

Contents

Preface	ix
Acknowledgements	xi
Resources that accompany this book	xii
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	9
1.4 Summary and conclusions	10
1.5 Further reading	10
1.6 Exercises	10
Chapter 2 Family trees: organizing materials and processes	13
2.1 Introduction and synopsis	14
2.2 Getting materials organized: the materials tree	14
2.3 Organizing processes: the process tree	18
2.4 Process–property interaction	21
2.5 Material property charts	22
2.6 Computer-aided information management for materials and processes	24
2.7 Summary and conclusions	25
2.8 Further reading	26
2.9 Exercises	26
2.10 Exploring design using CES	28
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	34
3.4 The strategy: translation, screening, ranking and documentation	36
3.5 Examples of translation	39
3.6 Summary and conclusions	43
3.7 Further reading	43
3.8 Exercises	44
3.9 Exploring design using CES	46

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	56
4.4 The science: what determines density and stiffness?	58
4.5 Manipulating the modulus and density	69
4.6 Summary and conclusions	73
4.7 Further reading	74
4.8 Exercises	74
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	89
5.4 Plotting limits and indices on charts	95
5.5 Case studies	99
5.6 Summary and conclusions	106
5.7 Further reading	107
5.8 Exercises	107
5.9 Exploring design with CES	109
5.10 Exploring the science with CES Elements	109
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: the origins of strength and ductility	118
6.5 Manipulating strength	127
6.6 Summary and conclusions	135
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	149
7.4 Case studies	154
7.5 Summary and conclusions	158
7.6 Further reading	159

7.7	Exercises	159
7.8	Exploring design with CES	161
Chapter 8 Fracture and fracture toughness		163
8.1	Introduction and synopsis	164
8.2	Strength and toughness	164
8.3	The mechanics of fracture	166
8.4	Material property charts for toughness	172
8.5	Drilling down: the origins of toughness	174
8.6	Manipulating properties: the strength–toughness trade-off	178
8.7	Summary and conclusions	181
8.8	Further reading	181
8.9	Exercises	182
8.10	Exploring design with CES	183
8.11	Exploring the science with CES Elements	183
Chapter 9 Shake, rattle and roll: cyclic loading, damage and failure		185
9.1	Introduction and synopsis	186
9.2	Vibration and resonance: the damping coefficient	186
9.3	Fatigue	187
9.4	Charts for endurance limit	194
9.5	Drilling down: the origins of damping and fatigue	195
9.6	Manipulating resistance to fatigue	196
9.7	Summary and conclusions	198
9.8	Further reading	199
9.9	Exercises	199
9.10	Exploring design with CES	202
Chapter 10 Keeping it all together: fracture-limited design		203
10.1	Introduction and synopsis	204
10.2	Standard solutions to fracture problems	204
10.3	Material indices for fracture-safe design	205
10.4	Case studies	209
10.5	Summary and conclusions	220
10.6	Further reading	221
10.7	Exercises	221
10.8	Exploring design with CES	224
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	229
11.4	The physics of friction and wear ³	231

11.5	Design and selection: materials to manage friction and wear	235
11.6	Summary and conclusions	240
11.7	Further reading	241
11.8	Exercises	241
11.9	Exploring design with CES	243

Chapter 12 Agitated atoms: materials and heat **245**

12.1	Introduction and synopsis	246
12.2	Thermal properties: definition and measurement	246
12.3	The big picture: thermal property charts	249
12.4	Drilling down: the physics of thermal properties	251
12.5	Manipulating thermal properties	257
12.6	Design to exploit thermal properties	258
12.7	Summary and conclusions	268
12.8	Further reading	269
12.9	Exercises	270
12.10	Exploring design with CES	271
12.11	Exploring the science with CES Elements	272

