

Contents

Preface V

List of Contributors XXIII

- 1 **The Interfacial Chemistry of Adhesion:
Novel Routes to the Holy Grail? 1**
J. F. Watts
Abstract 1
 - 1.1 **Introduction 1**
 - 1.2 **Development of a Model Interphase 3**
 - 1.3 **The Buried Interface 8**
 - 1.4 **Conclusion 15**
Acknowledgments 15
References 15

- 2 **Modeling Fundamental Aspects of the Surface Chemistry
of Oxides and their Interactions with Coupling Agents 17**
*P. Schiffels, M. Amkreutz, A. T. Blumenau, T. Krüger, B. Schneider,
T. Frauenheim, and O.-D. Hennemann*
Abstract 17
 - 2.1 **Introduction: Atomistic Simulations in Adhesion 17**
 - 2.2 **Prediction of Surface Properties: Ideal Reconstructions
on α -SiO₂ (0001) 19**
 - 2.3 **Organic Components of the Adhesive and Substrate-Adhesive
Interaction 23**
 - 2.4 **Conclusion and Outlook 29**
References 30

- 3 **Adhesion at the Nanoscale: an Approach by AFM 33**
M. Brogly, O. Noel, C. Castelein, and J. Schultz
Abstract 33
 - 3.1 **Introduction 34**
 - 3.2 **Materials and Methods 34**

3.2.1	Preparation of Oxidized Silica Surface	35
3.2.2	Grafting of Functionalized SAMs onto Silicon Wafer	35
3.2.3	Crosslinking and Functionalization of PDMS Networks	35
3.2.4	Characterization of the SAMs	36
3.3	Results and Discussion	37
3.3.1	Force–Distance Cume Measurements and AFM Calibration	37
3.3.1.1	Force–Distance Cume Features	37
3.3.1.2	The DD Curve (Contact Mode)	37
3.3.1.3	AFM Calibration	38
3.3.1.3.1	Determination of the Spring Constant of the Cantilever	38
3.3.1.3.2	Nonlinearity of the Quadrant of Photodiodes	38
3.3.1.3.3	Scan Rate of the Cantilever	38
3.3.1.3.4	Systematic Check	39
3.3.2	Force–Distance Curves on Rigid Systems of Controlled Surface Chemistry	39
3.3.3	Force–Distance Measurements on Polymers	40
3.3.3.1	Force–Indentation Measurements on Polymers	40
3.3.3.2	Force–Indentation Curves on Systems of Controlled Surface Chemistry and Controlled Mechanical Properties	42
3.4	Conclusion	45
	References	45
4	Organization of PCL-b-PMMA Diblock Thin Films: Relationship to the Adsorption Substrate Chemistry	47
	<i>T. Elzein, M. Brogly, and J. Schultz</i>	
	Abstract	47
4.1	Introduction	47
4.2	Materials and Methods	48
4.2.1	PCL-b-PMMA Diblocks	48
4.2.2	Infrared Spectroscopy	49
4.2.2.1	Transmission	49
4.2.2.2	Polarization-Modulation Infrared Reflection–Absorption Spectroscopy (PM-IRRAS)	49
4.2.3	Atomic Force Microscopy (AFM)	50
4.3	Results and Discussion	50
4.3.1	PCL-b-PMMA Bulk Characterization	50
4.3.2	PCL-b-PMMA Thin Films on OH-Functionalized Cold Substrates	51
4.3.3	PCL-b-PMMA Thin Films on Gold Substrates	55
4.4	Conclusion	56
	References	57

Adhesion and Friction Properties of Elastomers at Macroscopic and Nanoscopic Scales 59

S. Bistac and A. Galliano

Abstract 59

- 5.1 Introduction 59
- 5.2 Materials and Methods 60
- 5.3 Results and Discussion 62
 - 5.3.1 Adherence Energy 62
 - 5.3.2 Macroscale Friction 64
 - 5.3.3 Nanoscale Friction and Adhesion 65
- 5.4 Conclusion 68
- References 69

Chemical Structure Formation and Morphology in Ultrathin Polyurethane Films on Metals 71

