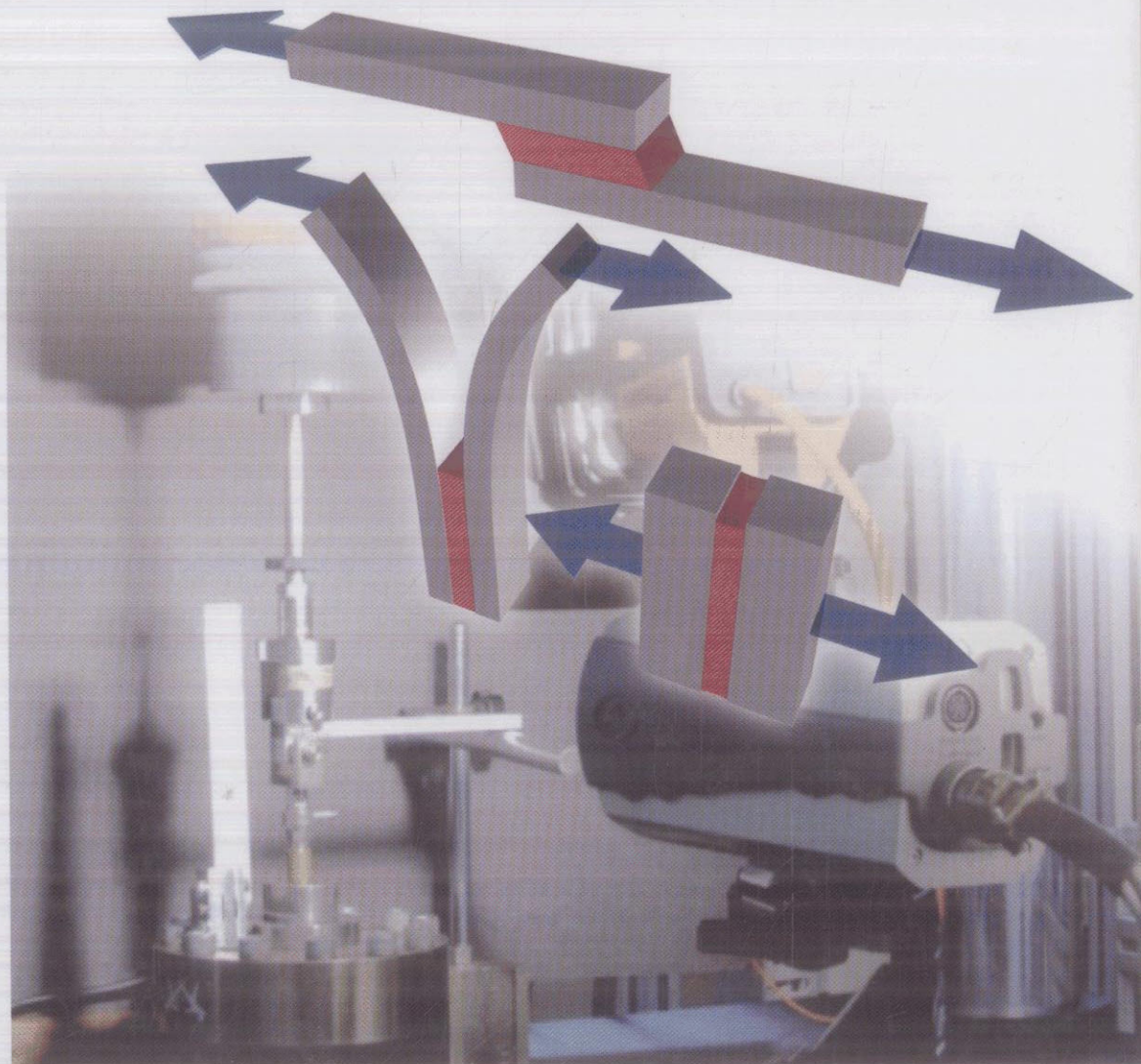


Edited by Lucas F.M. da Silva, David A. Dillard,
Bamber R.K. Blackman, Robert D. Adams

