

Principles of Soldering

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ASM International
The Materials Information Society

Materials Park, Ohio 44073-0002
www.asminternational.org

First printing, April 2004

Prepared under the direction of the ASM International Technical Book Committee (2003–2004), Charles A. Parker, Chair.

ASM International staff who worked on this project include Charles Moosbrugger, Acquisitions Editor; Bonnie Sanders, Manager of Production; Kathy Dragolich and Nancy Hrivnak, Production Editors; Kathryn Muldoon, Production Assistant; and Scott Henry, Assistant Director of Reference Publications.

Library of Congress Cataloging-in-Publication Data
Humpston, Giles.
Principles of soldering / Giles Humpston, David M. Jacobson.
p. cm.
Includes bibliographical references and index.
ISBN 0-87170-792-6
1. Solder and soldering. 2. Brazing. I. Jacobson, David M. II. Title.

TS610.H84 2004
671.5'6—dc22 2003058379
SAN: 204-7586

ASM International®
Materials Park, OH 44073-0002
www.asminternational.org

Printed in the United States of America

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Preface

Since the first edition of *Principles of Soldering and Brazing*, published in 1993, the authors have received valuable feedback from readers representing a wide range of technical interests. This has prompted the decision to expand the text and organize it into two companion books, one covering soldering and the other brazing. This first book primarily aims at providing information about soldering in a form that is hopefully readily accessible and as easy to assimilate as possible. Priority is given to the fundamental principles that underlie this field of technology rather than recipes for making joints. The largely artificial distinctions between soldering and brazing are preserved because, despite their many commonalities, it has been found that practicing engineers are either concerned with soldering or brazing and seldom are involved with both simultaneously. The planned companion book, *Principles of Brazing,* addresses this complementary need. A large proportion of the literature on soldering and brazing may be charged with being heavy on description and light on critical analysis. We have endeavored to redress the balance, while striving to avoid being unduly simplistic or overly mathematical in our approach. Admittedly we may not always have succeeded in this aim.

As in *Principles of Soldering and Brazing*, we have striven to maintain the focus on the fundamental aspects of soldering and have deliberately avoided entering into specific joining technologies in detail. At the same time, we recognize that the range and extent of the knowledge base of metal joining is not immediately obvious, and it requires a fairly deep understanding of materials. To cite a single example, nichrome (an alloy of nickel and chromium), which is a perfectly satisfactory and widely used metallization for soldering, is rendered useless if the solder contains bismuth. If there is an evident bias towards electronic and photonics applications, this reflects the recent professional orientation of the authors. Some topics are inevitably not accorded due consideration, although it is hoped that sufficient references are provided to enable the reader to pursue these further.

No attempt has been made to gather a comprehensive list of published papers. Those that are included have been selected because they are useful basic texts, cover important subject matter, or relate to exemplary pieces of work, whether in respect of methodology, technique, or other noteworthy features. It was felt that if the value of the book depended on its bibliography, it would rapidly become dated. The advent of computer search facilities and databases of scientific journal and conference abstracts should enable the reader who wishes to find references on a specific topic to obtain further information without too much difficulty. The search term "lead-free solder" will yield an astounding 25,000+ publications in the public domain, virtually none of which are more than 10 years old.

The reader should note that all compositions given in this book are expressed in weight percentage in accordance with the standard industrial practice. These have, for the most part, been rounded to the nearest integer. The ratio of elements in intermetallic compounds, again by convention, refers to the *atomic weight* of the respective constituents. The general convention used for specifying alloy compositions is that adopted by the alloy phase diagram community, namely in the alphabetical order of the elements, by chemical symbol. We have not been entirely rigorous in this regard as it is sometimes helpful to group alloys by the dominant constituents. Minor additions to bulk compositions are given in order of concentration; for example, Pb-62Sn-0.5Lu-0.02Ce.

Specific references are given with each chapter. For those wishing to read more generally on particular topics, the authors would recommend the texts listed as Selected References at the end of this preface.

Many phase diagrams are subject to ongoing research, resulting in continued improvement in the accuracy and detail of the information. The most recent version of a diagram may be identified by consulting the latest cumulative index of phase diagrams, published in the Cumulative Index of the periodical *Journal of Phase Equilibria* (ASM International). This will refer to the source of the thermodynamically assessed diagram of interest. The reader is advised that the four compendia of binary phase diagrams published in the 1960s, '70s and '80s (colloquially referred to as Hansen, Elliott, and Shunk) are now known to contain many errors and omissions.

Information on new developments in soldering and brazing is scattered throughout a wide range of periodicals, as reflected in the sources cited in the references appended to the individual chapters. To keep abreast of the literature, the authors have found especially useful the following abstract publications: *Metals Abstracts* and *Science Abstracts*. Technical libraries can provide automated searches against specified key words as a monthly service.

We wish to thank our many colleagues and ex-colleagues for their helpful advice and encouragement, particularly James Vincent, for insights into lead free soldering.

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David M. Jacobson

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About the Authors

Giles Humpston took a first degree in metallurgy at Brunel University in 1982, followed by a Ph.D. on the constitution of solder alloys in 1985. He has since been employed by several leading industrial companies, where he has been involved with determining alloy phase diagrams and developing processes and procedures for producing precise and high-integrity soldered, brazed, and diffusion-bonded joints to a wide variety of metallic and nonmetallic materials. His expertise extends to fine-pitch flip-chip, new materials development, and packaging and interconnection for electronics, radio frequency, and optical products. He is the cited inventor on more than 75 patents, the author of more than 60 papers, and recipient of six international awards for his work on soldering and brazing.

