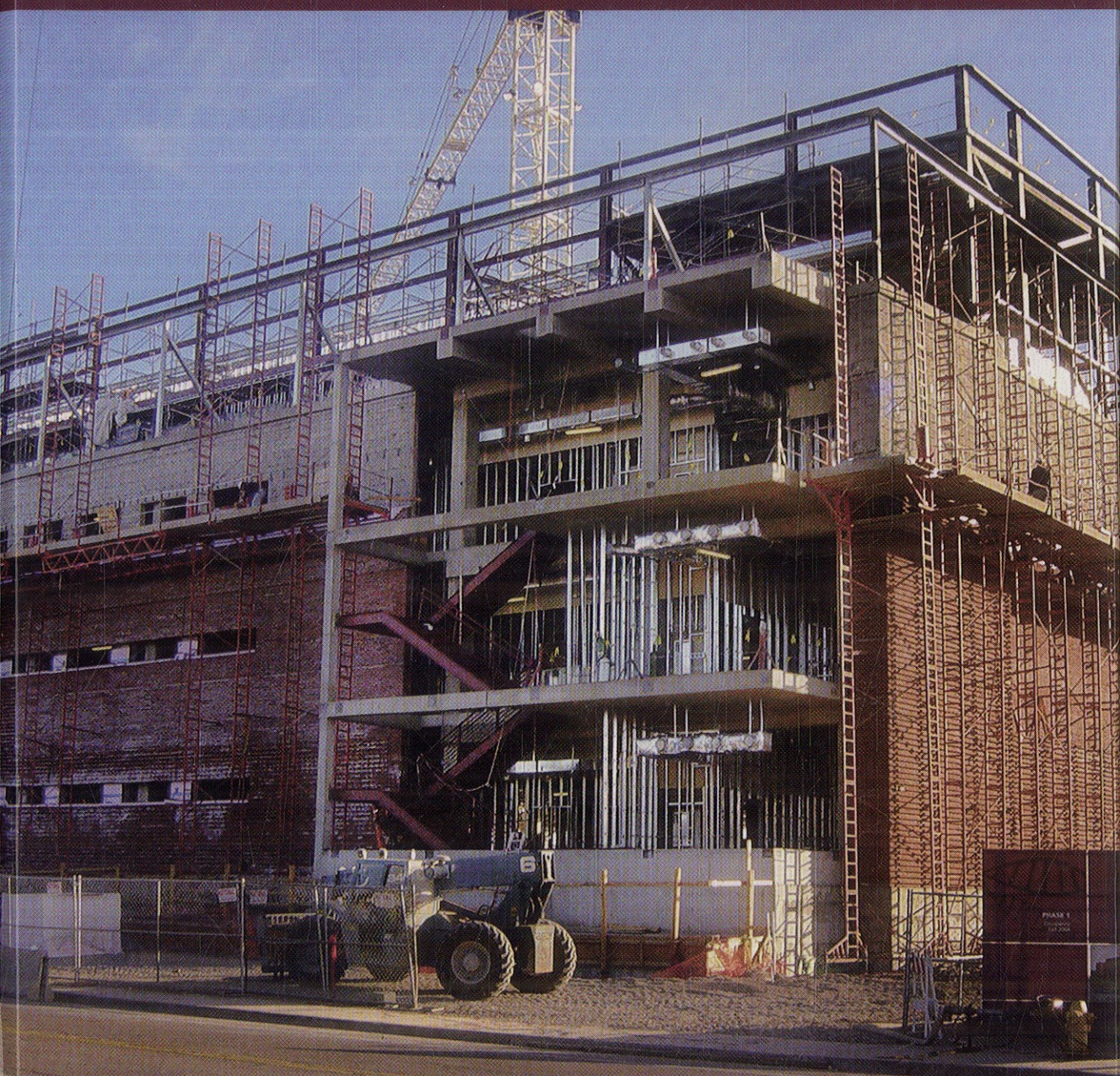


Third Edition

MATERIALS FOR CIVIL AND CONSTRUCTION ENGINEERS

Michael S. Mamlouk ■ John P. Zaniewski



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



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**

X Contents

- 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



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 Gyratory 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