 WILEY-VCH

Testing Adhesive Joints

Best Practices



Contents

About the Editors XXI

List of Contributors XXIII

1	Manufacture of Quality Specimens	1
1.1	Preparing Bulk Specimens by Hydrostatic Pressure	1
	<i>Lucas F.M. da Silva</i>	
1.1.1	Introduction	1
1.1.2	Principle	2
1.1.3	Metallic Mold	3
1.1.4	Silicone Frame	4
1.1.5	Adhesive Application	6
1.1.6	Cure	7
1.1.7	Specimen Machining	7
1.1.8	Results	7
1.2	Preparing Bulk Specimens by Injection	8
	<i>Stefanos Giannis</i>	
1.2.1	Introduction	8
1.2.2	Mold	9
1.2.3	Centrifuge	10
1.2.4	Cure	11
1.2.5	Final Specimen Preparation and Testing	11
1.3	Preparing Bulk Specimens by Pouring	12
	<i>Robert D. Adams</i>	
1.3.1	Introduction	12
1.3.2	Nature of Adhesives Supplied	13
1.3.3	Mixing	13
1.3.4	Pouring	14

1.3.5	Effect of Size	14
1.3.6	Specimen Production	14
1.4	Preparing Lap Joints with Flat Adherends	15
	<i>Lucas F.M. da Silva</i>	
1.4.1	Introduction	15
1.4.2	Mold	15
1.4.3	Substrate Preparation and Mounting	16
1.4.4	Adhesive Application and Assembly	18
1.4.5	Cure	21
1.4.6	Specimen Cleaning	21
1.5	Simple Methods for the Preparation of Single Lap Joints Specimens	22
	<i>Edoardo Nicoli</i>	
1.5.1	Introduction	22
1.5.2	Single Lap Joint (SLJ) Specimens	22
1.5.3	Traditional Methods for SLJ Bonding	23
1.5.4	The Idea for a New Fixture for SLJ Bonding	23
1.5.5	The Fixture	24
1.6	Preparing Thick Adherend Shear Test Specimens	26
	<i>Lucas F.M. da Silva</i>	
1.6.1	Introduction	26
1.6.2	Mold	28
1.6.3	Substrate Preparation	29
1.6.4	Adhesive Application and Assembly	29
1.6.5	Cure	30
1.6.6	Specimen Cleaning	30
1.7	Modified Thick Adherend Shear Test	31
	<i>Jean-Yves Cognard and Romain Créac'hcadec</i>	
1.7.1	Specimen Geometry	31
1.7.2	Bonded Specimen Geometry	33
1.7.3	Machining of the Samples with Beaks	36
1.8	Preparing Butt Joints	37
	<i>Lucas F.M. da Silva, Stefanos Giannīs, and Robert D. Adams</i>	
1.8.1	Introduction	37
1.8.2	Mold	37
1.8.3	Substrate Preparation	38
1.8.4	Adhesive Application and Assembly	39
1.8.5	Cure	40
1.8.6	Specimen Cleaning	40
1.8.7	Alternative Manufacturing Method	40