C. Wehlack and W. Possart

Abstract 71

- 6.1 Introduction 71
- 6.2 Materials and Methods 72
 - 6.2.1 Sample Preparation 72
 - 6.2.2 Experimental Characterization 74
 - 6.2.3 IR Spectra Calculation 74
 - 6.2.4 IR Band Assignment 75
- 6.3 Results and Discussion 76
 - 6.3.1 Curing at Room Temperature 76
 - 6.3.2 Morphology of Thin Films 79
 - 6.3.3 Chemical Structure of Cured Films 80
- 6.4 Conclusion 85
- Acknowledgments 86
- References 87

Properties of the Interphase Epoxy–Amine/Metal: Influences from the Nature of the Amine and the Metal 89

M. Aufray and A. A. Roche

Abstract 89

- 7.1 Introduction 89
- 7.2 Materials and Methods 90
 - 7.2.1 Materials 90
 - 7.2.2 Thermal Analysis (DSC) 91
 - 7.2.3 Micro-Infrared Spectroscopy (μ -FTIR) 91
 - 7.2.4 Fourier Transform Near-Infrared Spectroscopy (FT-NIR) 92
 - 7.2.5 Inductively Coupled Plasma Spectroscopy (ICP) 92
 - 7.2.6 X-Ray Diffraction (XRD) 92
 - 7.2.7 Polarized Optical Microscopy (POM) Coupled with a Hot Stage Apparatus 92

7.3	Results and Discussion	93
7.3.1	Interphase Formation Mechanisms	93
7.3.2	Formation of New Networks	94
7.3.3	Crystallization of "Modified" IPDA	94
7.3.4	Modification of Mechanical Properties	95
7.3.5	Comparison of Coatings and Metal–Bulk Interphases	97
7.3.6	Influence of the Stoichiometric Ratio	100
7.4	Conclusion	101
	Acknowledgments	102
	References	102
8	Mapping Epoxy Interphases	103
	<i>M. Munz, J. Chung, and G. Kalinka</i>	
	Abstract	103
8.1	Introduction	104
8.2	Stiffness Mapping by Indentation Techniques	106
8.2.1	SFM-Based Stiffness Mapping in Force Modulation Microscopy (FMM) Mode	106
8.2.2	Depth-Sensing Micro-indentation (DSI)	108
8.3	Some Fundamental Aspects of Interphase Mapping by Indentation Techniques	110
8.3.1	Artifacts Induced by Topography	110
8.3.2	Artifacts Induced by the Extent of the Stress Field Beneath the Indenter	114
8.4	Two Cases of Mapped Epoxy Interphases	116
8.4.1	The Cu/Epoxy Interphase	116
8.4.2	The PVP/Epoxy Interphase	118
8.5	Conclusion	121
	Acknowledgments	122
	References	122
9	Mechanical Interphases in Epoxies as seen by Nondestructive High-Performance Brillouin Microscopy	125
	<i>J. K. Krüger, U. Müller, R. Bactavatchalou, D. Liebschner, M. Sander, W. Possart, C. Wehlack, J. Baller, and D. Rouxel</i>	
	Abstract	125
9.1	Introduction	125
9.2	Brillouin Spectroscopy on Thermal Phonons and Other Elementary Excitations	126
9.2.1	An Introduction to the Physics of Classical Brillouin Spectroscopy	126
9.2.2	The Kinematic View of Brillouin Spectroscopy	129
9.2.3	Scattering Geometries and Other Pitfalls	129
9.2.4	Brillouin Microscopy	132
9.3	Mechanical Interphases at Polymer–Substrate Interfaces	134

9.3.1	The Polymer Model System	134
9.3.2	Epoxy/Silicone Rubber Interphase	134
9.3.3	Epoxy/Metal Interphases	136
9.3.3.1	Technical Bulk Metals: Cu, Al	137
9.3.3.2	Thin Evaporated Metal Substrates: Al, Cu, Au, Mg	138
9.3.3.3	Discussion	141
9.4	Conclusion	142
	Acknowledgments	142
	References	142

