
Contents

Preface	xv
Editors Biographies	xix
Part I Nanocomposites: Structure and Properties	1
Chapter 1 Carbon Nanotube-Reinforced Polymers: a State of the Art Review	3
1 Introduction	3
2 General Problems in Nanocomposite Technology	4
3 Experimental	6
3.1 Manufacturing of Multiple-Wall Carbon Nanotubes	6
3.2 Treatment of Carbon Nanotubes	7
3.3 Matrix Polymers	7
3.4 Electron Microscopy	7
3.5 Dynamic-Mechanical Thermal Analysis	8
4 Results	8
4.1 Comparison of the Multiple-Wall Carbon Nanotubes Studied	8
4.2 Purification	10
4.3 CNT/Epoxy Composites: Dispersion, Matrix Bonding, and Functionalization	11
4.3.1 Dispersion	11
4.3.2 Nanotube-Matrix Interaction	13
4.3.3 Functionalization	13
4.4 Microscopy	15
4.4.1 Matrix Bonding to the Nanotubes	15
4.4.2 Crack Bridging and Telescopic Pull-Outs	16
4.5 Thermal and Mechanical Properties	17
4.6 Electrical Properties	18
5 Conclusions	21
6 Acknowledgements	21
7 References	22

Chapter 2 Application of Non-Layered Nanoparticles in Polymer Modification	25
1 Introduction	25
2 Surface Treatment and Compounding	27
2.1 Raw Materials	27
2.2 Pregrafting of the Nanoparticles by Irradiation	27
2.3 Characterization of the Irradiation Products	28
2.4 Preparation of PP-Based Nanocomposites and Their Characterization	28
2.5 Preparation of Epoxy-Based Nanocomposites and Their Characterization	29
3 Thermoplastic Systems	29
3.1 Effect of Irradiation Grafting Polymerization on the Nanoparticles	29
3.2 Tensile Properties	30
3.3 Fractography	35
4 Thermosetting Systems	36
4.1 Interfacial Interactions in the Composites	36
4.2 Curing Behavior	38
4.3 Friction and Wear Performance	38
5 Conclusions	42
6 Acknowledgements	43
7 References	43
Chapter 3 Reinforcement of Thermosetting Polymers by the Incorporation of Micro- and Nanoparticles	45
1 Introduction	45
2 Manufacturing of Thermosetting Nanocomposites	47
3 Properties of Nanocomposites	50
3.1 Stress-Strain Behavior	50
3.2 Impact Behavior	54
3.3 Stiffness-Impact Energy Relationship	55
3.4 Dynamic Mechanical Properties	56
3.5 Wear Performance	57
4 Acknowledgements	60
5 References	60
Chapter 4 Polyimides Reinforced by a Sol-Gel Derived Organosilicon Nanophase: Synthesis and Structure-Property Relationships	63
1 Nanocomposites Based on Flexible-Chain Polymers	63
2 Nanocomposites Based on Semi-Rigid Chain Polymers (Polyimides)	66

2.1 <i>In Situ</i> Generation of an Organosilicon Nanophase	67
2.2 Structural Characterization	68
2.3 Water Uptake	69
2.4 Thermomechanical Performance	70
2.5 Dielectric Properties	72
3 Conclusions	73
4 Acknowledgements	74
5 References	74
Chapter 5 Layered Silicate/Rubber Nanocomposites via Latex and Solution Intercalations	77
1 Concept of Nanoreinforcement	77
2 Production of Rubber/Clay Nanocomposites	78
2.1 Latex Intercalation	79
2.1.1 Nanocomposites from Rubber Latex	79
2.1.2 Nanocomposites from Latex Blends	81
2.1.3 Radiation-Vulcanized NR Latex	84
2.2 Solvent-Assisted Intercalation	87
3 Future Issues	88
4 Acknowledgements	88
5 References	89
Chapter 6 Property Improvements of an Epoxy Resin by Nanosilica Particle Reinforcement	91
1 Introduction and State of the Art	91
2 Preparation and Characterization Techniques	94
2.1 Basic Material Components	94
2.2 Preparation of Nanosilica-Filled Epoxy Composites	94
2.3 Structural and Mechanical Analysis	95
2.3.1 Microstructure	95
2.3.2 Viscosity Studies of the Unfilled and Filled Resin	95
2.3.3 Mechanical Properties	95
2.3.4 Tribological Properties	96
2.3.5 Failure Analysis	96
3 Microstructural and Rheological Details	96
3.1 Particle Distribution	96
3.2 Viscosity	98
4 Mechanical Properties	99
4.1 Three-Point Bending	99
4.2 Microhardness	99
4.3 Fracture Toughness	101
4.4 Tribological Properties	101
5 Conclusions	103

