

Contents

1	Introduction	1
1.1	Historical Introduction	1
1.2	Technical Introduction	14
1.3	A Road map for Using This Text	21
	References	24
 Part I Materials		
2	Asphalt Binders	27
2.1	Introduction	27
2.2	Production of Asphalt Binders	29
2.3	Chemical Properties	30
2.3.1	The Need to Understand Binder Chemistry	30
2.3.2	Attributes of Chemical Properties and Methods of Measurement	32
2.3.3	Microstructure of Asphalt Binders	40
2.3.4	Relationship Between Microstructure and Engineering Properties of Asphalt Binder	46
2.3.5	Concluding Thoughts on the Chemical Properties of Asphalt Binders	48
2.4	Aging in Asphalt Binders	48
2.4.1	Steric Hardening	49
2.4.2	Volatilization and Oxidative Aging	50
2.4.3	Simulating Aging in Asphalt Binders	51
2.5	Mechanical Properties	52
2.5.1	Scope	52
2.5.2	Significance of Mechanical Properties of Binder and Challenges	53
2.5.3	Time Dependency	55
2.5.4	Temperature Dependency	60
2.5.5	Age Dependency	65

2.5.6	Typical Measurement Techniques	65
2.5.7	Desired Binder Properties to Produce Durable Asphalt Mixtures and PG System	68
2.5.8	Limitations of the PG System	69
2.6	Properties of Liquid Asphalt Binder	70
2.7	Exercises	72
	Additional Reading	75
	References	76
3	Aggregates	79
3.1	Introduction	79
3.2	Sources of Mineral Aggregates	80
3.3	Physical Attributes of Mineral Aggregates	82
3.3.1	Size and Gradation	82
3.3.2	Cleanliness	92
3.3.3	Toughness and Hardness	96
3.3.4	Durability or Soundness	101
3.3.5	Shape, Angularity, and Texture	104
3.3.6	Impact of Aggregate Characteristics on Engineering Properties	114
3.3.7	Absorption	117
3.4	Exercises	119
	References	120
4	Chemical and Mechanical Processes Influencing Adhesion and Moisture Damage in Hot Mix Asphalt Pavements	123
4.1	Background	123
4.1.1	Detachment	123
4.1.2	Displacement	124
4.1.3	Spontaneous Emulsification	125
4.1.4	Pore Pressure	125
4.1.5	Hydraulic Scour	126
4.1.6	pH Instability	127
4.1.7	Environmental Effects on the Aggregate–Asphalt System	128
4.2	Adhesion Theories	128
4.2.1	Chemical Reaction	129
4.2.2	Surface Energy and Molecular Orientation	135
4.2.3	Mechanical Adhesion	136
4.3	Cohesion Theories	138
4.4	Combining Theories	139
4.5	Nature of Asphalt–Aggregate Interaction	140
4.5.1	Adhesive Failure Versus Cohesive Failure	140
4.5.2	Effect of Aggregate Characteristics	142

