

PRACTICAL | **INDUCTION
HEAT
TREATING**

Second Edition

Richard E. Haimbaugh



ASM
INTERNATIONAL

Materials Park, Ohio 44073-0002

www.asminternational.org

Copyright © 2015
by
ASM International®
All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the written permission of the copyright owner.

First printing, August 2015

Great care is taken in the compilation and production of this book, but it should be made clear that NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE GIVEN IN CONNECTION WITH THIS PUBLICATION. Although this information is believed to be accurate by ASM, ASM cannot guarantee that favorable results will be obtained from the use of this publication alone. This publication is intended for use by persons having technical skill, at their sole discretion and risk. Since the conditions of product or material use are outside of ASM's control, ASM assumes no liability or obligation in connection with any use of this information. No claim of any kind, whether as to products or information in this publication, and whether or not based on negligence, shall be greater in amount than the purchase price of this product or publication in respect of which damages are claimed. THE REMEDY HEREBY PROVIDED SHALL BE THE EXCLUSIVE AND SOLE REMEDY OF BUYER, AND IN NO EVENT SHALL EITHER PARTY BE LIABLE FOR SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES WHETHER OR NOT CAUSED BY OR RESULTING FROM THE NEGLIGENCE OF SUCH PARTY. As with any material, evaluation of the material under end-use conditions prior to specification is essential. Therefore, specific testing under actual conditions is recommended.

Nothing contained in this book shall be construed as a grant of any right of manufacture, sale, use, or reproduction, in connection with any method, process, apparatus, product, composition, or system, whether or not covered by letters patent, copyright, or trademark, and nothing contained in this book shall be construed as a defense against any alleged infringement of letters patent, copyright, or trademark, or as a defense against liability for such infringement.

Comments, criticisms, and suggestions are invited, and should be forwarded to ASM International.

Prepared under the direction of the ASM International Technical Book Committee (2014–2015), Chadwick Korthuis, Chair.

ASM International staff who worked on this project include Scott Henry, Director, Content & Knowledge-Based Solutions; Karen Marken, Senior Managing Editor; Sue Sellers, Content Development and Business Coordinator; Madrid Tramble, Manager of Production; Kate Fornadel, Senior Production Coordinator; Diane Whitelaw, Production Coordinator.

Library of Congress Control Number: 2015941238
ISBN-13: 978-1-62708-089-7
ISBN 10: 1-62708-089-9
SAN: 204-7586

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

Printed in the United States of America

To the memory of my father, Omer, who started my training in induction; for my youngest brother, Dave, who continues to practice commercial induction heat treating; my brother, Kurt, who has always been a leader; and my wife, Carol, who supports me and checks when my office is too quiet.

About the Author

Dick Haimbaugh's first practical experience with induction heat treating occurred in 1946 when he was eleven years old. With the purchase of two war surplus General Electric radio frequency induction heaters, his father had started a commercial heat treating company to specialize in induction heat treating. After pestering his father for work, Dick was shown how to load hub caps into a coil, push the "on" button, and then remove the hub caps from the coil when they had been induction heat treated. He took about 2 hours to induction anneal 250 hub caps.



He worked for his father through high school and college. In his senior year in college where he was majoring in metallurgical engineering, and while working as a lab assistant for graduate students, Dick asked his father for help with the coil design for a spark gap unit. The coil pulled so much power that the cables to the power supply started smoking.

Following graduation from the University of Illinois, Dick worked for a short time for Allison Division of General Motors. Then during his Army service, he worked as a mechanical engineer in the Army Rocket Guided Missile section at Redstone Arsenal. Upon leaving the Army, Dick returned to work for his father while also attending the University of Chicago where he earned an MBA degree. Since that time, he has been involved in all aspects of commercial induction heat treating, with active participation as a lifetime member of ASM International, chairing and participating in various ASM committees, working with Handbook Committees, as well as contributing to several of the MEI courses.

Over the years, Dick has trained the personnel at Induction Heat Treating Corp. in the knowledge needed for commercial heat treating production, and he has consulted for various companies including General Elec-

tric and the Center for Metals Fabrication. He has participated as an induction heat treating expert in two Heat Treating Conferences sponsored by ASM International and plans to remain active in the industry.

Dick retired in 2005 and lives in Florida with a great life of social activities, golf, tennis and just plain fun. He teaches ASM's *Practical Induction Heat Treating Course* at ASM's Metals Park, and he loves to help anyone having questions or problems involving induction heat treating.

Preface to the Second Edition

Throughout the years, many books and articles have been written about induction heat treating. In the author's opinion, *Induction Heat Treatment of Steel*, Lee Semiatin and Dave Stutz, 1986, was an excellent early source for induction heating and metallurgical theory. The First Edition of this book was published in 2001. Since then knowledge of the science and practice of induction heat treating has continued to grow. ASM Handbook Volume 4C, *Induction Heating and Heat Treatment*, was published in 2014 and is considered by the author to be the most complete and detailed handbook on induction heating and heat treatment published to date. Much of the material contained in this Second Edition was taken from this Handbook.

The author's company has the experience of processing more than 20,000 orders a year in commercial induction heat treating. This book is written to complete the tie-in of the metallurgy, theory, and practice of induction heat treating from a hands-on explanation of what floor people need to know. Explanations contain language and terms that need to be understood. Operating information and a progression from process analysis to standards and quality control are presented.

The early chapters, 1 through 7, provide explanations of theory to the detail that the author feels is needed in order to understand induction and the metallurgy of induction. Chapters 8 to 10 deal with production aspects of induction. Chapter 11 reviews and presents a process for analysis of applications, including selection of frequency, power requirements, and the selection of different types of fixturing to meet production requirements. Chapter 12 discusses standards and inspection for induction, while Chapter 13 deals with identification and resolution of problems found with induction hardened parts. The final chapters discuss quality control and maintenance.

