

Hand Soldering Basics

A new guideline under development highlights hand soldering as an engineering technology

BY PAUL T. VIANCO

The origins of soldering can be traced back several thousands of years to artisans in the Mediterranean region who used it to fabricate items ranging from household utensils to jewelry. The obvious advantage was the low melting temperature of the filler metals that allowed soldering to be used with the modest heat sources that were available at the time. Because artisans practiced soldering as a craft, they considered materials and processes to be proprietary information. Even today, some soldering methods are not readily divulged between craftsmen in the jewelry-making community.

Soldering remained largely an artisan's craft up to the Industrial Revolution in the nineteenth century. As populations grew and inhabited cities, it was necessary to develop an infrastructure that could deliver centralized services such as water, waste removal, and gas for lighting purposes. Services were brought to dwellings by iron, copper, and steel conduits that were joined together with solder filler metals — Fig. 1. The availability of portable energy sources, including combustible gases followed by electricity, allowed pipe systems to be assembled on-site, which significantly reduced the project cost. All of the work was performed by craftsmen who formed the ranks of plumbers and other pipefitters.

The twentieth century brought about the increased use of electricity, and with it, the development of radio and other electronic components. Soldering was a very effective means to connect copper wires as well as to assemble rheostats, transformers, and other devices. At that time, all of the soldering was performed by hand. There became an increased awareness of hand soldering as an industrial process, al-



Fig. 1 — A long-standing structural application of hand soldering is in the plumbing trades. (Photo courtesy of the Copper Development Association, Inc., New York, N.Y.)

beit primarily still as a craft and certainly not yet as a technology.

The electronics revolution of the last fifty years saw a transition from hand-soldered electronic products to those made by large-volume, mass production techniques. Automated and semiautomated manufacturing processes are being used to precisely control the filler metal, flux, and application of heat in order to assemble tens of thousands of very small solder joints in a process time of 45–60 s and with defect levels of tens of parts per million or less.

Today, soldering is considered a technology driven by the electronics industry. It is critical that engineers understand materials' compatibility, process control, and long-term solder joint reliability. Yet, in spite of the many advances that have been made toward optimizing large-volume

manufacturing processes, applications remain that are performed by hand soldering because of technical and/or economic advantages. In the electronics industry, there are accredited certification programs administered by professional organizations (e.g., IPC-Association Connecting Electronics Industries) that train individuals in the soldering of circuit boards and related electronic interconnections. Those same organizations provide acceptance specifications that assess the quality of such solder joints.

However, in the case of structural hand soldering, there is a noticeable lack of accredited certification programs and specifications, in spite of the long history that hand soldering has had in the trades and artists' communities. The American Welding Society provides a quality-related document pertaining to structural soldering titled B2.3: 2008, *Specification for Soldering Procedure and Performance Qualification*. Otherwise, most certification programs are in-house and typically address the fabrication of solder joints that are relevant to that company's products and services. Often, operators are provided with only a sufficient amount of information to maintain the assembly line throughput.

The C3B Soldering Subcommittee of the AWS C3 Brazing and Soldering Committee has long-recognized that there is a gap in the availability of accredited specifications and certification programs. But, more so, there is a gap in the fundamental knowledge base that is crucial to support hand soldering as an engineering technology. Therefore, the C3 Committee has taken action toward eliminating that knowledge gap. The first step was to begin developing American National Standards

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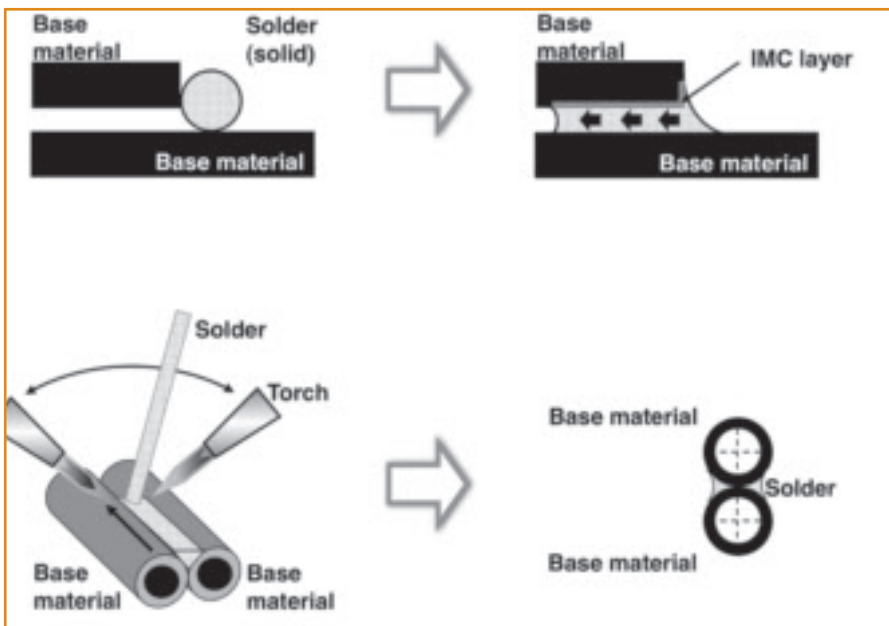


