Contents

Preface xxix
Acknowledgements xxxix
Editors xli
Contributors xliii

Part I
Fundamentals 1
PETER DOMONE AND MARIOS SOUTSOS

1 Atoms, bonding, energy and equilibrium 3

1.1 Atomic structure 3
1.2 Bonding of atoms 6
1.2.1 Ionic bonding 6
1.2.2 Covalent bonding 7
1.2.3 Metallic bonds 9
1.2.4 Van der Waals bonds and the hydrogen bond 10
1.3 Energy and entropy 11
1.3.1 Stable and metastable equilibrium 12
1.3.2 Mixing 12
1.3.3 Entropy 13
1.3.4 Free energy 13
1.4 Equilibrium and equilibrium diagrams 14
1.4.1 Single component diagrams 15
1.4.2 Two-component diagrams 16
1.4.3 Eutectic systems 18
1.4.4 Intermediate compounds 19
References 21

2 Mechanical properties of solids 23

2.1 Stress, strain and stress–strain curves 23
2.2 Elastic behaviour and the elastic constants 26
2.2.1 The elastic moduli 26
2.2.2 Poisson's ratio 27
2.2.3 Relationships between the elastic constants 28
2.2.4 Work done in deformation 29

2.3 *Plastic deformation* 29
2.4 *Failure in tension* 31
2.5 *True stress and strain* 32
2.6 *Behaviour in compression* 33
2.6.1 *Plastic deformation of ductile materials* 33
2.6.2 *Failure of brittle materials* 33
2.7 *Behaviour under constant load: Creep* 35
2.8 *Behaviour under cyclic loading: Fatigue* 37
2.8.1 *Fatigue life and S/N curves* 37
2.8.2 *Cumulative fatigue damage: Miner's rule* 39
2.9 *Impact loading* 40
2.10 *Variability, characteristic strength and the Weibull distribution* 41
2.10.1 *Descriptions of variability* 42
2.10.2 *Characteristic strength* 43
2.10.3 *The Weibull distribution* 45
References 46

3 Structure of solids 47

3.1 *Crystal structure* 47
3.2 *Imperfection and impurities* 52
3.3 *Crystal growth and grain structure* 53
3.4 *Ceramics* 54
3.5 *Polymers* 56
Reference 58

4 Fracture and toughness 59

4.1 *Theoretical strength* 59
4.2 *Fracture mechanics* 61
Reference 65

5 Liquids, viscoelasticity and gels 67

5.1 *Liquids* 67
5.2 *Viscoelastic behaviour* 69
5.3 *Gels and thixotropy* 71

6 Surfaces 73

6.1 *Surface energy* 73
6.2 *Wetting* 74
6.3 *Adhesives* 76
6.4 *Adsorption* 78
6.5 *Water of crystallisation* 79

7 Electrical and thermal properties 81

7.1 *Electrical conductivity* 81

7.2 Thermal conductivity 82
7.3 Coefficient of thermal expansion 82

Example questions for Part I Fundamentals 83

Further reading for Part I Fundamentals 85

Part II
Metals and alloys **87**
MARIOS SOUTSOS AND PETER DOMONE

8 Deformation and strengthening of metals 89

8.1 Elasticity and plasticity 89
8.2 Dislocation movement 89
8.3 Dislocation energy 91
8.4 Strengthening of metals 91
8.4.1 Grain size 92
8.4.2 Strain hardening 93
8.4.3 Annealing 93
8.4.4 Alloying 93
8.4.5 Quenching and tempering 94
8.5 Strengthening, ductility and toughness 95
References 95

9 Forming of metals 97

9.1 Castings 97
9.2 Hot working 97
9.3 Cold working 99
9.4 Joining 99
9.4.1 Welding 99
9.4.2 Brazing, soldering and gluing 100
9.4.3 Bolting and riveting 101
Reference 101

10 Oxidation and corrosion 103

10.1 Dry oxidation 103
10.2 Wet corrosion 104
10.3 The electromotive series 104
10.4 Localised corrosion 106
10.4.1 Intergranular attack 106
10.4.2 Concentration cell corrosion 106
10.4.3 Stress corrosion cracking 107
10.4.4 Corrosion fatigue 107
10.5 Corrosion prevention 107