Structure Formation in Barnacle Adhesive 143

M. Wiegemann

Abstract 143

10.1	Introduction	143
10.2	Barnacles	144
10.2.1	General Aspects of Barnacle Settlement	144
10.2.2	Biochemical Characterization of Barnacle Cement	145
10.2.3	Substrate-Specific Formation of Barnacle Adhesive	146
10.2.4	Substrate-Specific Morphology of Barnacle Base	147
10.2.5	Phenomenological Approach to Adhesive Structure Formation and Morphology Changes	148
10.3	Homologous (?) Structure Formation of Biological Adherates on Hydrophobic Surfaces	150
10.4	Theoretical Colloid Approach to Structure Formation in Barnacle Adhesive	152
10.5	Conclusions	154
	Acknowledgments	154
	References	154

Adhesion Molecule-Modified Cardiovascular Prostheses: Characterization of Cellular Adhesion in a Cell Culture Model and by Cellular Force Spectroscopy 157

U. Bakowsky, C. Ehrhardt, C. Loebach, P. Li, C. Kneuer, D. Jahn, D. Hoekstra, and C.-M. Lehr

Abstract 157

11.1	Introduction	158
11.2	Materials and Methods	160
11.2.1	Chemicals for the Modification	160
11.2.2	Implant Materials	160
11.2.3	Modification of the PTFE Surface	160
11.2.4	Scanning Force Microscopy	162
11.2.5	Fourier Transform Infrared Spectroscopy	163
11.2.6	Environmental Scanning Electron Microscopy	163
11.2.7	Confocal Laser Scanning Microscopy (CLSM)	163
11.2.8	Isolation and Culture of HUVECs	164

11.2.9	Endothelialization of PTFE Films	164
11.3	Results and Discussion	165
11.3.1	Wet-Chemical Modification of PTFE Polymer Film	165
11.3.2	Cell Adhesion Experiments	166
11.3.2.1	Adhesion and Cultivation in Static Culture	166
11.3.2.2	Perfusion Experiments	166
11.3.3	Cell Adhesion Force Measurements	167
11.4	Conclusion	169
	Acknowledgments	170
	References	171
 12	Surface Engineering by Coating of Hydrophilic Layers: Bioadhesion and Biocontamination	175
	C. Legeay and F. Poncin-Epaillard	
	Abstract	175
12.1	Introduction	175
12.1.1	The Need for Bioadhesion of Biomaterials	175
12.1.2	Mechanism of Bioadhesion	176
12.2	Surface Engineering	177
12.2.1	Surface Preparation	177
12.2.2	Surface Sterilization	178
12.3	Results and Discussion	178
12.3.1	Hydrophobic Cold Plasma Treated Surfaces in Ophthalmology	178
12.3.2	Hydrophilic Cold Plasma Treated Surfaces Based on Polyvinylpyrrolidone (PVP) or Natural Derivative Coatings	179
12.3.2.1	Grafting of Monomer onto Plasma-Pretreated Surfaces	180
12.3.2.2	Coating with Commercial Native or Synthetic Polymers	181
12.3.3	Examples	183
12.3.3.1	With Different Biomolecules, i.e., Proteins	184
12.3.3.2	Implantation (<i>ex in vivo</i>)	184
12.3.3.3	In vivo Implantation	185
12.4	Conclusion	186
	References	187
 13	New Resins and Nanosystems for High-Performance Adhesives	189
	R. Mülhaupt	
	Abstract	189
13.1	Introduction	190
13.2	Tailor-Made Polymers and Properties on Demand	190
13.2.1	Controlled Polymerization and Catalysis	191
13.2.2	Functional Polymers from the Life Sciences	192
13.2.3	Reactive Extrusion and Isocyanate-Free Polyurethane Chemistry	193
13.3	Nanosystems	194
13.3.1	The Nano Challenge	194
13.3.2	Nanophase Separation	196

13.3.3	Nanomolecules as Molecular Nanoparticles	198
13.3.4	POSS and Nanocomposites	200
13.4	Conclusion	201
	Acknowledgments	202
	References	202