1.9	Preparing Napkin Ring Specimens	42
	<i>Robert D. Adams</i>	
1.9.1	Introduction	42
1.9.2	Adherends	42
1.9.3	Joint Manufacture–Alignment Jig	44
1.9.4	Introduction of the Adhesive	45
1.9.5	Final Specimen Preparation	46
1.10	Preparing T Joint Specimens	46
	<i>Lucas F.M. da Silva and Robert D. Adams</i>	
1.10.1	Introduction	46
1.10.2	Mold	47
1.10.3	Substrates Preparation	48
1.10.4	Adhesive Application and Assembly	49
1.10.5	Cure	49
1.10.6	Specimens Cleaning	50
1.10.7	Results	50
1.11	Preparing Flexible-to-Rigid Peel Specimens	51
	<i>Stefanos Giannis</i>	
1.11.1	Introduction	51
1.11.2	Mold	51
1.11.3	Adherend Preparation	52
1.11.4	Adhesive Application and Assembly	53
1.11.5	Cure	54
1.11.6	Final Specimen Preparation	54
1.12	Preparing Specimens for Fracture Properties: Double Cantilever Beam and Tapered Double Cantilever Beam	55
	<i>Bamber R.K. Blackman</i>	
1.12.1	Introduction	55
1.12.2	Bonding Jigs	56
1.12.3	Specimen Dimensions	58
1.12.3.1	DCB Specimens	58
1.12.3.2	TDCB Specimens	58
1.12.4	Substrate Conditioning and Preparation	59
1.12.4.1	Storage and Substrate Conditioning	59
1.12.4.2	Surface Pretreatment	59
1.12.5	Adhesive Application and Forming the Joint	61
1.12.5.1	Adhesive Handling and Application	61
1.12.5.2	Control of Bondline Thickness	61
1.12.5.3	Introduction of the Initial Crack	62
1.12.6	Cure	62
1.12.7	Final Specimen Preparation	62

1.13	Preparing Bonded Wood Double Cantilever Beam (DCB) Specimens	63
	<i>Hitendra K. Singh, Edoardo Nicoli, and Charles E. Frazier</i>	
1.13.1	Introduction	63
1.13.2	Aspects of Wood Bonding	64
1.13.3	Sample Preparation	65
1.13.3.1	Wood Preparation	65
1.13.3.2	Adhesive Types	66
1.13.3.3	DCB Specimen Preparation	66
1.13.3.4	Judging the Sample Quality by Adhesive Penetration	68

1.14	Modified Arcan Test	69
	<i>Jean-Yves Cognard, Laurent Sohier, Bernard Gineste, and Romain Créac'hcadec</i>	
1.14.1	The Arcan-Type Device	69
1.14.2	A Modified Arcan Test	70
1.14.3	Interfaces Assembly Machine	72
1.14.4	Stress Distribution in the Joint	73
	References	76

2 Quasi-Static Constitutive and Strength Tests 79

2.1	Quasi-Static Testing of Bulk Tensile Specimens	79
	<i>Lucas F.M. da Silva</i>	
2.1.1	Introduction	79
2.1.2	Specimen Geometry	79
2.1.3	Gripping System	81
2.1.4	Load and Displacement Measurement	81
2.1.5	Testing Speed and Environmental Conditions	82
2.1.6	Properties Determination	83

2.2	Uniaxial and Bulk Compression	85
	<i>Patricia Roumagnac and Patrick Heuillet</i>	
2.2.1	Introduction	85
2.2.2	Uniaxial Compression – Experimental Methods	85
2.2.2.1	Rubbery and Soft Materials	85
2.2.2.2	Stiffer Materials	85
2.2.3	Hydrostatic Compression – Experimental Methods	87
2.2.3.1	Rubbery and Soft Materials	88
2.2.3.2	Stiffer Material	89
2.2.4	Hydrostatic Compression – Testing Device	90
2.2.5	Hydrostatic Compression – Pressure and Change in Volume Measurement	91
2.2.6	Hydrostatic Compression – Testing Procedure	92

