

Contents

Preface	x
About the Author	xi
CHAPTER 1 Structure of Metals and Alloys	1
Atomic Bonding and Crystal Structure	1
<i>Space Lattices and Crystal Systems</i>	2
Crystal Imperfections and Plastic Deformation.	4
<i>Point Defects</i>	4
<i>Line Defects</i>	4
<i>Surface or Planar Defects</i>	6
<i>Volume Defects</i>	8
Crystalline Structure of Metals	8
<i>Face-Centered Cubic System</i>	9
<i>Hexagonal Close-Packed System</i>	12
<i>Body-Centered Cubic System</i>	12
Grains and Grain Boundaries	13
Diffusion.	14
<i>Heat Treatment and Diffusion</i>	15
Solid Solutions.	16
<i>Substitutional Solid Solutions</i>	17
<i>Interstitial Solid Solutions</i>	18
<i>Solubility Limits</i>	18
Equilibrium Phase Diagrams	21
Using Equilibrium Phase Diagrams.	24
<i>Lever Rule</i>	26
CHAPTER 2 Fundamentals of Steel Heat Treatment	29
Introduction	29
Constitution of Iron	32
<i>Iron Phase Transformation</i>	33
Phases of Heat-Treated Steel	37
<i>The Iron-Carbon Phase Diagram</i>	37
<i>Austenite</i>	38
<i>Ferrite</i>	39
<i>Pearlite and Bainite</i>	41
<i>Proeutectoid Ferrite and Cementite</i>	43
<i>Martensite</i>	47
<i>Tempered Martensite</i>	50

CHAPTER 3 Transformation of Austenite and Quenching of Steel	55
Isothermal Transformation Diagrams	55
<i>Effects of Alloying</i>	56
Continuous Cooling Transformation Diagrams	61
Quenching of Steel	63
Mechanism of Quenching	65
<i>Cooling Curves</i>	65
Quenching Process Variables	68
<i>Quenchants</i>	68
<i>Quenchant Agitation</i>	70
<i>Metallurgical Aspects of Quenching</i>	71
Residual Stresses and Distortion	74
Quench Cracking	76
CHAPTER 4 Hardness and Hardenability of Steels	79
Introduction	79
Jominy End-Quench Testing	79
Hardenability Correlation Curves	84
Jominy Equivalence Charts	85
Factors Affecting Hardenability	87
<i>Effect of Alloys on Hardenability during Quenching</i>	88
<i>Effect of Alloys on the Tempering Response (After Hardening)</i>	89
<i>Effect of Carbon on Hardenability Data</i>	90
Hardenability Limits and H-Steels	90
CHAPTER 5 Classification of Carbon and Low-Alloy Steels	95
Residual Elements	96
Carbon Steels	98
<i>Higher Manganese Carbon Steels</i>	99
<i>Boron-Treated Carbon Steels</i>	100
<i>H-Steels</i>	102
<i>Free-Machining Carbon Steels</i>	102
<i>Effects of Free-Machining Additives</i>	105
Low-Alloy Steels	106
<i>Low-Alloy Manganese Steels</i>	108
<i>Low-Alloy Molybdenum Steels</i>	109
<i>Low-Alloy Chromium-Molybdenum Steels</i>	111
<i>Low-Alloy Nickel-Chromium-Molybdenum Steels</i>	113
<i>Low-Alloy Nickel-Molybdenum Steels (46xx and 48xx Series)</i>	117
<i>Low-Alloy Chromium Steels</i>	117
<i>Low-Alloy Silicon-Manganese Steels</i>	121
Mechanical Properties and Grain Size	121
<i>Steel Deoxidation Practice and Grain Size</i>	123
CHAPTER 6 Annealing of Metals and Normalizing of Steel	127
Recovery, Recrystallization, and Grain Growth	129
<i>Recovery</i>	129
<i>Recrystallization</i>	131
<i>Grain Growth</i>	133
Subcritical Annealing of Steel	134
<i>Time-Temperature Relations</i>	136
<i>Process Annealing</i>	137
Critical-Range Annealing of Steel	139

