material surface.

Dewetting can also occur when soldering to thin films and finishes that are used to enhance the solderability of ceramics, glasses, and difficult-to-solder metals and alloys such as cast irons, stainless steels, aluminum, etc. Although the coatings must be solderable, the underlying base material need not be so. At those locations where the solderable finish has been dissolved away through excessively long contact with the molten solder, nonwettable base material surface is exposed. As the molten solder coating becomes thinner towards the end of the soldering process, dewetting may subsequently occur.

It is important to recognize that a large quantity of solder can hide the marginal solderability of a base material surface (see Figure 1.7). It is for this reason that acceptability specifications call for the inspector to be able to see the edges of

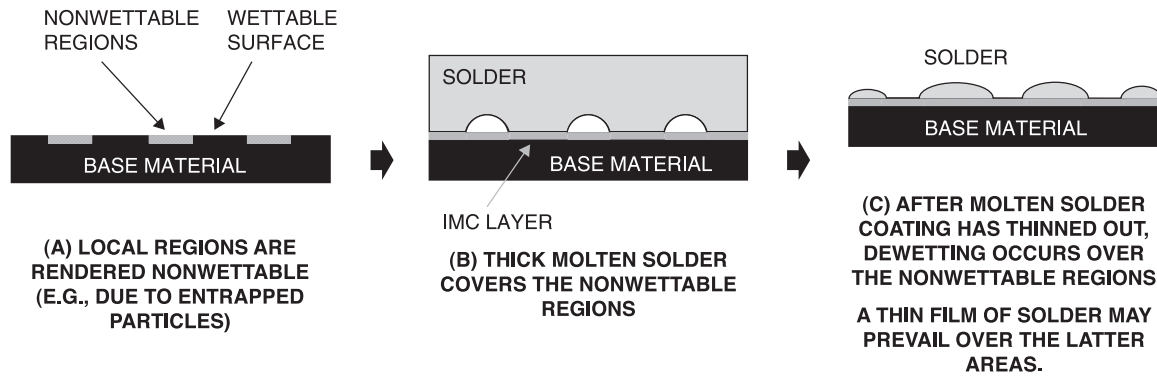


Figure 1.7—Dewetting Phenomenon caused by Local Nonwetable Areas on a Generally Wetable Base Material Surface

the base material(s) in order to confirm that an overly thick solder coating is not hiding a marginally solderable surface. Dewetting will likely appear later on during subsequent soldering activities (e.g., rework or solder joint repair) when a thinner molten solder coating develops on the part.

1.3 Heating process. The heat source must provide sufficient thermal energy to the base material to support flux activation as well as melting, wetting, and spreading of the filler metal over the faying surfaces to create the joint. Activation of the flux material refers to providing the thermal energy needed to support the chemical reactions that are responsible for the removal of oxide layers from the base metal *and* from the surface of the molten solder. As for fully melting the solder alloy, the heat source must provide sufficient thermal energy to raise the filler metal above its liquidus temperature. Raising the solder to a temperature that is only slightly above its solidus point will give the filler metal a pasty consistency that slows wetting-and-spreading activity or results in premature solidification. Instead, a 20°C to 40°C [68°F to 104°F] additional temperature margin above the liquidus temperature is desired to prevent these two process problems. There is little benefit to increasing the solder temperature beyond that margin.

Temperature is the traditional metric used to quantify the thermal energy contained within any material. However, the *flow* of heat into the base material (and filler metal) is based upon the temperature of the heat source *and* the exposure time of the base material to the source. Thus, exposing the flux, base material, and solder to modest temperatures, but over long periods of time can have the same effect as a short-term exposure to a higher temperature as the total heat energy delivered to the joint is the same value.

The obvious consequence of too little thermal energy provided by the heat source is the failure to make a successful solder joint, or within the time limits required by an overall manufacturing process. Similarly, there are consequences to the use of excessive thermal energy during the soldering process:

(1) There is reoxidation of the faying surfaces. The resulting oxide layer may become too thick to be removed by the flux. The thickness of the surface oxide can often be qualitatively assessed by the color of the surface. For example, the surface of copper will progress from shiny orange, to red-orange, to light brown, and finally to very dark brown as the oxide becomes thicker. Overheating nickel- and iron-based materials is less obvious; however, the degradation to solderability can be very significant.

(2) Excessive heating can degrade base material finishes. Multiple layer finishes are often used to enhance the solderability of hard-to-solder base materials. A nickel-solderable layer followed by a gold protective finish is a common example. Excessive heat input can cause the solderable layer to diffuse through the protective finish, reaching the exposed surface and subsequently oxidizing there. The result is a loss of solderability. Although of a lesser concern with Ni-Au finishes, the loss of solderability is very severe in Cu-Au finishes because of the rapid diffusion of copper (Cu) into the gold (Au) layer (in fact, to prevent interdiffusion between Cu and Au, a nickel barrier layer is deposited between the two coatings.)

(3) Excessive heating of the base material can cause microstructural changes that degrade its physical and mechanical properties. Mechanisms such as recovery and recrystallization, as well as the overaging of precipitation-hardened alloys can

result in a loss of mechanical strength, hardness and, in some cases, corrosion resistance. *The lower the solidus temperature of the particular base metal or alloy, the greater the likelihood of microstructural changes that can impact physical and mechanical properties.* For example, greater care must be exercised when soldering to low-temperature aluminum (Al) and magnesium (Mg) alloys as compared to a joining process for nickel-based alloys or refractory base materials.

The worst-case scenario is when the solidus temperature of the base material is exceeded during the heating process; the base material will melt. Even partial melting can cause a loss of structural integrity, possibly resulting in injury to the operator, damage to adjacent structures, and the increased likelihood of a service failure later on.

In the case of ceramic and glass base materials, the particular problem with excessive heating is the increased likelihood of cracking due to thermal shock. Rapid temperature changes cause temperature gradients in the material that generate local residual stresses that can exceed the material's strength. Thermal shock cracking can occur during rapid heat-up or cool-down steps. However, cracking may be particularly prevalent during cool-down after soldering. Not only can there be residual stresses caused by local temperature gradients within the base material, but there can also be added residual stresses caused by the mismatch of thermal expansion coefficients between different base materials comprising the joint structure during the temperature change.

(4) The flux is sensitive to the degree of heat input placed into the joint. The rosin-based and water-soluble (organic acid) fluxes are comprised of organic compounds that degrade rapidly when exposed to excessive thermal energy. Even the components of the more robust inorganic (plumber's) fluxes can be degraded by prolonged exposure to high temperatures.

Flux degradation may appear at the initial stages of the soldering process as indicated by its ineffectiveness to remove tarnish from the base material surface. Also, the flux may become hard (in a process referred to as *polymerization*) and adhere to the base material surface, forming a barrier between the latter and the molten solder. In either case, solderability deteriorates or is lost completely. On the other hand, the effects of flux degradation may become apparent after the joint is successfully completed. The flux can form tenacious residues that cannot always be removed by post-assembly cleaning processes (with the exception of mechanical abrasion, which is *not* a recommended practice for a finished solder joint). Hard flux residues pose several potential concerns:

- (a) The residues can prevent the proper fitup between two parts in the next assembly.
- (b) Residue may impair the inspection of the solder joint.
- (c) The cosmetic appearance of the joint will be degraded.
- (d) The residues may become corrosive later on under humid environments.

(5) The properties of the filler metal are probably the least sensitive to the heat input into the joint. The most significant difficulty created by overheating is oxidation of the molten solder surface. A thick oxide film increases the apparent surface tension of the solder, which can hamper wetting and spreading activity as well as capillary flow. In extreme cases, the oxide layer becomes excessively thick so as to form a crust that will encapsulate the molten solder, thereby preventing any flow whatsoever.

In the case of most hand soldering operations with an electrical iron, there is insufficient thermal energy in the tip for its temperature to come close to the boiling temperature of the solder alloy or the boiling points of its constituent elements such as antimony (Sb), bismuth (Bi), copper (Cu), silver (Ag), tin (Sn), or even low melting point elements gallium (Ga) and indium (In). On the other hand, the temperature of a torch flame can range from 2538°C [4600°F] for natural gas to over 3982°C [7200°F] for hydrogen. Prolonged exposure to a torch flame could boil the solder, thereby causing a loss of some low melting temperature constituents first. The result is a change to the physical (in particular, melting behavior) and mechanical properties of the solder after solidification.

The heating process can affect a filler metal paste. Elevated temperatures will degrade the organic components of the paste, which include the flux as well as other chemistries that give the paste its thixotropic properties. Thus, the solder cannot effectively wet and spread over the faying surfaces.

Performing the heating process in a controlled atmosphere will reduce the degree of base material oxidation as well as degradation to the flux and organic components in solder paste. In the case of hand soldering, it is difficult to tightly control the atmosphere around the joint unless the process is performed in a glove box. A typical inerting procedure for a hand soldering operation is to simply direct a stream of inert gas (e.g., nitrogen) onto the joint area in order to displace the air. The local oxygen level is reduced, but to only a limited degree. Unfortunately, the flowing gas will cause convective heat loss from the joint area, thereby necessitating longer heat-up times and/or a heat source with a larger capacity. Lastly, it is necessary to ventilate the released inert gas from the work area to prevent an asphyxiation hazard to the operator(s).

Clearly, the time-temperature profile used to hand solder a joint will differ between applications. The type and geometry of base materials as well as the flux, solder alloy, and selected heat source all affect the process profile. However, there are nominal parameters that can be used to guide the development of hand soldering procedures.

The preheat portion of the process has two functions. First, it must activate the flux. Secondly, the preheat segment brings the base materials close to the solidus temperature of the filler metal prior to the final ramp-up to melting. The nominal parameters are:

Preheat temperature (flux activation):	150 °C to 170 °C [302 °F to 338 °F]
Preheat temperature (base material heat-up):	10 °C to 30 °C [50 °F to 86 °F] below the solidus temperature
Preheat time (includes flux activation and base material heat-up):	30 s to 90 s

The next portion of the time-temperature profile is that of the actual soldering process that supports the wetting and spreading action of the molten filler metal. The nominal parameters are:

Soldering time: 5 s to 20 s
Soldering temperature: 20 °C to 40 °C [36 °F to 72 °F] above the liquidus temperature

It must be understood that soldering processes having parameters outside of these windows can be used successfully. However, when doing so, the process engineer and operator must be more vigilant in terms of the degradation modes that were previously described and elaborated upon further in the guidelines below.