6 Acknowledgements	104
7 References	104
Part II Special Characterization Methods and Modeling	107
Chapter 7 Micro-Scratch Testing and Finite Element Simulation of Wear Mechanisms of Polymer Composites	109
1 Introduction	109
2 Micro-Scratch Testing	110
3 The Representative Wear Mechanisms	113
4 Wear Considerations by Finite Element Contact Analysis	114
4.1 Finite Element Macro/Micro-Contact Models	115
4.2 Normal Fiber Orientation	116
4.3 Parallel Fiber Orientation	118
4.4 Anti-Parallel Fiber Orientation	120
5 Finite Element Simulation of the Fiber/Matrix Debonding	121
5.1 Debonding Model and Interface Elements	122
5.1.1 Interface Elements	122
5.1.2 Conditions of Debonding	123
5.1.3 Unloading Considerations	125
5.1.4 The Debonding Algorithm	125
5.2 Calculations for N-Oriented Carbon Fibers in a PEEK Matrix	126
6 Conclusions	129
7 Acknowledgements	130
8 References	130
Chapter 8 Determination of the Interface Strength of Polymer-Polymer Joints by a Curved Interface Tensile Test	133
1 Introduction	133
2 Curved Interface Tensile Test	136
3 Stress Calculation by Finite-Element Analysis	137
3.1 Flat Interface	138
3.2 Curved Interface	138
4 Experimental Observations	140
4.1 Materials and Specimen Preparation	140
4.2 Tensile Tests and Strain Estimation	142
4.3 Determination of the Adhesion Strength	144
5 Conclusions and Outlook	145
6 References	146

Chapter 9 Manufacturing and Characterization of Microfibrillar Reinforced Composites from Polymer Blends	149
1 Introduction	149
2 Materials, Processing, and Characterization Techniques	151
3 Structure and Properties of MFCs	153
3.1 Structure and Properties of MFCs Based on PET/PP Blends	153
3.1.1 Morphology	153
3.1.2 Mechanical Properties of the Drawn Blends After Processing	157
3.2 Structure and Properties of MFCs Based on LCP/PPE Blends	159
3.2.1 Morphology	159
3.2.2 Mechanical Properties of Injection Molded LCP/PPE Blends with MFC Structure	162
4 Conclusions	164
5 Acknowledgements	165
6 References	165
Chapter 10 Tribological Characteristics of Micro- and Nanoparticle Filled Polymer Composites	169
1 Introduction	169
2 Influence of Particle Size: from Micro- to Nanometer	170
3 Influence of the Nanoparticle Volume Content	171
4 Particle-Filled Polytetrafluoroethylene	174
5 Integration of Inorganic Particles	
With Traditional Fillers	175
5.1 Inorganic Particles and Other Fillers	175
5.2 Combinative Effect of Nanoparticles and Short Carbon Fibers	175
6 Conclusion	182
7 Acknowledgement	182
8 References	182
Part III Macrocomposites: Processing and Application	187
Chapter 11 Production of Thermoplastic Towpregs and Towpreg-Based Composites	189
1 Introduction	189
2 Raw Materials	190
3 Production of Towpregs	190
3.1 Process and Equipment Description	190