Full Annealing of Steel	140
Isothermal Annealing	142
Annealing for Microstructure	144
<i>Pearlite Formation</i>	144
<i>Spheroidizing</i>	147
<i>Graphitization</i>	150
Solution or Quench Annealing	150
Decarburization and Scaling	151
<i>Decarburization</i>	151
<i>Scaling</i>	152
Prepared Atmospheres	154
<i>Exothermic Gas</i>	154
<i>Dissociated Ammonia</i>	154
<i>Steam Atmospheres</i>	154
<i>Nitrogen with 0.5% Propylene Additive</i>	155
Normalizing	155
<i>Purpose of Normalizing</i>	155
<i>Normalizing Practice</i>	157
Furnaces	157
<i>Furnace Equipment for Normalizing</i>	158
Induction Heating	159
CHAPTER 7 Hardening and Tempering of Steel	163
Austenitizing	163
<i>Austenitizing by Induction Heating</i>	164
<i>Surface Protection of Parts</i>	166
Hardening	166
<i>Induction Hardening</i>	168
Quenching Systems	168
<i>Quenching Mediums</i>	169
Other Quenching Techniques	173
<i>Austempering</i>	174
<i>Martempering</i>	176
Difficulties Associated with Hardening of Steel	178
<i>Quench Cracking</i>	178
Tempering	180
<i>Metallurgical Changes Caused by Tempering</i>	181
<i>Stages of Tempering</i>	182
<i>Tempering Temperatures</i>	183
Equipment for Tempering	183
<i>Tempering in Air Furnaces</i>	183
<i>Tempering in Liquid Baths</i>	184
<i>Induction Tempering</i>	184
Principal Tempering Variables	185
<i>Effect of Steel Composition</i>	185
<i>Effect of Prior Microstructure</i>	188
<i>Tempering versus Stress Relief</i>	190
<i>Effect of Tempering on Dimensions</i>	190
<i>Effect of Cooling from Tempering Temperature</i>	191
Embrittlement from Tempering	192
<i>Blue Brittleness</i>	192
<i>Temper Embrittlement</i>	192
<i>500 °F Embrittlement</i>	193
<i>400 to 500 °C Embrittlement</i>	193

Multiple Tempering	193
<i>Elimination of Retained Austenite</i>	193
Protective-Atmosphere Tempering	194
<i>Exothermic Gas for Protection</i>	194
<i>Tempering in Molten Salt</i>	194
<i>Steam Treating and Tempering</i>	195
Selective Tempering	195
<i>Prompt Tempering</i>	195
Selection of Tempering Temperature	196
Precipitation Hardening	196
<i>Effect of Carbon</i>	197
<i>Effect of Other Elements</i>	198
<i>Advantages of Precipitation Hardening</i>	199
CHAPTER 8 Heat Treatment of Carbon and Low-Alloy Steels.	203
Carbon Steel Classification for Heat Treating	205
<i>Group I (0.08 to 0.25% C)</i>	205
<i>Group II (0.30 to 0.50% C)</i>	206
<i>Group III (0.55 to 0.95% C)</i>	206
Tempering of Quenched Carbon Steels	207
Austempering of Steel	207
<i>Quenching Mediums for Austempering</i>	208
Carbon Steel Heat Treating Practices	209
<i>1008 to 1019, 12xx, and 11xx Carbon Steels</i>	210
<i>1020 Recommended Practice</i>	212
<i>1035 Recommended Practice</i>	212
<i>1045, 1045H Recommended Practice</i>	212
<i>1050 Recommended Practice</i>	213
<i>1060 Recommended Practice</i>	213
<i>1070 Recommended Practice</i>	213
<i>1080 Recommended Practice</i>	213
<i>1095 Recommended Practice</i>	213
<i>1137 Recommended Practice</i>	214
<i>1141 Recommended Practice</i>	214
<i>1144 Recommended Practice</i>	214
<i>1151 Recommended Practice</i>	214
<i>1522 and 1522H Recommended Practice</i>	214
<i>15B41H Recommended Practice</i>	215
<i>1552 Recommended Practice</i>	215
<i>1566 Recommended Practice</i>	215
Cast Carbon Steels	215
Low-Alloy Steels	216
<i>H-Steels and Restricted Hardenability</i>	217
<i>Free-Machining Alloy Steels</i>	217
Effects of Alloying and Hardenability	217
Low-Alloy Steel Heat Treating Practices	219
<i>Effects of Tempering</i>	220
<i>4037 and 4037H Recommended Practice</i>	220
<i>4140 and 4140H Recommended Practice</i>	220
<i>4340 and 4340H Recommended Practice</i>	222
<i>E52100 Recommended Practice</i>	223
Austempering	223
Martempering (Marquenching)	223
Air-Hardening Steel	224