2. Base Materials

2.1 Solderability. Adequate solderability of base material(s) begins with the requirement that the faying surface, whether of the base material itself or of a solderable coating over the base material, supports the *wetting* process. Wetting is the establishing of a metallurgical reaction between the liquid solder and the base material faying surface (or solderable finish surface). The reaction product is typically an Intermetallic Compound (IMC) layer. Solderability refers to the spontaneous wetting *and* spreading of molten solder over the faying surfaces. The ability of the molten solder to spontaneously spread over the surfaces, as well as into gaps and holes (see Figures 1.4 and 1.5), is particularly necessary in hand soldering as the operator is limited in terms of other activities that can be performed simultaneously to enhance the process.

Adequate solderability requires that the base material faying surface be free of organic contaminants such as oils (including fingerprints), greases, lubricants or mold-release agents (in particular, silicone-based compounds), and paint, as well as be free of inorganic contaminants such as oxides and corrosion layers. These contaminants form a barrier that prevents the metallurgical reaction from taking place. Contaminants are removed by precleaning the faying surface. Precleaning measures include mechanical abrasion (both organic and inorganic contaminants), solvents (organic contaminants), and chemical strippers (inorganic contaminants). Also, proper handling precautions can minimize the contamination of already-clean surfaces.

NOTE: Soldering fluxes simply do not have sufficient strength or universality to remove organic contaminants or the range of inorganic contaminants (e.g., corrosion products or heavy oxides/scales) that can develop on a base material surface. Hence, precleaning processes are required to remove such layers prior to the soldering operation.

A second factor impacting solderability is the geometry of the base material, particularly that of the solder joint. Although the base material geometry is usually predetermined by the design engineer (e.g., form, fit, and function), the process engineer and operator must be aware of the effect of geometry on solderability, and thus where necessary, to alter the hand soldering process to obtain an adequate joint. For example, the desire to uniformly heat the joint area may require special techniques to accommodate different thermal masses caused by different physical dimensions or dissimilar base materials having different thermal properties. More heat must be applied to the larger part, or to the part having the higher thermal conductivity, in order to maintain a uniform temperature distribution.

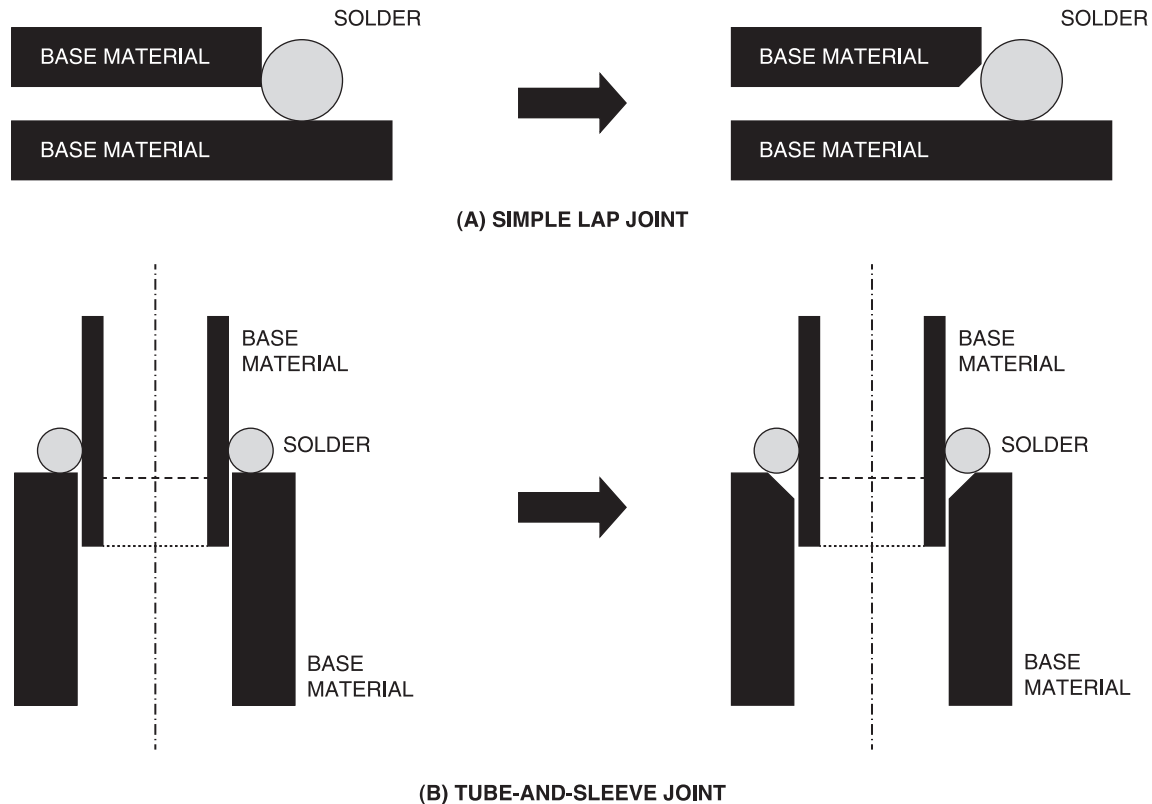
On the other hand, nonuniform heating can be an advantage. Molten solder is drawn over the faying surface or through a gap *toward a region of higher temperature*. This phenomenon can actually assist wetting and spreading, as well as the capillary flow of molten solder; however, the operator must exercise caution with this technique to avoid overheating the base materials.

The geometry of the solder joint can also directly affect the spreading and capillary flow action of molten solder. Foremost is the effect of the gap thickness. The flow of tin-based solders generally becomes hindered through gaps greater than 0.38 mm [0.015 in] or gaps smaller than 0.025 mm [0.0010 in]. The preferred gap is in the range of 0.076 mm to 0.15 mm [0.0030 in to 0.0060 in]. A nonuniform joint gap will affect the flow of molten solder according to these bounding conditions as well.

Molten solder has difficulty flowing around corners because of a driving force to minimize surface area. Chamfers are used to promote the flow of molten solder around a corner or into the gap, as illustrated in Figure 2.1, for the cases of (A) the simple lap joint and (B) the tube-and-sleeve joint.

Similar geometric considerations must be given to the flow of molten solder after it has entered the gap. The solder melts and begins to flow into the gap as shown in Figures 2.2(A) and 2.2(B). As the flowing solder reaches points (a) and (b) in Figure 2.2(C), it must create a greater surface area to round those two corners. The surface tension of the molten solder will not allow it to contact the edge and corner surfaces of (a) and (b); the molten solder will take on the surface geometry shown by the solid curve in Figure 2.2(D). Since it is necessary for the solder to contact the surfaces for wetting and subsequent spreading to occur, solder flow (dotted curves) is hindered. A chamfer at (a) and a rounded corner at (b) will assist solder flow around the corner.

Blind holes or gaps are difficult geometries for solder to fill [see Figure 2.3(A)]. Flux volatiles and air become trapped ahead of the molten solder, preventing the latter's further movement needed to complete the joint [see Figure 2.3(B)]. The introduction of a "bleed" or inspection hole at the opposite end of the gap provides an escape path for flux volatiles and air to exit from the joint [see Figure 2.3(C)]. The flow of solder into the bleed hole confirms that solder filled the gap upon inspection.



Note: The use of a preplaced solder preform is illustrated.

Figure 2.1—Chamfers Used on Base Material Corners to Assist Solder Wetting and Spreading Around Corners into Gaps

Gravity serves as an ancillary force for solder wetting and spreading. The vertical orientation of the surface or gap allows gravity to assist the solder flow. Unfortunately, in the case of very large gaps or holes, gravity can also cause molten solder to drain away from joint. The operator may have some flexibility in terms of orienting the base materials to take advantage of gravity effects; however, this flexibility is not always available, particularly in the field assembly of tubing and pipes.

2.2 Temperature Sensitivity. The hand soldering process must also take into account the temperature sensitivities of the base material as well as those of nearby structures. Damage to the base materials can include cracking due to thermal shock, dimensional changes such as shrinkage and warping, as well as changes to the intrinsic physical and mechanical properties. All of these degradation modes can affect immediate performance and the long-term reliability of both the base material(s) and solder joint.

In the case of ceramic and glassy materials or even very brittle metal alloys, the relatively low-processing temperatures associated with soldering do not significantly affect their intrinsic mechanical or physical properties. However, ceramics and glasses are sensitive to thermal shock. Thermal shock specifically refers to the residual stresses, particularly tensile stresses that can be generated by nonuniform temperature distributions within the base material due to excessively fast heating and cooling rates. Rapid heating and cooling rates are a particular concern in hand soldering due to the localized heat sources—e.g., a soldering iron or torch.

Residual stresses can also be generated during the cooling step as there are differences of thermal expansion coefficients between dissimilar base materials that have been soldered together. These stresses set up after the solder has solidified. The formation of thermal expansion mismatch stresses is illustrated in Figure 2.4. Base material 1 has a higher thermal expansion coefficient (α_1) than base material 2 (α_2). At A on the time-temperature profile, the temperature is just above