Dr. Humpston is a licensed amateur radio enthusiast and has published several articles and reviews on electronics, radio, and computing. His other interests include exploring vertical-axis wind turbines, building power inverters, flying radio controlled gliders, wine making, and growing bonsai. He lives with his wife, Jacqueline, and their three children in a small village in Buckinghamshire, England and San José (Silicon Valley), California.

David M. Jacobson graduated in physics from the University of Sussex in 1967 and obtained his doctorate in materials science there in 1972. Between 1972 and 1975 he lectured in materials engineering at the Ben Gurion University, Beer-Sheva, Israel, returning as Visiting Senior Lecturer in 1979-1980. Having gained experience in brazing development with Johnson Matthey Ltd., he extended his range of expertise to soldering at the Hirst Research Centre, GEC-Marconi Ltd., which he joined in 1980. Currently, he holds the position of senior research associate at the Centre for Rapid Design and Manufacture, Buckinghamshire Chilterns University College in High Wycombe. He is the author of more than 80 scientific and technical publications in materials science and technology and more than a dozen patents. He has been awarded three prestigious awards for his work on brazing.

Dr. Jacobson's principal outside interests are archaeology and architectural history, focusing on the Near East in the Graeco-Roman period. He has published extensively in these fields on subjects that extend to the numismatics and early metallurgy of that region. He recently completed a Ph.D. thesis on Herodian architecture at King's College, London, and teaches part-time in this subject area at University College, London. Dr. Jacobson is married with two grown-up children and lives in Wembley, England, close to the internationally famous football stadium.

Giles Humpston and David Jacobson are the coauthors of the book *Principles of Soldering and Brazing,* which was published by ASM International in 1993, with more than 4000 copies sold.

History

Origins of Solders and Soldering

The word *solder* derives from the Old French, *soudure*, which in turn stems from the Latin s*olidare*, which means to fasten together. Its earliest use in a completely English context as a noun meaning "a fusible metallic alloy used for uniting less fusible metal surfaces or parts" dates to about 1350. It is interesting to note that in 19th century English, just as in modern French, the "l" would have been omitted and the word pronounced "sod-der," a form that still persists in the United States of America today.

Although the origin of solders and soldering is lost to antiquity, it is possible to speculate on how the invention arose. Lead was first obtained as a by-product of silver production. Silver extraction from ores involved cupellation of lead, and the base metal was then recovered from the litharge [Tylecote 1976]. The softness and malleability of lead were clearly recognized, and there exist examples of lead being used as a setting agent to fix posts in the ground and lock morticed stones. It was observed that in this instance the lead filler could give a stronger joint than a simple friction grip. Lead was used by the Mesopotamians (3000 B.C.) to join pieces of copper together, although perhaps more by luck than design since pure lead does not wet copper at all readily. The Romans are known to have produced lead separately from silver, taking advantage of the fact that this metal can be easily extracted from its sulfide ore, galena, simply by roasting the mineral in air [Tylecote 1976].

The earliest examples of tin are Egyptian and date from 2000 B.C. What might be construed as a manufactured solder alloy has been found in King Tutankhamun's tomb (1350 B.C.), although there is some debate among scholars about the deliberateness of the metallurgy of this joint.

Solders comprising alloys of lead and tin were almost certainly used during the Iron Age [Tylecote 1962]. By the Roman Imperial period there is evidence, both from literary sources and from surviving artifacts, that lead-tin solders were in regular use. Pliny the Elder (1st century A.D.) speaks of *tertiarum*, an alloy of two parts of (black) lead and one part of white lead (tin) being used for joining metal pipes [Pliny, *Natural History* xxxiv 161 (Rackham 1952)]. Pliny also remarks that the price of this alloy is 20 denarii per pound. With 25 denarii (silver pieces weighing approximately 4 gm, or 0.14 oz, each) to 1 gold aureaus of close to 8 gm (0.28 oz), the price of Roman solder works out at $70 per kilogram, assuming that gold has maintained its purchasing power since Pliny's day. The current price for the same alloy (Pb-33Sn) is lower by an order of magnitude, which indicates how much more precious solder was in antiquity.

An analysis of soldered joints in Roman artifacts has shown that both tin-rich and lead-rich alloys were used. The solder in a force-pump from Roman Silchester contains lead to tin in a weight ratio of close to 3 to 1, which is similar to the composition of plumbers' solder [Tylecote 1962]. Elsewhere, solders containing mainly tin (80 to 100% Sn), have been encountered in finds from 4th and 5th century sites in Britain [Lang and Hughes 1991].

Soldering, unlike many Roman crafts, either did not die out during the Dark Ages or enjoyed an early revival. The soldering iron, not mentioned at all in Classical times, was well known and in widespread use by the early Middle Ages. Soldering was used for joining the lead strips in stained glass windows, with the oldest complete examples being the Five Prophets windows in Augsburg Cathedral that date from the late 11th century. From 1700 onwards it is clear that soldering was well established with the appearance of "tinsmiths" and "white-iron men" as trades. Newcomen's discovery of the effectiveness of the internally condensing steam engine in 1708 is attributed to the faulty repair, by soldering, of a blowhole in the cast bronze cylinder. This permitted a spray of external condenser water into the cylinder and the development of the internal condenser; a design that was not superseded until Watt developed the separate condenser nearly 70 years later.

Modern soldering practice dates to the early 20th century when improved extraction techniques, which enabled exotic metals to be available at affordable cost, coupled with the appearance of alloy phase diagrams, gave rise to the diversity of alloys now available.

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