4.5.3	Calculation of Asphalt–Aggregate Bond Strength	145
4.6	Thermodynamic Approach	149
4.7	Application of Surface Energy to Predict Moisture Damage in Asphalt Mixtures	158
4.8	Effect of Asphalt Composition on Adhesion.	160
4.8.1	Asphalt Composition	160
4.8.2	Elemental Composition	160
4.8.3	Molecular Structure	160
4.8.4	Bonds Among Asphalt Molecules	160
4.8.5	Polar Versus Nonpolar Molecules	161
4.8.6	Asphalt Model.	162
4.8.7	Multifunctional Organic Molecules	163
4.9	Asphalt Chemistry and Adhesion	165
4.9.1	Effect of Aggregate Properties on Adhesion	165
4.9.2	Pore Volume and Surface Area	166
4.9.3	pH of Contacting Water.	166
4.10	Surface Potential.	172
4.11	SHRP Research on Aggregate Surface Chemistry.	173
4.12	SHRP Adhesion Model.	174
4.13	SHRP Stripping Model.	174
4.14	Ways to Improve Adhesion	174
4.14.1	Interaction of Acidic Aggregates and Asphalt with Alkaline Amine Compounds	174
4.14.2	Effect of Hydrated Lime on Adhesive Bond	175
4.14.3	Other Chemical Treatments	176
4.15	Dusty and Dirty Aggregates	177
4.15.1	General Mechanisms of Bond Disruption with Dirty or Dusty Aggregates.	177
4.15.2	Modification of Dusty and Dirty Aggregates to Improve Asphalt–Aggregate Interaction.	178
4.16	Exercises.	178
4.17	Summary and Conclusions	179
	References.	180
5	Modifiers and Fillers	187
5.1	Introduction	187
5.2	Principles of Modification.	191
5.2.1	Acid Modification	191
5.2.2	Palierne Model	192
5.2.3	Suspension Limit.	193
5.3	Application of Modification to Bitumen	194
5.3.1	Compatibility.	194
5.3.2	Structure of Polymer-Modified Bitumen	195

- 5.3.3 Practical Consequences 195
- 5.4 Extenders 196
 - 5.4.1 Sulfur 196
- 5.5 Additives that Promote Improved Bond Between Aggregate and Binder 199
- 5.6 Fillers 203
 - 5.6.1 Active Filler: Hydrated Lime 203
 - 5.6.2 Hydrated Lime: Aggregate Surface Modifier 205
 - 5.6.3 Rheology of Filler Stiffening Effect 206
 - 5.6.4 Effects of Hydrated Lime on Low-Temperature Flow Properties 211
 - 5.6.5 Influence of Filler on Damage in Asphalt Mastic 214
 - 5.6.6 Effect of Hydrated Lime on Microstructural Model of Asphalt 218
 - 5.6.7 Hydrated Lime: Chemical and Physicochemical Interactions 219
 - 5.6.8 Other Literature to Support Lime–Bitumen Interaction 222
- 5.7 Polymer Modification 224
 - 5.7.1 Plastomers 224
 - 5.7.2 Thermoplastic Elastomers 225
- 5.8 Summary 229
- 5.9 Exercises 230
- References 231
- 6 Mastics and Mortars 237**
 - 6.1 Introduction 237
 - 6.2 Mastics 238
 - 6.2.1 Mechanical Role of Filler Particles in Mastic 239
 - 6.2.2 Physicochemical Interactions of Filler Particles in Mastic 243
 - 6.2.3 Considerations During Mixture Design 246
 - 6.3 Mortars or Fine Aggregate Matrix 247
 - 6.3.1 Applications of Fine Aggregate Matrix 247
 - 6.3.2 Design of Fine Aggregate Matrix 253
 - 6.4 Summary 256
 - 6.5 Exercises 256
 - References and Additional Reading 257
- 7 Asphalt Mixtures 261**
 - 7.1 Introduction 261
 - 7.2 Methods to Fabricate Laboratory Specimens 263
 - 7.3 Design for Optimal Binder Content 269
 - 7.3.1 What is Optimal Binder Content? 269
 - 7.3.2 Mixture Volumetrics 270

- 7.3.3 Examples of Methods to Determine Optimum Binder Content 274
- 7.4 Summary 279
- 7.5 Exercises. 279
- References. 281

8 Failure Mechanisms and Methods to Estimate Material

- Resistance to Failure 283**
- 8.1 Introduction 283
- 8.2 Understanding the Role of Pavement Versus Materials in Distress Evolution. 284
- 8.3 Failure Mechanisms 285
 - 8.3.1 Rutting. 286
 - 8.3.2 Fatigue Cracking 290
 - 8.3.3 Transverse Cracking 293
 - 8.3.4 Moisture-Induced Damage. 296
 - 8.3.5 Aging 299
 - 8.3.6 Bleeding or Flushing 300
- 8.4 Terminology and Typical Approaches to Characterize Distresses 301
 - 8.4.1 Measuring Performance Indicators and Material Properties. 301
 - 8.4.2 Concept of Continuum 303
- 8.5 Examples of Test and Analytical Methods to Characterize Properties and Distresses. 304
 - 8.5.1 Complex Modulus 304
 - 8.5.2 Rutting. 309
 - 8.5.3 Fatigue Cracking 315
 - 8.5.4 Low Temperature Cracking 328
 - 8.5.5 Moisture-Induced Damage. 331
- 8.6 Exercises. 336
- References. 336

