

Contents

Preface	xiv
Acknowledgements	xvii

Part

Atomic structure, Arrangement, and Movement

1 Introduction to Materials	2
1.1 Introduction	2
1.2 Types of Materials	2
1.3 Structure-Property-Processing Relationship	7
1.4 Environmental Effects on Material Behaviour	11
1.5 Materials Design and Selection	13
Summary	14
Glossary	15
Problems	16
2 Atomic Structure	18
2.1 Introduction	18
2.2 The Structure of the Atom	18
2.3 The Electronic Structure of the Atom	19
2.4 Atomic Bonding	23
2.5 Binding Energy and Interatomic Spacing	30
Summary	33
Glossary	33
Problems	35
Design Problems	36
3 Atomic Arrangement	38
3.1 Introduction	38
3.2 Short-Range Order Versus Long-Range Order	38
3.3 Unit Cells	40
3.4 Allotropic or Polymorphic Transformations	47
3.5 Points, Directions, and Planes in the Unit Cell	48
3.6 Interstitial Sites	58

3.7	Ionic Crystals	61
3.8	Covalent Structures	64
3.9	X-Ray Diffraction	67
	Summary	70
	Glossary	71
	Problems	73
	Design Problems	79
4	Imperfections in the Atomic Arrangement	80
4.1	Introduction	80
4.2	Dislocations	80
4.3	Significance of Dislocations	87
4.4	Schmid's Law	88
4.5	Influence of Crystal Structure	90
4.6	Point Defects	91
4.7	Surface Defects	97
4.8	Control of the Slip Process	102
	Summary	104
	Glossary	105
	Problems	107
5	Atom Movement in Materials	111
5.1	Introduction	111
5.2	Stability of Atoms	111
5.3	Diffusion Mechanisms	113
5.4	Activation Energy for Diffusion	115
5.5	Rate of Diffusion (Fick's First Law)	115
5.6	Composition Profile (Fick's Second Law)	126
5.7	Diffusion and Materials Processing	130
	Summary	132
	Glossary	133
	Problems	134
	Design Problems	136

Part

2

Controlling the Microstructure and Mechanical Properties of Materials

6	Mechanical Testing and Properties	140
6.1	Introduction	140
6.2	The Tensile Test: Use of the Stress-Strain Diagram	140
6.3	Properties Obtained from the Tensile Test	144
6.4	The Bend Test for Brittle Materials	149
6.5	True Stress – True Strain	152
6.6	The Hardness Test: Its Nature and Use	154

6.7	The Impact Test	159
6.8	Properties Obtained from the Impact Test	160
6.9	Fracture Toughness	163
6.10	The Importance of Fracture Mechanics	165
6.11	The Fatigue Test	166
6.12	Results of the Fatigue Test	168
6.13	Application of Fatigue Testing	169
6.14	The Creep Test	173
6.15	Use of Creep Data	175
	Summary	177
	Glossary	178
	Problems	181
	Design Problems	186
7	Strain Hardening and Annealing	188
7.1	Introduction	188
7.2	Relationship of Cold Working to the Stress-Strain Curve	188
7.3	Strain-Hardening Mechanisms	190
7.4	Properties versus Percent Cold Work	191
7.5	Microstructure and Residual Stresses	195
7.6	Characteristics of Cold Working	199
7.7	The Three Stages of Annealing	202
7.8	Control of Annealing	204
7.9	Annealing and Materials Processing	205
7.10	Hot Working	207
7.11	Superplastic Forming	209
	Summary	209
	Glossary	210
	Problems	212
8	Principles of Solidification Strengthening and Processing	216
8.1	Introduction	216
8.2	Nucleation	216
8.3	Growth	220
8.4	Solidification Time and Dendrite Size	221
8.5	Cooling Curves	226
8.6	Casting or Ingot Structure	227
8.7	Solidification of Polymers	229
8.8	Solidification Defects	230
8.9	Casting Processes	235
8.10	Solidification and Metals Joining	238
	Summary	239
	Glossary	240
	Problems	243

