SOLDERING HANDBOOK

3rd Edition

American Welding Society

Soldering Handbook

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by

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1. Fundamentals of Soldering Technology

1.1 Introduction

Joining processes, which attach two or more substrates or base materials together, be they metals, ceramics, or plastics, can be considered as coming under one of two generalized methodologies: *filler material joining,* or *fusion joining.*

Filler material joining refers to the use of a third material to form a bond between the two base materials, and includes the processes of *soldering*, *brazing*, and *adhesive bonding*. The filler material must adhere to both base materials in order to effect an adequate bond. Although the bonding mechanism in such cases may cause chemical changes at the substrate material surfaces in order to promote adhesion, *at no time does the temperature of the substrates exceed their respective melting points*.

When the melting temperature of the substrate material is exceeded, the bond is formed by a *fusion joining* process, e.g., welding. In welding, the two substrates are joined by the intermixing of their mutually molten segments. A third material, also referred to as a filler material, may be simultaneously melted and added to the molten base materials.

Because metals have been an integral part of engineered structures since the dawn of civilization, filler material joining processes have a long history of use with these base materials. However, filler metal joining methodologies have also been applied to the other materials subsets, including ceramics and plastics.

Soldering and brazing are high-temperature filler *metal* processes that are used in many engineering applications. The difference between soldering and brazing is defined by the melting temperature of the filler metal. A filler metal which has a liquidus temperature below 450°C/842°F is referred to as a *solder material*, or simply a "solder"; a filler metal with a liquidus temperature exceeding 450°C/842°F is a *brazing filler metal*. Although the distinction between the two processes is determined solely by a melting property of the filler metals, the different temperature ranges have numerous attributes as well as drawbacks for the manufacturing processes that use either methodology. Some timely comparisons will be made throughout the text.

Lastly, it should be noted that the joining of two metals can also be realized by the use of adhesive materials, or "glues." Generally, issues that need to be resolved with the use of adhesives are:

(1) bulk strength levels to accommodate design loads;

(2) adhesion strength; and

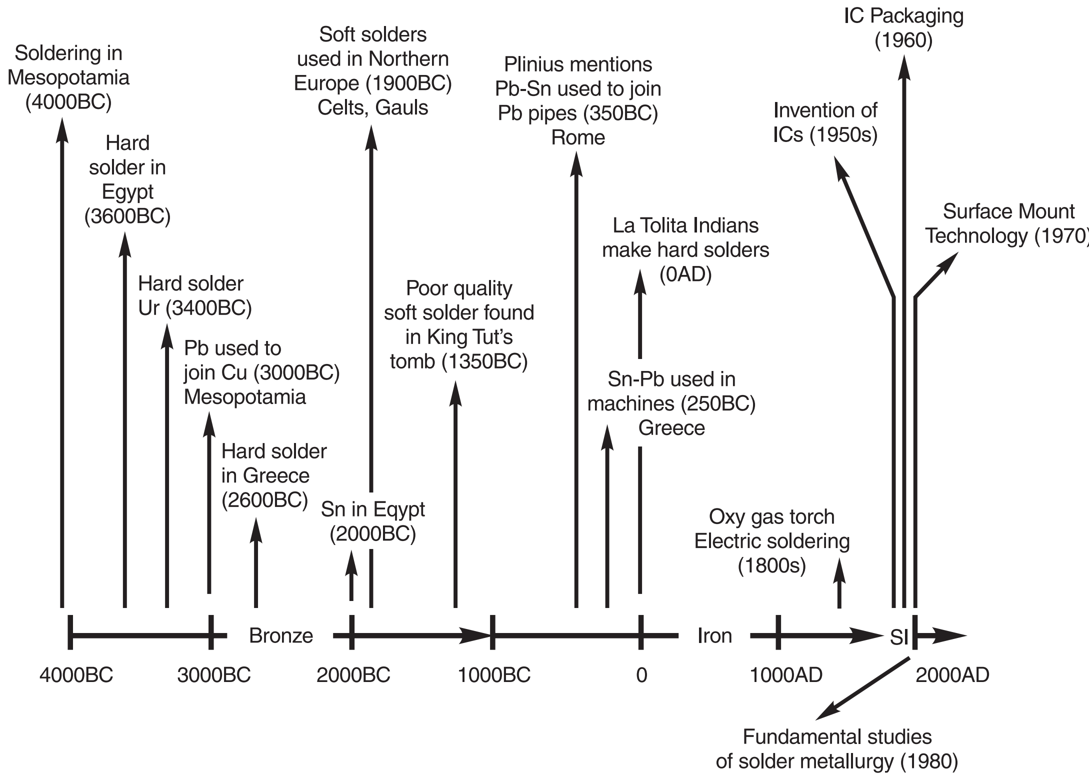
(3) property stability (aging) over the service lifetime of the joint.