The appendixes are meant to help more with design information and include some charts and data to help with production including tempering curves and hardenability curves. References are given for texts and authors to help those who desire a more detailed understanding of the theoretical aspects.

The author appreciates the help and material given by Bill Stueht, Robert Fuffini, George Welch, and Fred Specht.

Preface to the First Edition

Throughout the years, many books and articles have been written about induction heat treating. In the author's opinion, *Induction Heat Treatment of Steel*, Lee Semiatin and Dave Stutz, 1986, provides the best combination of induction heating and metallurgical theory to date.

There are many practical aspects that the books to date do not cover. The author's company has the experience of processing more than 20,000 orders a year in commercial induction heat treating. This book is written to complete the tie-in of the metallurgy, theory, and practice of induction heat treating from a hands-on explanation of what floor people need to know. Explanations contain language and terms that need to be understood. Operating information and a progression from process analysis to standards and quality control are presented.

The early chapters, 1 through 7, provide explanations of theory to the detail that the author feels is needed in order to understand induction and the metallurgy of induction. Chapters 8 to 10 deal with production aspects of induction. Chapter 11 reviews and presents a process for analysis of applications, including selection of frequency, power requirements, and the selection of different types of fixturing to meet production requirements. Chapter 12 discusses standards and inspection for induction, while Chapter 13 deals with identification and resolution of problems found with induction hardened parts. The final chapters discuss quality control and maintenance.

The appendixes are meant to help more with design information and include some charts and data to help with production including tempering curves and hardenability curves. References are given for texts and authors to help those who desire a more detailed understanding of the theoretical aspects.

The author appreciates the help and material given by Bill Stuehr of Induction Tooling and the material furnished by Robert Ruffini of Fluxtrol and George Welch of Ajax Magnathermic.

Contents

CHAPTER 1: History of Metallurgy and Induction Heating	1
History of Metallurgy	1
Induction Heating after World War II	3
Advantages of Induction Heating	6
CHAPTER 2: Theory of Heating by Induction	9
Resistance	9
Alternating Current and Electromagnetism	10
Hysteresis	11
Skin Effect and Reference Depth	12
Power Density	18
Conduction of Heat	21
CHAPTER 3: Induction Heat Treating Systems	25
Types of Power Supplies	26
Line Utility Requirements	33
Cooling Water Requirements	33
Power Supply Regulation	40
Quench Systems	51
Load Matching	52
Tuning of Solid-State Inverters	53
CHAPTER 4: Induction Coils	57
Classifications of Coils by Electromagnetic Field	57
Coil Design	59
Coil Characteristics versus Frequency	64
Basic Types of Coils	68

CHAPTER 5: Heat Treating Basics.	93
Iron and Steel	93
Iron/Iron Carbide	101
Classification of Heat-Treating Processes	104
Hardness and Hardenability	106
Induction Austenitization	111
The Transformation of Austenite	115
Fast Cooling of Austenite	120
Residual Stress and Induction Heat Treating	126
Distortion	133
Grain Size	134
CHAPTER 6: Quenching.	139
Three Stages of Quenching	139
Factors for Selection of Quenchant	141
Types of Quenchants	141
Comparison of Quenchant Curves	147
Quenching Methods	147
Selection of Quenchant	153
Methods of Reducing Contamination of Quenchants	154
CHAPTER 7: Tempering	155
Structural Changes and Stages of Tempering	156
Tempering Temperature	158
Tempering Time	159
Tempering Processes	160
Conclusion	170
CHAPTER 8: Cleaning and Rust Protection	173
Cleaning	173
Surface Finish	173
Rust Protection	174
CHAPTER 9: Decarburization and Defects.	175
Decarburization	175
Defects and Flaws	179
Stress and Quench Cracks	183
CHAPTER 10: Applications of Induction Heat Treatment	191
Surface-Hardening Applications	192
Through-Hardening Applications	210

CHAPTER 11: Induction Heat Treating Process Analysis.	215
Process Qualification	215
Work-Handling Equipment Selection	233
Examples	234
CHAPTER 12: Standards and Inspection.	245
Standards	245
Test Equipment	246
Nondestructive Testing (NDT).	250
Inspection for Induction.	259
CHAPTER 13: Nonconforming Product and Process Problems.	263
Improper Testing Procedures	263
Workpiece Has Defects as Received	265
CHAPTER 14: Quality Control	281
Formalized Quality Control	281
A Quality Induction Heat-Treating System	289
CHAPTER 15: Maintenance	293
Power Supplies and Heat Stations	293
Maintenance and Replacement of Capacitors	294
Controls, Programmable Logic Controllers (PLCs), and Computers	294
High-Frequency Electrical Output.	294
Induction Coil	295
Cooling Water Systems	296
Quench System	297
Heat Exchangers	299
Rust on Workpieces	299
Periodic Maintenance.	299
Mechanical Systems or Fixturing	300
APPENDIX 1: Metallurgical Definitions for Induction Heat Treating	301
APPENDIX 2: Scan Hardening	313
APPENDIX 3: Induction Coil Design and Fabrication.	317
Induction Coils.	317
Design for Use of Flux Concentrators	327
Computer-Aided Coil Design (CAD)	329

APPENDIX 4: Quench System Design	335
The Quench Cooling System	335
Quench Cooling System Design	339
APPENDIX 5: Tempering Curves	343
APPENDIX 6: Hardenability Curves	347
Index	357