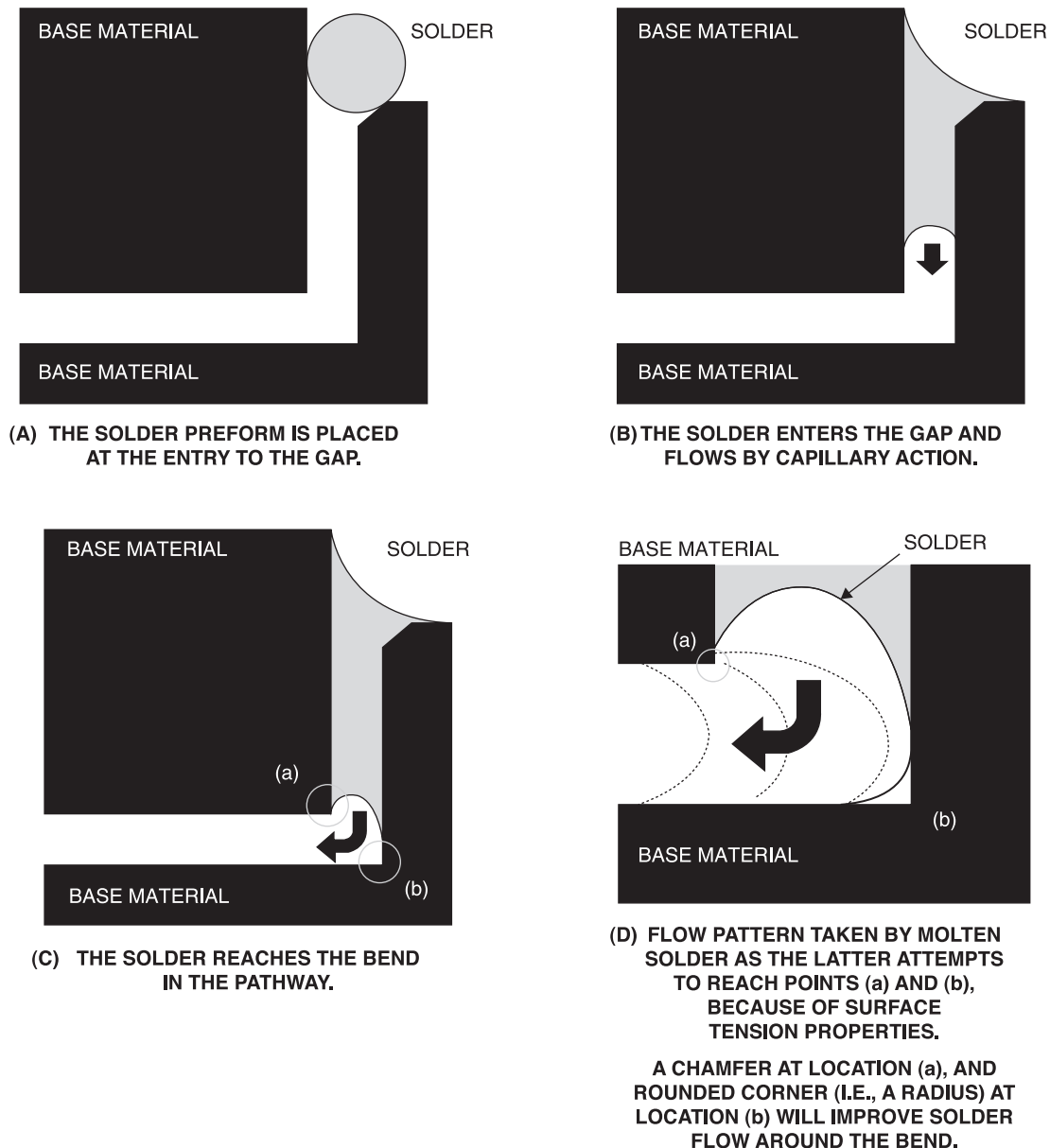
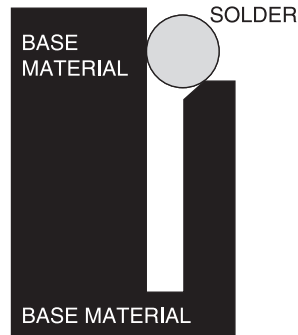


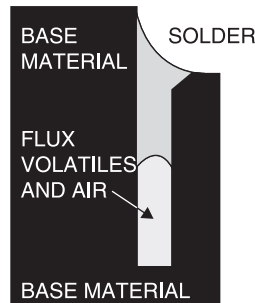
Figure 2.2—Flow of Molten Solder through a Gap having a Bend in the Pathway

the solidus point of the solder and the base materials have their starting dimensions. During the cooling stage B the solder is solid, but can deform. The two base materials contract, with base material 1 contracting more than base material 2. At the final temperature C, base material 1 is constrained from contracting any farther by base material 2. This results in a tensile residual stress in base material 1. Conversely, base material 2 is forced to contract to a greater degree by base material 1 than would be dictated by its thermal expansion coefficient, resulting in a compressive residual stress in it. Finally, the solder joint experiences a *shear residual stress* caused by the differential contraction of the base materials.

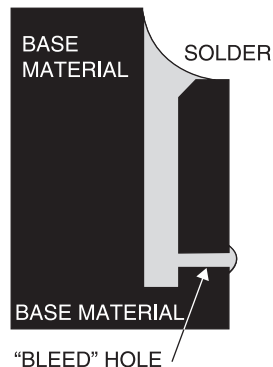
By having low solidus temperatures that reduce the magnitude of temperature change, tin- and indium-based solders (i.e., soft solders) provide a measure of deformation as a means to alleviate residual stresses in the base materials. The ability of lead-based solders to readily deform allows them to reduce residual stresses in dissimilar material joints, in spite of



(A) SOLDER PREFORM PLACED AT THE ENTRY TO THE GAP.



(B) THE FLOW OF MOLTEN SOLDER IS HINDERED BY THE ENTRAPMENT OF FLUX VOLATILES AND AIR THAT CANNOT READILY EXIT THE GAP.

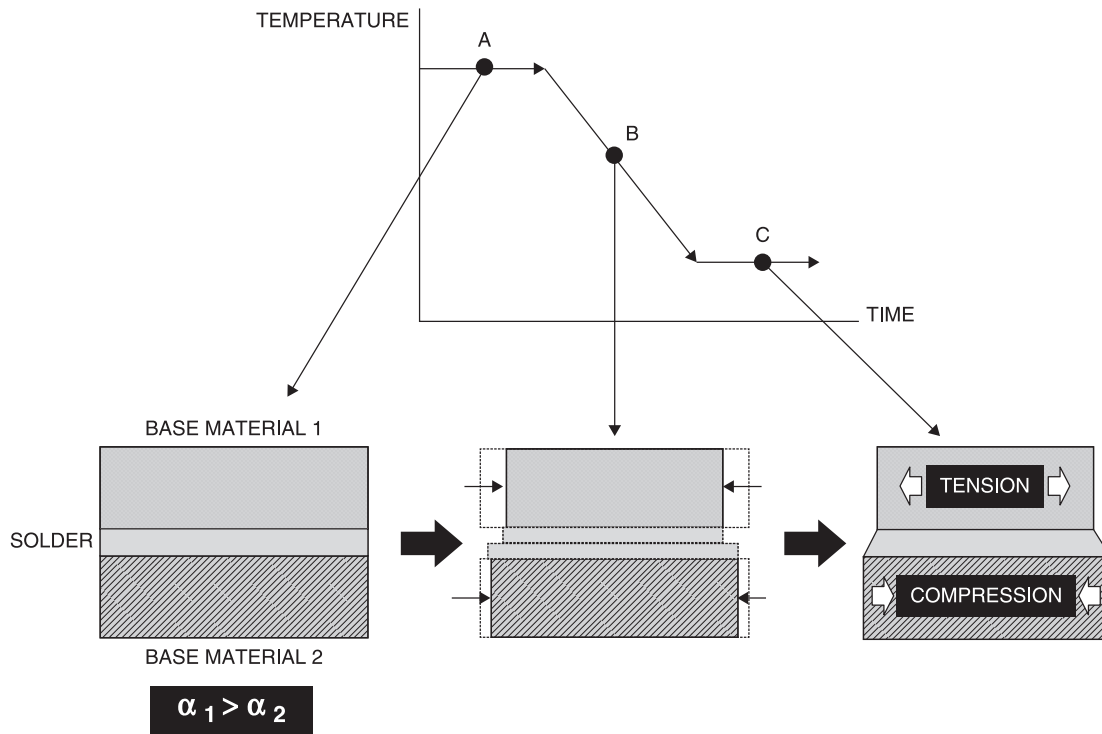


(C) A "BLEED" OR INSPECTION HOLE IS ADDED TO THE BOTTOM OF THE GAP TO ALLOW THE GASES TO ESCAPE. THE FLOW OF SOLDER THROUGH THE HOLE CONFIRMS FILLING OF THE GAP.

Figure 2.3—Soldering of a Blind Gap Joint

their relatively higher solidus temperatures. The higher melting temperature aluminum- and gold-based solders (i.e., hard solders) have a lesser capacity to deform and are less able to mitigate residual stresses in the base materials. Regardless of the filler metal type, the slower the cooling rate is, the greater the opportunity is for the filler metal to deform (creep) and as such, reduce residual stresses in the base materials.

The operator can minimize the residual stresses caused by thermal shock and the joining of dissimilar metals by slowing the heat-up and cool-down rates of the parts during the soldering process. Some hand soldering techniques are more effective in this regard (e.g., hot gas or torch) than others (e.g., solder iron or resistance soldering). The skill level of the operator is a necessary attribute in order for such procedures to be effective.



Notes:

1. Thermal expansion coefficient of base material 1 (α_1) is greater than that of base material 2 (α_2).
2. Tensile and compressive residual stresses develop in base materials 1 and 2, respectively.
3. The solder joint experiences a shear residual stress.

Figure 2.4—Development of Residual Stresses during Solder Joint Cooling caused by a Mismatch of Thermal Expansion Coefficients between Dissimilar Base Materials 1 and 2

The effect of soldering process temperatures on metallic base materials depends on the alloy composition and its melting properties. The likelihood of degradation increases with a decreasing base material solidus temperature. Of particular concern are the aluminum and magnesium metals and alloys. Possible effects include:

- (1) Dimensional instability such as warping;
- (2) Strength loss caused by the recovery and/or recrystallization of the microstructure; and
- (3) Partial melting of the base material itself.

The melting of the filler metal upon contact with the base material surface can provide an indication of the temperature of that base material. However, in the event that the margin between the base material solidus temperature and the soldering process temperature becomes too small to rely on this technique or the skill of the operator, then thermocouples should be attached to the base material to monitor its temperature during the soldering process.

The hand soldering process must consider the effects of high temperatures on nearby materials and structures. This factor is most critical when plastic parts or organic coatings (e.g., varnishes, paints, etc.) are present, or when performing field repairs. Excessive heat exposure can cause swelling or compositional changes that degrade the mechanical and physical properties of those structures or coatings. The operator can diminish such potential damage by:

- (1) Consciously directing the heat source away from nearby structures;
- (2) Minimizing the soldering time by using a heat source matched to the geometry and thermal properties of the base material(s); and
- (3) Using barriers between the joint and nearby structures.

The metallic base materials installment below addresses in more detail the different base material categories with respect to the development of a successful hand soldering process.

