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

ASM Handbook Volume 4B is the second of five volumes to be published on heat treatment. This significant expansion reflects the considerable economic and engineering importance of steel heat treatment and its varied methods, technologies, and applications. Expanded Handbook coverage of heat treatment also is fitting, given the 1913 origins of ASM International as the Steel Treaters Club, formed by Detroit blacksmith William Park Woodside.

Volume 4B continues from the extensive coverage in Volume 4A, Steel Heat Treating Fundamentals and Processes. This Volume covers the equipment and technological aspects of steel heat treatment. This includes instrumentation for process control and the various operational parameters that influence the effective and economical production of heat treated steel parts.

This Volume, like all Volumes of the ASM Handbook, is written, reviewed, and edited by recognized authorities. Their volunteer efforts give us a standard reference work of peer-consensus information that is authoritative, technically correct, understandable, and reliable. We thank the many volunteers for their contributions that help technically trained persons solve problems and undertake work with confidence. We are especially indebted to editors Jon Dossett, George Totten, Volker Schulze, Thomas Lübben, and Jürgen Hoffmeister.

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Preface

This Handbook continues coverage from Volume 4A, *Steel Heat Treating Fundamentals and Processes*. As with the last edition of this Volume, the goal is to provide a comprehensive reference that can be of use to the diverse heat treating community that includes researchers, engineers, technicians, and students. Each has different needs with regard to their level of work and practice.

This Volume covers the equipment, operational, and technological aspects of steel heat treatment. This includes instrumentation for process control and the various operational parameters that influence the effective and economical production of heat treated steel parts. The first article of this Volume introduces general aspects of process control. This article discusses survey methods to assess furnace temperature uniformity, which is one of the more critical variables in a heat treating operation. Other articles also describe cost estimating and the sources of problems during heat treatment, such as decarburization prior to or during heat treatment and cracking or distortion during quenching.

Updates and new articles also cover modern furnaces, heat-resistant equipment, controls, atmosphere control, temperature measurement, quenchants, quenching systems, and agitation. In addition, this Volume also gives a modern engineering perspective to the important problem of distortion and the control of residual stresses. This key topic is central in preventing many problems during steel heat treating. The engineering science (including computer modeling and simulation) of residual stress and distortion has relevance and increasing promise in practical production, whether it is process improvement for captive heat treaters or more flexible reliable results for the job-shop demands of commercial operations. In this effort, we especially thank Volker Schulze, Karlsruhe Institute of Technology, and Thomas Lübben, Stiftung Institut für Werkstofftechnik (Foundation Institute of Materials Science), for their editorial efforts on the subject of residual stress and distortion.

As in any *ASM Handbook* effort, compromises in scope and effort must occur. For example, more coverage on systems for handling and filtering quenchants could have been included. General equipment design and maintenance also could have been covered in more detail. In addition, some topics (such as the Appendix on “Heat Transfer Equations”) may be beyond the scope of typical heat treaters, who can successfully rely on practical “rules of thumb” for determining heating and cooling schedules. Nonetheless, the underlying can provide a foundation in analyzing unexpected circumstances.

Finally, we extend our thanks to the authors and reviewers who have taken the time to make this publication possible. It would have been impossible without them.
Policy on Units of Measure

By a resolution of its Board of Trustees, ASM International has adopted the practice of publishing data in both metric and customary U.S. units of measure. In preparing this Handbook, the editors have attempted to present data in metric units based primarily on Système International d’Unités (SI), with secondary mention of the corresponding values in customary U.S. units. The decision to use SI as the primary system of units was based on the aforementioned resolution of the Board of Trustees and the widespread use of metric units throughout the world.

For the most part, numerical engineering data in the text and in tables are presented in SI-based units with the customary U.S. equivalents in parentheses (text) or adjoining columns (tables). For example, pressure, stress, and strength are shown both in SI units, which are pascals (Pa) with a suitable prefix, and in customary U.S. units, which are pounds per square inch (psi). To save space, large values of psi have been converted to kips per square inch (ksi), where 1 ksi = 1000 psi. The metric tonne (kg) has sometimes been shown in megagrams (Mg). Some strictly scientific data are presented in SI units only.