2.2.7	Hydrostatic Compression – Results and Bulk Modulus Determination	92
2.3	Quasi-Static Testing of Bulk Compression on Flat Specimens	93
	<i>Lucas F.M. da Silva</i>	
2.3.1	Introduction	93
2.3.2	Specimen Geometry	93
2.3.3	Loading System	94
2.3.4	Load and Displacement Measurement	96
2.3.5	Testing Speed and Environmental Conditions	96
2.3.6	Properties Determination	96
2.4	Iosipescu (V-Notched Beam) Test	97
	<i>Bruce Duncan</i>	
2.4.1	Introduction	97
2.4.2	Test Specimens	97
2.4.3	Test Fixtures	99
2.4.4	Strain Measurement Principles	100
2.4.5	Accuracy and Reliability of the Iosipescu Method	103
2.5	Arcan (V-Notched Plate) Test	104
	<i>Bruce Duncan</i>	
2.5.1	Introduction	104
2.5.2	Test Fixtures and Specimens	104
2.5.3	Measurement Principles	107
2.6	Quasi-Static Testing of Butt Joints in Tension	113
	<i>Gregory L. Anderson</i>	
2.6.1	Introduction	113
2.6.2	Sample Geometry	114
2.6.3	Sample Preparation	116
2.6.4	Sample Testing	117
2.7	Shear Properties of Adhesives Measured by Napkin Rings and Solid Butt Joints in Torsion	118
	<i>Robert D. Adams</i>	
2.7.1	Introduction	118
2.7.2	Napkin Ring Test	119
2.7.3	Solid Butt Joint	120
2.7.4	Test Specimen	121
2.7.5	Torsion Machine	122
2.7.6	Measurement of Rotation	122
2.7.7	Some Typical Results	124

2.8	Quasi-Static Testing of Thick Adherend Shear Test Specimens	125
	<i>Lucas F.M. da Silva</i>	
2.8.1	Introduction	125
2.8.2	Specimen Geometry	126
2.8.3	Adherends	126
2.8.4	Gripping System	126
2.8.5	Load and Displacement Measurement	127
2.8.6	Testing Speed and Environmental Conditions	130
2.8.7	Failure Modes	130
2.8.8	Properties Determination	130
2.9	Modified Thick Adherend Shear Test	133
	<i>Jean-Yves Cognard and Romain Créac'hcadec</i>	
2.9.1	Measurement	134
2.9.2	Analysis of Experimental Results	134
2.9.3	Simplified Identification Method	136
2.9.4	Influence of Adhesive Thickness	137
2.9.5	Behavior under Cyclic Loadings	138
2.9.6	Experimental Requests	139
2.10	Quasi-Static Testing of Lap Joints	139
	<i>Lucas F.M. da Silva</i>	
2.10.1	Introduction	139
2.10.2	Specimen Geometry	140
2.10.3	Adherends	141
2.10.4	Gripping System	142
2.10.5	Load and Displacement Measurement	143
2.10.6	Testing Speed and Environmental Conditions	144
2.10.7	Failure Modes	145
2.10.8	Properties Determination	146
2.11	Modified Arcan Test	147
	<i>Jean-Yves Cognard, Laurent Sohier, Bernard Gineste, and Romain Créac'hcadec</i>	
2.11.1	Measurement	148
2.11.2	Experimental Results	149
2.11.3	Adhesive Behavior under Shear Loads	151
2.11.4	Strength Envelope in Terms of Stresses	153
2.11.5	Deformation of the Adhesive	154
2.12	Pin-and-Collar Test Method	155
	<i>Juana Abenojar, Yolanda Ballesteros, Juan C. del Real, and Miguel A. Martinez</i>	
2.12.1	Introduction	155

- 2.12.2 Sample Preparation 155
- 2.12.2.1 Materials 156
- 2.12.2.2 Preparation of the Adhesives and Surface Treatment 156
- 2.12.2.3 Adhesive Application: Procedure and Instrumentation 157
- 2.12.2.4 Specimen Fitting Out 158
- 2.12.3 Testing and Result Analysis 158
- References 160

3 Quasi-Static Fracture Tests 163

3.1 Measuring Bulk Fracture Toughness 163

Raymond A. Pearson

- 3.1.1 Introduction 163
- 3.1.2 Principle 163
- 3.1.3 Procedure 164
- 3.1.4 Fracture Mechanisms 167
- 3.1.5 Summary 167

