

CONTENTS

Preface xiv

About the Authors xviii

ONE

Materials Engineering Concepts 1

- 1.1 Economic Factors 2
- 1.2 Mechanical Properties 3
 - 1.2.1 • Loading Conditions 4
 - 1.2.2 • Stress–Strain Relations 5
 - 1.2.3 • Elastic Behavior 5
 - 1.2.4 • Elastoplastic Behavior 8
 - 1.2.5 • Viscoelastic Behavior 12
 - 1.2.6 • Temperature and Time Effects 17
 - 1.2.7 • Work and Energy 18
 - 1.2.8 • Failure and Safety 18
- 1.3 Nonmechanical Properties 21
 - 1.3.1 • Density and Unit Weight 21
 - 1.3.2 • Thermal Expansion 22
 - 1.3.3 • Surface Characteristics 23
- 1.4 Production and Construction 24
- 1.5 Aesthetic Characteristics 25
- 1.6 Sustainable Design 26
- 1.7 Material Variability 27
 - 1.7.1 • Sampling 28
 - 1.7.2 • Normal Distribution 29
 - 1.7.3 • Control Charts 29
 - 1.7.4 • Experimental Error 32

1.8 Laboratory Measuring Devices 32

- 1.8.1 • Dial Gauge 33
- 1.8.2 • Linear Variable Differential Transformer (LVDT) 33
- 1.8.3 • Strain Gauge 37
- 1.8.4 • Non-Contact Deformation Measurement Technique 38
- 1.8.5 • Proving Ring 38
- 1.8.6 • Load Cell 39

Summary 40

Questions and Problems 41

1.9 References 51



TWO

Nature of Materials 52

2.1 Basic Materials Concepts 52

- 2.1.1 • Electron Configuration 52
- 2.1.2 • Bonding 55
- 2.1.3 • Material Classification by Bond Type 58

2.2 Metallic Materials 58

- 2.2.1 • Lattice Structure 59
- 2.2.2 • Lattice Defects 63
- 2.2.3 • Grain Structure 64
- 2.2.4 • Alloys 67
- 2.2.5 • Phase Diagrams 67
- 2.2.6 • Combined Effects 73

2.3 Inorganic Solids 73

2.4 Organic Solids 75

- 2.4.1 • Polymer Development, Structure, and Cross-Linking 76
- 2.4.2 • Melting and Glass Transition Temperature 79
- 2.4.3 • Mechanical Properties 80

Summary 81

Questions and Problems 81

2.5 References 84

Appendix 483**Experiments**

1. Introduction to Measuring Devices 484
2. Tension Test of Steel and Aluminum 487
3. Torsion Test of Steel and Aluminum 490
4. Impact Test of Steel 493
5. Microscopic Inspection of Materials 496
6. Sieve Analysis of Aggregates 497
7. Specific Gravity and Absorption of Coarse Aggregate 501
8. Specific Gravity and Absorption of Fine Aggregate 503
9. Bulk Unit Weight and Voids in Aggregate 505
10. Slump of Freshly Mixed Portland Cement Concrete 508
11. Unit Weight and Yield of Freshly Mixed Concrete 511
12. Air Content of Freshly Mixed Concrete by Pressure Method 513
13. Air Content of Freshly Mixed Concrete by Volumetric Method 515
14. Making and Curing Concrete Cylinders and Beams 517
15. Capping Cylindrical Concrete Specimens with Sulfur or Capping Compound 521
16. Compressive Strength of Cylindrical Concrete Specimens 523
17. Flexural Strength of Concrete 526
18. Rebound Number of Hardened Concrete 529
19. Penetration Resistance of Hardened Concrete 531
20. Testing of Concrete Masonry Units 534
21. Viscosity of Asphalt Binder by Rotational Viscometer 537
22. Dynamic Shear Rheometer Test of Asphalt Binder 539
23. Penetration Test of Asphalt Cement 541
24. Absolute Viscosity Test of Asphalt 543
25. Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyrotory Compactor 545
26. Preparation of Asphalt Concrete Specimens Using the Marshall Compactor 548
27. Bulk Specific Gravity of Compacted Bituminous Mixtures 551
28. Marshall Stability and Flow of Asphalt Concrete 553
29. Bending (Flexure) Test of Wood 555
30. Tensile Properties of Plastics 561