Fig. 2 — Examples of the types of schematic diagrams used in this guideline to illustrate process steps and successful solder joint geometries.

Institute-approved specifications for soldering, beginning with the C3.11 document, *Torch Soldering*, which is currently in the final stages of review by the AWS Technical Activities Committee. The second step was development of a guideline dedicated to providing a basic understanding of the materials and process steps that underlie hand soldering. That document is titled *Guideline for Hand Soldering Practices*. The first draft has been completed and the document is currently in initial layout at AWS. The guideline is ideally suited for operators as well as manufacturing and process engineers. It is also an excellent resource for engineering and product managers.

Here is a summary description of the chapter topics. The first four chapters address the fundamental aspects of soldering, including base materials, filler metals, as well as fluxes and controlled environments. These chapters are not intended to be in-depth treatises on these topics; for that level of detail, the reader is referred to the corresponding chapters in the *AWS Soldering Handbook*, which was published in 2000. Instead, these chapters are intended to provide sufficient information to support the operator and manufacturing engineer in the development of new hand soldering processes as well as the troubleshooting of problematic processes.

The fifth chapter examines process development and is the heart of the text. The chapter is divided into 11 sections. The

sections that address specific hand soldering practices are listed below:

- Soldering with an iron,
- Soldering with a torch (flame),
- Soldering with hot air or a hot inert gas,
- Resistance soldering,
- Induction soldering, and
- Other hand soldering techniques.

Each section begins with a brief introduction. Next, the specific equipment is described that is used in the process. Then, the steps are listed for the general soldering process, including the placement of flux and the heat source on the base materials. In several sections, the soldering procedure details are further broken down into applications that are best suited for preforms, solder paste, or wire as the method to supply filler metal to the joint. In other chapters, the distinction is also made between soldering procedures for lap joints vs. those for butt joints.

There are sections within this chapter that address preassembly cleaning and fixtures, as well as postassembly cleaning. There is also a section that examines rework and repair of solder joints when they are performed by hand soldering.

The sixth chapter provides environ-

mental safety and health information. It has two sections: The first looks at the hazards of hand soldering while the second section examines regulations and guidelines. The objective of the latter section was not to provide an up-to-date list of relevant federal, state, and local regulations. Such a goal would be untenable, given their quantity as well as the rapid pace with which such regulations are changing at the present time. Rather, this chapter provides basic safety and environmental information for the operator and manufacturing engineer to consider when executing a hand soldering process. The user of the guideline is encouraged to obtain further details for their particular need or application.

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 surface artifacts. Therefore, photographs are used sparingly. Rather, greater use is made of schematic illustrations to demonstrate solder flow and fillet geometries — Fig. 2.

The C3 Committee members are enthusiastic about this new guideline. The document creates a technical framework from which to develop, and then properly execute, a hand soldering process that is appropriate for the choice of base materials, filler metal, and heat source for an application. ♦

Acknowledgment

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Microstructure and Electrochemical Properties of the Stainless Steel Bonding Zone Joined with a Fe-Based Amorphous Foil

The effect of temperature and holding time on the microstructure and corrosion resistance of the junction zone of AISI 316L stainless steel (SS) bonded to itself with Fe₇₅Cr₈P₁₀B₇ filler alloy was investigated at the Instituto de Investigaciones Metalurgicas, Mexico (Ref. 1). The brazing alloy was prepared in the form of amorphous ribbons, and its melting temperature was determined by differential thermal analysis to be 1571 K. The joining process was carried out in a chamber with controlled argon atmosphere by self-diffusion bonding at solid state at 1173 K for 20–40 min and by diffusion brazing at 1273 K for different holding times <40 min.

When joined by self diffusion, the change to the noncrystalline structure of the amorphous alloy and the formation of different phases made the dissimilar na-

ture of the alloys more significant and promoted selective dissolution coupled with crevice corrosion.