Influence of Proton Donors on the Cationic Polymerization of Epoxides 205

A. Hartwig, K. Koschek, and A. Lühning

Abstract 205

14.1	Introduction	206
14.2	Initiators for the Cationic Polymerization of Epoxides	207
14.3	Influence of Moisture on the Polymerization Kinetics	209
14.4	Modification of the Polymerization Behavior by the Addition of Alcohols	212
14.5	Conclusion	215
	Acknowledgments	215
	References	215

Novel Adhesion Promoters Based on Hyperbranched Polymers 217

A. Buchman, H. Dodiuk-Kenig, T. Brand, Z. Cold, and S. Kenig

Abstract 217

15.1	Introduction	218
15.2	Experimental	219
15.2.1	Bulk Hyperbranch Incorporation	219
15.2.2	HB Polymers as Adhesion Promoters	220
15.3	Results and Discussion	221
15.4	Conclusion	227
	References	228

Rheology of Hot-Melt PSAs: Influence of Polymer Structure 229

C. Derail and C. Marin

Abstract 229

16.1	Introduction	229
16.2	Main Features of the Viscoelastic Behavior of the Pure Components, Blends, and Full Adhesive Formulations	231
16.2.1	Rheological Experiments	231
16.2.2	Rheological Behavior of the Pure Components: [SI], [SIS], and Pure Blends	231
16.2.3	Rheological Behavior of the Full Adhesive Formulations	233
16.3	A Model of the Rheological Behavior	236
16.3.1	A Model for the Pure Copolymers	236
16.3.2	A Model for the Blends [SIS–SI]	239
16.3.3	A Model for the Full Adhesive Formulations [SIS–SI–Resin]	239
16.4	Discussion	240

16.4.1	Molecular Design	240
16.4.2	On the Variation of the Secondary Elastic Plateau Modulus	241
16.5	Conclusions	245
	Adtnowledgments	247
	References	247
17	Preparation and Characterization of UV-Gosslinkable Pressure-Sensitive Adhesives	249
	<i>H.-S. Do, S.-E. Kim, and H.-J. Kim</i>	
	Abstract	249
17.1	Introduction	249
17.2	Materials and Methods	252
17.2.1	Preparation of UV-Crosslinkable Acrylic PSA	252
17.2.2	Preparation of PSA Samples and UV Curing	253
17.2.3	FTIR-ATR Spectroscopy	253
17.2.4	DSC Measurement	254
17.2.5	PSA Performance	254
17.3	Results and Discussion	254
17.3.1	FTIR-ATR Measurements	254
17.3.2	PSA Performance	258
17.3.2.1	Probe Tack	258
17.3.2.2	Peel Strength	260
17.3.2.3	Shear Adhesion Failure Temperature (SAFT)	261
17.4	Conclusions	263
	References	263
18	Contribution of Chemical Interactions to the Adhesion Between Evaporated Metals and Functional Groups of Different Types at Polymer Surfaces	265
	<i>J. Friedrich, R. Mix, and C. Kühn</i>	
	Abstract	265
18.1	Introduction	266
18.1.1	Interactions Between Metal Atoms and Functional Groups at Polymer Surfaces	266
18.1.2	Preparation of the Plasma-Modified Polymer Surfaces	267
18.1.3	Interactions Between Evaporated Al and Functional Groups	269
18.1.4	Adhesive Bond Strength and Concentration of Functional Groups	269
18.2	Materials and Methods	270
18.2.1	Materials	270
18.2.2	Plasma Pretreatment of Polymers	271
18.2.3	Deposition of Adhesion-Promoting Plasma Polymer Layers	271
18.2.4	Surface Analysis	271
18.2.5	Labeling of Functional Groups	272
18.2.6	Contact Angle Measurements	272