10.5.1 Design 107
10.5.2 Coatings 108
10.5.3 Cathodic protection 108
10.6 Corrosion control 109
Reference 109

11 Iron and steel 111

11.1 Extraction of iron 111
11.2 Iron–carbon equilibrium diagram 112
11.3 Cast irons 114
11.4 Steel 115
11.4.1 Hot-rolled structural steels 116
11.4.2 Cold-rolled steels 120
11.4.3 Stainless steel 120
11.4.4 Steel reinforcement for concrete 121
11.4.5 Prestressing steel 122
11.5 Recycling of steel 123
References 124

12 Aluminium 125

12.1 Extraction 125
12.2 Aluminium alloys 125
12.3 Recycling of aluminium 127

Example questions for Part II Metals and alloys 128

Further reading for Part II Metals and alloys 129

Part III
Concrete 131
MARIOS SOUTSOS AND PETER DOMONE

13 Portland cements 137

13.1 Manufacture 137
13.2 Physical properties 138
13.3 Chemical composition 139
13.4 Hydration 141
13.5 Structure and strength of hcp 147
13.6 Water in hcp and drying shrinkage 149
13.7 Modifications of Portland cement 151
13.7.1 Setting, strength gain and heat output 151
13.7.2 Sulphate resistance 151
13.7.3 White cement 151

13.8 Cement standards and nomenclature 152
References 153

14 Admixtures **155**

14.1 Action and classification of admixtures 155
14.2 Plasticisers 156
14.3 Superplasticisers 157
14.4 Accelerators 159
14.5 Retarders 160
14.6 Air-entraining agents 161
14.7 Other types of admixtures 162
References 163

15 Additions **165**

15.1 Pozzolanic behaviour 166
15.2 Common additions 166
15.3 Chemical composition and physical properties 167
15.4 Supply and specification 168

16 Other types of cement **171**

16.1 Calcium aluminate cement 171
16.1.1 Manufacture and composition 171
16.1.2 Hydration and conversion 172
16.1.3 Uses 173
16.2 Alkali-activated cements 175
16.3 Geopolymer cements 175
16.4 Magnesium oxide-based cements 176
16.5 Waste-derived cements 176
References 176

17 Aggregates for concrete **179**

17.1 Types of primary aggregates 180
17.1.1 Normal-density aggregates 180
17.1.2 Lightweight aggregate 180
17.1.3 Heavyweight aggregates 180
17.2 Aggregate classification: Shape and size 180
17.3 Other properties of aggregates 184
17.3.1 Porosity and absorption 184
17.3.2 Elastic properties and strength 184
17.3.3 Surface characteristics 185
17.4 Secondary aggregates 185
References 185

18 Properties of fresh concrete 187

18.1 General behaviour 187
18.2 Measurement of consistence 188
18.2.1 Fundamental properties 188
18.2.2 Single-point tests 189
18.3 Factors affecting consistence 193
18.4 Loss of consistence 194
References 195

19 Early-age properties of concrete 197

19.1 Behaviour after placing 197
19.1.1 Segregation and bleeding 197
19.1.2 Plastic settlement 198
19.1.3 Plastic shrinkage 198
19.1.4 Methods of reducing segregation and bleed and their effects 199
19.2 Curing 200
19.3 Strength gain and temperature effects 200
19.3.1 Effect of temperature 200
19.3.2 Maturity 200
19.3.3 Heat of hydration effects 202
References 205

