

Contents

About the editors	xiii
List of contributors	xv
Woodhead Publishing Series in Metals and Surface Engineering	xvii
Introduction	xxi
Part One Fundamentals	1
1 Thermodynamics and kinetics of gas and gas–solid reactions	3
<i>J. T. Slycke, E. J. Mittemeijer, M. A. J. Somers</i>	
1.1 Introduction	3
1.2 Equilibria for gas-exchange reactions	6
1.3 Equilibria for gas–solid reactions	28
1.4 Kinetics of gas-exchange reactions	51
1.5 Kinetics of gas–solid reactions	75
1.6 Phase stabilities in the Fe-N, Fe-C and Fe-C-N systems	96
References	109
2 Kinetics of thermochemical surface treatments	113
<i>E. J. Mittemeijer, M. A. J. Somers</i>	
2.1 Introduction	113
2.2 Development of an interstitial solid solution	113
2.3 Precipitation of second phase particles in a supersaturated matrix	124
2.4 Product-layer growth at the surface	128
2.5 Conclusion	138
References	139
3 Process technologies for thermochemical surface engineering	141
<i>K-M. Winter, J. Kalucki, D. Koshel</i>	
3.1 Introduction	141
3.2 Different ways of achieving a hardened wear-resistant surface	141
3.3 Furnaces	144
3.4 Gaseous carburising	158
3.5 Gaseous carbonitriding	166
3.6 Gaseous nitriding and nitrocarburising	170
3.7 Variants of gaseous nitriding and nitrocarburising	176
3.8 Gaseous boriding	179
3.9 Plasma assisted processes: plasma (ion) carburising	182

3.10	Plasma (ion) nitriding/nitrocarburising	187
3.11	Implantation processes (nitriding)	190
3.12	Salt bath processes (nitrocarburising)	194
3.13	Laser assisted nitriding	196
3.14	Fluidised bed nitriding	199
	Acknowledgements	201
	References	202
Part Two Improved materials performance		207
4	Fatigue resistance of carburized and nitrided steels	209
	<i>J. Grosch</i>	
4.1	Introduction	209
4.2	The concept of local fatigue resistance	213
4.3	Statistical analysis of fatigue resistance	216
4.4	Fatigue behavior of carburized microstructures	218
4.5	Fatigue behavior of nitrided and nitrocarburized microstructures	227
4.6	Conclusion	236
	References	237
5	Tribological behaviour of thermochemically surface engineered steels	241
	<i>P. A. Dearnley, A. Matthews, A. Leyland</i>	
5.1	Introduction	241
5.2	Contact types	241
5.3	Wear mechanisms	244
5.4	Conclusions	263
	References	264
6	Corrosion behaviour of nitrided, nitrocarburised and carburised steels	267
	<i>H-J. Spies</i>	
6.1	Introduction	267
6.2	Corrosion behaviour of nitrided and nitrocarburised unalloyed and low alloyed steels: introduction	271
6.3	Nitriding processes and corrosion behaviour	271
6.4	Structure and composition of compound layers and corrosion behaviour	276
6.5	Post-oxidation and corrosion behaviour	280
6.6	Passivation of nitride layers	285
6.7	Corrosion behaviour in molten metals	287
6.8	Corrosion behaviour of nitrided, nitrocarburised and carburised stainless steels: introduction	287

6.9	Austenitic-ferritic and austenitic steels: corrosion in chloride-free solutions	290
6.10	Austenitic-ferritic and austenitic steels: corrosion in chloride-containing solutions	297
6.11	Ferritic, martensitic and precipitation hardening stainless steels	300
6.12	Conclusion	304
	References	305
Part Three Nitriding, nitrocarburizing and carburizing		311
7	Nitriding of binary and ternary iron-based alloys	313
	<i>E. J. Mittemeijer</i>	
7.1	Introduction	313
7.2	Strong, intermediate and weak Me–N interaction	314
7.3	Microstructural development of the compound layer in the presence of alloying elements	316
7.4	Microstructural development of the diffusion zone in the presence of alloying elements	318
7.5	Kinetics of diffusion zone growth in the presence of alloying elements	326
7.6	Conclusion	333
	References	337
8	Development of the compound layer during nitriding and nitrocarburising of iron and iron-carbon alloys	341
	<i>M. A. J. Somers</i>	
8.1	Introduction	341
8.2	Compound layer formation during nitriding in a NH_3/H_2 gas mixture	342
8.3	Nitrocarburising in gas	354
8.4	Compound layer development during salt bath nitrocarburising	366
8.5	Post-oxidation and phase transformations in the compound layer	368
8.6	Conclusion	370
	References	371
9	Austenitic nitriding and nitrocarburizing of steels	373
	<i>R. S. E. Schneider</i>	
9.1	Introduction	373
9.2	Phase stability regions of nitrogen-containing austenite	373
9.3	Phase transformation of nitrogen-containing austenite and its consequences for the process	376