18.2.7	Metal Deposition	272
18.2.8	Peel Strength Measurements	273
18.3	Results	273
18.3.1	Production of Polymer Surfaces Containing Functional Groups	273
18.3.2	Surface Free Energy Measurements	275
18.3.3	Peel Strength Measurements of Al-Plasma Modified PP Systems	276
18.3.4	Peel Strength of Al-Plasma-Produced Homopolymer-PP Systems	277
18.3.5	Peel Strength of Al-Plasma Copolymer-PP Systems	277
18.3.6	Plasma Pretreatment of PTFE Surfaces	279
18.3.7	Peel Strength Measurements of Al-PTFE Systems	281
18.3.7.1	Hydrogen Plasma Pretreatment of PTFE	281
18.3.7.2	Hydrogen Plasma Pretreatment of PTFE and Deposition of Plasma Polymer Layers	281
18.4	Discussion	282
18.4.1	Contribution of Chemical Bonds to the Resulting Adhesion Strength	282
18.4.2	Dependence of Adhesion Strength on Concentration of Functional Groups at the Polymer S	284
18.5	Conclusion	285
	References	286

**Alkene Pulsed Plasma Functionalized Surfaces:
An Interfacial Diels-Alder Reaction Study**

F. Siffer, J. Schultz, and V. Roucoules

Abstract 289

19.1	Introduction	289
19.2	Materials and Methods	290
19.3	Results and Discussion	292
19.3.1	Interfacial Chemistry	292
19.3.2	Cycloaddition	294
19.3.3	Kinetics	295
19.3.3.1	Monolayers	295
19.3.3.2	Plasma Polymer Thin Films	298
19.3.3.3	Comparison of Surface Reaction in Monolayers and Plasma Polymer Thin Films	299
19.4	Conclusion	302
	References	303

**Laser Surface Treatment of Composite Materials
to Enhance Adhesion Properties**

Q. Bénard, M. Fois, M. Crisel, and P. Laurens

20.1	Introduction	305
20.1.1	Why Treat a Composite Surface?	305

20.1.2	Available Treatments for Composite Surfaces	305
20.2	Materials and Methods	307
20.2.1	Composite Materials	307
20.2.2	Surface Analyses	307
20.2.3	Single Lap Shear Tests	308
20.3	Results and Discussion	308
20.3.1	Why Excimer Laser Treatment?	308
20.3.2	Excimer Laser Surface Treatment	310
20.3.2.1	Surface Characterization	310
20.3.2.2	Mechanical Tests	312
20.4	Conclusion	317
	References	318
21	Effects of the Interphase on the Mechanical Behavior of Thin Adhesive Films – a Modeling Approach	319
	<i>S. Diebels, H. Steeb, and W. Possart</i>	
	Abstract	319
21.1	Introduction	319
21.2	Theoretical Framework	322
21.3	Applications and Examples	325
21.3.1	Uniaxial Tension Test	326
21.3.2	Simple Shear Test	330
21.4	Conclusion	330
	References	333
22	Effect of the Diblock Content on the Adhesive and Deformation Properties of PSAs Based on Styrenic Block Copolymers	337
	<i>C. Creton, A. Roos, and A. Chiche</i>	
22.1	Introduction	337
22.2	Block Copolymer Based Adhesives	339
22.3	Effect of the Diblock Content on Adhesive and Deformation Properties	348
22.4	Understanding the Structure of the Extended Foam	350
22.5	Interfacial Fracture	356
22.6	Summary	360
	Acknowledgments	361
	References	361
23	Contact Mechanics and Interfacial Fatigue Studies Between Thin Semicrystalline and Glassy Polymer Films.	365
	<i>R. L. McSwain, A. R. Markowitz, and K. R. Shull</i>	
	Abstract	365
23.1	Introduction	365
23.2	Materials and Methods	369
23.2.1	Materials and Sample Preparation	369

23.2.2	Pull-Off Test	371
23.2.3	Cyclic Interfacial Fatigue Test	374
23.3	Results	374
23.4	Discussion	381
23.4.1	Wetting Behavior and PEO/TMPC Miscibility	381
23.4.2	PEO/TMPC Interfacial Width and Adhesion	382
23.4.3	PDMS Rupture	384
23.5	Conclusion	385
	Acknowledgments	385
	References	385