3.2 Quasi-Static Fracture Tests: Double Cantilever Beam and Tapered Double Cantilever Beam Testing 169

Bamber R.K. Blackman

- 3.2.1 Introduction 169
- 3.2.2 Test Specimens 170
- 3.2.3 Test Apparatus 170
- 3.2.4 DCB Testing 170
- 3.2.4.1 DCB Testing According to ASTM D3433 170
- 3.2.4.2 DCB Testing According to ISO 25217 171
- 3.2.5 TDCB Testing 174
- 3.2.5.1 TDCB Testing According to ASTM D3433 174
- 3.2.5.2 TDCB Testing According to ISO 25217 175
- 3.2.6 Test Experience 176

3.3 End-Notched Flexure 177

Raul D.S.G. Campilho

- 3.3.1 Introduction 177
- 3.3.2 Manufacturing of the Specimens 179
- 3.3.2.1 Preparation of the Adherends 179
- 3.3.2.2 Application of the Adhesive 180
- 3.3.2.3 Final Preparation of the Specimen 182
- 3.3.3 Testing of the Specimens 183
- 3.3.3.1 Testing Procedure 183
- 3.3.3.2 Available Data Reduction Schemes 185

3.4	Mode II Fracture Characterization of Bonded Joints Using the ELS Test	186
	<i>Marcelo F.S.F. de Moura and Nuno M.M. Dourado</i>	
3.4.1	Introduction	186
3.4.2	Specimen Geometry	187
3.4.3	Gripping System	188
3.4.4	Load and Displacement Measurement	188
3.4.5	Classical Data Reduction Schemes	189
3.4.6	Equivalent Crack Method	190
3.4.7	Analysis of Results	191
3.5	The Notched Torsion Test to Determine the Mode III Fracture Properties of Adhesives	191
	<i>Robert D. Adams</i>	
3.5.1	Introduction	191
3.5.2	Test Method	192
3.5.3	Determination of Fracture Toughness	193
3.5.4	Some Typical Results	193
3.6	Other Mixed Mode Adhesive Fracture Test Specimens	194
	<i>David A. Dillard</i>	
3.6.1	Introduction	194
3.6.2	The Fixed Ratio Mixed Mode (FRMM) Specimen	197
3.6.3	The Single Leg Bend (SLB) Specimen	198
3.6.4	The Cracked Lap Shear (CLS) Specimen	198
3.6.5	Failure Envelopes	199
3.6.6	Summary	201
3.7	Compact Mixed Mode (CMM) Fracture Test Method	201
	<i>John H.L. Pang</i>	
3.7.1	Introduction	201
3.7.2	Analysis of CMM Specimen with an Interlayer Crack	202
3.7.3	Analysis of CMM Specimen with an Interface Crack	205
3.7.4	Mixed Mode Fracture Toughness Test and Results	209
3.7.4.1	CMM Specimen Fracture Toughness for Interlayer Crack	209
3.7.4.2	CMM Specimen Fracture Toughness for Interface Crack	210
3.8	Mixed Mode Bending (MMB) with a Reeder and Crews Fixture	212
	<i>Peter Davies</i>	
3.8.1	Introduction	212
3.8.2	Specimen Geometry	212
3.8.3	Test Fixture	214
3.8.4	Test Procedure	214
3.8.5	Data Analysis	214
3.8.6	Test Experience	215