9 Solid Solution Strengthening and Phase Equilibrium	249
9.1 Introduction	249
9.2 Phases and the Unary Phase Diagram	249
9.3 Solubility and Solutions	252
9.4 Conditions for Unlimited Solid Solubility	254
9.5 Solid Solution Strengthening	256
9.6 Isomorphous Phase Diagrams	258
9.7 Relationship Between Properties and the Phase Diagram	266
9.8 Solidification of a Solid Solution Alloy	267
9.9 Nonequilibrium Solidification and Segregation	269
Summary	273
Glossary	274
Problems	275
Design Problems	280
10 Dispersion Strengthening by Solidification	281
10.1 Introduction	281
10.2 Principles of Dispersion Strengthening	281
10.3 Intermetallic Compounds	282
10.4 Phase Diagrams Containing Three-Phase Reactions	286
10.5 The Eutectic Phase Diagram	288
10.6 Strength of Alloys Containing the Eutectic Phase	296
10.7 Eutectics and Materials Processing	303
10.8 Nonequilibrium Freezing in the Eutectic System	305
10.9 Ternary Phase Diagrams	305
Summary	308
Glossary	309
Problems	311
Design Problems	315
11 Dispersion Strengthening by Phase Transformation and Heat Treatment	316
11.1 Introduction	316
11.2 Nucleation and Growth in Solid-State Reactions	316
11.3 Alloys Strengthened by Exceeding the Solubility Limit	320
11.4 Age Hardening or Precipitation Hardening	322
11.5 Effects of Ageing Temperature and Time	325
11.6 Requirements for Age Hardening	326
11.7 Use of Age Hardenable Alloys at High Temperatures	327
11.8 The Eutectoid Reaction	328
11.9 Controlling the Eutectoid Reaction	332
11.10 The Martensitic Reaction and Tempering	338
Summary	343
Glossary	344
Problems	346

Part

3

Engineering Materials

12 Ferrous Alloys	352
12.1 Introduction	352
12.2 Designations for Steels	352
12.3 Simple Heat Treatments	356
12.4 Isothermal Heat Treatments	359
12.5 Quench and Temper Heat Treatments	362
12.6 Effect of Alloying Elements	367
12.7 Application of Hardenability	370
12.8 Special Steels	373
12.9 Surface Treatments	374
12.10 Weldability of Steel	377
12.11 Stainless Steels	378
12.12 Phase Transformations in Cast Irons	381
12.13 Characteristics and Production of the Cast Irons	384
Summary	391
Glossary	392
Problems	396
Design Problems	400
13 Nonferrous Alloys	401
13.1 Introduction	401
13.2 Aluminium Alloys	401
13.3 Magnesium Alloys	412
13.4 Beryllium	414
13.5 Copper Alloys	415
13.6 Nickel and Cobalt	420
13.7 Titanium Alloys	424
13.8 Refractory Metals	431
Summary	432
Glossary	433
Problems	434
Design problems	436
14 Ceramic Materials	437
14.1 Introduction	437
14.2 The Structure of Crystalline Ceramics	438
14.3 The Structure of Crystalline Silicates	440
14.4 Imperfections in Crystalline Ceramic Structures	443
14.5 The Structure of Ceramic Glasses	450
14.6 Mechanical Failure of Ceramics	453
14.7 Deformation of Ceramics at High Temperatures	461
14.8 Processing and Applications of Ceramic Glasses	466
14.9 Processing and Applications of Glass-Ceramics	470
14.10 Processing and Applications of Clay Products	471

14.11	Processing and Applications of Advanced Ceramics	474
14.12	Refractories	478
14.13	Other Ceramic Materials and Applications	480
	Summary	481
	Glossary	482
	Problems	484
	Design problems	487
15	Polymers	488
15.1	Introduction	488
15.2	Classification of Polymers	488
15.3	Chain Formation by the Addition Mechanism	491
15.4	Chain Formation by the Condensation Mechanism	497
15.5	Degree of Polymerisation	499
15.6	Arrangement of Polymer Chains in Thermoplastics	501
15.7	Deformation and Failure of Thermoplastic Polymers	507
15.8	Controlling the Structure and Properties of Thermoplastics	516
15.9	Elastomers (Rubbers)	526
15.10	Thermosetting Polymers	531
15.11	Adhesives	535
15.12	Polymer Additives	536
15.13	Forming of Polymers	537
	Summary	540
	Glossary	541
	Problems	543
	Design problems	547
16	Composite Materials	549
16.1	Introduction	549
16.2	Dispersion-Strengthened Composites	549
16.3	True Particulate Composites	552
16.4	Fibre-Reinforced Composites	558
16.5	Characteristics of Fibre-Reinforced Composites	563
16.6	Manufacturing Fibres and Composites	570
16.7	Fibre-Reinforced Systems and Applications	576
16.8	Laminar Composite Materials	583
16.9	Examples and Applications of Laminar Composites	586
16.10	Sandwich Structures	588
	Summary	589
	Glossary	590
	Problems	592
17	Construction Materials	595
17.1	Introduction	595
17.2	The Structure of Wood	595
17.3	Moisture Content and Density of Wood	597
17.4	Mechanical Properties of Wood	600