20 Deformation of concrete 207

20.1 Drying shrinkage 207
20.1.1 Drying shrinkage of hcp 207
20.1.2 Mechanisms of shrinkage and swelling 209
20.1.2.1 Capillary tension 210
20.1.2.2 Surface tension or surface energy 211
20.1.2.3 Disjoining pressure 211
20.1.2.4 Movement of interlayer water 212
20.1.3 Drying shrinkage of concrete 212
20.1.3.1 Effect of mix constituents and proportions 212
20.1.3.2 Effect of specimen geometry 213
20.1.4 Prediction of shrinkage 214
20.2 Autogenous shrinkage 215
20.3 Carbonation shrinkage 215
20.4 Thermal expansion 215
20.4.1 Thermal expansion of hcp 216
20.4.2 Thermal expansion of concrete 216
20.5 Stress–strain behaviour 217
20.5.1 Elasticity of the hcp 217
20.5.2 Models for concrete behaviour 218
20.5.2.1 Model A: Phases in parallel 219
20.5.2.2 Model B: Phases in series 220
20.5.2.3 Model C: Combined 220

20.5.3 *Measured stress–strain behaviour of concrete* 221
20.5.4 *Elastic modulus of concrete* 222
20.5.5 *Poisson's ratio* 223
20.6 *Creep* 223
20.6.1 *Factors influencing creep* 225
20.6.2 *Mechanisms of creep* 226
20.6.2.1 *Moisture diffusion* 226
20.6.2.2 *Structural adjustment* 226
20.6.2.3 *Microcracking* 227
20.6.2.4 *Delayed elastic strain* 227
20.6.3 *Prediction of creep* 227
References 227

21 Strength and failure of concrete 229

21.1 *Strength tests* 229
21.1.1 *Compressive strength* 229
21.1.2 *Tensile strength* 232
21.1.2.1 *Splitting test* 232
21.1.2.2 *Flexural test* 233
21.1.3 *Relationship between strength measurements* 234
21.2 *Factors influencing strength of Portland cement concrete* 235
21.2.1 *Transition/interface zone* 235
21.2.2 *Water/cement ratio* 236
21.2.3 *Age* 238
21.2.4 *Temperature* 239
21.2.5 *Humidity* 239
21.2.6 *Aggregate properties, size and volume concentration* 240
21.3 *Strength of concrete containing additions* 241
21.4 *Cracking and fracture in concrete* 243
21.4.1 *Development of microcracking* 243
21.4.2 *Creep rupture* 244
21.4.3 *The fracture mechanics approach* 245
21.5 *Strength under multiaxial loading* 246
References 247

22 Concrete mix design 249

22.1 *The mix design process* 249
22.1.1 *Specified concrete properties* 249
22.1.2 *Constituent material properties* 250
22.1.3 *Initial estimate of mix proportions* 250
22.1.4 *Laboratory trial mixes* 251
22.1.5 *Full-scale trial mixes* 251
22.2 *U.K. method of 'Design of normal concrete mixes' (BRE, 1997)* 251
22.2.1 *Target mean strength* 251
22.2.2 *Free water/cement ratio* 252

22.2.3 Free water content 252
22.2.4 Cement content 252
22.2.5 Total aggregate content 253
22.2.6 Fine and coarse aggregate content 254
22.3 Mix design with additions 255
22.4 Design of mixes containing admixtures 256
22.4.1 Mixes with plasticisers 256
22.4.2 Mixes with superplasticisers 256
22.4.3 Mixes with air-entraining agents 257
22.5 Other mix design methods 257
References 257

23 Non-destructive testing of hardened concrete **259**

23.1 Surface hardness: Rebound (or Schmidt) hammer test 259
23.2 Ultrasonic pulse velocity test 261
23.3 Resonant frequency test 263
23.4 Near-to-surface tests 264
23.5 Other tests 266
References 266

24 Durability of concrete **267**

24.1 Transport mechanisms through concrete 267
24.2 Measurements of flow constants for cement paste and concrete 270
24.2.1 Permeability 270
24.2.2 Diffusivity 273
24.2.3 Sorptivity 274
24.3 Degradation of concrete 276
24.3.1 Attack by sulphates 276
24.3.2 The thaumasite form of sulphate attack 279
24.3.3 Sea water attack 280
24.3.4 Acid attack 281
24.3.5 Alkali–aggregate and alkali–silica reaction 281
24.3.6 Frost attack: Freeze–thaw damage 285
24.3.7 Fire resistance 287
24.4 Durability of steel in concrete 288
24.4.1 General principles of the corrosion of the steel in concrete 289
24.4.2 Carbonation-induced corrosion 290
24.4.3 Chloride-induced corrosion 292
References 295