Case Hardening	224
<i>Carburizing Steels</i>	225
<i>Carbonitriding Steels</i>	226
<i>Ferritic Nitrocarburizing</i>	227
<i>Nitriding Steels</i>	228
<i>Steels for Induction or Flame Hardening</i>	229
CHAPTER 9 Heat Treatment of Stainless Steels.	233
Composition of Stainless Steels	234
Classification of Stainless Steels	236
<i>Ferritic Stainless Alloys</i>	240
<i>Austenitic Stainless Alloys</i>	240
<i>Duplex (Ferritic-Austenitic) Stainless Alloys</i>	241
<i>Martensitic Stainless Alloys</i>	241
<i>Precipitation-Hardening Stainless Alloys</i>	241
Heat Treatment Processes	242
<i>General Practices</i>	242
Wrought Ferritic Stainless Alloys	243
<i>Annealing</i>	246
<i>Possible Heat Treating Problems</i>	246
Wrought Austenitic Stainless Alloys	248
<i>Alloying</i>	250
<i>Sensitization</i>	251
<i>Intermediate Phases (σ, χ, and Laves)</i>	252
<i>Annealing</i>	253
<i>Bright Annealing</i>	257
<i>Stress Relieving of Austenitic Grades</i>	257
Wrought Duplex Stainless Alloys	260
<i>Annealing of Duplex Stainless Steels</i>	261
Wrought Martensitic Stainless Alloys	264
<i>Heat Treatment Preparations</i>	265
<i>Annealing</i>	266
<i>Hardening and Tempering</i>	267
Wrought Precipitation—Hardening Stainless Steels	271
<i>Martensitic PH Stainless Steels</i>	274
<i>Semiaustenitic Wrought PH Stainless Steels</i>	276
<i>Austenitic PH Stainless Steel</i>	279
Special Considerations for Stainless Steel Castings	280
<i>Ferritic, Austenitic, and Mixed Ferritic-Austenitic Casting Alloys</i>	280
<i>Martensitic Casting Alloys</i>	282
<i>Precipitation-Hardening Casting Alloys</i>	282
CHAPTER 10 Heat Treatment of Tool Steels.	285
Classification of Tool Steels	286
<i>Powder Metallurgy (PM) and Proprietary Tool Steels</i>	287
Principles and Processes of Tool Steel Heat Treating	289
Normalizing and Annealing	293
<i>Normalizing</i>	293
<i>Annealing</i>	294
Hardening and Tempering	296
<i>Stress Relieving</i>	297
<i>Preheating</i>	297
<i>Austenitizing</i>	299
<i>Quenching</i>	305

<i>Tempering</i>	306
Distortion	308
<i>Other Factors Associated with Distortion</i>	309
Unalloyed and Low-Alloy Cold-Worked Tool Steels	311
<i>Class W: Water-Hardening Steels</i>	311
<i>Class O—Oil-Hardening Cold-Worked Steels</i>	312
<i>Class L: Low-Alloy Special-Purpose Steels</i>	314
<i>Class S: Shock-Resisting Steels</i>	315
<i>Class F: Carbon-Tungsten Special-Purpose Steels</i>	316
Medium and High-Alloy Cold-Worked Tool Steels	317
<i>Class A: Medium-Alloy, Air-Hardening, Cold-Worked Steels</i>	318
<i>Class D: High-Carbon, High-Chromium, Cold-Worked Steels</i>	319
Mold Steels	319
<i>Class P: Plastic Mold Steels</i>	319
Hot-Worked Steels	320
<i>Class H: Hot-Worked Steels</i>	320
<i>Hardening</i>	322
High-Speed Tool Steels	323
<i>Class M and T: High-Speed Tool Steels</i>	323
<i>Heat Treatment of High-Speed Tool Steels</i>	325
18% Nickel Maraging Steels	329
CHAPTER 11 Heat Treatment of Cast Irons	331
General Considerations	332
<i>Critical Temperature Range of Cast Irons</i>	334
<i>Temperature Control</i>	334
<i>Atmosphere Control</i>	335
Stress Relief	336
<i>Selecting Stress-Relief Temperatures</i>	338
<i>Other Stress-Relief Methods</i>	339
Annealing	339
Normalizing	341
Through Hardening and Tempering	342
<i>Austenitizing</i>	342
<i>Quenching</i>	342
<i>Tempering</i>	344
<i>Austempering</i>	344
Surface Hardening of Cast Irons	346
<i>Metalurgical Aspects</i>	346
<i>Applied Energy Surface Hardening</i>	347
<i>Nitriding of Cast Irons</i>	348
CHAPTER 12 Heat Treatment of Aluminum and Other Nonferrous Alloys	351
Annealing of Cold-Worked Metals	352
<i>Recovery</i>	353
<i>Recrystallization</i>	354
Precipitation Hardening	356
Aluminum Alloys	357
<i>Age Hardening Process</i>	361
Cobalt Alloys	367
Copper Alloys	368
<i>Precipitation-Hardening Copper Alloys</i>	370
<i>Spinodal-Hardening Copper Alloys</i>	372
<i>Order-Hardening Copper Alloys</i>	372

<i>Athermal (Martensitic-Type) Transformation Hardening of Copper Alloys</i>	372
Magnesium Alloys	373
Nickel Alloys	377
Titanium Alloys	380
Other Nonferrous Alloys	383
<i>Heat Treatable Silver Alloys</i>	383
<i>Heat Treatable Gold Alloys</i>	384
<i>Lead and Tin Alloys</i>	385
Index	387