Index 563

THREE

Steel 85

- 3.1 Steel Production 87
- 3.2 Iron–Carbon Phase Diagram 89
- 3.3 Heat Treatment of Steel 93
 - 3.3.1 • Annealing 93
 - 3.3.2 • Normalizing 94
 - 3.3.3 • Hardening 95
 - 3.3.4 • Tempering 95
 - 3.3.5 • Example of Heat Treatment 95
- 3.4 Steel Alloys 95
- 3.5 Structural Steel 97
 - 3.5.1 • Structural Steel Grades 97
 - 3.5.2 • Sectional Shapes 100
 - 3.5.3 • Specialty Steels in Structural Applications 101
- 3.6 Cold-Formed Steel 106
 - 3.6.1 • Cold-Formed Steel Grades 106
 - 3.6.2 • Cold-Formed Steel Shapes 107
 - 3.6.3 • Special Design Considerations for Cold-Formed Steel 109
- 3.7 Fastening Products 109
- 3.8 Reinforcing Steel 111
 - 3.8.1 • Conventional Reinforcing 111
 - 3.8.2 • Steel for Prestressed Concrete 115
- 3.9 Mechanical Testing of Steel 116
 - 3.9.1 • Tension Test 116
 - 3.9.2 • Torsion Test 119
 - 3.9.3 • Charpy V Notch Impact Test 122
 - 3.9.4 • Bend Test 124
 - 3.9.5 • Hardness Test 125
 - 3.9.6 • Ultrasonic Testing 125
- 3.10 Welding 126
- 3.11 Steel Corrosion 129
 - 3.11.1 • Methods for Corrosion Resistance 130
- Summary 131
- Questions and Problems 131
- 3.12 References 139

FOUR

Aluminum 140

- 4.1 Aluminum Production 143
- 4.2 Aluminum Metallurgy 145
 - 4.2.1 • Alloy Designation System 147
 - 4.2.2 • Temper Treatments 148
- 4.3 Aluminum Testing and Properties 151
- 4.4 Welding and Fastening 156
- 4.5 Corrosion 157
 - Summary 157
 - Questions and Problems 157
- 4.6 References 162

FIVE

Aggregates 163

- 5.1 Aggregate Sources 164
- 5.2 Geological Classification 165
- 5.3 Evaluation of Aggregate Sources 165
- 5.4 Aggregate Uses 166
- 5.5 Aggregate Properties 167
 - 5.5.1 • Particle Shape and Surface Texture 169
 - 5.5.2 • Soundness and Durability 171
 - 5.5.3 • Toughness, Hardness, and Abrasion Resistance 172
 - 5.5.4 • Absorption 173
 - 5.5.5 • Specific Gravity 175
 - 5.5.6 • Bulk Unit Weight and Voids in Aggregate 177
 - 5.5.7 • Strength and Modulus 178
 - 5.5.8 • Gradation 178
 - 5.5.9 • Cleanness and Deleterious Materials 194
 - 5.5.10 • Alkali–Aggregate Reactivity 195
 - 5.5.11 • Affinity for Asphalt 197
- 5.6 Handling Aggregates 198
 - 5.6.1 • Sampling Aggregates 199

- Summary 200
 Questions and Problems 200
 5.7 References 209

SIX

Portland Cement, Mixing Water, and Admixtures 210

- 6.1 Portland Cement Production 210
 6.2 Chemical Composition of Portland Cement 211
 6.3 Fineness of Portland Cement 213
 6.4 Specific Gravity of Portland Cement 214
 6.5 Hydration of Portland Cement 214
 6.5.1 • Structure Development in Cement Paste 216
 6.5.2 • Evaluation of Hydration Progress 216
 6.6 Voids in Hydrated Cement 218
 6.7 Properties of Hydrated Cement 218
 6.7.1 • Setting 218
 6.7.2 • Soundness 220
 6.7.3 • Compressive Strength of Mortar 221
 6.8 Water–Cement Ratio 221
 6.9 Types of Portland Cement 222
 6.9.1 • Standard Portland Cement Types 222
 6.9.2 • Other Cement Types 225
 6.10 Mixing Water 226
 6.10.1 • Acceptable Criteria 226
 6.10.2 • Disposal and Reuse of Concrete Wash Water 228
 6.11 Admixtures for Concrete 228
 6.11.1 • Air Entrainers 229
 6.11.2 • Water Reducers 230
 6.11.3 • Retarders 233
 6.11.4 • Hydration-Control Admixtures 234
 6.11.5 • Accelerators 234
 6.11.6 • Specialty Admixtures 235
 6.12 Supplementary Cementitious Materials 236
 Summary 239
 Questions and Problems 240
 6.13 References 245