17.5	Expansion and Contraction of Wood	602
17.6	Plywood	603
17.7	Concrete Materials	603
17.8	Properties of Concrete	606
17.9	Reinforced and Prestressed Concrete	610
17.10	Asphalt	611
	Summary	611
	Glossary	612
	Problems	613
	Design Problems	613

Part

4

Physical Properties of Engineering Materials

18	Electrical Behaviour of Materials	618
18.1	Introduction	618
18.2	Ohm's Law and Electrical Conductivity	618
18.3	Band Theory	623
18.4	Controlling the Conductivity of Metals	626
18.5	Superconductivity	630
18.6	Conductivity in Other Materials	634
18.7	Intrinsic Semiconductors	636
18.8	Extrinsic Semiconductors	639
18.9	Applications of Semiconductors to Electrical Devices	645
18.10	Manufacture and Fabrication of Semiconductor Devices	649
18.11	Insulators and Dielectric Properties	650
18.12	Dipoles and Polarisation	651
18.13	Dielectric Properties and Their Control	654
18.14	Dielectric Properties and Capacitors	658
18.15	Dielectric Properties and Electrical Insulators	660
18.16	Piezoelectricity and Electrostriction	661
18.17	Ferroelectricity	663
	Summary	664
	Glossary	665
	Problems	668
	Design Problems	671
19	Magnetic Behaviour of Materials	672
19.1	Introduction	672
19.2	Magnetic Dipoles and Magnetic Moments	672
19.3	Magnetisation, Permeability, and the Magnetic Field	674
19.4	Interactions Between Magnetic Dipoles and the Magnetic Field	676
19.5	Domain Structure and the Hysteresis Loop	679
19.6	Application of the Magnetisation-Field Curve	681
19.7	The Curie Temperature	685
19.8	Magnetic Materials	686
	Summary	692

Glossary	693
Problems	694
Design Problems	696
20 Optical Behaviour of Materials	697
20.1 Introduction	697
20.2 The Electromagnetic Spectrum	697
20.3 Examples and Use of Emission Phenomena	698
20.4 Interaction of Photons with a Material	708
20.5 Photonic Systems and Materials	721
Summary	723
Glossary	724
Problems	725
Design Problems	727
21 Thermal Properties of Materials	728
21.1 Introduction	728
21.2 Heat Capacity and Specific Heat	728
21.3 Thermal Expansion	731
21.4 Thermal Conductivity	736
21.5 Thermal Shock	740
Summary	741
Glossary	742
Problems	743
Design Problems	744
Part 5	
Protection Against Deterioration and Failure of Materials	
22 Corrosion and Wear	748
22.1 Introduction	748
22.2 Chemical Corrosion	748
22.3 Electrochemical Corrosion	750
22.4 The Electrode Potential in Electrochemical Cells	753
22.5 The Corrosion Current and Polarisation	758
22.6 Types of Electrochemical Corrosion	758
22.7 Protection Against Electrochemical Corrosion	764
22.8 Microbiological Degradation and Biodegradable Polymers	770
22.9 Oxidation and Other Gas Reactions	771
22.10 Wear and Erosion	775
Summary	777
Glossary	778
Problems	781
Design Problems	783

23 Failure – Origin, Detection, and Prevention	784
23.1 Introduction	784
23.2 Determining the Fracture Mechanism in Metal Failures	784
23.3 Fracture in Nonmetallic Materials	794
23.4 Source and Prevention of Failures in Metals	795
23.5 Nondestructive Testing Methods	800
Summary	814
Glossary	815
Problems	816
Design Problems	819
Answers to selected problems	820
Appendix A: Selected Physical Properties of Elements	830
Appendix B: The Atomic and Ionic Radii of Selected Elements	832
Appendix C: The Electronic Configuration of Each of the Elements	834
Index	836
Periodic Table of the Elements	854