25 Special concretes **297**

25.1 Lightweight aggregate concrete 297
25.2 High-density aggregate concrete 298
25.3 No-fines concrete 299
25.4 Sprayed concrete 299

25.5 High-strength concrete 300
25.6 Flowing concrete 301
25.7 Self-compacting concrete 302
25.8 Underwater concrete 303
25.9 Foamed concrete 304
25.10 Aerated concrete 305
References 305

26 Recycling of concrete 307

26.1 Recycling of fresh concrete 307
26.2 Recycling of concrete after demolition 307
References 309

Example questions for Part III Concrete 310

Further reading for Part III Concrete 312

Part IV
Polymers **319**
VASILEIOS KOUTSOS

27 Polymers: Types, properties and applications 321

27.1 Polymeric materials 321
27.1.1 Thermoplastic polymers 321
27.1.2 Thermosetting polymers 321
27.1.3 Foamed polymers 322
27.2 Processing of thermoplastic polymers 322
27.2.1 Profile production 323
27.2.2 Film-blown plastic sheet 323
27.2.3 Blow-moulded hollow plastic articles 323
27.2.4 Co-extrusion items 323
27.2.5 Highly orientated grid sheets 323
27.3 Polymer properties 324
27.3.1 Mechanical properties 324
27.3.2 Time-dependent characteristics 324
27.4 Applications and uses of polymers 328
27.4.1 Sealants 328
27.4.2 Adhesives 329
27.4.3 Elastomers 330
27.4.4 Geosynthetics 330
27.4.4.1 Geotextiles 331
27.4.4.2 Geomembranes 331
27.4.4.3 Geo-linear elements 331
27.4.4.4 Geogrids 332
27.4.4.5 Geocomposites 332

References 332
Bibliography 332

Example questions for Part IV Polymers 334

Further reading for Part IV Polymers 335

Part V
Fibre composites **337**
PHILIP PURNELL

28 Reinforcing fibre materials 341

28.1 Glass fibres 341
28.2 Carbon fibres 344
28.3 Polymer fibres 345
28.3.1 Aramid fibres 346
28.4 Natural fibres 346
28.5 Steel fibres 347
28.6 Asbestos fibres 348
References 349

29 Reinforcing fibre architecture 351

29.1 Volume fraction 351
29.2 Reinforcement elements 352
29.3 Reinforcement layouts 353
29.3.1 Fibre length and the critical length 353
29.3.2 Fibre orientation 354
29.3.3 Efficiency factors 355
29.3.4 Textile reinforcement 356
References 358

30 Matrices 359

30.1 Fibre-reinforced polymer matrices 359
30.2 Fibre-reinforced concrete matrices 359
References 360

31 Interfaces and bonding 361

31.1 Interfaces and bonding in frp 361
31.1.1 Coupling agents and surface treatments 361
31.1.2 Bonding 362
31.2 Interfaces and bonding in frc 362
31.2.1 Interfacial morphology and properties 362
31.2.2 Bonding 363
References 364

32 Mechanical behaviour and properties of composites 365

32.1 Fundamental composite properties 365
32.1.1 Longitudinal stiffness 365
32.1.2 Transverse stiffness 366
32.1.3 Intermediate behaviour, efficiency factors and composite strength 367
32.2 Complex composite behaviour 368
32.3 Laminate composite behaviour (frp) 369
32.4 Brittle matrix composite theory (frc) 370
32.4.1 Composite materials approach 371
32.4.2 Critical fibre volume fraction 371
32.4.3 Primary frc: ACK theory and multiple cracking 373
32.4.4 Post-cracking behaviour 375
32.4.5 Failure, post-peak behaviour and secondary frc 376
32.4.6 Intermediate behaviour 377
32.4.7 High modulus/high V_f behaviour 377
32.4.8 Fracture mechanics approach 378
32.4.9 Crack suppression 378
32.4.10 Crack stabilisation 379
32.4.11 Fibre/matrix debonding 381
32.5 Typical mechanical properties 382
References 384