2.3 Metallic Base Materials. In general, a metallurgical reaction in support of wetting will occur between solder alloys having indium (In), tin (Sn), or zinc (Zn) as a component, and base metal alloys having aluminum (Al), copper (Cu), gold (Au), iron (Fe), nickel (Ni), palladium (Pd), platinum (Pt), and silver (Ag). The reaction layer is composed of one or more intermetallic compounds (IMCs) and is generally $1\text{ }\mu\text{m}$ to $3\text{ }\mu\text{m}$ [3.93×10^{-5} in to 11.8×10^{-5} in] thick for nominal hand soldering operations that are 10 s or less in duration (see Figure 1.2).

The IMC layer will grow in thickness as the soldering temperature increases; however, it will not grow significantly thicker for longer soldering times (with the exception of the palladium base material). Rather, there will be an increase in the extent of base material dissolution into the molten solder. The extent of copper dissolution is observed in Figure 2.5 for a 60 s exposure to molten 100Sn (melting point: 232°C [450°F]) held at 300°C [572°F]. The IMC layer is the light gray layer on the wetted side.

Besides process time and temperature conditions, the extent of base metal dissolution is a function of (molten) solder composition and base material composition. In the case of tin (Sn)-based solders, a higher tin content causes a faster dissolution rate. This effect is observed in Figure 2.6, which shows the dissolution rates of copper wire by several tin-based alloys.² This plot also illustrates the significant role of temperature on dissolution rate.

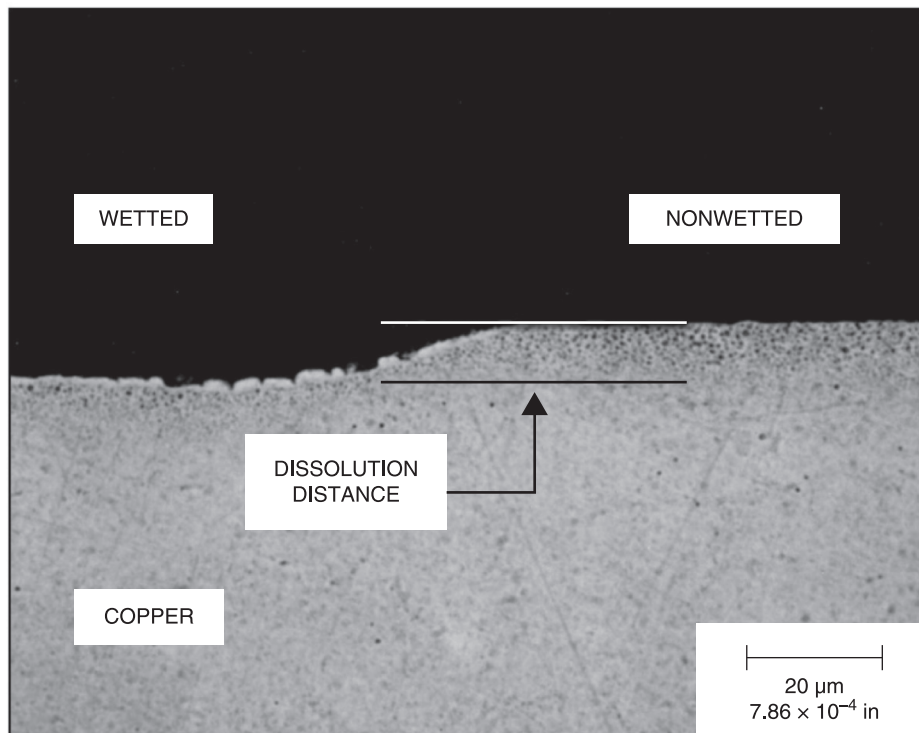


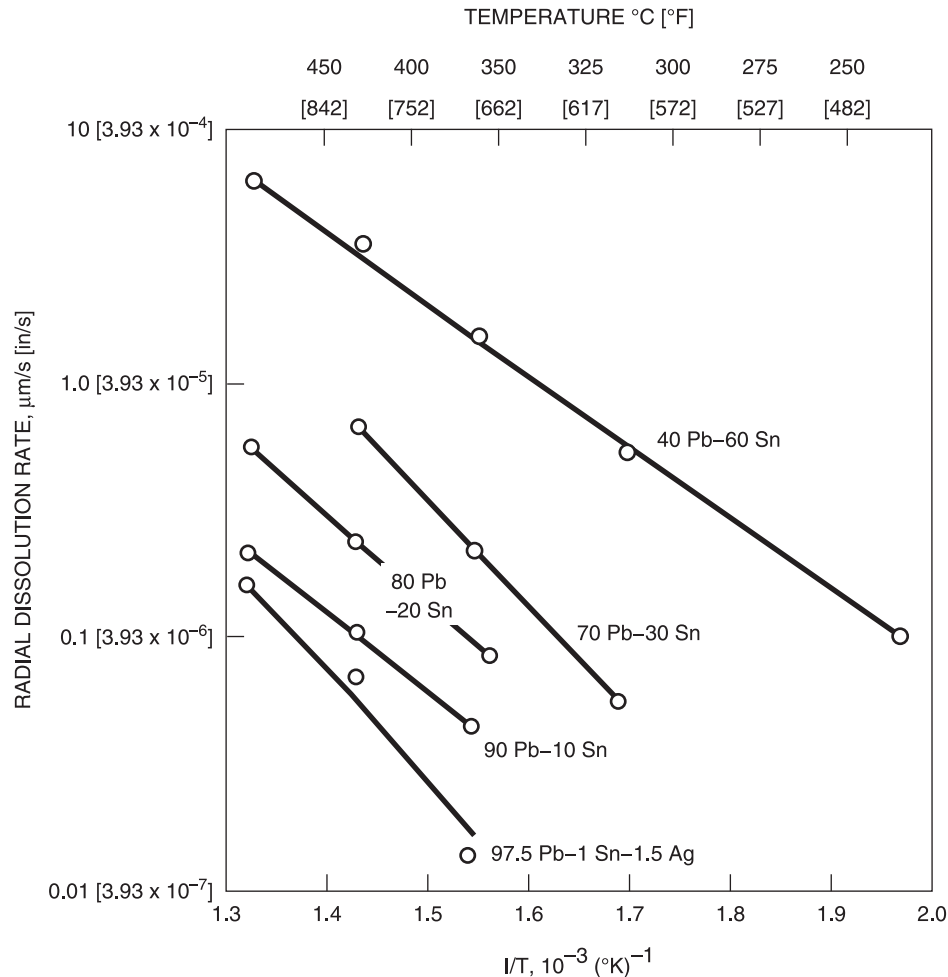
Image courtesy of Sandia National Laboratories

Note: Exposure time is 60 s and the tin (Sn) temperature is 300°C [572°F].

Source: Reproduced from *AWS Soldering Handbook*, 1999, Figure 1.70, American Welding Society.

Figure 2.5—Optical Micrograph Showing Dissolution of Copper (Cu) Base Metal by Molten 100Sn

² Bader, W. G., 1975, Lead Alloys for High-Temperature Soldering of Magnetic Wire, *Welding Journal* 54(10): 370s–375s.



Source: Reproduced from *AWS Soldering Handbook*, 1999, Figure 1.69, American Welding Society.

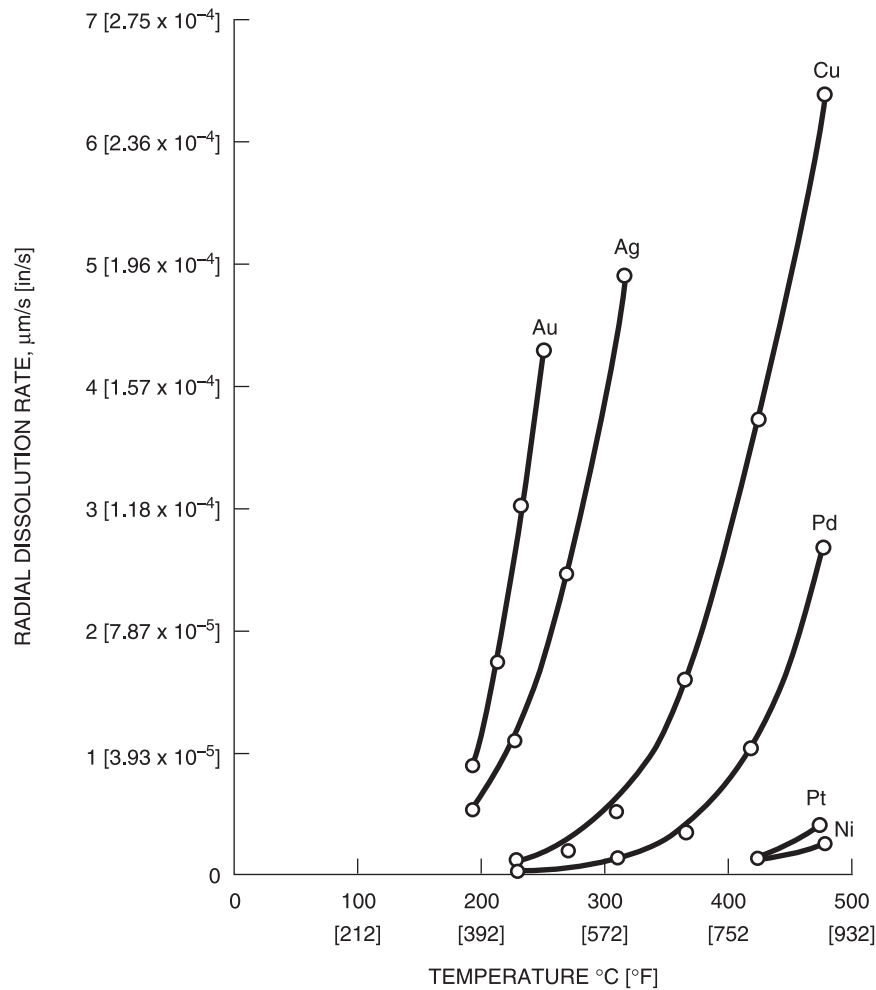
Figure 2.6—Graph of Dissolution Rate as a Function of Molten Solder Temperature Showing Effect of Tin (Sn) Content in Tin (Sn)-based Filler Metals

The dissolution rate is also sensitive to the base metal composition. Figure 2.7 is a graph of the dissolution rate as a function of base metal composition and temperature when exposed to molten 60Sn-40Pb solder.³ For example, gold (Au) dissolves into the molten solder at a considerably faster rate than copper (Cu). On the other hand, iron (Fe) (not shown), nickel (Ni), and platinum (Pt) have significantly slower dissolution rates than copper (Cu).