9.4	Phase stability and layer growth during austenitic nitriding and nitrocarburizing	380
9.5	Properties resulting from austenitic nitriding and nitrocarburizing	383
9.6	Solution nitriding and its application	386
	References	389
10	Classical nitriding of heat treatable steel	393
	<i>L. Barrallier</i>	
10.1	Introduction	393
10.2	Steels suitable for nitriding	393
10.3	Microstructure and hardness improvement	394
10.4	Nitriding-induced stress in steel	397
10.5	Nitriding and improved fatigue life of steel	405
	References	410
11	Plasma-assisted nitriding and nitrocarburizing of steel and other ferrous alloys	413
	<i>E. Roliński</i>	
11.1	Introduction	413
11.2	Glow discharge during plasma nitriding: general features	415
11.3	Sputtering during plasma nitriding	424
11.4	Practical aspects of sputtering and redeposition of the cathode material during plasma nitriding	427
11.5	Plasma nitriding as a low-nitriding potential process	430
11.6	Role of carbon-bearing gases and oxygen	435
11.7	Practical aspects of differences in nitriding mechanism of plasma and gas nitriding processes	437
11.8	Best applications of plasma nitriding and nitrocarburizing	441
11.9	Methods for reducing plasma nitriding limitations	447
	Acknowledgements	449
	References	449
12	ZeroFlow gas nitriding of steels	459
	<i>L. Maldzinski, J. Tacikowski</i>	
12.1	Introduction	459
12.2	Improving gas nitriding of steels	460
12.3	Current gas nitriding processes	460
12.4	The principles of ZeroFlow gas nitriding	461
12.5	Thermodynamic aspects of nitriding in atmospheres of NH_3 and of two-component $\text{NH}_3 + \text{H}_2$ and $\text{NH}_3 + \text{NH}_3\text{diss.}$ mixes	462
12.6	Kinetic aspects of nitriding in atmospheres of NH_3 and of two-component $\text{NH}_3 + \text{H}_2$ and $\text{NH}_3 + \text{NH}_3\text{diss.}$ mixes	464
12.7	Using the ZeroFlow process under industrial conditions	466
12.8	Applications of the ZeroFlow method	467

12.9	Conclusion	481
	References	482
13	Carburizing of steels	485
	<i>B. Edenhofer, D. Joritz, M. Rink, K. Voges</i>	
13.1	Introduction	485
13.2	Gaseous carburizing	487
13.3	Low pressure carburizing	506
13.4	Hardening	514
13.5	Tempering and sub-zero treatment	520
13.6	Material properties	524
13.7	Furnace technology	532
13.8	Conclusion	549
	References	549
Part Four Low temperature carburizing and nitriding		555
14	Low temperature surface hardening of stainless steel	557
	<i>M. A. J. Somers, T. L. Christiansen</i>	
14.1	Introduction	557
14.2	The origins of low temperature surface engineering of stainless steel	558
14.3	Fundamental aspects of expanded austenite	566
	References	577
15	Gaseous processes for low temperature surface hardening of stainless steel	581
	<i>M. A. J. Somers, T. L. Christiansen</i>	
15.1	Introduction	581
15.2	Surface hardening of austenitic stainless steel	586
15.3	Residual stress in expanded austenite	598
15.4	Prediction of nitrogen diffusion profiles in expanded austenite	602
15.5	Surface hardening of stainless steel types other than austenite	605
15.6	Conclusion and future trends	612
	References	613
16	Plasma-assisted processes for surface hardening of stainless steel	615
	<i>J. P. Lebrun</i>	
16.1	Introduction	615
16.2	Process principles and equipment	615
16.3	Microstructure evolution	620

16.4	Properties of surface hardened steels	627
16.5	Conclusion and future trends	630
	References	632
17	Applications of low-temperature surface hardening of stainless steels	633
	<i>J. P. Lebrun</i>	
17.1	Introduction	633
17.2	Applications in the nuclear industry	633
17.3	Applications in tubular fittings and fasteners	638
17.4	Miscellaneous applications	642
17.5	Conclusion	644
	References	647
Part Five Dedicated thermochemical surface engineering methods		649
18	Boriding to improve the mechanical properties and corrosion resistance of steels	651
	<i>I. E. Campos-Silva, G. A. Rodríguez-Castro</i>	
18.1	Introduction	651
18.2	Boriding of steels	657
18.3	Mechanical characterisation of borided steels	664
18.4	Corrosion resistance of steels exposed to boriding	690
18.5	Conclusion	695
	References	697
19	The thermo-reactive deposition and diffusion process for coating steels to improve wear resistance	703
	<i>T. Arai</i>	
19.1	Introduction	703
19.2	Growth behavior of coatings	708
19.3	High temperature borax bath carbide coating	716
19.4	High temperature fluidizing bed carbide coating	722
19.5	Low temperature salt bath nitride coating	725
19.6	Properties of thermo-reactive deposition (TRD) carbide/nitride coated parts	728
19.7	Applications	733
19.8	Conclusion	733
	References	734

20 Sherardizing: corrosion protection of steels by zinc diffusion coatings	737
<i>F. Natrup, W. Graf</i>	
20.1 Introduction	737
20.2 Pretreatment, surface preparation and processing	738
20.3 Diffusion heat treatment	739
20.4 Post-treatment, inspection and quality control	746
20.5 Corrosion behavior and mechanical properties	748
20.6 Applications	749
20.7 Sources of further information and advice	749
References	750
21 Aluminizing of steel to improve high temperature corrosion resistance	751
<i>V. A. Ravi, T. K. Nguyen, J. C. Nava</i>	
21.1 Introduction	751
21.2 Thermodynamics	753
21.3 Kinetics	755
21.4 Aluminizing of austenitic stainless steel – experimental examples	759
21.5 Applications	764
21.6 Conclusion	765
Acknowledgements	765
References	766
Index	769