33 Manufacture of fibre composites 385

33.1 Manufacture of frp for construction 385
33.1.1 Manual processes for frp 385
33.1.2 Semi-automated processes for frp 387
33.1.3 Automated processes for frp 388
33.2 Manufacture of frc 389
33.2.1 Cast premix 389
33.2.2 Sprayed premix 390
33.2.3 Dual-spray systems 391
33.2.4 Hand lay-up 391
33.2.5 Automated systems 392
References 393

34 Applications of fibre composites in construction 395

34.1 Applications for frp in construction 395
34.1.1 Structural systems 395
34.1.2 Rehabilitation systems 397
34.1.3 Concrete column confinement 400
34.1.4 Internal concrete reinforcement 401
34.1.5 Hybrid systems 402
34.1.6 Bridge enclosures 403

34.2 Applications for frc in construction 404
34.2.1 Architectural cladding: Glass-frc 404
34.2.2 Tunnel linings: Steel-frc and polymer-frc 405
34.2.3 Industrial flooring: Steel-frc and polymer-frc 407
34.2.4 Sheet materials for building: Natural-frc 409
34.2.5 Permanent formwork: Glass-frc 409
References 410

35 Durability 413

35.1 Durability of frp 414
35.1.1 Moisture and solutions 414
35.1.2 Temperature effects 414
35.1.3 Ultraviolet radiation 415
35.1.4 Fatigue 415
35.1.5 Creep 415
35.1.6 Bond durability in strengthening systems 416
35.1.7 Durability of frp rebars 416
35.1.8 Material degradation models for frp 416
35.2 Durability of frc 417
35.2.1 Multifilament/microfibre frc 417
35.2.2 Monofilament/macrofibre frc 418
35.2.3 Property loss mechanisms 419
35.2.4 Fibre weakening 419
35.2.5 Continued matrix hydration 419
35.2.6 Designing durable frc 422
35.2.7 Modelling and service life prediction 422
References 423

36 Recycling 425

36.1 Recycling of frp 425
36.2 Recycling of frc 426
References 426

Example questions for Part V Composites 427

Further reading for Part V Composites 429

Part VI
Glass 431
GRAHAM DODD

37 Manufacture and processing 433

37.1 Manufacturing of flat glass 433
37.1.1 Glassmaking materials 433

37.1.2 Composition 433
37.1.3 Constituents and microstructure of glass 434
37.1.4 Historical processes 434
37.1.5 Rolled glass (including wired and polished wired) 435
37.1.6 Float glass 435
37.1.7 Fusion-draw process 436
37.2 Coatings 436
37.2.1 Low emissivity 437
37.2.2 Solar control 437
37.2.3 Selective, high performance 437
37.2.4 Self-cleaning 437
37.3 Strengthening processes 438
37.3.1 Toughening (tempering) and the heat soak test 438
37.3.2 Heat strengthening 439
37.3.3 Chemical strengthening 440
37.4 Forming processes 440
37.4.1 Bending 440
37.4.2 Bending and tempering 440
37.4.3 Channel glass 441
37.5 Decoration processes 441
37.5.1 Sand blasting 441
37.5.2 Acid etching 441
37.5.3 Fritting 442
37.5.4 Stained glass 442
37.5.5 Printing 442
37.6 Laminating 442
37.7 Insulating unit manufacture 444
37.8 Fire-resisting glasses 445
References 446

38 Properties and performance **447**

38.1 Physical properties 447
38.2 Mechanical properties 447
38.2.1 Patterns of breakage 447
38.2.2 Strength of glass 447
38.2.3 Static fatigue 450
38.2.4 Post-breakage characteristics of laminated glass combinations 450
38.2.4.1 Annealed/annealed 450
38.2.4.2 Heat strengthened/heat strengthened 451
38.2.4.3 Toughened/toughened 451
38.2.4.4 Toughened/heat strengthened 451
Reference 451