SEVEN

Portland Cement Concrete 246

7.1 Proportioning of Concrete Mixes 246

- 7.1.1 • Basic Steps for Weight and Absolute Volume Methods 247
- 7.1.2 • Mixing Concrete for Small Jobs 263

7.2 Mixing, Placing, and Handling Fresh Concrete 266

- 7.2.1 • Ready-Mixed Concrete 266
- 7.2.2 • Mobile Batcher Mixed Concrete 267
- 7.2.3 • Depositing Concrete 267
- 7.2.4 • Pumped Concrete 267
- 7.2.5 • Vibration of Concrete 270
- 7.2.6 • Pitfalls and Precautions for Mixing Water 272
- 7.2.7 • Measuring Air Content in Fresh Concrete 272
- 7.2.8 • Spreading and Finishing Concrete 274

7.3 Curing Concrete 274

- 7.3.1 • Ponding or Immersion 280
- 7.3.2 • Spraying or Fogging 280
- 7.3.3 • Wet Coverings 280
- 7.3.4 • Impervious Papers or Plastic Sheets 281
- 7.3.5 • Membrane-Forming Compounds 282
- 7.3.6 • Forms Left in Place 282
- 7.3.7 • Steam Curing 283
- 7.3.8 • Insulating Blankets or Covers 283
- 7.3.9 • Electrical, Hot Oil, and Infrared Curing 285
- 7.3.10 • Curing Period 285

7.4 Properties of Hardened Concrete 285

- 7.4.1 • Early Volume Change 285
- 7.4.2 • Creep Properties 286
- 7.4.3 • Permeability 286
- 7.4.4 • Stress–Strain Relationship 287

7.5 Testing of Hardened Concrete 289

- 7.5.1 • Compressive Strength Test 290
- 7.5.2 • Split-Tension Test 292
- 7.5.3 • Flexure Strength Test 293
- 7.5.4 • Rebound Hammer Test 294
- 7.5.5 • Penetration Resistance Test 295
- 7.5.6 • Ultrasonic Pulse Velocity Test 296
- 7.5.7 • Maturity Test 296

- 7.6 Alternatives to Conventional Concrete 297**
- 7.6.1 • Self-Consolidating Concrete 297
 - 7.6.2 • Flowable Fill 299
 - 7.6.3 • Shotcrete 301
 - 7.6.4 • Lightweight Concrete 302
 - 7.6.5 • Heavyweight Concrete 303
 - 7.6.6 • High-Strength Concrete 304
 - 7.6.7 • Shrinkage-Compensating Concrete 305
 - 7.6.8 • Polymers and Concrete 305
 - 7.6.9 • Fiber-Reinforced Concrete 305
 - 7.6.10 • Roller-Compacted Concrete 306
 - 7.6.11 • High-Performance Concrete 307
- Summary 308**
- Questions and Problems 308**
- 7.7 References 313**

EIGHT

Masonry 315

- 8.1 Masonry Units 315**
- 8.1.1 • Concrete Masonry Units 316
 - 8.1.2 • Clay Bricks 321
- 8.2 Mortar 324**
- 8.3 Grout 324**
- 8.4 Plaster 325**
- Summary 325**
- Questions and Problems 325**
- 8.5 References 328**

NINE

Asphalt Binders and Asphalt Mixtures 329

- 9.1 Types of Asphalt Products 332**
- 9.2 Uses of Asphalt 334**
- 9.3 Temperature Susceptibility of Asphalt 337**