The joints produced at 1273 K for 40 min exhibited no porosity in the reaction zones and presented the best quality. Scanning electron microscopy (SEM) characterization of the bonding zone revealed an improvement in the quality of the joints brazed at 1173 K for 20 min and longer. These samples had continuous base metal-filler alloy interfaces with minimum porosity. At 1273 K, the bonding interfaces diffused and for the samples held for 40 min completely vanished and porosity disappeared. Even the presence of particle precipitates in the bonding zone showed acceptable resistance to localized corrosion in nonaggressive electrolytes.

The SEM study revealed that irregularly precipitated particles and other phases of about 10 microns in size formed in the interlayer during the joining process. The presence of σ phase in samples bonded at 1273 K promoted preferential dissolution in the bonding zone in NaCl solution.

Imidazole Containing Surface Treating Agent to Improve the Solderability of Printed Circuit Boards with Lead-Free Solders

A surface-treating agent, which significantly improves wetting and spreading of lead-free solders on copper substrate, was invented and tested by Shikoku Chemicals Corp., Kagawa, Japan (Ref. 2). The active component in the surface-treating agent is an imidazole compound such as 2-Benzyl-5-methyl-4-(4-octylphenyl)imidazole or 2-(40Butylbenzyl)-5-hexyl-4-phenylimidazole added in the amount of 0.15–0.20 wt-%.

Also, the surface treating agent contains acetic acid 20–30 wt-%, levulinic acid 10 wt-%, copper acetate 0.05–0.10 wt-%, zinc acetate 0.9–2 wt-%, potassium chloride, or bromide, or iodide 0.05–0.07 wt-%, copper iodide 0.02 wt-%, and optionally formic acid 5 wt-%. All components are dissolved in deionized water, and the pH is adjusted to the value of 2.7 with ammonia water.

A printed circuit (or wiring) board is dipped in the surface-treating agent for



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120–180 s at 40°C, washed with water, and dried. The solderability test was carried out using the standard tin-lead eutectic solder and a lead-free solder Sn-3Ag-0.5Cu at 245°C in air. The solder flow-up rate reached 100% for the Sn-Pb solder and 94–96% for the lead-free solder after the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on copper was improved by 45–50% for the eutectic Sn-Pb solder and by 15% for the lead-free solder.

Transient Liquid Phase Soldering of Copper Using Tin Interlayer

An original transient liquid phase (TLP) soldering process of copper under 2%H/98%N forming gas and slight compression was studied in The University of Nottingham, UK (Ref. 3). A thin interlayer of pure tin foil 25 microns thick was sandwiched between two pieces of 100 microns (0.004 in.) thick copper foil as a base metal, compressed by 122 g loose weight

and reflowed at 260°, 300°, and 340°C for 5–480 min.

Two adjacent layers of Cu_6Sn_5 and Cu_3Sn intermetallics were observed at the interface between Sn and Cu, whereby microstructures showed Cu_6Sn_5 scallops and Cu_3Sn columnar crystal morphologies. There is the pronounced difference in thicknesses of the Cu_6Sn_5 and Cu_3Sn layers formed at the two original boundary planes in the Cu/Sn/Cu samples.

After the residual Sn had been consumed completely, the Cu_3Sn layer grew at the expense of the previously formed Cu_6Sn_5 layer until it disappeared. The final TLP joint consisted of two layers ~2 microns thick of Cu_3Sn columnar crystals that were perpendicular to the original Cu/Sn boundary planes. Diffusion kinetics of the interfacial reactions in the Cu/Sn/Cu system is characterized by activation energy 84.59 ± 25.84 kJ/mol, and the Cu_6Sn_5 and Cu_3Sn growth is derived from a range of Sn interlayer thicknesses. A type of grain boundary/molten channel-controlled growth of Cu_6Sn_5 has a time dependence similar to that for the volume

diffusion-controlled growth.

These results provide new insight into the mechanism and kinetics of the interfacial reaction between liquid tin and solid copper, and other similar metallic liquid/solid systems.

A Wedge Fracture Toughness Test for Brazed Joints

It is well known that standard specimens used for testing fracture toughness of solid materials are not well suited for testing brazed joints because they are difficult to reproducibly precrack by fatigue. Scientists at the University of California, Santa Barbara, Calif., designed and tested a new original, double cantilever beam (DCB) specimen to measure fracture toughness of brazed joints, which allows promotion of crack stability using a simple precracking fixture (Ref. 4).