39 Design and applications **453**

39.1 Design of glazing and selection of glass type 453

39.2 Deflection limits for glazing 453
39.2.1 Deflection criteria 453
39.2.2 Guidance from standards 454
39.3 Design stresses and load factors 454
39.3.1 Strength of laminated glass 454
39.4 Windows 455
39.4.1 Design of insulating units 455
39.5 Glass walls and structural glass assemblies 456
39.6 Skylights 456
39.7 Floors and stairs 456
39.8 Glazing for security 456
References 457

40 Service and end of life 459

40.1 Durability 459
40.1.1 Cleaning 459
40.1.2 Protection on site 459
40.1.3 Failure of double-glazed units 460
40.1.4 Delamination of laminated glass 460
40.2 What to do if glass breaks 460
40.3 Disposal and recycling 460
References 461

Example questions for Part VI Glass 462

Further reading for Part VI Glass 463

Part VII
Timber **465**
JOHN M. DINWOODIE

41 Structure of timber and the presence of moisture 469

41.1 Structure at the macroscopic level 469
41.2 Structure at the microscopic level 471
41.3 Molecular structure and ultrastructure 477
41.3.1 Chemical constituents 477
41.3.1.1 Cellulose 477
41.3.1.2 Hemicelluloses and lignin 480
41.3.1.3 Extractives 481
41.3.1.4 Minerals 481
41.3.1.5 Acidity 481
41.3.2 The cell wall as a fibre composite 482
41.3.3 Cell wall layers 483
41.4 Variability in structure 486

41.5 Appearance of timber in relation to its structure 487
41.5.1 Texture 487
41.5.2 Figure 487
41.5.2.1 Grain 488
41.5.2.2 Growth rings 489
41.5.2.3 Rays 489
41.5.2.4 Knots 489
41.5.3 Colour 490
41.6 Mass–volume relationships 491
41.6.1 Density 491
41.6.2 Specific gravity 492
41.6.3 Density of the dry cell wall 494
41.6.4 Porosity 494
41.7 Moisture in timber 494
41.7.1 Equilibrium moisture content 494
41.7.2 Determination of moisture content 495
41.7.3 The moisture content of green timber 496
41.7.4 Removal of moisture from timber 497
41.7.5 Influence of structure 497
41.7.6 Fibre saturation point 498
41.7.7 Sorption 499
41.8 Flow in timber 499
41.8.1 Bulk flow and permeability 501
41.8.1.1 Flow of fluids 501
41.8.1.2 Flow paths in timber 502
41.8.1.3 Timber and the laws of flow 505
41.8.2 Moisture diffusion 506
41.8.3 Thermal conductivity 507
References 508

42 Deformation in timber **511**

42.1 Introduction 511
42.2 Dimensional change due to moisture 511
42.2.1 Shrinkage 511
42.2.1.1 Anisotropy in shrinkage 511
42.2.1.2 Practical significance 513
42.2.2 Movement 513
42.3 Thermal movement 515
42.4 Deformation under load 516
42.4.1 Elastic deformation 517
42.4.1.1 Orthotropic elasticity and timber 520
42.4.1.2 Factors influencing the elastic modulus 520
42.4.2 Viscoelastic deformation 526
42.4.2.1 Creep 527
References 539