9.4	Chemical Properties of Asphalt	340
9.5	Superpave and Performance Grade Binders	342
9.6	Characterization of Asphalt Cement	342
9.6.1	• Performance Grade Characterization Approach	342
9.6.2	• Performance Grade Binder Characterization	343
9.6.3	• Traditional Asphalt Characterization Tests	348
9.7	Classification of Asphalt	350
9.7.1	• Asphalt Binders	350
9.7.2	• Asphalt Cutbacks	356
9.7.3	• Asphalt Emulsions	356
9.8	Asphalt Concrete	357
9.9	Asphalt Concrete Mix Design	358
9.9.1	• Specimen Preparation in the Laboratory	358
9.9.2	• Density and Voids Analysis	362
9.9.3	• Superpave Mix Design	365
9.9.4	• Superpave Refinement	374
9.9.5	• Marshall Method of Mix Design	374
9.9.6	• Evaluation of Moisture Susceptibility	382
9.10	Characterization of Asphalt Concrete	383
9.10.1	• Indirect Tensile Strength	384
9.10.2	• Diametral Tensile Resilient Modulus	384
9.10.3	• Freeze and Thaw Test	386
9.10.4	• Superpave Asphalt Mixture Performance Tests	386
9.11	Hot Mix Asphalt Concrete Production and Construction	390
9.11.1	• Production of Raw Materials	390
9.11.2	• Manufacturing Asphalt Concrete	390
9.11.3	• Field Operations	391
9.12	Recycling of Asphalt Concrete	394
9.12.1	• RAP Evaluation	395
9.12.2	• RAP Mix Design	395
9.12.3	• RAP Production and Construction	395
9.13	Additives	397
9.13.1	• Fillers	397
9.13.2	• Extenders	397
9.13.3	• Polymer Modified Asphalt	397
9.13.4	• Antistripping Agents	399
9.13.5	• Others	399
9.14	Warm Mix	399

Summary 401

Questions and Problems 402

9.15 References 409

TEN

Wood 411

- 10.1 Structure of Wood 413**
 - 10.1.1 • Growth Rings 413
 - 10.1.2 • Anisotropic Nature of Wood 415
- 10.2 Chemical Composition 416**
- 10.3 Moisture Content 417**
- 10.4 Wood Production 419**
 - 10.4.1 • Cutting Techniques 421
 - 10.4.2 • Seasoning 422
- 10.5 Lumber Grades 423**
 - 10.5.1 • Hardwood Grades 424
 - 10.5.2 • Softwood Grades 425
- 10.6 Defects in Lumber 426**
- 10.7 Physical Properties 429**
 - 10.7.1 • Specific Gravity and Density 429
 - 10.7.2 • Thermal Properties 429
 - 10.7.3 • Electrical Properties 431
- 10.8 Mechanical Properties 431**
 - 10.8.1 • Modulus of Elasticity 431
 - 10.8.2 • Strength Properties 432
 - 10.8.3 • Load Duration 432
 - 10.8.4 • Damping Capacity 433
- 10.9 Testing to Determine Mechanical Properties 433**
 - 10.9.1 • Flexure Test of Structural Members (ASTM D198) 434
 - 10.9.2 • Flexure Test of Small, Clear Specimen (ASTM D143) 436
- 10.10 Design Considerations 437**
- 10.11 Organisms that Degrade Wood 437**
 - 10.11.1 • Fungi 438
 - 10.11.2 • Insects 438
 - 10.11.3 • Marine Organisms 438
 - 10.11.4 • Bacteria 438

10.12 Wood Preservation 439
10.12.1 • Petroleum-Based Solutions 439
10.12.2 • Waterborne Preservatives 439
10.12.3 • Application Techniques 440
10.12.4 • Construction Precautions 440

10.13 Engineered Wood Products 441
10.13.1 • Structural Panels/Sheets 443
10.13.2 • Structural Shapes 445
10.13.3 • Composite Structural Members 455

Summary 456
Questions and Problems 456

10.14 References 462



ELEVEN

Composites 463

11.1 Microscopic Composites 465
11.1.1 • Fiber-Reinforced Composites 465
11.1.2 • Particle-Reinforced Composites 467
11.1.3 • Matrix Phase 467
11.1.4 • Fabrication 467
11.1.5 • Civil Engineering Applications 468

11.2 Macroscopic Composites 473
11.2.1 • Plain Portland Cement Concrete 473
11.2.2 • Reinforced Portland Cement Concrete 474
11.2.3 • Asphalt Concrete 474
11.2.4 • Engineered Wood 475

11.3 Properties of Composites 475
11.3.1 • Loading Parallel to Fibers 476
11.3.2 • Loading Perpendicular to Fibers 477
11.3.3 • Randomly Oriented Fiber Composites 479
11.3.4 • Particle-Reinforced Composites 479

Summary 480
Questions and Problems 480

11.4 References 482