The specimen (Fig. 1) is loaded with a 30-deg silicon nitride wedge and simply supported. For the brazed joint measurements, the specimen dimensions are as follows: $a = 2.54$ mm, $b = 6.35$ mm, $d = 3.81$ mm, $h = 4.76$ mm, $L = 9.17$ mm, and $t = 1.27$ mm. The design of the DCB specimen is guided by analytical solutions for energy release rate and compliance. Measurements of fracture toughness use both fractographic and compliance methods to ascertain crack length.

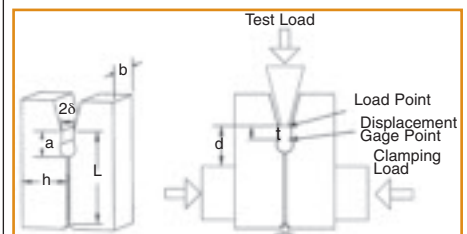


Fig. 1 — The simply supported, double cantilever beam specimen is loaded with a 30-deg silicon nitride wedge.

The approach confirming test was carried out with 304 stainless brazed joints and Nicrobraz® 31 filler metal. The joints had fracture toughness ~ 1 kJ/m² that is significantly greater than that for intermetallic constituents. Approximately half of the toughening was attributed to plastic stretch of the ductile phase within the eutectic. The rest was attributed to dissipation within a plastic zone of the joint, where the crack was attracted to the interface.

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A Solder Glass Frit for Joining Alumina Ceramic

Despite the relatively low strength of joints, glass solders have many advantages for bonding ceramics. These include the following: a) chemical compatibility with a base ceramic material; b) comparable coefficient of thermal expansion; c) good wetting and adherence to ceramics; and d) melting, viscosity, and flowability controlled in a wide range.

Authors from the Singapore Institute of Manufacturing Technology have studied the process of bonding Al_2O_3 ceramic plates using Schott® Solder Glass GO17-393 and measured bonding strength depending on surface treatment, spreading, and voids in the glass (Ref. 5).

Soldering was carried out in a vacuum furnace at 425°–575°C (795°–1067°F) for 5–25 min under pressure 5 kg. Surface treatment with phosphoric acid provided the best conditions of wetting ceramic resulting in a contact angle of 10 deg compared to 22 deg of the alumina ceramic as received and 17 deg of ceramic treated with sulfuric acid.

However, it was found that surface treatment is not necessarily positive in promoting bonding strength. In opposite to metal solders, the capillary effect does not work effectively during ceramic bonding by glass solders because the bonding strength is not governed by wetting the contact angle. Ceramic joints in “as-received” conditions exhibited significantly higher strength, while ceramic joints treated for the lowest contact angle had the lowest tensile strength.

Testing results showed that bonding strength of joints is mainly governed by the soldering temperature and time, and surface roughness of ceramic. The lower bonding temperature of 425°C provides the highest tensile strength of joints, while rising the temperature to 575°C decreased strength for about 40%. Besides, samples bonded above 500°C displayed porous joints.

Au-Sn-In Solder for Processing Compatibility with Lead-Free, Tin-Based Solders

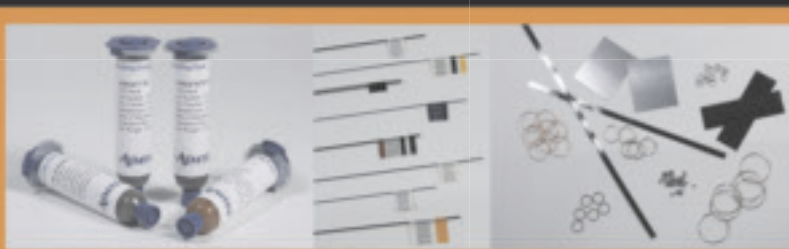
Currently, semiconductor devices are sealed using gold-tin solder with the gold content ranging 78–81 wt-% and tin content 19–21 wt-%. This Au-Sn eutectic solder has been in use for more than 40 years, and has a melting temperature of 280°C (536°F), which is compatible with all traditional Sn-Pb solders that have soldering

and post-sealing temperatures below 245°C. Lead-free, Sn-Ag-Cu solders that came to the industry in the last decade have a melting temperature at 217°C and require processing at 270°C that is dangerously close to the 280°C melting point of the Au-Sn alloy used for sealing electronic devices.

A new Au-Sn-In solder invented by Williams Advanced Materials, Inc., Buffalo, N.Y., has a melting temperature of 300°–320°C (572°–608°F) that makes it compatible with a semiconductor die attach and hermetic sealing of electronic packages after soldering using contemporary lead-free solders (Ref. 6).

