Table of Contents

1	**Transformation of Steels During Cooling**	
	By H. P. Hougardy	1
1.1	Introduction	1
1.2	Constitution of Iron Alloys	1
1.3	Kinetics of Transformation	3
1.3.1	Principles	3
1.3.2	Microstructures of Steels	4
1.3.2.1	Types of Microstructure	4
1.3.2.2	Ferrite and Pearlite	4
1.3.2.3	Martensite	5
1.3.2.4	Bainite	7
1.3.2.5	Influence of Transformation Temperature	11
1.3.2.6	Tempering	11
1.3.3	Mechanical Properties of Microstructures	12
1.3.4	Transformation Diagrams	12
1.3.4.1	Austenitization	12
1.3.4.2	Isothermal Transformation	14
1.3.4.3	Transformation During Continuous Cooling	15
1.4	Factors Influencing the Transformation	15
1.4.1	Austenitizing Conditions	15
1.4.2	Cooling Rate	15
1.4.3	Alloying Elements	15
1.5	Description of Transformation in Components	16
1.6	Calculation of Transformation and Properties	17
	References	17
2	**Mechanical Properties of Ferrous and Nonferrous Alloys After Quenching**	
	By H. J. Spies	19
2.1	Objectives of Quenching	19
2.2	Influence of Heat Treatment Structures on the Mechanical Properties	21
2.2.1	Ferrous Materials	21
2.2.2	Precipitation-Hardenable Aluminium Alloys	29
2.3	Characterization of Transformation Behaviour	33
	References	39

Bibliografische Informationen
http://d-nb.info/911091203

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

3	**Thermo- and Fluiddynamic Principles of Heat Transfer During Cooling**	
	By F. Mayinger	41
3.1	Phenomena of Heat Transfer During Immersion Cooling	41
3.2	Single Phase Convection	48
3.2.1	Heat Transfer Equations for Forced Convection	53
3.2.2	Heat Transfer Equations for Natural Convection	54
3.3	Two Phase Heat Transfer	55
3.3.1	Free Convection Boiling	55
3.3.2	Forced Convection Boiling	57
3.3.3	Heat Transfer with Film Boiling	63
3.3.4	Transition Boiling	65
3.3.5	Critical Heat Flux	66
3.3.6	Immersion Cooling	67
	List of Symbols	69
	List of Subscripts	70
	References	71
4	**Heat Transfer During Cooling of Heated Metallic Objects with Evaporating Liquids**	
	By R. Jeschar, E. Specht and Chr. Köhler	73
4.1	Mechanism of Heat Transfer	73
4.2	Film Quenching	75
4.3	Immersion Quenching	81
4.4	Spray Quenching	89
	References	92
5	**Wetting Kinematics**	
	By H. M. Tensi	91
5.1	Introduction	93
5.2	Definition of the Wetting Process	93
5.3	Model of Vapour Blanket Breakdown During Immersion Cooling of Metallic Bodies	97
5.4	Effect of Wetting Process on Cooling Behaviour	99
5.5	Impact of Quenchant Properties on Wetting Process	102
5.6	Impact of Sample Properties on Wetting Process	110
5.7	Summary	114
5.8	List of Symbols	115
	References	116
6	**Residual Stresses After Cooling**	
	By E. Macherauch and O. Vöhringer	117
6.1	Introduction	117
6.2	Some Fundamentals	119
6.2.1	Definitions of Residual Stresses	119
6.2.2	Quenching of Steel Cylinders	123
6.2.3	Transformation Processes of Austenitized Steels During Quenching	127

