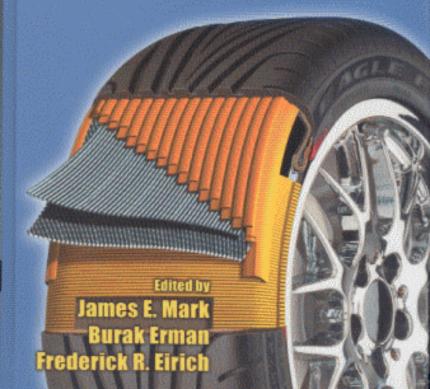


The Science and Technology of

RUBBER

THIRD EDITION



Contents

Contributors xi
Preface to the Third Edition xiii
Preface to the Second Edition xv
Preface to the First Edition xvii

Rubber Elasticity: Basic Concepts and Behavior

A. N. Gent

- I. Introduction 1
- II. Elasticity of a Single Molecule 2
- III. Elasticity of a Three-Dimensional Network of Polymer Molecules 5
- IV. Comparison with Experiment 10
- V. Continuum Theory of Rubber Elasticity 12
- VI. Second-Order Stresses 20
- VII. Elastic Behavior Under Small Deformations 21
- VIII. Some Unsolved Problems in Rubber Elasticity 25
 Acknowledgments 26

References 26

2 Polymerization: Elastomer Synthesis Roderic P. Quirk and Deanna L. Gamochak Pickel

- I. Introduction 29
- II. Classification of Polymerization Reactions and Kinetic Considerations 30
- III. Polyaddition/Polycondensation 34
- IV. Chain Polymerization by Free Radical Mechanism 36
 - V. Emulsion Polymerization 44
- VI. Copolymerization 55
- VII. Chain Polymerization by Cationic Mechanism 61

Contents

νi

5

C. M. Roland
 I. Introduction 105 II. Chemical Composition 106 III. Sequence Distribution of Repeat Units 109 IV. Chain Architecture 111 V. Glass Transition and Secondary Relaxation
The Molecular Basis of Rubberlike Elasticity
Burak Erman and James E. Mark
 I. Introduction 157 II. Structure of a Typical Network 158 III. Elementary Molecular Theories 160 IV. More Advanced Molecular Theories 168 V. Phenomenological Theories and Molecular Structure 172 VI. Swelling of Networks and Responsive Gels 173 VII. Enthalpic and Entropic Contributions to Rubber Elasticity: Force-Temperature Relations 176 VIII. Direct Determination of Molecular Dimensions 177 IX. Single-Molecule Elasticity 178 References 181
The Viscoelastic Behavior of Rubber
K. L. Ngai and Donald J. Plazek
I. Introduction 183 II. Definitions of Measured Quantities, $J(t)$, $G(t)$, and $G^*(\omega)$, and Spectra $L(\log \lambda)$ and $H(\log \tau)$ 184

VIII. Chain Polymerization by Anionic Mechanism 69 IX. Stereospecific Chain Polymerization and

X. Graft and Block Copolymerization 89

Structure Characterization in the Science

References 96

and Technology of Elastomers

Copolymerization by Coordination Catalysts 79

Contents Vii

	 VII. The Calculation of the Tear Energy of Elastomers from Their Viscoelastic Behavior 211 VIII. Theoretical Interpretation of Viscoelastic Mechanisms and Anomalies 216 IX. Appendix: Nomenclature 230 References 233
6	Rheological Behavior and Processing of Unvulcanized Rubber James L. White
	Julios L. Willio
	I. Introduction 237 II. Basic Concepts of Mechanics 242
	III. Rheological Properties 245
	IV. Boundary Conditions 269
	V. Mechanochemical Behavior 271
	VI. Rheological Measurements 275
	VII. Processing Technology 283
	VIII. Engineering Analysis of Processing 298
	References 310
7	Vulcanization
	Aubert Y. Coran
	I. Introduction 321
	II. Definition of Vulcanization 322
	III. Effects of Vulcanization on Vulcanizate
	Properties 323
	IV. Characterization of the Vulcanization Process 325
	V. Vulcanization by Sulfur Without Accelerator 328
	VI. Accelerated-Sulfur Vulcanization 331
	VII. Vulcanization by Phenolic Curatives, Benzoquinone
	Derivatives, or Bismaleimides 349
	VIII. Vulcanization by the Action of Metal Oxides 354
	IX. Vulcanization by the Action of Organic
	Peroxides 356
	X. Dynamic Vulcanization 361
	References 364