Local and Global Aspects of Adhesion Phenomena in Soft Polymers

M.-F. Vallat

	Abstract	387
24.1	Introduction	387
24.2	The Molecular Interphase	388
24.2.1	Autohesion of Polyisoprene	389
24.2.2	Autoadhesion of EPDM	393
24.3	Macroscopic Interphases	395
24.3.1	Vulcanized Elastomers	395
24.3.2	Polyurethane Joints	398
24.4	Conclusion	400
	References	401

Calibration and Evaluation of Nonlinear Ultrasonic Transmission Measurements of Thin-Bonded Interfaces

S. Hirsekorn, A. Koka, S. Kurzenhäuser, and W. Arnold

	Abstract	403
25.1	Introduction	403
25.2	Experimental and Calibration Procedure	404
25.3	Calibrated Ultrasonic Transmission Measurements	406
25.4	Ultrasonic Measurement and Destructive Tests	410
25.5	Conclusion	418
	Acknowledgments	418
	References	419

Debonding of Pressure-Sensitive Adhesives: A Combined Tack and Ultra-Small Angle X-Ray Scattering Study

E. Maurer, S. Loi, and P. Müller-Buschbaum

	Abstract	421
26.1	Introduction	421
26.2	<i>In-Situ</i> Small Angle Scattering Using Synchrotron Radiation	423
26.3	Microscopically Inaccessible Substructures	426
26.4	Conclusion	432

Acknowledgments 433

References 433

27 Nondestructive Testing of Adhesive Curing in Glass–Metal Compounds by Unilateral NMR 435

K. Kremer, B. Blümich, F.-P. Schmitz, and J. Seitzer

Abstract 435

27.1 Introduction 436

27.2 Nuclear Magnetic Resonance (NMR) and the NMR-MOUSE 436

27.3 Quality Control 437

27.4 Application 438

27.5 Conclusion and Outlook 442

Acknowledgments 442

References 443

28 Chemical Processes During Aging in Ultra-thin Epoxy Films on Metals 445

A. Meiser, C. Wehlack, and W. Possart

Abstract 445

28.1 Introduction 445

28.2 Experimental 447

28.2.1 Sample Preparation 447

28.2.2 Aging Conditions 447

28.3 Results and Discussion 448

28.3.1 Crosslinking 448

28.3.2 Additional Aging Effects 451

28.3.3 Band Assignment and Chemical Aging Processes 458

28.4 Conclusion 462

Acknowledgments 463

References 463

29 Depth-Resolved Analysis of the Aging Behavior of Epoxy Thin Films by Positron Spectroscopy 465

J. Kanzow, F. Faupel, W. Egger, P. Sperr, C. Kögel, C. Wehlack, A. Meiser, and W. Possart

Abstract 465

29.1 Introduction 465

29.2 Materials and Methods 466

29.3 Results 467

29.3.1 PALS Investigation of an Unaged Epoxy Film 468

29.3.2 PALS Investigation of Aged Epoxy Films 469

29.3.3 Further Investigations of Aged Epoxy Films 471

29.4 Discussion and Conclusion 474

Acknowledgments 476

References 476

Epoxies on Stainless Steel – Curing and Aging 479*D. Fata, C. Bockenheimer, and W. Possart*

Abstract 479

- 30.1 Introduction 480
- 30.2 Materials and Methods 481
 - 30.2.1 Materials 481
 - 30.2.2 Sample Preparation 482
 - 30.2.3 Aging Experiments 482
 - 30.2.4 Characterization of Aged Specimens 483
- 30.3 Results and Discussion 484
 - 30.3.1 The RT Curing Epoxy System (EP1) 484
 - 30.3.1.1 Curing of EP1 484
 - 30.3.1.2 Thermal Aging of EP1 after Post-Curing at 40°C 487
 - 30.3.1.3 Hydro-thermal Aging of EP1 492
 - 30.3.2 The Hot-Curing Epoxy System (EP2) 495
 - 30.3.2.1 Curing of EP2 495
 - 30.3.2.2 Thermal Aging of EP2 498
 - 30.3.2.3 Hydro-thermal Aging of EP2 500
- 30.4 Conclusion 503
- Acknowledgment 505
- References 505