The rate of base material dissolution is also dependent upon the geometry of the base material part. Round shapes such as wire, as well as the corners of rectangular features, will dissolve faster than flat surfaces or reentrant (concave) corners. Base material dissolution is an important issue when soldering to very thin sheet or ribbon materials as the loss of base material can degrade the function of the structure.

Surface contamination can be categorized as organic or inorganic. It is the inorganic contaminant in the form of an oxide layer or corrosion product that is typically of particular concern for base metal or alloy compositions. Nevertheless, organic contaminants are mentioned because they must be removed prior to the removal of inorganic contaminants using water-based solutions. Most water-based cleaning solutions cannot penetrate organic films.

³ Bader, W. G., 1969, Dissolution of Au, Ag, Pd, Pt, Cu, and Ni in a Molten Tin-Lead Solder, *Welding Journal* 48(12): 551s–557s.



Source: Adapted from *AWS Soldering Handbook*, 1999, Figure 1.68, American Welding Society

Figure 2.7—Graph of Dissolution Rate as a Function of 60Sn-40Pb (wt.%) Solder Temperature Showing Effect of Base Metal Composition

Organic contaminants include oils (e.g., human, animal, or petroleum), greases (e.g., lubricants and mold releases), and coatings (e.g., paints, varnishes, and inks). They can be removed using mechanical abrasion (e.g., file, sandpaper, steel wool, bead blasting, etc.), saponified (soapy) water-based products, or solvents (e.g., acetone, alcohol, and fluorocarbon materials). The use of mechanical abrasion, such as sand paper or blasting techniques, can embed nonwetable media into the surface, thereby degrading solderability. Entrapped abrasive particles can be released from the base metal surface by chemical etchants that remove a thin layer of material from the surface. Saponifier solutions and solvents must be thoroughly rinsed from the surface to prevent the formation of residues that can reduce solderability.

Inorganic surface contaminations include oxidation layers (e.g., the rust on iron-based materials) as well as corrosion by-products that are typically chloride and/or sulfide compounds. The tenacity of inorganic contaminants (i.e., their ability to resist chemical attack or mechanical removal) depends on their chemistry as well as thickness. Inorganic contamination can be removed by mechanical abrasion or through chemical treatments using alkaline or acid solutions. Several candidate solutions are listed according to base material in Table 2.1. Additional comprehensive procedures and lists can be found in the *AWS Soldering Handbook*.⁴ Table 2.1 provides general chemistries from which the operator can adjust the compositions, solution temperatures, and exposure times in order to prepare the surface for soldering.

⁴ Vianco, P., 1999, *AWS Soldering Handbook*, 3rd Edition, Miami, Florida: American Welding Society.

Table 2.1
Common Solutions for Removing Inorganic Surface Contaminants

Metal/Alloy	Inorganic Cleaning Chemistry
Silver (Ag) ^a	20 ml NH ₄ OH, 10 ml to 20 ml H ₂ O ₂ , 10 ml to 20 ml H ₂ O
Aluminum (Al) ^b	10 g NaOH, 90 ml H ₂ O (60 °C to 70 °C [140 °F to 158 °F], 5 min to 15 min, 50% HNO ₃ rinse) 45 ml HCl, 15 ml HNO ₃ , 15 ml HF, 25 ml H ₂ O (10 s to 15 s)
Copper (Cu) ^c	10 ml to 25 ml HCl (25%), 90 ml to 75 ml H ₂ O (25 °C to 40 °C [77 °F to 104 °F], 1 min to 45 min) 5 ml to 10 ml H ₂ SO ₄ (77%), 95 ml to 90 ml H ₂ O (70 °C to 82 °C [158 °F to 180 °F], 2 min to 15 min) 11 ml to 50 ml HNO ₃ (70%), 89 ml to 50 ml H ₂ O (25 °C [77 °F], 2 min to 5 min)
Nickel (Ni) ^d	4 ml HF, 32 ml HNO ₃ (70%), 64 ml H ₂ O
Lead (Pb) ^e	75 ml glacial acetic acid, 25 ml H ₂ O ₂ , (30%) (5 s to 15 s)
Tin (Sn) ^f or Zinc (Zn) ^g	2 ml HCl, 98 ml Ethanol or H ₂ O 2 ml HNO ₃ , 98 ml Ethanol or H ₂ O
Low Carbon Steels ^h	5 ml to 10 ml H ₂ SO ₄ (77%), 95 ml to 90 ml H ₂ O (70 °C to 82 °C [158 °F to 180 °F], 2 min to 15 min) 10 ml to 25 ml HCl (25%), 90 ml to 75 ml H ₂ O (30 °C to 85 °C [86 °F to 185 °F], 10 min to 45 min)
Stainless Steels ⁱ	10 ml H ₂ SO ₄ , 10 ml HCl (25%), 80 ml H ₂ O 20 ml HNO ₃ (70%), 30 ml HF, 50 ml H ₂ O

^a ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 551.

^b ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 352.

^c Schwartz, M., *Brazing: For the Engineering Technologist*, 1995, London: Chapman and Hall, p. 316–318

^d ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 435.

^e ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 416.

^f ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 450.

^g ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 488.

^h ASM International (ASM), ASM Metals Handbook, 1985, Vol. 9, Materials Park, OH: ASM International, p. 172.

ⁱ ASM International (ASM), Source Book on Stainless Steels, 1976, Materials Park, OH: ASM International, pp. 365–368.

Corrosion by-products, once removed, will generally not reform again on the base material surface as long as the proper storage and handling procedures are exercised. On the other hand, oxidation can be expected to resume to various degrees immediately following the cleaning process. For example, copper will retain its solderability hours or even days after oxide removal, while aluminum and its alloys lose solderability within several seconds of exposure to air. It is recommended that the soldering process be performed as soon as possible after oxide removal to optimize solderability.

2.4 Coatings

There are situations that present poor solderability for hand soldering processes that can be remedied by the use of coating:

(1) Poor solderability can be attributed to properties inherent to the base material, such as the tenacious oxide layer of aluminum and magnesium alloys as well as the refractory metals—e.g., molybdenum, tantalum, titanium, etc. Similarly, poor solderability can also occur in alloys having high concentrations of nonsolderable additions—e.g., dispersion-strengthened alloys that contain SiO₂, Al₂O₃, Cr₂O₃, or NiO particles as alloy additions. A coating can be used to improve the solderability of the corresponding surfaces by covering those particles.

(2) Poor solderability can arise in applications having what are otherwise solderable base material surfaces, but for which the hand soldering process cannot be optimized. For example, there can be a loss of solderability arising from prolonged heat-up times that cause excessive surface reoxidation. This situation arises for very large parts. A coating can be used to protect the faying surface from oxidation thereby allowing the completion of the process.

(3) A third case in which the soldering process drives the need for a coating occurs when the exposure time to molten solder causes an unacceptable degree of base metal dissolution—e.g., thin sheet or ribbons. A coating, having a slower rate of dissolution than the base material, can serve as a barrier layer between the molten solder and base material. Of course, the coating surface must demonstrate satisfactory solderability. That coating is often overlaid with a second protective layer to maintain the solderability of the first coating surface.

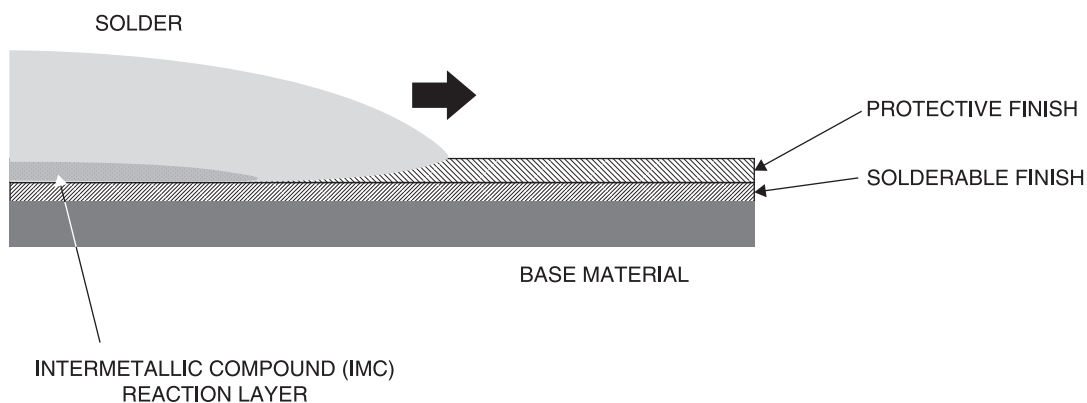
There are several coating methodologies used to address each of these scenarios. The first and third scenarios take place when the base material is inherently unsolderable or when a wettable base material experiences excessive dissolution by the molten solder. Then, a solderable finish is deposited on the base material. Candidate solderable finishes are copper (Cu) and nickel (Ni). A subsequent protective finish may be deposited over Cu to protect its solderability. However, a protective finish is *required* over a Ni solderable layer to prevent the loss of solderability due to oxidation. Protective finishes include gold (Au), palladium (Pd), platinum (Pt), silver (Ag), tin (Sn), as well as any one of the Sn-Pb alloys.

The stack-up of solderable and protective finishes, as well as their behavior during the soldering process, are illustrated in Figure 2.8. The protective finish is removed by the molten solder. In the case of Sn and Sn-Pb alloy coatings, these finishes melt during the soldering process. Therefore, their surfaces need not be entirely free of contamination or oxidation. On the other hand, the noble metal protective finishes, having significantly higher melting temperatures, are removed by dissolution into the molten solder. In order for the dissolution process to take place, the molten solder must be able to wet the protective finish surface; thus, those surfaces must be free of organic or inorganic contaminants. Lastly, the solder wets the surface of the solderable finish, which must exhibit satisfactory solderability.

In the second scenario, the solderability of the base material faying surface must be protected from contamination or oxidation; only the protective finish is then required on the base material surface. Gold (Au), palladium (Pd), platinum (Pt), and silver (Ag), as well as tin (Sn), or any one of the Sn-Pb alloys can be used as a protective finish. The protective finish is dissolved and/or melted into the molten solder. As noted above, the surfaces of the noble metals must be solderable for them to be dissolved into the molten solder. When using only a protective finish, the base metal surface must be solderable to complete the joint as well.