3.9	Mixed Mode Fracture Testing	216
	<i>Aboutaleb Ameli, Shahrokh Azari, Marcello Papini, and Jan K. Spelt</i>	
3.9.1	Introduction and Background	216
3.9.2	Specimen Configuration and Preparation	217
3.9.3	Fracture Test and Loading System	218
3.9.4	Load and Crack Length Measurement	218
3.9.5	Calculation of Fracture Energy and Phase Angle	221
3.9.5.1	Beam Theory	221
3.9.5.2	Beam-on-Elastic-Foundation Model	221
3.9.6	Fracture Energy Envelopes	222
3.9.7	R-Curve Measurement	222
3.10	Fracture of Wood Double Cantilever Beam (DCB) Specimens	224
	<i>Edoardo Nicoli, Hitendra K. Singh, and Charles E. Frazier</i>	
3.10.1	Introduction	224
3.10.2	Factors Influencing Fracture in Wood	225
3.10.3	Bonded Wood Testing	226
3.10.4	Analysis of Fracture Data of Bonded Wood	227
3.11	The T-Peel Test	229
	<i>David A. Dillard</i>	
3.11.1	Introduction	229
3.11.2	T-Peel Test Configurations and Fracture Mechanics Interpretation	230
3.11.3	Specimen Preparation	236
3.11.4	Testing	238
3.11.5	Interpreting Results	238
3.11.6	Locus of Failure	241
3.11.7	Summary	243
3.12	Peel Testing at 180°	244
	<i>Stefanos Giannis</i>	
3.12.1	Introduction	244
3.12.2	Specimens	244
3.12.3	Test Machine, Fixtures, and Procedure	245
3.12.4	Data Collection and Analysis	246
3.12.5	Failure Mode Identification	247
3.13	The Floating Roller Peel Test	248
	<i>Robert D. Adams</i>	
3.13.1	Introduction	248
3.13.2	Test Specifications	249
3.13.3	Finite Element Analysis and Experimental Investigation of the Peel Test	250

3.14	Climbing Drum Peel Test	251
	<i>Keith B. Armstrong</i>	
3.14.1	Introduction	251
3.14.2	Materials	252
3.14.3	Test Procedure	253
3.14.4	Failure Modes	256
3.14.5	Results	256
3.15	The Analysis of Peel Tests	257
	<i>Neal Murphy and Luiz F. Kawashita</i>	
3.15.1	Introduction and Background	257
3.15.2	Definition of Adhesive Fracture Energy	257
3.15.3	Determination of Plastic Work in Bending	259
3.15.4	Determination of Root Rotation Using a Beam on Elastic Foundation Analysis	261
3.15.5	Determination of the Adhesive Fracture Energy Using ICPeel (Digitized)	263
3.15.6	Analysis of T-Peel Tests	265
	References	266
4	Higher Rate and Impact Tests	273
4.1	Dynamic Elastic Modulus	273
	<i>Lucas F.M. da Silva and Robert D. Adams</i>	
4.1.1	Introduction	273
4.1.2	Dynamic Tensile Modulus	273
4.1.3	Dynamic Shear Modulus	276
4.2	The Pendulum Impact Test for Adhesives and Adhesive Joints	280
	<i>Robert D. Adams</i>	
4.2.1	Introduction	280
4.2.2	Izod and Charpy Tests	280
4.2.3	ASTM Block Impact Test	281
4.2.4	Instrumented Pendulum Impact Test	281
4.3	Higher Rate and Impact Tests: Fracture at High Rates	284
	<i>Bamber R.K. Blackman</i>	
4.3.1	Introduction	284
4.3.2	High-Rate Mode I Testing	284
4.3.2.1	Introduction	284
4.3.2.2	Experimental Considerations	285
4.3.2.3	Analytical Considerations	286
4.3.2.4	Fracture Behavior	287
4.3.3	High-Rate Mode II and Mixed-Mode Testing	287
4.3.4	Test Experience	288