Chapter 13 Running hot: using materials at high temperatures **275**

13.1	Introduction and synopsis	276
13.2	The temperature dependence of material properties	276
13.3	Charts for creep behavior	281
13.4	The science: diffusion and creep	284
13.5	Materials to resist creep	293
13.6	Design to cope with creep	296
13.7	Summary and conclusions	304
13.8	Further reading	305
13.9	Exercises	305
13.10	Exploring design with CES	308
13.11	Exploring the science with CES Elements	308

Chapter 14 Conductors, insulators and dielectrics **311**

14.1	Introduction and synopsis	312
14.2	Conductors, insulators and dielectrics	313
14.3	Charts for electrical properties	317
14.4	Drilling down: the origins and manipulation of electrical properties	320
14.5	Design: using the electrical properties of materials	331
14.6	Summary and conclusions	338
14.7	Further reading	338
14.8	Exercises	339
14.9	Exploring design with CES	341
14.10	Exploring the science with CES Elements	343

Chapter 15 Magnetic materials	345
15.1 Introduction and synopsis	346
15.2 Magnetic properties: definition and measurement	346
15.3 Charts for magnetic properties	351
15.4 Drilling down: the physics and manipulation of magnetic properties	353
15.5 Materials selection for magnetic design	358
15.6 Summary and conclusions	363
15.7 Further reading	363
15.8 Exercises	364
15.9 Exploring design with CES	365
15.10 Exploring the science with CES Elements	366
Chapter 16 Materials for optical devices	367
16.1 Introduction and synopsis	368
16.2 The interaction of materials and radiation	368
16.3 Charts for optical properties	373
16.4 Drilling down: the physics and manipulation of optical properties	375
16.5 Optical design	381
16.6 Summary and conclusions	382
16.7 Further reading	383
16.8 Exercises	383
16.9 Exploring design with CES	384
16.10 Exploring the science with CES Elements	385
Chapter 17 Durability: oxidation, corrosion and degradation	387
17.1 Introduction and synopsis	388
17.2 Oxidation, flammability and photo-degradation	388
17.3 Oxidation mechanisms	390
17.4 Making materials that resist oxidation	392
17.5 Corrosion: acids, alkalis, water and organic solvents	395
17.6 Drilling down: mechanisms of corrosion	396
17.7 Fighting corrosion	401
17.8 Summary and conclusions	404
17.9 Further reading	405
17.10 Exercises	405
17.11 Exploring design with CES	406
17.12 Exploring the science with CES Elements	407
Chapter 18 Heat, beat, stick and polish: manufacturing processes	409
18.1 Introduction and synopsis	410
18.2 Process selection in design	410
18.3 Process attributes: material compatibility	413
18.4 Shaping processes: attributes and origins	414

18.5	Joining processes: attributes and origins	423
18.6	Surface treatment (finishing) processes: attributes and origins	426
18.7	Estimating cost for shaping processes	427
18.8	Computer-aided process selection	432
18.9	Case studies	434
18.10	Summary and conclusions	443
18.11	Further reading	444
18.12	Exercises	445
18.13	Exploring design with CES	446
18.14	Exploring the science with CES Elements	447
Chapter 19 Follow the recipe: processing and properties		449
19.1	Introduction and synopsis	450
19.2	Microstructure of materials	450
19.3	Microstructure evolution in processing	454
19.4	Processing for properties	462
19.5	Case studies	464
19.6	Making hybrid materials	472
19.7	Summary and conclusions	474
19.8	Further reading	475
19.9	Exercises	476
19.10	Exploring design with CES	477
Chapter 20 Materials, processes and the environment		479
20.1	Introduction and synopsis	480
20.2	Material consumption and its growth	480
20.3	The material life cycle and criteria for assessment	483
20.4	Definitions and measurement: embodied energy, process energy and end of life potential	484
20.5	Charts for embodied energy	490
20.6	Design: selecting materials for eco-design	493
20.7	Summary and conclusions	497
20.8	Appendix: some useful quantities	498
20.9	Further reading	498
20.10	Exercises	499
20.11	Exploring design with CES	501
Index		503