43 Strength and failure in timber 543

43.1 Introduction 543
43.2 Determination of strength 543
43.2.1 Test piece size and selection 543
43.2.1.1 Use of small clear test pieces 544
43.2.1.2 Use of structural-size test pieces 544
43.2.2 Standardised test procedures 544
43.3 Strength values 544
43.3.1 Derived using small clear test pieces 544
43.3.2 Derived using structural-size test pieces 546
43.4 Variability in strength values 547
43.5 Inter-relationships among the strength properties 548
43.5.1 Modulus of rupture (bending strength) and modulus of elasticity 548
43.5.2 Impact bending and total work 548
43.5.3 Hardness and compression perpendicular to the grain 548
43.6 Factors affecting strength 548
43.6.1 Anisotropy and grain angle 549
43.6.2 Knots 550
43.6.3 Density 550
43.6.4 Ring width 551
43.6.5 Ratio of latewood to earlywood 552
43.6.6 Cell length 553
43.6.7 Microfibrillar angle 553
43.6.8 Chemical composition 553
43.6.9 Reaction wood 554
43.6.9.1 Compression wood 554
43.6.9.2 Tension wood 554
43.6.10 Moisture content 554
43.6.11 Temperature 555
43.6.12 Time 556
43.6.12.1 Rate of loading 557
43.6.12.2 Duration of load 557
43.7 Strength, toughness, failure and fracture morphology 559
43.7.1 Classical approach 559
43.7.1.1 Tensile strength parallel to the grain 559
43.7.1.2 Compression strength parallel to the grain 562
43.7.1.3 Static bending 564
43.7.1.4 Toughness 564
43.7.1.5 Fatigue 565
43.7.2 Engineering approach to strength and fracture 567
43.8 Structural design in timber 567
43.8.1 Visual grading 567
43.8.2 Machine grading 568

43.8.3 Strength classes 568
43.8.4 Structural design 568
References 570

44 Durability of timber 573

44.1 Introduction 573
44.2 Chemical, physical and mechanical agencies affecting durability and causing degradation 573
44.2.1 Photochemical degradation 573
44.2.2 Chemical degradation 574
44.2.3 Thermal degradation 574
44.2.4 Mechanical degradation 574
44.3 Natural durability and attack by fungi and insects 575
44.3.1 Natural durability 575
44.3.2 Nature of fungal decay 577
44.3.3 Nature of insect attack 578
44.3.4 Marine borers 579
44.4 Performance of timber in fire 579
44.4.1 Methods of assessing reaction to fire of constructional materials 581
44.4.1.1 The U.K. position 582
44.4.1.2 The use of national and CEN standards 582
References 583

45 Processing and recycling of timber 585

45.1 Introduction 585
45.2 Mechanical processing 585
45.2.1 Solid timber 585
45.2.1.1 Sawing and planing 585
45.2.1.2 Steam bending 587
45.2.2 Wood-based panels (board materials) 587
45.2.2.1 Plywood 588
45.2.2.2 Particleboard (chipboard) 590
45.2.2.3 MDF (dry-process fibreboard) 591
45.2.2.4 Wet-process fibreboard 591
45.2.2.5 OSB (oriented strand board) 592
45.2.2.6 CBPB (cement bonded particleboard) 592
45.2.2.7 Comparative performance of the wood-based boards 592
45.2.3 Laminated timber 593
45.2.4 Engineered structural lumber 595
45.2.5 Mechanical pulping 595
45.2.6 Recycling of timber waste 596
45.2.6.1 Case study 1 597
45.2.6.2 Case study 2 597
45.2.6.3 Case study 3 597

45.3 Chemical processing 597
45.3.1 Treatability 597
45.3.1.1 Preservatives and preservation 598
45.3.1.2 Flame retardants 600
45.3.1.3 Dimensional stabilisers and durability enhancers 601
45.3.2 Chemical pulping 602
45.3.3 Other chemical processes 603
45.4 Thermal processing 604
45.5 Finishes 604
45.5.1 Flame-retardant coatings 606
References 607

Example questions for Part VII Timber 609

Further reading for Part VII Timber 610

Part VIII
Masonry: Brickwork, blockwork and stonework **613**
PAULO B. LOURENÇO

46 Materials and components for masonry 617

46.1 Basic terminology 617
46.2 Materials used for manufacture of units and mortars 619
46.2.1 Rocks, sand and fillers 619
46.2.1.1 Rock (or stone) 619
46.2.1.2 Sand: Nature and composition 619
46.2.1.3 Mortar and rendering sands 619
46.2.1.4 Fly ash (pulverised fuel ash) 620
46.2.1.5 Chalk ($CaCO_3$) 620
46.2.2 Clays 620
46.2.3 Lightweight aggregates 621
46.2.4 Binders 622
46.2.4.1 Cement 622
46.2.4.2 Masonry cement 622
46.2.4.3 Lime and hydraulic lime 622
46.2.4.4 Calcium silicate 623
46.3 Other constituents and additives 623
46.3.1 Organic plasticisers 623
46.3.2 Latex additives 623
46.3.3 Pigments 624
46.3.4 Retarders 624
46.3.5 Accelerators 624
46.4 Mortar 624
46.4.1 Properties of freshly mixed (unset) mortar 625