Part II Mechanics

- 9 Mechanics of Continuous Solids 341**
- 9.1 Introduction 341
- 9.2 Mathematical Preliminaries 341
 - 9.2.1 Index Notation. 342
 - 9.2.2 Scalars, Vectors, and Tensors 344
 - 9.2.3 Linearity 346
 - 9.2.4 Laplace Transforms 346
 - 9.2.5 Carson Transforms. 348
 - 9.2.6 The Heaviside Step Function. 348
 - 9.2.7 The Convolution Integral. 348

9.2.8	The Dirac Delta Function	350
9.2.9	The Divergence Theorem	351
9.2.10	The Reynolds Transport Theorem	351
9.3	Kinematics and Strain	352
9.4	Kinetics and Stress	355
9.4.1	The Traction Vector	355
9.4.2	The Stress Tensor	356
9.4.3	Stress Transformations	358
9.4.4	Principal Stresses	360
9.4.5	Deviatoric Stresses	362
9.4.6	Stress Analysis Using Mohr's Circle	364
9.5	Conservation Laws	375
9.5.1	Conservation of Mass	376
9.5.2	Conservation of Charge	376
9.5.3	Conservation of Momentum	376
9.5.4	Conservation of Energy	378
9.5.5	The Entropy Production Inequality	380
9.6	Summary	381
9.7	Problems	382
	References	387
10	One-Dimensional Constitutive Theory	389
10.1	Introduction	389
10.2	One-Dimensional Constitutive Experiments	391
10.3	Elastic Material Model	394
10.4	Viscous Material Model	397
10.5	Viscoelastic Material Model	399
10.6	Elasto-Plastic Material Model	409
10.7	Viscoplastic Material Model	411
10.8	Thermo- and Hygro-Type Material Models	411
10.9	Summary	415
10.10	Problems	416
	References	417
11	Elasticity and Thermoelasticity	419
11.1	Introduction	419
11.2	Multidimensional Linear Elasticity	419
11.2.1	The Linear Elastic Boundary Value Problem	420
11.2.2	Thermodynamic Constraints on Elastic Material Behavior	424
11.2.3	Material Symmetry	426
11.2.4	Solution Techniques for the Linear Elastic Boundary Value Problem	435
11.2.5	Micromechanics	440

11.3	Multidimensional Linear Thermoelasticity	445
11.4	Thermodynamic Constraints on Thermoelastic Material Behavior	446
11.5	The Linear Thermoelastic Initial Boundary Value Problem	448
	11.5.1 Two-Way Coupled Thermoelasticity	450
	11.5.2 One-Way Coupled Thermoelasticity	450
11.6	Modeling the Effects of Moisture on Roadway Performance	454
11.7	Summary	457
11.8	Problems	457
	References	459
12	Viscoelasticity and Thermoviscoelasticity	461
12.1	Introduction	461
12.2	Multi-dimensional Linear Viscoelasticity	462
	12.2.1 The Linear Viscoelastic Initial Boundary Value Problem	464
	12.2.2 Thermodynamic Constraints on Linear Viscoelastic Material Behavior	466
	12.2.3 Material Symmetry	470
12.3	Methods for Solving Viscoelastic IBVPs	473
	12.3.1 Direct Analytic Method	474
	12.3.2 Separable Correspondence Principle	477
	12.3.3 Laplace Transform Correspondence Principles	483
12.4	Material Property Characterization of Viscoelastic Media	485
	12.4.1 Creep Tests	486
	12.4.2 Ramp Tests	490
	12.4.3 Relaxation Tests	494
	12.4.4 Accelerated Characterization Tests	495
	12.4.5 Time–Temperature Superposition Tests	502
12.5	Mechanical Analogs for Creep Compliances and Relaxation Moduli	504
	12.5.1 The Kelvin Model for Creep Compliances	504
	12.5.2 The Wiechert Model for Relaxation Moduli	505
	12.5.3 Power Laws	506
12.6	Procedures for Curve Fitting	507
	12.6.1 Prony Series Model	507
	12.6.2 Power Law Model	509
	12.6.3 Frequency Sweeps	510
12.7	Multi-dimensional Linear Thermoviscoelasticity	514
	12.7.1 Thermodynamic Constraints on Thermoviscoelastic Material Behavior	515