4.4	High-Strain-Rate Testing of Adhesive Specimens and Joints by Hopkinson Bar Technique	289
	<i>Luca Goglio and Marco Peroni</i>	
4.4.1	Introduction	289
4.4.2	Hopkinson Bar Techniques	289
4.4.3	Specimens Preparation and Geometries	292
4.4.4	Processing of the Results and Discussion	293
4.5	Clamped Hopkinson Bar	297
	<i>Chiaki Sato</i>	
4.5.1	Introduction	297
4.5.2	Clamped Hopkinson Bar Equipment	298
4.5.2.1	Configuration	298
4.5.2.2	Principles	300
4.5.3	Impact Strength Determination of Adhesively Bonded Joints	303
4.5.3.1	Tensile Impact Tests	304
4.5.3.2	Torsional Impact Tests	304
4.5.3.3	Combined Impact Tests	304
4.6	Testing of Adhesive Bonds under Peel and Shear Loads at Increased Velocities	309
	<i>Klaus Dilger, Michael Frauenhofer, and Stefan Kreling</i>	
4.6.1	Introduction	309
4.6.2	Single Lap Shear Tests at Elevated Testing Velocities	310
4.6.2.1	Materials and Specimen Preparation	310
4.6.2.2	Testing	311
4.6.3	Combined Peel and Pull Loads (Short Peel Specimen)	312
4.6.3.1	Specimen Geometry	312
4.6.3.2	Manufacturing and Testing of Short Peel Specimen	313
4.6.4	Interpretation of Test Results	314
	References	316
5	Durability	319
5.1	Measurement of the Diffusion Coefficient	319
	<i>Stefanos Giannis</i>	
5.1.1	Introduction	319
5.1.2	Mechanisms of Diffusion	320
5.1.3	Mass Uptake and Diffusion Coefficient Measurement	321
5.1.4	Specimens	321
5.1.5	Procedure	321
5.1.6	Applicability	322

5.2	Tests with Moisture	323
	<i>Peter Davies</i>	
5.2.1	Introduction	323
5.2.2	Standard Sample Conditioning	323
5.2.3	Conditioning Equipment	324
5.2.4	Bulk Adhesive Conditioning	324
5.2.5	Adhesive Assembly Conditioning	326
5.2.6	An Improved Test Procedure	327
5.3	Durability Testing Using Open-Faced Specimens	328
	<i>Aboutaleb Ameli, Naresh Varma Datla, Shahrokh Azari, Marcello Papini, and Jan K. Spelt</i>	
5.3.1	Introduction	328
5.3.2	Specimen Preparation and Configuration	328
5.3.2.1	Primary Bonding	330
5.3.2.2	Aging	330
5.3.2.3	Secondary Bonding	331
5.3.3	Fracture Testing	332
5.3.4	Fatigue Testing	334
5.4	Tests with Temperature	335
	<i>Paul Ludwig Geiss</i>	
5.4.1	Introduction	335
5.4.2	General Test Procedures	336
5.4.3	Compilation of Test Results	338
5.4.4	Lifetime Prediction	339
5.4.5	Standards Related to Creep Testing at Elevated Temperatures	341
5.5	The Wedge Test	343
	<i>Jacques Cognard</i>	
5.5.1	Introduction	343
5.5.2	The Mechanics of the Wedge Test	344
5.5.3	Experimental Details	345
5.5.3.1	Dimensions	345
5.5.3.2	Measurements of Fracture Length	346
5.5.3.3	Variations	347
5.5.4	Results	348
5.5.4.1	Value of the Fracture Energy	348
5.5.5	The WT and the Evaluation of Durability	348
5.5.5.1	Influence of the Temperature	349
5.5.5.2	Influence of the Environment	349
5.5.5.3	Water	349
5.5.5.4	Relative Humidity	350
5.5.5.5	Surface Treatment	350
5.5.6	Correlation between WT and Normal Use	350