6.3 Stresses During Quenching of Cylinders with Ideal Linear-Elastic Deformation Behaviour . . . 133
6.3.1 Shrinking Stresses Due to Local and Temporal Differences in Thermal Shrinking . . . 133
6.3.2 Transformation Stresses Due to Local and Temporal Stresses in Phase Transformations . . . 135
6.3.3 Superposition of Shrinking and Transformation Stresses . . . 136
6.4 Residual Stresses After Quenching of Cylinders with Real Elastic-Plastic Deformation Behaviour . . . 137
6.4.1 Plastic Deformations Due to Shrinking and Phase Transformations . . . 137
6.4.2 General Aspects of Shrinking, Transformation and Hardening Residual Stresses . . . 139
6.4.3 Characteristic Examples of Stresses and Residual Stresses in Differently Quenched Plain Carbon and Low Alloy Steels . . . 147
6.5 Residual Stresses After Quenching of Carburized Steels . . . 155
6.5.1 Some Fundamentals . . . 155
6.5.2 Characteristic Examples . . . 161
6.6 Residual Stresses After Quenching of Steels with Induction Heated Surface Layers . . . 168
6.6.1 Quenching Without Transformation . . . 168
6.6.2 Quenching Combined with Transformation . . . 169
6.7 Residual Stresses After Self-Quenching of Steels with Laser-Heated Surface Layers . . . 174
6.7.1 Quenching After Austenitizing . . . 174
6.7.2 Quenching After Melting . . . 178
References . . . 180

7 Effect of Workpiece Surface Properties on Cooling Behaviour
By F. Moreaux and G. Beck . . . 182

7.1 Effect of Quenching Conditions on Liquid Vaporization Types . . . 182
7.1.1 Transition Between Film-Boiling and Nucleate-Boiling . . . 183
7.1.2 Instability of Film-Boiling in Sub-Cooled Water . . . 184
7.1.3 Cooling Law Calculation . . . 189
7.2 Influence on the Workpiece Surface's Thermophysical Properties . . . 191
7.2.1 Influence of the Initial Workpiece-Liquid Contact on the Cooling Process . . . 191
7.2.2 Surface Thermal Resistance Effect on the Cooling Process . . . 196
7.2.3 Influence of the Surface Condition on the Cooling Process . . . 200
7.3 Quenching Control by Adding a Solute to the Water . . . 200
7.3.1 Aqueous Solutions of Inorganic Solutes . . . 200
7.3.2 Organic Polymer Aqueous Solution . . . 202
References . . . 206

8 Determination of Quenching Power of Various Fluids . . . 208

8.1 Methods and Standards for Laboratory Tests of Liquid Quenchants
By H. M. Tensi . . . 208
8.1.1 Laboratory Test for Industrial Quenching Oils . . . 209

8.1.2 Laboratory Test for Industrial Polymer Quenchants 210
8.1.3 Representation of Results 218
References 218
List of Symbols 219
8.2 Concept of the Grossmann's H-Value and its Shortcomings
By B. Liščić 219
8.2.1 Theoretical Background and Definition of the "Quenching Severity H" . 219
8.2.2 The Use and Evaluation of *H*-Values 221
8.2.3 Shortcomings of the *H*-Value 227
8.3 Practical Problems when Measuring Temperature
Within Quenching Specimens
By B. Liščić 232
8.4 Measurement and Recording of the Quenching Intensity in
Workshop Practice Based on Heat-Flux-Density
By B. Liščić 234
8.4.1 Concept and Aims of the Temperature Gradient Method 234
8.4.2 Description of the Method 235
8.5 Definition and Evaluation of the Quenching Intensity
By B. Liščić 243
8.6 Possibilities of Automatic Control of the Quenching Process
By B. Liščić 244
References 247

9 Types of Cooling Media and Their Properties
By W. Luty 248

9.1 Required Properties 248
9.2 General Classification and Comparison of Quenchants 249
9.3 Water as a Quenching Medium 254
9.3.1 General Characteristic 254
9.3.2 Effect of the Temperature of Quenching Water upon its Quenching Power 256
9.3.3 Effect of Agitation Rate 258
9.3.4 Effect of Water Contamination 259
9.4 Water Solutions of Non-Organic Salts and Alkali 260
9.5 Water-Oil Emulsions 263
9.6 Aqueous Polymer Solutions 266
9.6.1 General Characteristic 267
9.6.2 Performance Characteristics 274
9.6.3 How to Use Polymer Quenchants 277
9.7 Mineral Quenching Oils 280
9.7.1 Composition of Quenching Oils 281
9.7.2 Classification and General Description of Quenching Oils 285
9.7.3 Physical and Chemical Properties 287
9.7.4 Quenching Power of Oils 291
9.7.5 Effects of Oils Temperature and Agitation 295
9.7.6 Contamination of Quenching Oils with Water 297
9.7.7 Ageing Process in Quenching Oils 300
9.7.8 Hot Quenching Oils 301