In terms of the hand soldering process, the operator must be aware of process limitations associated with the use of protective and solderable finishes:

- (1) The hand soldering process must allow for the complete dissolution of the protective layer into the solder, particularly in the case of the noble metal layers [gold (Au), palladium (Pd), and platinum (Pt)]. Failure to fully dissolve these layers can result in subsequent, rapid, solid-state IMC layer growth that may degrade the mechanical integrity of the solder/base material interface.
- (2) The solderable finish has a limited thickness. Prolonged contact with molten solder can potentially dissolve away the layer. As the presence of a solderable finish precludes the need for the base material to be wettable, the complete dissolution of the solderable finish into the solder can lead to dewetting defects.
- (3) The solderable finish remains as a permanent component of the solder joint. Therefore, the coating must remain adherent to the base material surface. The solderable coating can delaminate from the base material during an excessively long exposure to very high temperatures or due to thermal shock caused by very rapid temperature changes.



Note: The completed joint requires that the solder form a metallurgical bond with the solderable finish and that the solderable finish remain adherent to the base material.

Figure 2.8—Molten Solder Wetting and Spreading Over a Base Material with Solderable and Protective Finishes

2.5 Nonmetallic Base Materials—Ceramics and Glasses

The nonmetallic base materials are generally the ceramics and glasses. There has been little study on the direct soldering of organic materials, although certainly some of the high-temperature thermosetting plastics—e.g., bakelite—could withstand the heat. Metallic coatings would be required to provide solderability. The hand soldering of ceramic and glass materials is used to assemble small electronic components as well as in many art forms.

The important consideration when soldering to ceramics and glasses is their sensitivity to thermal shock. Owing to their low thermal conductivities, rapid heating or cooling can generate temperature gradients in these materials (e.g., between the surface and interior regions) that create regions of different thermal expansion or contraction that generate residual stresses. The greater the temperature gradient, the higher are those stresses until a crack develops in the part. Consideration is paid to thermal shock during *both* the heat-up as well as cool-down steps of the soldering process. The cooling step of the soldering process poses an added concern when glass or ceramic is joined to a dissimilar material, whether the latter is another nonmetallic material, or particularly when it is a metallic part. In the presence of the solder joint, additional residual stresses are caused by a mismatch of thermal expansion coefficients between the different base materials (see Figure 2.4). Too rapid a cooling step does not allow the solder to deform as the mechanism for alleviating those residual stresses. The retention of those stresses can lead to cracks in the nonmetallic materials.

Added care must be exercised when hand soldering nonmetallic base materials with an iron. Initially, the soldering iron provides little margin that allows the operator to minimize heating and cooling rates. Secondly, the very localized heat source of the tip can create large temperature gradients in the base material. A technique for controlling the heating or cooling rate is to preheat the parts on a hot plate prior to the soldering step. The hot plate temperature depends on the solidus temperature of the filler metal. In the case of 63Sn-37Pb solder that has a solidus (and liquidus) temperature of 183°C [361°F], a hot plate temperature between 150°C and 170°C [302°F and 338°F] is adequate. A preheat temperature of 190°C to 200°C [374°F to 392°F] can be used for the higher-melting temperature, tin (Sn)-rich solders such as 96.5Sn-3.5Ag and 95Sn-5Sb. Note that these temperatures are above the typical range of flux activation temperatures of 120°C to 170°C [248°F to 338°F]. Thus, the flux will be activated under these temperatures, and therefore, should only be applied immediately prior to soldering. Preheat temperatures of 220°C to 290°C [428°F to 554°F] may be required for the gold (Au)-based and lead (Pb)-based solders that melt between 250°C and 327°C [482°F and 591°F]. Care must be exercised so that the higher preheat temperatures do not cause thermal damage to the base material, do not degrade solderability, or thermally decompose any flux that is in place. The soldering step is usually performed directly on the hot plate so that the cooling rate can be controlled by adjusting the power setting. An oven can be used to control the heating rate of the parts and cooling rate of the soldered assembly; however, the parts usually have to be removed from the oven to perform the soldering process, which can lead to interim temperature fluctuations.

Similar temperature gradient concerns pertain to using a soldering torch to join nonmetallic materials. Fortunately, the torch offers a greater flexibility for controlling the heating and cooling rates as it provides a more diffuse heat source. Unfortunately, a torch flame is at a considerably higher temperature than is a soldering iron tip so that the nonmetallic part can be quickly damaged when care is not exercised by the operator.

Nonmetallic materials are generally unsolderable with most filler metals. Two solder alloys are exceptions: indium (In)-containing filler metals and so called “active” solders that can wet directly to some glasses and ceramics. Otherwise, ceramics and glasses must be coated with a metallic film to provide solderability. The application of metallic coatings to ceramics and glasses is referred to as metallization technology. The two general metallization technologies are *thin film* and *thick film*.

Thin film metallization technology refers to one of two techniques: Physical Vapor Deposition (PVD) such as evaporation or sputtering, and Chemical Vapor Deposition (CVD). There are generally three layers to the metallization “stack-up.” First, an adhesion layer is deposited onto the base material surface to serve as a “glue” that bonds the subsequent thin metal films to the ceramic or glass base material. Commonly used adhesion layers are: chromium (Cr), molybdenum (Mo), titanium (Ti), and tungsten (W). Their strong affinity for oxygen or nitrogen establishes a bond between the oxide and nitride chemistries of many glasses and ceramics. In addition, these metals exhibit sufficient metallic bonding to be adherent to the subsequent metal layer that forms the solderable finish. Solderable metal layers that are also deposited by PVD or CVD techniques include copper (Cu), iron (Fe), or nickel (Ni). Lastly, the protective finish is deposited over the solderable layer, preferably without exposing the latter to air that would cause oxidation of the surface. Protective layers are typically one of the noble metals: gold (Au), palladium (Pd), platinum (Pt), and silver (Ag). The functions of the solderable and protective finish were described in the previous section.

Thin film layers, whether deposited by PVD or CVD, are limited to maximum thicknesses of 1.0 μm to 4.0 μm [40 μin to 160 μin]. Besides the economics of prolonged deposition times, the maximum thicknesses are limited in order to prevent the buildup of intrinsic residual stresses in the films that may cause delamination. Such stresses are of particular concern with Ni as well as refractory adhesion layers including Mo, Ti, and Cr. Prolonged deposition times increase the heating of the base metal. When soldering to thin film layers, attention must be given to the very limited thickness of the solderable layer. Prolonged contact with molten solder can cause complete dissolution of the solderable layer, typically signified by dewetting. The adhesion layer surface is unsolderable.

The thickness of the solderable or protective finishes can be bolstered to 4.0 μm to 10 μm [160 μin to 400 μin] using follow-on electroplating or electroless plating processes. Both electroplated and electroless plated films cannot be deposited directly on to a ceramic or glass surface because the latter materials are not electrically conductive. The PVD or CVD layers can serve as conductive “seed layers” that will accept the subsequent plated coatings.

Thick film metallization technology is the second technique for placing a solderable layer on a nonmetallic surface. As the term implies, these coatings are considerably thicker than PVD or CVD layers. They are also usually deposited by screen printing followed by a firing step. Thick film layers range from 10 μm to 30 μm [0.0004 in to 0.0012 in] thick and have compositions of copper (Cu), gold (Au), nickel (Ni), and silver (Ag), as well as a range of Au- or Ag-based alloys. Alloying elements are typically palladium (Pd) and platinum (Pt). The thick film layer begins as an ink that is comprised of metal particles, glass particles, and binder. The ink is screen printed on the surface and then dried to remove volatiles. Lastly, the ink is fired at temperatures of 800°C to 900°C [1472°F to 1652°F] for a duration of 10 min to 20 min. The metal particles sinter together to form the semicontinuous layer. The glass particle phase moves to the interface where they bind the metal to the ceramic. The Scanning Electron Microscope (SEM) images in Figure 2.9 show solder joints made to a Au-Pt-Pd thick film layer bonded to an alumina ceramic base material. The solders are: (A) 63Sn-37Pb ($T_{\text{eutectic}} = 183^\circ\text{C}$ [361°F]) and (B) 96.5Sn-3.5Ag ($T_{\text{eutectic}} = 221^\circ\text{C}$ [430°F]). The porosity of the thick film layer (20% to 40% by volume) results from the sintering of the metal particles.⁵ The pores are extensively interconnected so that the molten solder can readily penetrate the metal layer, which can accelerate the latter's dissolution. A greater extent of penetration/dissolution occurs for the 96.5Sn-3.5Ag solder [see Figure 2.9(B)] due to its higher tin (Sn) content and the need for a higher processing temperature.

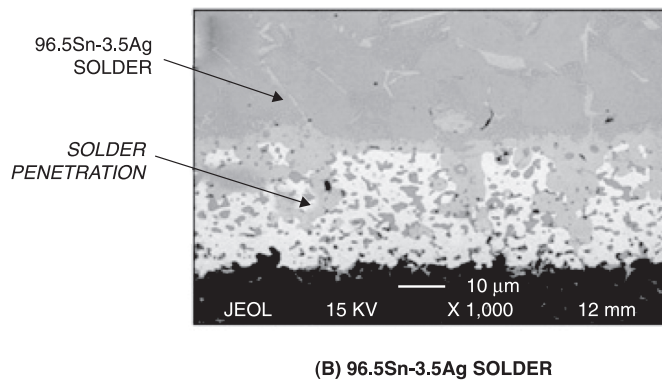
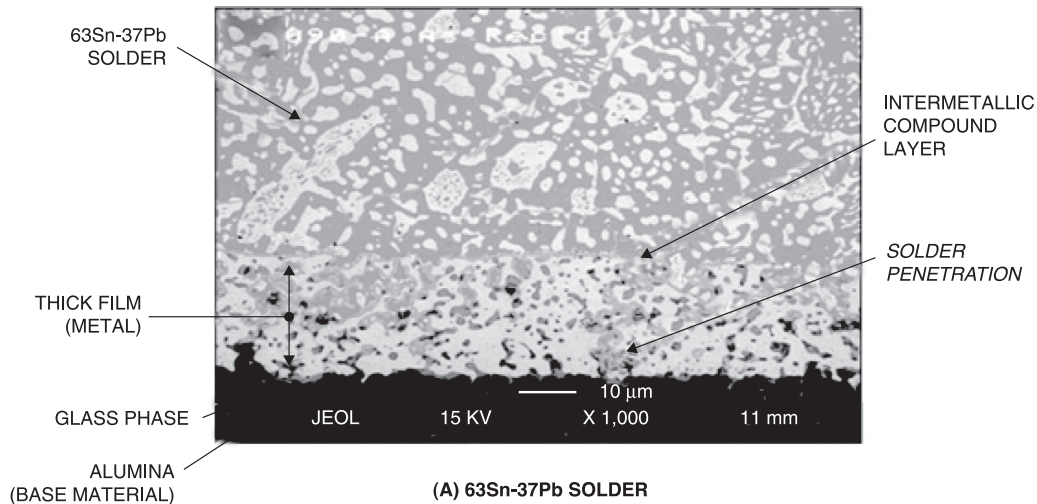
There are several factors to consider when hand soldering to a thick film coating. As indicated above, the molten solder readily infiltrates the porous structure of the layer. The additional surface area of the pores accelerates the layer dissolution. Complete dissolution of the metal component of the thick film exposes the underlying glass adhesion layer and base material, both of which are unsolderable, resulting in the dewetting defect. Therefore, the soldering process should minimize the time that the molten solder is in contact with the layer. Thick films containing platinum (Pt) dissolve at a slower rate and are often used if lengthy or multiple soldering processes are used.

