

Contents

Preface	xiii
Acknowledgements	xvii
Resources that accompany this book	xix
Chapter 1 Introduction: materials—history and character	1
1.1 Materials, processes and choice	2
1.2 Material properties	4
1.3 Design-limiting properties	8
1.4 Summary and conclusions	9
1.5 Further reading	10
1.6 Exercises	10
Chapter 2 Family trees: organising materials and processes	13
2.1 Introduction and synopsis	14
2.2 Getting materials organised: the materials tree	14
2.3 Organising processes: the process tree	17
2.4 Process–property interaction	20
2.5 Material property charts	21
2.6 Computer-aided information management for materials and processes	23
2.7 Summary and conclusions	24
2.8 Further reading	25
2.9 Exercises	26
2.10 Exploring design using CES	27
2.11 Exploring the science with CES Elements	28
Chapter 3 Strategic thinking: matching material to design	29
3.1 Introduction and synopsis	30
3.2 The design process	30
3.3 Material and process information for design	33
3.4 The strategy: translation, screening, ranking and documentation	35
3.5 Examples of translation	39
3.6 Summary and conclusions	42
3.7 Further reading	43
3.8 Exercises	43
3.9 Exploring design using CES	45

Chapter 4 Stiffness and weight: density and elastic moduli	47
4.1 Introduction and synopsis	48
4.2 Density, stress, strain and moduli	48
4.3 The big picture: material property charts	57
4.4 The science: what determines density and stiffness?	59
4.5 Manipulating the modulus and density	70
4.6 Summary and conclusions	73
4.7 Further reading	75
4.8 Exercises	75
4.9 Exploring design with CES	77
4.10 Exploring the science with CES Elements	78
Chapter 5 Flex, sag and wobble: stiffness-limited design	81
5.1 Introduction and synopsis	82
5.2 Standard solutions to elastic problems	82
5.3 Material indices for elastic design	90
5.4 Plotting limits and indices on charts	97
5.5 Case studies	100
5.6 Summary and conclusions	107
5.7 Further reading	108
5.8 Exercises	108
5.9 Exploring design with CES	109
5.10 Exploring the science with CES Elements	110
Chapter 6 Beyond elasticity: plasticity, yielding and ductility	111
6.1 Introduction and synopsis	112
6.2 Strength, plastic work and ductility: definition and measurement	112
6.3 The big picture: charts for yield strength	116
6.4 Drilling down: strength and ductility	119
6.5 Manipulating strength	127
6.6 Summary and conclusions	136
6.7 Further reading	136
6.8 Exercises	137
6.9 Exploring design with CES	138
6.10 Exploring the science with CES Elements	138
Chapter 7 Bend and crush: strength-limited design	141
7.1 Introduction and synopsis	142
7.2 Standard solutions to plastic problems	142
7.3 Material indices for yield-limited design	151
7.4 Case studies	155
7.5 Summary and conclusions	160
7.6 Further reading	161

7.7	Exercises	161
7.8	Exploring design with CES	163
Chapter 8 Fracture and fracture toughness		165
8.1	Introduction and synopsis	166
8.2	Strength and toughness	166
8.3	The mechanics of fracture	167
8.4	Material property charts for toughness	174
8.5	Drilling down: the origins of toughness	176
8.6	Manipulating properties: the strength–toughness trade-off	180
8.7	Summary and conclusions	183
8.8	Further reading	183
8.9	Exercises	184
8.10	Exploring design with CES	185
8.11	Exploring the science with CES Elements	185
Chapter 9 Shake, rattle and roll: cyclic loading, damage and failure		187
9.1	Introduction and synopsis	188
9.2	Vibration and resonance: the damping coefficient	188
9.3	Fatigue	189
9.4	Charts for endurance limit	197
9.5	Drilling down: the origins of damping and fatigue	198
9.6	Manipulating resistance to fatigue	200
9.7	Summary and conclusions	202
9.8	Further reading	202
9.9	Exercises	202
9.10	Exploring design with CES	204
Chapter 10 Keeping it all together: fracture-limited design		205
10.1	Introduction and synopsis	206
10.2	Standard solutions to fracture problems	206
10.3	Material indices for fracture-safe design	207
10.4	Case studies	211
10.5	Summary and conclusions	222
10.6	Further reading	222
10.7	Exercises	223
10.8	Exploring design with CES	225
Chapter 11 Rub, slither and seize: friction and wear		227
11.1	Introduction and synopsis	228
11.2	Tribological properties	228
11.3	Charting friction and wear	230

viii Contents

11.4	The physics of friction and wear	232
11.5	Design and selection: materials to manage friction and wear	234
11.6	Summary and conclusions	239
11.7	Further reading	240
11.8	Exercises	240
11.9	Exploring design with CES	241

Chapter 12 Agitated atoms: materials and heat 243

12.1	Introduction and synopsis	244
12.2	Thermal properties: definition and measurement	244
12.3	The big picture: thermal property charts	248
12.4	Drilling down: the physics of thermal properties	251
12.5	Manipulating thermal properties	255
12.6	Design to exploit thermal properties	257
12.7	Summary and conclusions	266
12.8	Further reading	267
12.9	Exercises	267
12.10	Exploring design with CES	269
12.11	Exploring the science with CES Elements	270