12.7.2	The Linear Thermoviscoelastic Initial Boundary Value Problem.	518
12.7.3	Two-Way Coupled Linear Thermoviscoelasticity.	518
12.7.4	One-Way Coupled Thermoviscoelasticity	520
12.8	Nonlinear Viscoelasticity	521
12.9	Summary	524
12.10	Problems.	524
	References.	528
13	Plasticity, Viscoplasticity, and Fracture.	531
13.1	Introduction	531
13.2	Multi-dimensional Plasticity	533
13.2.1	The Stress–Elastic Strain Relationship.	534
13.2.2	The Yield Criterion	536
13.2.3	The Flow Rule.	548
13.2.4	The Workhardening Rule.	555
13.3	The Elastoplastic Initial Boundary Value Problem	566
13.4	Multi-dimensional Viscoplasticity.	567
13.5	Multi-dimensional Thermoviscoplasticity	570
13.5.1	Thermodynamic Constraints on Thermoviscoplastic Material Behavior	572
13.5.2	The Thermoviscoplastic Initial Boundary Value Problem.	574
13.6	Methods for Modeling Cracking.	578
13.6.1	Damage Mechanics	580
13.6.2	Fracture Mechanics	581
13.7	Summary	587
13.8	Problems.	587
	References.	591
14	Computational Methods for Roadway Analysis and Design.	593
14.1	Introduction	593
14.2	Fundamentals of the Finite Element Method.	597
14.2.1	Construction of the Heat Transfer and Moisture Finite Element Platforms.	600
14.2.2	Construction of the Finite Element Heat Transfer Equations for a Single Element.	602
14.2.3	Construction of the Mechanics Finite Element Platform.	605
14.2.4	Construction of an Incrementalized Variational Form of the Mechanics Field Equations	606
14.2.5	Construction of the Finite Element Mechanics Equations for a Single Element.	609
14.2.6	Choosing an Appropriate Element.	611

- 14.2.7 Assembly of the Global Mechanics Finite Element Equations. 613
- 14.2.8 Accounting for Nonlinearity with Newton Iteration 615
- 14.3 Implementation of Constitutive and Fracture Models to a Mechanics Finite Element Code 619
 - 14.3.1 Implementation of Plasticity 619
 - 14.3.2 Implementation of Viscoelasticity 626
 - 14.3.3 Implementation of a Cohesive Zone Model 632
- 14.4 Summary 634
- 14.5 Problems 635
- 15 Computational Modeling Applications. 637**
 - 15.1 Introduction 637
 - 15.2 Computational Techniques for Road way Design and Analysis Using the Finite Element Method. 637
 - 15.2.1 Computational Micromechanics 637
 - 15.2.2 Simulating the Resilient Modulus Test 640
 - 15.2.3 Multi-scaling 644
 - 15.3 Summary 689
 - 15.4 Problems 689
 - References 690
- Index 691**



<http://www.springer.com/978-3-319-58441-6>

Modeling and Design of Flexible Pavements and
Materials

Little, D.; Allen, D.H.; Bhasin, A.

2018, XXI, 693 p. 327 illus., 167 illus. in color.,

Hardcover

ISBN: 978-3-319-58441-6