Unlike gold (Au) and platinum (Pt), palladium (Pd) and silver (Ag) are not immune to surface oxidation. The silver (Ag) oxide is not very tenacious. However, silver (Ag) also forms a more tenacious tarnish layer caused by its reaction with sulfur (S) in the air. The oxides of silver (Ag) and palladium (Pd), as well as silver (Ag) tarnish, are commonly removed by burnishing the surface with a nylon-bristle brush or pencil eraser in order to improve solderability.

Thick film layers are relatively robust against thermal shock. However, the underlying ceramic or glass may not be so. Thus, it is prudent practice to preheat the base material prior to performing the soldering process to minimize the risk of fracture at the thick film/base material interface or in the base material under the thick film layer.

It was noted above that *indium (In)-containing solders* and the so called *active solders* can wet directly to some ceramics and glasses. Elemental indium and the alloy, 52In-48Sn ($T_{\text{eutectic}} = 118^\circ\text{C}$ [244°F]), exhibit this property. The wetting mechanism occurs between the oxide compound(s) in the glass or ceramic and the oxide of indium (In) or the Indium-Tin-Oxide (ITO) of the alloy. The active solders are based on the 96.5Sn-3.5Ag (wt.%) eutectic alloy ($T_{\text{eutectic}} = 221^\circ\text{C}$ [430°F]), but contain alloy additions of titanium (Ti) and several lanthanide elements. These alloy additions participate in a reaction with the nonmetallic surfaces that bonds the solder to the base material under typical soldering temperatures.

⁵ Hernandez, C. and Vianco, P., 1999, Effect of Thick Film Firing Conditions on the Solderability and Structure of Au-Pt-Pd Conductor for Low-Temperature Co-Fired Ceramic Substrates, *Proc. InterPACK '99 Conference*, New York, NY: ASME International.



Images courtesy of Sandia National Laboratories

Figure 2.9—SEM Images showing Solder Joints made to a Au-Pt-Pd Thick Film Layer bonded on an Alumina Ceramic Base Material

Although the indium-containing and active solders exhibit wettability to nonmetallic base materials, they have poor solderability due to a lack of spontaneous spreading on their surfaces. Therefore, the necessary spreading activity is created by either (1) manually spreading of the molten filler metal using the soldering iron tip or other tool in conjunction with the heat source or (2) applying pressure between the two base materials that forces the molten filler metal to cover the faying surfaces.

3. Filler Metals

3.1 Materials Technology

There are a wide range of filler metal compositions that are available for hand soldering. By definition, solder filler metals are distinguished from those used for brazing by having a liquidus temperature that is less than 450 °C [842 °F].⁶ The appropriate solder alloy is determined initially by the design engineer to satisfy the following criteria:

- (1) minimum strength requirement under all service temperature conditions;
- (2) avoid remelting by next-assembly processes and acceptance tests;
- (3) provide a suitable cosmetic appearance (e.g., the jewelry trades); and
- (4) address toxicity and environmental requirements.

Further consideration is given to the filler metal composition based upon the need for a practical and cost-effective (hand) assembly process.

Generally, commercial solder compositions can be obtained in several forms for hand soldering as listed in Table 3.1. There are wires of various diameters, preforms that are cut to the desired footprint and thickness, as well as solder pastes. Solder pastes are a mixture of the metal powder, a flux, and thixotropic agents that bind the components into a single material and give it its spreading properties. The off-the-shelf availability of any composition in any one of these forms will depend upon market demand and the ease of fabrication. For example, solder compositions containing bismuth (Bi) and gold (Au) are typically more brittle and as such are more difficult to form into wire or preforms.

Only those solder having a flux component – flux core wire or solder paste – have a shelf life limitation, more so the solder paste. Although the refrigeration (not freezing) of these products will prolong their shelf life, consistent, well-controlled solder processes are best assured by using flux core wire and paste within the manufacturer's guidelines.

Table 3.1
Forms of Solder Materials

Form	Description
Pig	Rectangle, 22.5 kg to 45 kg [50 lbs to 100 lbs]
Cake or Ingot	Rectangle or disk, 1.5 kg to 4.5 kg [3 lb to 10 lb]
Bar ^a	Numerous lengths, typically 30 cm [12 in] and a cross section of 1.91 cm × 1.91 cm [0.75 × 0.75 in]
Foil, Sheet, or Ribbon	Various lengths, widths and thicknesses down to 0.013 mm [0.0005 in] depending on material formability
Wire (solid) ^{a,b}	Nominal diameters of 0.25 mm to 6.35 mm [0.010 in to 0.250 in]
Wire (flux cored) ^{a,b}	Nominal diameters of 0.25 mm to 6.35 mm [0.010 in to 0.250 in] with the center core containing a rosin-based or water soluble flux jelly
Preforms	Variety of shapes and thickness; minimum dimensions are constrained by material formability and tooling tolerances
Thin Films	Coatings deposited by electroplating process, as well as the physical vapor deposition techniques of evaporation and sputtering; Thicknesses: 100 µm to 10 µm [3.9 µin to 390 µin]

^a Reference ASTM B32-91, *Standard Specification for Solder Metal*.

^b Reference ISO 12224-1, *Solder wire, solid and flux cored—Specification and test methods—Part 1: Classification and performance requirements*.

Source: Adapted from AWS *Soldering Handbook*, 1999, Table 2.1, American Welding Society.

⁶ It is noted that the term *silver soldering* has often been used, particularly in the plumbing community, to refer to the use of one of the silver (Ag) containing alloys, typically, the 96Sn-4Ag (wt.%) composition.

The manufacturing of solder preforms requires rolling and punching operations, as well as other tooling operations that can add a significant cost premium to the price of preforms. The lack of filler metal availability in the desired form may require a change of composition for the application.

Specifications such as [ASTM B32](#), *Standard Specification for Solder Metal*,⁷ and ISO/DIS 9453, *Soft solder alloys—Chemical compositions and forms*,⁸ provide the chemical compositions for Sn-Pb, Sn-Pb-Sb, Sn-Pb-Ag, and Pb-Ag (see Tables 3.2 and 3.3). Standard J-STD-006, *Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications*,⁹ lists these as well and other solder compositions. It is important to use the latest revisions of these and other specifications in order to have the most up-to-date composition and melting properties information.

Filler metals may also be placed at the joint as a coating on the base material surface. The coatings may be deposited by an electroplating process or by Physical Vapor Deposition (PVD; e.g., evaporation or sputtering). The specific technique depends upon the elemental components in the alloy composition and the desired thickness. Because these coatings are usually intended to serve as protective finishes, they are too thin to provide the quantity of filler metal necessary to actually complete a joint. The exceptions are those applications that use solder coatings to assemble very small mechanical and electronic devices.

The selected filler metal affects the hand soldering process in several ways. First and foremost, there are the melting properties of the solder. The filler metal can melt at a single temperature [this occurs when the solder is a single elemental metal such as tin (Sn), lead (Pb), indium (In), zinc (Zn), etc.], or when the solder alloy is at a *eutectic composition*.

In the case of *noneutectic* compositions, the solder melts over a temperature range determined by the *solidus temperature*, T_s , and the *liquidus temperature*, T_l . At temperatures less than the solidus temperature, the solder is fully solid. Upon heating the solder above the solidus temperature, the alloy starts to melt. Between T_s and T_l , the solder has a mushy or pasty consistency as it is a mixture of liquid and solid particles. Hence, the temperature range of $T_s < T < T_l$ is often referred to as the *pasty range* or *mushy zone*. As the process temperature approaches T_l , the percentage of liquid increases and the quantity of solid particles decreases in the solder, which becomes more liquid-like. Therefore, the flow behavior of the molten solder alloy is determined by its composition—eutectic or noneutectic—and in the latter case, by the soldering temperature relative to T_s and T_l temperatures. At the liquidus temperature and above, the solder has completely melted and is fully a liquid.

Hand soldering processes can use filler metals having a range of consistencies. A 100% liquid solder typically has the optimum flow characteristics for filling smaller gaps and holes. It is for this reason that elemental metal filler metals or eutectic compositions are most often preferred for a soldering process. Also, these eutectic filler metals are 100% liquid at the lowest temperature for that composition.

On the other hand, there are applications that benefit from the filler metal having a pasty consistency. For example, the filler metal having a pasty consistency is less likely to run out of a large gap or hole. Also, a filler metal that is pasty allows the operator to move or “work” the solder over the faying surfaces. This attribute is important when using the solder to coat a base material or for many jewelry applications.

The wetting and spreading behavior of solder preforms depends upon the composition’s oxidation behavior. A solder preform will develop an oxide layer in storage and during heat-up of the joint. If that oxide layer becomes sufficiently thick, it remains as a skin around the molten filler metal because it is too tenacious to be removed by the flux. Solderability is significantly degraded. Such an oxide skin is less of a concern for the Sn-based solders; however, it can be a factor in the wetting and spreading of aluminum (Al)-, gold (Au)-, indium (In)-, lead (Pb)- and zinc (Zn)-based solder preforms. Coating the preform with a flux prior to heating will minimize the extent of oxidation.