Chapter 13 Running hot: using materials at high temperatures 273

13.1	Introduction and synopsis	274
13.2	The temperature dependence of material properties	274
13.3	Charts for creep behaviour	280
13.4	The science: diffusion and creep	282
13.5	Materials to resist creep	292
13.6	Design to cope with creep	295
13.7	Summary and conclusions	302
13.8	Further reading	303
13.9	Exercises	303
13.10	Exploring design with CES	305
13.11	Exploring the science with CES Elements	306

Chapter 14 Conductors, insulators and dielectrics 307

14.1	Introduction and synopsis	308
14.2	Conductors, insulators and dielectrics	309
14.3	Charts for electrical properties	314
14.4	Drilling down: the origins and manipulation of electrical properties	316
14.5	Design: using the electrical properties of materials	328
14.6	Summary and conclusions	334
14.7	Further reading	335
14.8	Exercises	335

14.9	Exploring design with CES	337
14.10	Exploring the science with CES Elements	339

Chapter 15 Magnetic materials 341

15.1	Introduction and synopsis	342
15.2	Magnetic properties: definition and measurement	342
15.3	Charts for magnetic properties	348
15.4	Drilling down: the physics and manipulation of magnetic properties	350
15.5	Materials selection for magnetic design	355
15.6	Summary and conclusions	360
15.7	Further reading	360
15.8	Exercises	361
15.9	Exploring design with CES	361
15.10	Exploring the science with CES Elements	363

Chapter 16 Materials for optical devices 365

16.1	Introduction and synopsis	366
16.2	The interaction of materials and radiation	366
16.3	Charts for optical properties	371
16.4	Drilling down: the physics and manipulation of optical properties	372
16.5	Optical design	380
16.6	Summary and conclusions	381
16.7	Further reading	381
16.8	Exercises	381
16.9	Exploring design with CES	382
16.10	Exploring the science with CES Elements	383

Chapter 17 Durability: oxidation, corrosion, degradation 385

17.1	Introduction and synopsis	386
17.2	Oxidation, flammability and photo-degradation	387
17.3	Oxidation mechanisms	389
17.4	Resistance to oxidation, burning and photo-degradation	393
17.5	Corrosion: acids, alkalis, water and organic solvents	395
17.6	Drilling down: mechanisms of corrosion	395
17.7	Fighting corrosion	403
17.8	Summary and conclusions	416
17.9	Further reading and software	416
17.10	Exercises	417
17.11	Exploring design with CES	418
17.12	Exploring the science with CES Elements	419

Chapter 18 Heat, beat, stick and polish: manufacturing processes	421
18.1 Introduction and synopsis	422
18.2 Process selection in design	422
18.3 Process attributes: material compatibility	424
18.4 Shaping processes: attributes and origins	426
18.5 Joining processes: attributes and origins	434
18.6 Surface treatment (finishing) processes: attributes and origins	437
18.7 Estimating cost for shaping processes	438
18.8 Computer-aided process selection	442
18.9 Case studies	443
18.10 Summary and conclusions	453
18.11 Further reading	454
18.12 Exercises	454
18.13 Exploring design with CES	455
18.14 Exploring the science with CES Elements	457
Chapter 19 Follow the recipe: processing and properties	459
19.1 Introduction and synopsis	460
19.2 Processing for properties	461
19.3 Microstructure of materials	463
19.4 Microstructure evolution in processing	466
19.5 Metals processing	479
19.6 Non-metals processing	493
19.7 Making hybrid materials	496
19.8 Summary and conclusions	499
19.9 Further reading	500
19.10 Exercises	500
19.11 Exploring design with CES	502
Chapter 20 Materials, processes and the environment	503
20.1 Introduction and synopsis	504
20.2 Material consumption and its growth	504
20.3 The material life cycle and criteria for assessment	507
20.4 Definitions and measurement: embodied energy, process energy and end of life potential	509
20.5 Charts for embodied energy	513
20.6 Design: selecting materials for eco-design	515
20.7 Summary and conclusions	520
20.8 Appendix: some useful quantities	521
20.9 Further reading	522
20.10 Exercises	522
20.11 Exploring design with CES	524

Guided Learning Unit 1: simple ideas of crystallography	GL1-1
PART 1: Introduction and synopsis	GL1-2
PART 2: Crystal structures	GL1-2
PART 3: Interstitial space	GL1-6
PART 4: Describing planes	GL1-8
PART 5: Describing directions	GL1-10
PART 6: Ceramic crystals	GL1-12
PART 7: Polymer crystals	GL1-16
Guided Learning Unit 2: Phase diagrams and phase transformations	GL2-1
Introduction and synopsis	GL2-2
PART 1: Key terminology	GL2-3
PART 2: Simple phase diagrams, and how to read them	GL2-7
PART 3: The iron-carbon diagram	GL2-23
PART 4: Interpreting more complex phase diagrams	GL2-27
PART 5: Phase transformations and microstructural evolution	GL2-33
PART 6: Equilibrium solidification	GL2-35
PART 7: Equilibrium solid-state phase changes	GL2-48
PART 8: Non-equilibrium solid-state phase changes	GL2-55
Appendix: Data for engineering materials	A-1
Index	I-1