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The solder contains 17.5–20.5 wt-% of tin, 2–6 wt-% of indium, and gold in the balance; the exemplary solder contains Sn 19.3 wt-% and In 4.5 wt-%. Advantageously, the new solder permits post sealing operations at temperatures greater than 270°C (518°F) without reflowing and subsequent loss of seal integrity.

Modified Water Drop Method of Evaluating Soldering Fluxes for Electrochemical Migration Propensity

Electrochemical migration (ECM) is a unique corrosion-related reliability concern in consumer electronic products because it results from a combination of such factors as applied electric potential, humidity, and ionic contaminants. The traditional temperature-humidity-bias (THB) test is long (from 30 to 300 days) and requires a large number of samples for statistical evaluation that increase the cost of testing. The alternative water drop (WD) method is quicker by a factor of 100 at a fraction of the cost.

However, reproducibility is a problem with the WD method.

A modified WD method for soldering flux evaluation was developed and tested by Nokia, Irving, Tex. (Ref. 7). Though the scatter in data was significant, this WD test method can be used to identify fluxes that performed significantly better than others. The following four principles were selected to provide comparing the relative propensity of ECM depending on the flux type during soldering of printed wire boards: (a) Select different finishes such as Cu, Ag, and Sn. It was expected that more than one metal may participate in the ECM dendrite formation; (b) select a voltage gradient that is representative of actual portable consumer electronics, esp. 7.5 V/mm; (c) select different fluxes used in lead-free soldering; and (d) perform WD tests using deionized water to rank alternatives based on propensity for ECM related failure.

Results indicated that a clear ranking was established among four soldering fluxes. In addition, among the different metals, the silver finishing was found to

have the highest ECM propensity across all fluxes.

High-Velocity Cold Spraying Powders for Cleaning Surface and Applying Brazing Filler Metals onto a Substrate

General Electric Co., Schenectady, N.Y., developed a cost-effective method for applying brazing filler metals onto superalloy parts of gas turbine engines (Ref. 8). Cold gas dynamic spraying (or kinetic metallization) is a process that uses fine metal powders that are accelerated by a gas stream and impacted against a surface to form a coating. The metal particles collide with the surface, resulting in plastic deformation and bonding of these particles to the substrate and other particles. There is no melting of the particles.

The braze filler metal powder that first impacts the substrate acts as a blasting media and cleans the surface to be brazed by removing a thin layer of surface material. The layer removed is more than zero and less than 1 micron, but it is sufficient to substantially remove any surface oxides.

After the braze filler powder removes the oxide layer, the powder begins to adhere and bond to the surface.

For example, a braze alloy layer was formed using Ni-7Cr-3Fe-3B-4.1Si powder at an argon spray temperature of about 315°C (600°F). The formed layer was about (80 microns) 0.003 in. thick. The formed layer had no oxides between the braze alloy layer and the superalloy substrate, which was then successfully brazed in a vacuum furnace.

Vacuum Brazing of Carbon-Fiber Composites with Aluminum Filler Metals

Brazing of carbon-fiber composites at a low temperature can be done using aluminum filler metals. This process was tested, and the strength of brazed joints was measured in Shandong University, Jinan, China (Ref. 9). Pure aluminum and Alloy Al-5Ti-1B (wt-%) were applied as brazing filler metals. Vacuum brazing of C_f/C composite with aluminum was carried out at 700°C (1292°F) and 730°C (1346°F), while brazing with the Al-5Ti-1B filler metal occurred at 720°C (1328°F) and 750°C (1382°F) for 20–30 min. Flat parts to be joined were compressed at 0.375 MPa (0.054 ksi) during heating and cooling.

Aluminum filler metals exhibited sat-

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isfactory wetting of the base material at a temperature above 700°C, but also poor flowability. However, diffusion of liquid filler metals into porous carbon composite under pressure resulted in the formation of solid, dense joint metal characterized by shear strength 9.1–9.4 MPa (1.3 ksi) for Al filler metal, and 10.6 MPa (1.5 ksi) for Al-5Ti-1B filler metal.

Increasing the brazing temperature not only improves the fluidity of brazing alloys, but it also prevents coarsening grains in the joint microstructure and improves the quality of brazed joints. Slightly lower strength of aluminum brazed joints can be explained by a bigger thickness of the joint zone, about 200 microns, while joints brazed with the Al-5Ti-1B alloy had a thickness of only 60 microns. Boron proved to be a grain refiner that also resulted in better quality of the joint metal. ♦

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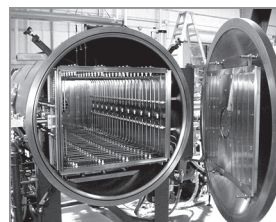
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