If the application permits, the thick oxide layer of a preform can be disrupted by mechanical movement between the base materials. Once the oxide skin is broken, molten filler metal can wet the base material surface. The oxide becomes small inclusions in the filler metal that generally do not affect the performance of the joint.

⁷ ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428–2959, USA.

⁸ ISO standards are published by the International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56 – CH-1211 Geneva 20, Switzerland.

⁹ J Standards are published by the Association Connecting Electronics Industries (IPC), 3000 Lakeside Drive, 309 S, Bannockburn, IL 60015.

Lastly, it is important to understand filler metal strength as a function of melting properties. As completely solid materials, solders have relatively low strengths when compared to most base materials. Moreover, that strength diminishes further as the temperature increases and approaches the solidus point of the composition. The filler metal is considered to have *zero strength* at, or above, the solidus temperature ($T > T_s$). Therefore, the operator must not disturb or otherwise subject the joint to mechanical forces, including the removal of fixtures, until after the solder has solidified ($T < T_s$). Disturbing the joint prior to complete solidification can cause misalignment between base materials and voids in the solder. It is good practice to avoid placing mechanical loads on the joint until it can be touched or is below 50°C [122°F] to avoid damage to it.

3.2 Processing Effects

A brief introduction will describe the alloy compositions that are commonly used for hand soldering. More in-depth discussions of the various solder alloys, including the details of their physical and mechanical properties, can be found in the *AWS Soldering Handbook*.¹⁰

The definition of a solder is that its liquidus temperature is less than 450°C [842°F]. Metals or alloys having liquidus temperatures in excess of 450°C [842°F] are considered to be brazing alloys. The ternary eutectic 62.5Ga-21.5In-16Sn alloy has a liquidus temperature of 10.7°C [51°F], which means that it is liquid at room temperature (like mercury). Or, the liquidus temperature can reach 424°C [795°F] as in case of the 55Ge-45Al binary eutectic composition.

The noneutectic solders may be used purposely at a process temperature within the pasty range between the solidus and liquidus temperatures. Otherwise, it is preferable that the soldering process temperature be 20°C to 40°C [68°F to 104°F] *above* the liquidus temperature of the alloy. This temperature margin assures that the solder will remain molten in spite of local temperature gradients within the base material part geometries. More importantly, the temperature margin prevents premature solidification of the solder caused by the dissolution of protective finishes as well as the partial dissolution of solderable finishes or base material into the filler metal. These “contaminants” change the solder composition, and thus, alter its solidus and liquidus temperatures, which may increase or decrease, depending upon the specific contaminant. The higher process temperatures assure that the solder remains molten when contaminants increase the solidus and/or liquidus temperatures. An even greater temperature margin will be required as a joint becomes thinner because there will be an increased concentration of dissolved contaminants caused by the smaller volume of filler metal.

Solder compositions have been listed in industrial specifications. The purpose of these specifications is to establish a consistent alphanumeric name, as well as to standardize their compositions, including impurities. In some cases, U.S. documents were the basis for international specifications so that composition requirements are generally very similar. (It is the certification *process* that may be different.) These specifications are periodically updated by the governing organizations to reflect new compositions or significant variations to existing filler metals. Not all solder alloys are included in specifications. This point is especially true of experimental solders that, although they are commercially available, are not sold in sufficient quantities to warrant the manufacturer’s time and expense to have them certified for a specification. In these cases, the user should insist upon a document that certifies the composition of that product lot.

The operator should always confirm that the filler metal composition complies with the work instruction, drawing, or other control document prior to its use. Many solder alloys have the same visual appearance. Therefore, the only means to distinguish different compositions is by the container in which they are stored. Often, work instructions prohibit two different solder alloys from being present in an assembly area at the same time in order to avoid an accidental mix-up of composition.

It was noted above that solder coatings can be applied to base material surfaces (generally as a protective finish) by electroplating or physical vapor deposition (evaporation or sputtering) techniques. In the case of electroplating processes, it is difficult to control the composition, precisely, for binary and higher-order solder coatings. The exceptions are the Sn-Pb coatings that have a long developmental history. Therefore, it is prudent to perform a postdeposition assay of the coating to certify that it meets the desired composition.

The composition of the molten filler metal is altered during the soldering process by the complete dissolution of protective finishes as well as partial dissolution of solderable coatings or the base metal. The extent to which the molten filler metal composition is altered during the soldering process will depend upon the following factors:

¹⁰ Vianco, P., 1999, *AWS Soldering Handbook*, 3rd Edition, Miami, Florida: American Welding Society.

- (1) solder temperature and soldering time;
- (2) the compositions of the base material or solderable finish;
- (3) the composition of the filler metal;
- (4) the thickness of protective finishes;
- (5) the quantity of molten solder within the joint gap; and
- (6) whether the molten solder flows into the joint by capillary action or experiences little movement such as when used as a preform.

Contamination of the molten filler metal during hand soldering changes its composition and thus, its melting properties. Generally, contaminants lower the solidus temperature and raise the liquidus temperature, thereby creating a pasty range in elemental metal and eutectic compositions, or increasing the pasty range of noneutectic filler metals. A reduction in the solidus temperature is more an issue of meeting maximum service temperature requirements without remelting the already-completed solder joint. On the other hand, an increase of the liquidus temperature and associated extension of the pasty range can have two potentially deleterious effects on the soldering process. First, the molten filler metal may completely solidify before filling the gap and/or completing the fillet. This phenomenon is referred to as *constitutional solidification* or *isothermal solidification*. The result is a defective joint. The second phenomenon, which is a direct consequence of the widened pasty range, is the in situ precipitation of second phase particles that impede the flow of molten filler metal required to fill holes and gaps, or to form a satisfactory fillet.

It should be noted that some metallic contaminants actually improve solderability. The case in particular is that of gold (Au), which is also one of the more commonly used protective finishes.¹¹ It has been observed that gold (Au) lowers the surface tension of molten tin (Sn)-based solders. A lower surface tension improves wetting and spreading as well as capillary flow properties.

3.3 Standards and Specifications

The following standards are used today to specify solder materials. In the United States, the documents are:

- [ASTM B32](#), *Standard Specification for Solder Metal*¹²
- *IPC J-STD-006, Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications*¹³

The international document is:

- *ISO/DIS 9453, Soft solder alloys—Chemical compositions and forms*¹⁴

Although IPC J-STD-006 specifies “Electronic Soldering Applications,” this standard can also be used to procure filler metals for structural soldering applications. Some suppliers may simply stock material to one specification or the other, based upon the requests of their predominant customers.

Shown in Tables 3.2 and 3.3 are *abbreviated* lists of filler metals selected from the ASTM and ISO standards. The tables illustrate the formats that show nominal compositions, impurity levels, as well as solidus and liquidus temperatures. The reader is reminded to obtain the most current revisions to these documents in order to be aware of new compositions and updates to already existing chemistries.

¹¹ Lopez, E., Vianco, P., and Rejent, J., 2003, Solderability Testing of 95.5Sn-3.9Ag-0.6Cu Solder on Oxygen-Free, High-Conductivity Copper and Au-Ni Plated Kovar™, *Journal of Electronic Materials* 32(4): 254–260.

¹² ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

¹³ IPC standards are published by the Association Connecting Electronics Industries, 3000 Lakeside Drive, 309 S, Bannockburn, IL 60015.

¹⁴ ISO standards are published by the International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland.

Table 3.2
Partial Listing of Sn-Pb, Sn-Pb-Sb, Sn-Pb-Ag, and Pb-Ag Compositions from ASTM B32, Standard Specification for Solder Metal

Alloy	Composition, % ^a										Solidus		Liquidus		
	Sn	Pb	Sb	Ag	Cu	Cd	Al	Bi	As	Fe	Zn	°C	°F	°C	°F
Sn70	69.5–71.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.03	0.02	0.005	183	361	193	377
Sn63	62.5–63.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.03	0.02	0.005	183	361	183	361
Sn62	61.5–62.5	bal	0.50	1.75–2.25	0.08	0.001	0.005	0.25	0.03	0.02	0.005	179	354	189	372
Sn60	59.5–61.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.03	0.02	0.005	183	361	190	374
Sn50	49.5–51.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.025	0.02	0.005	183	361	216	421
Sn45	44.5–46.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.025	0.02	0.005	183	361	227	441
Sn40A	39.5–41.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	183	361	238	460
Sn40B	39.5–41.5	bal	1.8–2.4	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	185	365	231	448
Sn35A	34.5–36.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	183	361	247	447
Sn35B	34.5–36.5	bal	1.6–2.0	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	185	365	243	470
Sn30A	29.5–31.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	183	361	255	491
Sn30B	29.5–31.5	bal	1.4–1.8	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	185	365	250	482
Sn25A	24.5–26.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	183	361	266	511
Sn25B	24.5–26.5	bal	1.1–1.5	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	185	365	263	504
Sn20A	19.5–21.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	183	361	277	531
Sn20B	19.5–21.5	bal	0.8–1.2	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	184	363	270	517
Sn15	14.5–16.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	225	437	290	554
Sn10A	9.0–11.0	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	268	514	302	576
Sn10B	9.0–11.0	bal	0.20	1.7–2.4	0.08	0.001	0.005	0.25	0.02	0.02	0.005	268	514	299	570
Sn5	4.5–5.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	308	586	312	594
Sn2	1.5–2.5	bal	0.50	0.015	0.08	0.001	0.005	0.25	0.02	0.02	0.005	316	601	322	611
Ag1.5	0.75–1.25	bal	0.40	1.3–1.7	0.30	0.001	0.005	0.25	0.02	0.02	0.005	309	588	309	588
Ag2.5	0.25	bal	0.40	2.3–2.7	0.30	0.001	0.005	0.25	0.02	0.02	0.005	304	580	304	580
Ag5.5	0.25	bal	0.40	5.0–6.0	0.30	0.001	0.005	0.25	0.02	0.02	0.005	304	580	380	716

^a Limits are maximum percentages, unless shown as a range or stated otherwise. For purposes of determining conformance to these limits, an observed value or calculated value obtained from analysis shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the specified limit, in accordance with the rounding method of ASTM E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.

^b Temperatures given are approximations and are for information only.

Source: Adapted, with permission, from ASTM International, ASTM B32-08, Standard Specification for Solder Metal, Table 1.