

钎焊手册

Manual of Brazing and soldering

张启运 庄鸿寿 主编

Editors-in Chief ZHANG Qiyun and ZHUANG Hongshou

机械工业出版社

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本手册是一本应用理论和实际工作经验总结并重的工具书。全书按被钎焊的母材为主线进行叙述：对铝、铜、钢、不锈钢、高温耐热合金、难熔金属、钛、锆、铍、镁、硬质合金、碳、金刚石、半导体、陶瓷、贵金属、复合材料、特种材料的钎焊，包括部分材料的软钎焊都给了详尽的描述和进行资料的收集。本书每一章的作者都是在该领域中有多年工作经验和科研成果的专家和技术人员。本书的内容有较大的深度和广度。

本手册还加强应用理论的阐述，特别是第1章绪论中首次将界面传质理论通俗地引入钎焊领域并用以阐明和控制钎焊过程，有较新的意义。

本手册适用于机械、电子、家电等部门从事金属材料精密连接技术工作的科研、生产技术人员，并可供相关专业大专院校师生参考。

This manual is a reference book for brazing and soldering which are thoroughly discussed both in theory and practice. Treatment of the subject follows after the materials to be brazed or soldered instead of method and technique. Alloy brazing and soldering of aluminum, copper, steel, stainless steel, high melting metal, refractory metal, titanium, zirconium, beryllium, magnesium, carbon, diamond, hard-metal, semiconductor, ceramic, precious metal, composite metal and so on are described in detail. At the same time, the related materials together with the information are comprehensively collected.

The authors are all experts or engineers with broad knowledge and specialized experience in the various fields of brazing and soldering. The contents of this manual have a remarkable depth and breadth.

In the Chapter 1, the theory of interfacial mass-transfer is introduced into this field for the first time. It is helpful towards contribution to explanation and control of brazing and soldering process.

The manual is a suitable reference for producers and engineers who are engaged in the corresponding manufacture and investigation and also teachers and students interested in brazing and soldering.

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前 言 Preface

钎焊是当今高技术中一项精密的连接技术，在航天、航空、汽车、化工、机械、电子和家电等军用、民用工业中得到广泛的应用。我国目前正处于钎焊技术迅速发展的阶段，在高校、研究单位和工厂中从事科研和应用的工作者以十万计。

世界发达国家如美国、日本、前苏联等都有自己的《钎焊手册》出版，其中美国焊接学会钎焊委员会编的《钎焊手册》和《软钎焊手册》在我国已有中译本。我国多年来尚未有比较完善充实、专门的钎焊手册出版。在国外出版的手册中虽各有特色但多有不尽人意之处，例如有的只偏重于综述，具体的钎焊内容只一带而过；有的又过于偏重设备和装置的叙述而较少重视钎焊过程的各个环节和重要数据、资料的交代。鉴于这种情况，在机械工业出版社的倡导下，邀请了国内多位在高校、研究单位和工厂工作多年的、有钎焊实践经验的学者和专家来共同编写了这本具有中国特色的《钎焊手册》，它资料丰富、内容翔实、原理实际并重而且能充分反映我国钎焊的水平并力争能跟上世界前进的步伐。

本书特点是便于读者获得钎焊有关的资料、信息和知识；它具有一定的起点而又不是一本多篇论文的专著；本手册条目分明，易于查找，每一部分又以一定深度（包括原理、材料和工艺）进行叙述，既适用于不同水平的工作者解决生产问题又适用于有关单位进一步开展研究工作的需要。书中以被钎焊的母材为主线展开各个章节的叙述，而不用那种以方法和材料为主线的横向写作方式。我们认为所采取的这种方式既有利于读者的查找，又有利于作者充分展开自己的专长和经验介绍。当然这种写作方式难免会出现一些重复，我们已尽力进行了协调。

本书还努力评述、汇集了世界钎焊科技近 20 年来的最新成就并引入文献，以备那些想进一步深入研究的读者得以索引。

本书还有一个特点是对标题和图表均注入了英译文，我们衷心希望这本书能走向世界。此外，在华人世界里不乏广大的专家同行，但由于多年的隔离，名词术语多不统一，我们也希望英译文能使大家取得更多的沟通。

经过各位作者一年多的共同努力，这本手册终于和读者见面了，反观起来，和我们原先的设想还有相当的距离，也还有不少欠妥之处，希望对本书感兴趣的读者不吝指教，使这本手册能够更臻于完善。

编 者

1998 年 10 月

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第 1 章 绪 论

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Chapter 1 Introduction

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1.1 钎焊方法的原则和特点 Principle and characteristic of brazing and soldering technique

钎焊和熔焊方法不同，常规钎焊是采用（或过程中自动生成）比母材熔化温度低的钎料，操作温度采取低于母材固相线而高于钎料液相线的一种焊接技术。钎焊时钎料熔化为液态而母材保持为固态，液态钎料在母材的间隙中或表面上润湿、毛细流动、填充、铺展、与母材相互作用（溶解，扩散或产生金属间化合物）、冷却凝固形成牢固的接头，从而将母材联结在一起。例如钎焊纯铝（熔点 660℃）采用 Al-Si 共晶钎料（熔化温度 577℃），操作温度取 590~630℃，钎缝中产生溶解与扩散反应。

钎焊时工件常整体加热（如炉中钎焊）或钎缝周围大面积均匀加热，因此工件的相对变形量以及钎焊接头的残余应力都比熔焊小得多，易于保证工件的精密尺寸。

钎料的选择范围较宽，为了防止母材组织和特性的改变，可以选用液相线温度相应低的钎料进行钎焊，熔焊则没有这种选择的余地。

只要钎料、钎剂和钎焊方法选择得当，可使接头做到无需加工而能“天衣无缝”，这是熔焊一般难以到的。此外，只要适当改变钎焊条件，还有利于多条钎缝或大批量的工件的同时或连续钎焊。

由于钎焊反应只在母材数微米至数十微米以下界面进行，一般不牵涉母材深层的结构，因此特别有利于异种金属之间，甚至金属与非金属，非金属与非金属之间的连接，这也是熔焊方法做不到的。

钎焊还有一个优点，即钎缝可作热扩散处理而加强钎缝的强度。当钎料的组元与母材存在一定的固溶度时，延长保温时间可使钎缝的某些组元向母材深层扩散，最终使钎缝在显微镜下“消失”。

钎焊方法的弱点主要在钎料与母材的成分和性质多数情况下不可能非常接近，有时相去甚远，例如用重金属钎料钎焊铝，这就难免不产生接头与母材间不同程度的电化学腐蚀。此外，钎料的选择和界面反应的特点都存在一定的局限，在钎焊大多数材料时，钎接头与母材不能达到等强度，只能用增加搭接面积来解决问题。

钎焊一词俄文称 пайка，英文中则没有对应的词，只有 Brazing（硬钎焊）和 Soldering（软钎焊），中国台湾则称“硬钲”和“软钲”。根据国家标准将使用钎料液相线温度 450℃ 以上的钎焊称作硬钎焊，在 450℃ 以下的称为软钎焊。有些文献报告中习惯上不规范地更加细分，分成高温、中温、低温钎焊。例如铝的钎焊将 500~630℃ 范围内称为高温铝钎焊。300~500℃ 称中温铝钎焊，而低于 300℃ 的称低温铝钎焊。铜及其它金属合金的钎焊有时也