5.6	Fatigue	351
	<i>Erol Sancaktar</i>	
5.6.1	Introduction	351
5.6.2	Static Fatigue and Delayed Failure of Adhesive Joints	351
5.6.2.1	Creep and Delayed Failure	351
5.6.2.2	Examples of Temperature-Dependent Delayed Failure Behavior	352
5.6.3	Dynamic Fatigue of Adhesive Joints under Monotonic and Cyclic Loading Conditions	355
5.6.3.1	Cyclic Loading Fatigue	355
5.6.3.2	Strain Energy Release Rates	358
5.6.3.3	Crack Propagation under Mixed-Mode Cyclic Loading	361
5.6.3.4	Examples of Mixed-Mode Fatigue Measurements with the Use of ILLMS	361
5.6.3.5	Results and Discussion on Examples of Mixed-Mode Fatigue Measurements with the Use of ILLM Specimen	368
5.7	Mixed-Mode Fatigue Testing of Adhesive Joints	369
	<i>Shahrokh Azari, Aboutaleb Ameli, Marcello Papini, and Jan K. Spelt</i>	
5.7.1	Introduction	369
5.7.2	Specimen Preparation	369
5.7.3	Fatigue Testing	371
5.7.3.1	Fatigue Loading	371
5.7.3.2	Crack Length Measurement	372
5.7.3.3	Strain Energy Release Rate Calculation	373
5.7.4	Observations	373
5.7.4.1	Effect of Mode Ratio and Applied G	374
5.7.4.2	Effect of Bondline Thickness	375
5.7.4.3	Effect of Substrate Material	375
5.8	Measurement of Time-Dependent Crack Growth	375
	<i>Jan K. Spelt</i>	
5.8.1	Introduction	375
5.8.2	Measurement of Creep Crack Growth	376
5.8.3	Discussion	379
5.9	Curvature Mismatch Fracture Test for Subcritical Debonding	379
	<i>David A. Dillard</i>	
5.9.1	Introduction	379
5.9.2	Curvature Mismatch Specimen Configuration	380
5.9.3	Preparing Specimens	381
5.9.4	Conducting Tests	382
5.9.5	Data Analysis	383
5.9.6	Specimen Adaptations	384
	References	386

6	Other Test Methods	389
6.1	Thermal Characterization	389
	<i>John Comyn</i>	
6.1.1	Thermal Properties of Adhesives	389
6.1.2	Methods Available	390
6.1.3	Instrumental Methods	390
6.1.3.1	Differential Scanning Calorimetry	390
6.1.3.2	Thermomechanical Analysis	392
6.1.3.3	Dynamic Mechanical Thermal Analysis	392
6.1.3.4	Thermogravimetric Analysis	392
6.1.3.5	Thermal Conductivity of Adhesives	393
6.1.4	Other Methods	393
6.1.4.1	Dilatometry	393
6.1.4.2	Minimum Film Formation Temperature of Latex Adhesives	393
6.1.4.3	Torsion Pendulum	395
6.2	Dynamic Mechanical Analysis with a Vibrating Beam Method	395
	<i>Lucas F.M. da Silva and Robert D. Adams</i>	
6.2.1	Introduction	395
6.2.2	Manual Damping Measurement	396
6.2.3	Automatic Damping Measurement	399
6.3	Bimaterial Curvature Method for Residual Stress and Thermal Expansion Coefficient Determination	402
	<i>David A. Dillard and Yongqiang Li</i>	
6.3.1	Introduction	402
6.3.2	Specimen Configuration	404
6.3.3	Specimen Preparation	406
6.3.4	Conducting Tests	406
6.3.5	Analysis	408
6.3.6	Summary	409
6.4	The Pull-Off Test	409
	<i>David A. Dillard</i>	
6.4.1	Introduction	409
6.4.2	Specimen Configuration and Analysis	410
6.4.3	Testing Procedure and Analysis	411
6.4.4	Specimen Options	412
6.4.5	Summary	413
6.5	Shaft-Loaded Blister Test	414
	<i>Masoud Khabiry and Kai-tak Wan</i>	
6.5.1	Introduction	414
6.5.2	Loading Configuration: SLBT	414

6.5.3	Theoretical Model (SLBT)	415
6.5.4	Circular Punch Test (CPT): a Modified Shaft-Loaded Blister Test	417
6.5.5	Theoretical Model (CPT)	418
6.6	Tests under Hydrostatic Pressure	419
	<i>Peter Davies</i>	
6.6.1	Introduction	419
6.6.2	Test Fixture	420
6.6.3	Test Procedure	422
6.6.4	Data Analysis	423
	References	423
	Index	427