To clarify some illustrations, only one set of units is presented on artwork. References in the accompanying text to data in the illustrations are presented in both SI-based and customary U.S. units. On graphs and charts, grids corresponding to SI-based units usually appear along the left and bottom edges. Where appropriate, corresponding customary U.S. units appear along the top and right edges.

Data pertaining to a specification published by a specification-writing group may be given in only the units used in that specification or in dual units, depending on the nature of the data. For example, the typical yield strength of steel sheet made to a specification written in customary U.S. units would be presented in dual units, but the sheet thickness specified in that specification might be presented only in inches.

Data obtained according to standardized test methods for which the standard recommends a particular system of units are presented in the units of that system. Wherever feasible, equivalent units are also presented. Some statistical data may also be presented in only the original units used in the analysis.

Conversions and rounding have been done in accordance with IEEE/ASTM SI-10, with attention given to the number of significant digits in the original data. For example, an annealing temperature of 1570 °F contains three significant digits. In this case, the equivalent temperature would be given as 855 °C; the exact conversion to 854.44 °C would not be appropriate. For an invariant physical phenomenon that occurs at a precise temperature (such as the melting of pure silver), it would be appropriate to report the temperature as 961.93 °C or 1763.5 °F. In some instances (especially in tables and data compilations), temperature values in °C and °F are alternatives rather than conversions.

The policy of units of measure in this Handbook contains several exceptions to strict conformance to IEEE/ASTM SI-10; in each instance, the exception has been made in an effort to improve the clarity of the Handbook. The most notable exception is the use of g/cm³ rather than kg/m³ as the unit of measure for density (mass per unit volume).

SI practice requires that only one virgule (diagonal) appear in units formed by combination of several basic units. Therefore, all of the units preceding the virgule are in the numerator and all units following the virgule are in the denominator of the expression; no parentheses are required to prevent ambiguity.
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Contents