Scanning Kelvin Probe Studies of Ion Transport and De-adhesion Processes at Polymer/Metal Interfaces 507*K. Wapner and C. Grundmeier*

Abstract 507

- 31.1 Introduction 508
- 31.2 Theory and Experimental Set-Up of a Scanning Kelvin Probe 509
- 31.3 Applications of Scanning Kelvin Probe Studies in Adhesion Science 514
 - 31.3.1 Diffusion of Ions into Metal/Adhesive Interfaces 514
 - 31.3.2 Corrosive Degradation of the Polymer/Metal Interface 516
 - 31.3.2.1 Cathodic Delamination on Adhesive-Coated Iron 516
 - 31.3.2.2 Anodic Delamination (Filiform Corrosion) on Coated Aluminum 518
 - 31.3.3 Detection of Wet Debonding 520
 - 31.3.4 A New Scanning Kelvin Probe Blister Test 521
- Acknowledgment 523
- References 523

32	Advanced Mass Transport Applications with Elastic Bonding of Sandwich Components 525
	<i>S. Koch, A. Starlinger, and X. Wang</i>
	Abstract 525
32.1	Introduction 525
32.2	Stress Distribution in Different Joints 526
32.2.1	Stress Distribution in Bolted Joints 527
32.2.2	Stress Distribution in a Stiff Adhesive Joint 528
32.2.3	Stress Distribution in an Elastic Adhesive Joint 529
32.3	Applications of Flexible Adhesives in Mass Transportation Systems 529
32.3.1	GRP Front Cab 530
32.3.2	Application in Tram Design 530
32.4	Methods of Modeling Flexible Adhesives 531
32.4.1	Modeling Methods for Detailed Local Analysis 532
32.4.2	Modeling Methods for Large Global Structural Analysis 533
32.4.3	Comparison of the TR08 Results from FE Analysis and from Measurement on Lathen Test Track 534
32.5	Joint Design, Production, and Testing 535
32.5.1	Production of Adhesive Joints 536
32.5.2	Joint Testing 536
32.6	Conclusion 537
	References 537
33	Adhesive Joints for Modular Components in Railway Applications 539
	<i>C. Nagel, M. Brede, M. Calomfirescu, J. Sauer, E.A. Ullrich, T. Fertig, and O.-D. Hennemann</i>
	Abstract 539
33.1	Introduction 539
33.2	Adhesives and Adherends 540
33.3	Surface Pretreatment 541
33.4	Mechanical Behavior of Adhesives and Joints 542
33.4.1	Elastic–Plastic Properties of Structural Adhesive Systems 543
33.4.2	Hyperelastic Properties of Flexible Adhesive Systems 544
33.4.3	Creep Behavior of Adhesive Joints 545
33.4.4	Fatigue Properties of Adhesive Joints 547
33.5	Environmental Influences and Design of Structures 550
33.6	Conclusion 553
	Acknowledgment 553
	References 554

Behavior of Dismantlable Adhesives**Including Thermally Expansive Microcapsules 555***Y. Nishiyama and C. Sato*

Abstract 555

34.1 introduction 555

34.2 Materials and Methods 557

34.2.1 Materials 557

34.2.2 Volume Expansion of the Cured Bulk Adhesive 558

34.2.3 Dismantlability of Joints Bonded with the Dismantlable
Adhesive 559

34.2.4 Bond Strength of the Dismantlable Adhesive 559

34.2.5 PVT (Pressure–Volume–Temperature) Tests 560

34.3 Results and Discussion 561

34.3.1 Volume Expansion of the Cured Bulk Adhesive 561

34.3.2 Dismantlability of Joints Bonded with the Dismantlable
Adhesive 562

34.3.3 Bond Strength of the Dismantlable Adhesive 564

34.3.4 PVT Relationship of Microcapsules and Dismantlable Adhesive 565

34.3.5 Discussion 567

34.5 Conclusion 567

References 568

Subject Index 569