Although adhesives will certainly not replace the filler metal joining methodologies of brazing and soldering, they are finding many niche applications.

Soldering is a relatively old technology. Shown in Figure 1.1 is a time line which illustrates the 6000-year history of soldering [1][1]. Written details of the earliest uses of soldering are rare, since the art was generally practiced by slaves and considered unimportant to historians who, generally, belonged to society's upper class. Archeological evidence of soldering from the earliest periods (4000 to 2000 BCE) is limited to artifacts, primarily jewelry and adornments, constructed with gold (Au)-based solders, since these materials were very resistant to corrosive deterioration. Artifacts having tin (Sn) based solders, the foundation of today's soldering technology, are less prevalent, since Sn and Sn-based alloys more readily succumbed to corrosion by rainwater and naturally occurring chemicals in the ground.

The earliest practices with nonprecious metal solders were evidenced through the use of pure lead (Pb) by the

1. The numbers in brackets correspond to those in the references in Annex E.



(Reprinted by permission, The Metallurgical Society, TMS. Journal of Metals, *Vol. 45, No. 7, "Issues in the Replacement of Lead-Bearing Solders," P. Vianco and D. Frear, p. 14, Fig. 1.)*

Figure 1.1—Historical time line of soldering technology.

Mesopotamians in c. 3000 BCE to join copper (Cu) pieces. Pure Pb has a melting temperature of 327°C/621°F. Tin was not readily available to the Mediterranean cultures at that time. Tin and Sn-Pb solders were developed by the Celtic and Gaul cultures of Northern Europe in c. 1900 BCE, owing to the rich Sn ore deposits of that region. At that time, Sn-Pb solders were used to assemble tools and cooking utensils that were made largely of Cu and Cu-based alloys. The Romans used Sn-Pb solders to seal the Pb liners of their aqueducts.

As with the rest of Western Civilization during the Middle Ages, soldering experienced little progress, being limited to the making of jewelry and common household implements. However, the Industrial Revolution quickly expanded the use of soldering technology, particularly with the availability of portable heat sources, i.e., compressed gas for torches and electricity for the resistive heaters in soldering irons. Plumbing, including conduit and radiators, food and water containers, as well as light-duty tools and sheet-metal construction for automobile fenders and panels were some of the many uses to which soldering was applied. However, it was the advent of electronics in the early 20th century, and its continuing evolution to the present day, which has quickly become the hallmark application of soldering technology.

Today, soldering technology can be categorized into two general fields based upon application:

(1) *electronics soldering,* which describes the assembly of silicon microchip devices, printed circuit boards, motherboards, and connectors for the purpose of electrical signal transmission; and

(2) *structural soldering,* which pertains to the role that is primarily that of mechanical fastening, i.e., non-electronic applications.

Clearly, many of the advances in soldering technology over the past half-century, both in the development of materials as well as new processes, have taken place in the electronics arena. However, these new materials and processes as well as an enhanced understanding of electronic solder joint properties can be applied equally to structural soldering applications. Failure to incorporate this increased understanding of solder joint behavior into larger scale, structural applications will only result in higher-than-necessary manufacturing costs, and an increased likelihood of poor product reliability. Irrespective of the source of innovation, all of soldering