Introduction ................................................. 1
Steel Heat Treating Process Control—An Introduction . 3
Time-Temperature Profiles ................................... 4
Temperature Uniformity Surveys ............................. 6
Furnace Atmospheres ....................................... 10
Quenching Parameters ....................................... 12
Process and Product Capabilities .......................... 13
Design of Experiments ...................................... 14
Test Coupons ............................................... 17
Mechanical Motion Components ............................ 18
Calculation of Heat Treating Costs
J.L. Dossett ............................................. 20
Introduction ............................................. 20
Operational Details ......................................... 20
Cost Separation ............................................ 21
Collecting Use/Cost Data .................................. 21
Cost Component Allocations ................................. 22
Determining the Cost of Endothermic Generator Gas .... 23
Summary .................................................. 24
Problems Associated with Heat Treating
Laura C.F. Canale, Jan Vatavuk, George E. Totten, and Xinmin Luo ........................................ 29
Phase Transformations During Heating and Cooling .... 30
Cooling and Steel Metallurgical Transformation ....... 32
Tempering (Drawing) ........................................ 35
Effect of Materials and Process Design on Distortion ... 39
Quenching .................................................. 45
Machining ................................................. 51
Grinding .................................................. 52
Retained Austenite .......................................... 55
Nonmetallic Inclusions ...................................... 58
Alloy Depletion ........................................... 61
High-Temperature Transformation Products ............ 61
Decarburization ........................................... 61
Carbides .................................................. 63
Influential Microstructural Features ....................... 64
Shot Peening .............................................. 68
Final Comments .......................................... 69
Steel Decarburization—Mechanisms, Models, Prevention,
Correction, and Effects on Component Life
Roger N. Wright ........................................... 74
General Chemical Reactions ................................ 74
Diffusion-Based Models ..................................... 74
The Role of Ferrite in Decarburization .................... 76
Isothermal Phase Transformations during Decarburization ........................................... 76
Impact of Alloying on Vulnerability to Decarburization ........................................... 76
Impact of Decarburization on the Properties of Steels and Cast Irons ....................... 76
Technological Operations (Process Stages) That Potentially Can Cause Decarburization .... 77
Representative Decarburization Data ....................... 77
Practical Implications for Induction Hardening .......... 79
Heat Treatment Systems and Controls ................. 81
Types of Heat Treating Furnaces
Alexey Sverdlin ............................................. 83
Batch-Type Furnaces ....................................... 84
Continuous-Type Furnaces ................................ 94
Recuperation or Regeneration ................................ 101
Temperature Uniformity .................................... 104
Insulation of Heat Treating Furnaces ...................... 105
Furnace Safety ............................................. 105
Furnace Atmospheres for Heat Treating
Ralph Poor, Steve Ruoff, and Thomas Philips .......... 108
Practical Flow Formula ..................................... 108
Fundamentals of Gases ..................................... 108
Principal Gases and Vapors ................................ 109
Furnace Atmosphere Gas Reactions ....................... 110
Classifications of Prepared Atmospheres ................. 112
Furnace Atmosphere Hazards ................................ 113
Generated Exothermic-Based Atmospheres ............... 115
Generated Endothermic-Based Atmospheres .............. 117
Generated Exothermic-Endothermic-Based Atmospheres ........................................... 119
Industrial Gas Nitrogen-Based Atmospheres .......... 121
Argon Atmospheres ....................................... 126
Hydrogen Atmospheres ................................... 127
Atmospheres for Backfilling, Partial Pressure Operation, and Quenching in Vacuum .......... 131
Evaluating Atmosphere Requirements ..................... 133
Furnace Atmosphere Controls in Heat Treating
Jim Oakes and John Lutz ................................... 135
Fundamentals of Heat Treating Atmospheres ............ 135
Carbon Potential Control .................................. 136
Furnace Atmosphere Control ............................... 137
Supply Atmosphere Control ................................ 138
Control of Input Gas ....................................... 139
Laboratory Analysis of Gas Composition ................. 140
Sampling of Atmospheres for Analysis .................... 141
Sampling of Atmospheres for Control ................. 143
Analyzers ............................................... 143
Analyzer Recommendations ............................... 150
Temperature Control in Heat Treating
Peter Sherwin ............................................... 152
Factors Affecting Temperature Control .................... 152
Temperature-Control Instrumentation ..................... 153
Temperature Scales ........................................ 154
Thermocouples ........................................... 154
Thermocouple Practices .................................... 157
Resistance Temperature Detectors ......................... 160
Noncontact Temperature Sensors ......................... 160
Measurement and Control Instruments .................... 164
Energy-Flow Regulators .................................... 167
SAE-AMS 2750 Specification ................................ 168
Furnace Controls
Jason Walls, Frank Pietracupa, Eric Boltz, and Janusz Szymborski .................................. 170
Mechanical Motion Components .......................... 170
Residual Stresses and Distortion in Thermochemically Treated Steels

B. Clausen, M. Steinbacher, and F. Hoffmann

Development of Residual Stresses in Carburized Steels

Stress Development in Parts Due to Case Hardening

Distortion Affected by the Carburization of Steels

Development of Distortion during Hardening as a Subject of Time-Temperature-Transformation Diagram

Distinction of Distortion Due to Heating

Distinction of Distortion Due to Carburization and Hardening

Development of Residual Stresses in Nitrided Steels

Residual Stress Generation during Different Process Steps

Diffusion Zone

Compound Layer

General Remarks

Influence of the Nitriding Process

Distinction of Distortion Due to Nitriding of Steels

Influence of the Alloy Content

Influence of the Geometry of the Parts

Prediction of Distortion

Distortion Engineering

B. Clausen, T. Lübben, and R. Rentsch

Distortion Engineering, Level 1—Identification of Distortion-Relevant Parameters and Variables

Distortion Engineering, Level 2—Identification of the Distortion-Relevant Mechanisms

Distortion Engineering, Level 3—Development of Approaches for the Compensation of Distortion

Modeling and Simulation of Steel Heat Treatment—Prediction of Microstructure, Distortion, Residual Stresses, and Cracking

C. Simsir

Fundamentals of Simulation of Heat Treatments

Material Data

Process Data

Validation of Simulations

Application Examples

Summary and Outlook

Reference Information

Guide to Furnace Atmospheres

Properties of Gases

Furnace Atmospheres

Combustion Efficiency

Combustion Properties and Heat Transfer

Heating and Holding Times

Heating Times

Hardening

Tempering

Heat-Transfer Equations

Heat Conduction

Convection Heat Transfer

Thermal Radiation

Index