46.4.2 *Properties of hardened mortar* 626
46.4.3 *Thin-bed and lightweight mortars* 628
46.5 *Fired clay bricks and blocks* 628
46.5.1 *Forming and firing* 628
46.5.1.1 *Soft mud process* 628
46.5.1.2 *Stiff plastic process* 629
46.5.1.3 *Wirecut process* 629
46.5.1.4 *Semi-dry pressing* 630
46.5.1.5 *Drying and firing in Hoffman kilns* 630
46.5.1.6 *Drying and firing in tunnel kilns* 631
46.5.1.7 *Clamps* 632
46.5.1.8 *Intermittent kilns* 632
46.5.2 *Properties* 632
46.6 *Calcium silicate units* 635
46.7 *Concrete and manufactured stone units* 635
46.7.1 *Production processes for concrete units* 636
46.7.1.1 *Casting concrete* 636
46.7.1.2 *Pressing of concrete* 636
46.7.1.3 *Curing* 636
46.7.2 *Concrete products* 637
46.7.2.1 *Dense aggregate concrete blocks and concrete bricks* 637
46.7.2.2 *Manufactured stone masonry units* 637
46.7.2.3 *Lightweight aggregate concrete blocks* 638
46.8 *Aircrete (AAC)* 638
46.8.1 *Manufacturing process* 639
46.8.2 *Properties* 639
46.9 *Natural stone units* 640
46.10 *Ancillary devices* 640
References 641

47 Masonry construction and forms 643

47.1 *Walls and other masonry forms* 643
47.2 *Bond patterns* 645
47.3 *Use of specials* 647
47.4 *Joint style* 649
47.5 *Workmanship and accuracy* 649
47.6 *Buildability, site efficiency and productivity* 649
47.7 *Appearance* 650
References 650

48 Structural behaviour and movement of masonry 651

48.1 *General considerations* 651
48.2 *Compressive loading* 653
48.2.1 *Axial loads* 653

48.2.2 *Stability: Slender structures and eccentricity* 656
48.2.3 *Concentrated load* 657
48.2.4 *Cavity walls in compression* 658
48.3 *Shear loading* 658
48.4 *Flexure (bending)* 660
48.5 *Tension* 663
48.6 *Elastic modulus* 664
48.7 *Building (seismic) behaviour* 665
48.8 *Movement and creep* 666
References 667

49 Non-structural physical properties of masonry 669

49.1 *Thermal performance* 669
49.2 *Resistance to damp and rain penetration* 671
49.3 *Moisture vapour permeability* 672
49.4 *Sound transmission* 673
49.5 *Fire resistance* 673
References 674

50 Deterioration, conservation and strengthening of masonry 675

50.1 *Chemical attack* 675
50.1.1 *Water and acid rain* 675
50.1.2 *Carbonation* 677
50.1.3 *Sulphate attack* 677
50.1.4 *Acids* 678
50.1.5 *Chlorides* 678
50.1.6 *Corrosion of embedded metals* 678
50.2 *Erosion* 678
50.2.1 *Freeze–thaw attack* 679
50.2.2 *Crypto-efflorescence (sub-florescence) damage* 680
50.2.3 *Abrasion* 680
50.3 *Stress effects* 681
50.4 *Staining* 681
50.4.1 *Efflorescence* 681
50.4.2 *Lime staining* 682
50.4.3 *Iron staining* 682
50.4.4 *Biological staining* 682
50.5 *Conservation of masonry* 683
50.5.1 *Principles* 683
50.5.2 *Replacement materials: Stone* 684
50.5.3 *Replacement materials: Clay bricks, terracotta ware, concrete and calcium silicate units* 685
50.5.4 *Replacement materials: Mortars* 685
50.5.5 *Selection of replacement materials* 686
50.5.6 *Repair methods* 686