9.7.9 Vacuum Quenching Oils 304
9.7.10 Fire Hazard and Safety Precautions 305
9.8 Saltbaths used in Martempering and Austempering 307
9.8.1 General Description 307
9.8.2 Salpetre Salts 309
9.8.3 Martempering and Austempering in Molten Alkalis and Alkali-Salt-Baths 313
9.8.4 Safety Precautions when Using Salpetre Baths 315
9.9 Gas Quenching 316
9.9.1 Air Quenching 316
9.9.2 In Situ Gas Quenching in Vacuum Furnaces 317
9.10 Fluidized Quenching Beds 324
9.10.1 Fluidization Effect 324
9.10.2 General Description 325
9.10.3 Effect of Technological Factors on the Quenching Power 327
9.10.4 The Range of Application of Fluidized Beds 334
References 339

10 Techniques of Quenching 341

10.1 Immersion Cooling (Direct Quenching)
By H. E. Boyer 341
10.2 Quenching Techniques
By H. E. Boyer 346
10.2.1 Interrupted Quenching Techniques 347
10.2.2 Rinse Quenching 347
10.2.3 Austempering 348
10.2.4 Martempering 351
10.2.5 Gas and Fog Quenching 353
10.2.6 Press and Cold Die Quenching 356
10.2.7 Self Quenching 359
10.3 Computer Controlled Spray Cooling
By P. Archambault and F. Moreaux 360
References 366
10.4 Intensive Steel Quenching Methods
By N. I. Kobasko 367
10.4.1 New Methods for Quenching Alloyed Steels Based on the
Heat Exchange Intensification 367
10.4.1.1 Methods of Quenching Alloy Steel Parts 370
10.4.1.2 Steel Quenching Method Based on the Mechanism of Non-Stationary
Nucleate Boiling 374
10.4.1.3 Application of New Methods for Quenching Parts of
Complex Configuration 375
10.4.2 Reasoning for a Promotion of the Reliability of Parts of Machines and
Tools Which were Hardened with Intensive Quenching Methods 380
10.4.3 Practical Use of New Quenching Methods and Perspective of Their Wide
Application in Industry, Based on the Development of New Equipment . 384
References. 388

11 Prediction of Hardness Profile in Workpiece, Based on Characteristic Cooling Parameters and Material Behaviour During Cooling 390

11.1 Prediction of Hardening Behaviour Using the Wetting Kinematics
By H. M. Tensi 390
11.1.1 Possibilities and Limits to Predict the Hardening Behaviour 390
11.1.2 Influence of Wetting on the Temperature Distribution during Quenching 392
11.1.3 Prediction of Hardening Behaviour Using the Wetting Kinematics 394
11.1.3.1 Calculation of the Surface Hardness 395
11.1.3.2 Calculation of the Hardness Distribution in Cross-Section of Cylindrical Specimens 399
11.1.3.3 Calculation of the Hardness Distribution in Specimens of Optional Geometries 403
References 407
List of Symbols 408
11.2 Predetermination of Hardness Results
By B. Liščić 409
11.2.1 The QTA-Method 409
List of Symbols 418
References 419
11.2.2 Relations Between Cooling Curves and Hardness Distribution (after K. E. Thelning)
By B. Liščić 419
References 425
11.2.3 IVF Method for Classification of Quenching Oils
By B. Liščić 425
References 428
11.2.4 Prediction of Hardness Values based on Cooling Parameter
By B. Liščić 428
References 435
11.2.5 Method CETIM for Prediction of Hardening Power of Quenching Oils
By B. Liščić 436
References 445
11.2.6 Calculation of Mechanical Properties According to Blondeau, Maynier, Dollet and Veillard-Baron
By T. Filetin 445
References 449
11.2.7 Own Databank for Quenching Intensities, Jominy Hardenability and Hardness Distribution on Test Specimens
By T. Filetin 450
11.2.8 Computer-Aided Prediction of Hardness Profile upon Quenching Using the Own Databank
By T. Filetin 456
References 466
11.2.9 Prediction of Structural Constituents and Hardness Values upon Quenching by Using CCT-Diagrams
By B. Liščić 466

References 476

Subject Index 477