III. The Glass Temperature 190 IV. Volume Changes During Curing 191 V. Viscoelastic Behavior Above $T_{\rm g}$ 195 VI. Viscoelastic Behavior of Other Model

Elastomers 201

VIII Contents

8 Reinforcement of Elastomers by Particulate Fillers

Jean-Baptiste Donnet and Emmanuel Custodero

- I. Introduction 367
- II. Preparation of Fillers 368
- III. Morphological and Physicochemical Characterization of Fillers 370
- IV. The Mix: A Nanocomposite of Elastomer and Filler 380
- V. Mechanical Properties of Filled Rubbers 386 References 396

9 The Science of Rubber Compounding

Brendan Rodgers and Walter Waddell

- I. Introduction 401
- II. Polymers 402
- III. Filler Systems 415
- IV. Stabilizer Systems 427
- V. Vulcanization System 433
- VI. Special Compounding Ingredients 441
- VII. Compound Development 445
- VIII. Compound Preparation 449
 - IX. Environmental Requirements in Compounding 450
 - X. Summary 452 References 453

10 Strength of Elastomers

A. N. Gent

- I. Introduction 455
- II. Initiation of Fracture 456
- III. Threshold Strengths and Extensibilities 463
- IV. Fracture Under Multiaxial Stresses 465
 - V. Crack Propagation 469
- VI. Tensile Rupture 479
- VII. Repeated Stressing: Mechanical Fatigue 485
- VIII. Surface Cracking by Ozone 488
 - IX. Abrasive Wear 489

Acknowledgments 492

References 493

Contents ix

11 The Chemical Modification of Polymers

A. F. Halasa, Jean Marie Massie, and R. J. Ceresa

- I. Introduction 497
- II. Chemical Modification of Polymers Within Backbone and Chain Ends 498
- III. Esterification, Etherification, and Hydrolysis of Polymers 500
- IV. The Hydrogenation of Polymers 503
- V. Dehalogenation, Elimination, and Halogenation Reactions in Polymers 505
- VI. Other Addition Reactions to Double Bonds 509
- VII. Oxidation Reactions of Polymers 512
- VIII. Functionalization of Polymers 512
 - IX. Miscellaneous Chemical Reactions of Polymers 513
 - X. Block and Graft Copolymerization 513 References 527

12 Elastomer Blends

Sudhin Datta

- I. Introduction 529
- II. Miscible Elastomer Blends 531
- III. Immiscible Elastomer Blends 538
- IV. Conclusion 550
 - V. Appendix 1: Acronyms for Common Elastomers 551 References 551

13 Thermoplastic Elastomers

Brian P. Grady and Stuart L. Cooper

- I. Introduction 555
- II. Synthesis of Thermoplastic Elastomers 560
- III. Morphology of Thermoplastic Elastomers 567
- IV. Properties and Effect of Structure 586
 - V. Thermodynamics of Phase Separation 594
- VI. Thermoplastic Elastomers at Surfaces 600
- VII. Rheology and Processing 606
- VIII. Applications 610 References 612

X Contents

14 Tire Engineering

Brendan Rodgers and Walter Waddell

- I. Introduction 619
- II. Tire Types and Performance 620
- III. Basic Tire Design 621
- IV. Tire Engineering 625
- V. Tire Materials 636
- VI. Tire Testing 651
- VII. Tire Manufacturing 655
- VIII. Summary 660 References 661

15 Recycling of Rubbers

Avraam 1. Isayev

- I. Introduction 663
- II. Retreading of Tire 665
- III. Recycling of Rubber Vulcanizates 665
- IV. Use of Recycled Rubber 682
- V. Pyrolysis and Incineration of Rubber 694
- VI. Concluding Remarks 695 Acknowledgments 696 References 696

Index 703