3.2 Relationships Between Final Properties and Processing Conditions	192
3.2.1 Parameters Affecting the Polymer Powder Deposition	192
3.2.2 Influence of the Processing Conditions on the Final Composite Properties	193
4 Production of Towpreg-Based Composites	194
4.1 Compression Molding	194
4.1.1 Process Description	194
4.1.2 Molding Conditions	194
4.2 Process Modeling	195
4.2.1 Isothermal Consolidation	196
4.2.2 Non-Isothermal Consolidation	197
4.2.3 Validation of the Consolidation Model	198
4.3 Pultrusion	200
4.3.1 Process Description	200
4.3.2 Processing Conditions	201
4.3.3 Process Modeling	201
4.4 Filament Winding	203
4.4.1 Process Description	203
4.4.2 Processing Conditions	203
4.4.3 Relationships Between Final Properties and Processing Conditions	204
4.5 Long Fiber-Reinforced Composite Stamping	206
4.5.1 Process Description	206
4.5.2 Processing Conditions	206
5 Composite Properties	206
5.1 Mechanical Properties of Continuous Fiber-Reinforced Composites	207
5.2 Mechanical Properties of Discontinuous Fiber-Reinforced Composites	207
6 Conclusions	211
7 Acknowledgements	211
8 References	212
Chapter 12 Manufacturing of Tailored Reinforcement for Liquid Composite Molding Processes	215
1 Introduction	215
2 Pre-selection of Sewing Thread	217
2.1 Selection Criteria	217
2.2 Polyester Thread in Global Preform Sewing	219
3 Tailored Reinforcements	220
4 Stitching Parameters and Their Influence on the Fiber-Reinforced Polymer Composites	221

4.1	Machine Parameters	221
4.1.1	Thread Tension	221
4.1.2	Presser Foot Pressure	223
4.2	Stitching Pattern	224
5	Quality Secured Preforming	225
5.1	Macro Preform Quality	225
5.2	Micro Preform Quality	225
5.3	Fiber Disturbance at Seams	226
6	Liquid Composite Molding Process for Net-Shape Preforms	227
6.1	Preform LCM Process Chain	227
6.2	Thermal Behavior of Seam in FRPC	228
7	Quality Management	228
8	Conclusions	231
9	Acknowledgements	231
10	References	231

Chapter 13 Deconsolidation and Reconsolidation of Thermoplastic Composites During Processing 233

1	Introduction	233
2	Experimental Observations	235
2.1	Void Growth	235
2.2	Migration of Voids	236
2.3	Squeezed Flow of Resin During Reconsolidation	237
3	Mechanistic Model of the Void Growth	238
3.1	Discussion of the Mechanism	238
3.2	Void-Growth Model	241
3.3	Theoretical Predictions	244
4	Thermal/Mechanistic Models of Migration of Voids	246
4.1	Discussion of Mechanisms	246
4.2	Thermal Analysis	246
4.3	Void Closure	249
4.4	Squeezed Creep Flow of Resin	251
5	Conclusions	253
6	Acknowledgement	253
7	References	253

Chapter 14 Long Fiber-Reinforced Thermoplastic Composites in Automotive Applications 255

1	Introduction	255
2	Long Glass Fiber-Reinforced Polypropylene with Mineral Fillers	257
3	Long Fiber-Reinforced Polyamide 66 with Minimized Water Absorption	259

4	Long Fiber-Reinforced Thermoplastic Styrene Resins for Car Interior Applications	259
5	Conclusions	261
6	References	261
Part IV Mechanical Performance of Macrocomposites		263
Chapter 15 Deformation Mechanisms in Knitted Fabric Composites		265
1	Introduction	265
2	Knitted Fabrics	267
3	Material Characterization and Deformation Behavior	268
3.1	Raw Materials	268
3.2	Material Characterization	268
3.2.1	Tensile Testing	268
3.2.2	V-Bending	268
3.2.3	Dome Forming	269
3.2.4	Cup Forming	269
4	Experimental Results and Grid Strain Analysis	269
4.1	Tensile Testing	269
4.2	V-bending	270
4.3	Dome Forming	271
4.4	Cup Forming	273
5	Textile Composite Deformation Mechanisms	274
5.1	Prepreg Flow Mechanisms	274
5.2	Macro-Level Fabric Deformation Modes	274
5.3	Micro-Level Fabric Deformation Modes	275
5.4	Textile Fabric Force-Displacement Curve	276
5.5	Experimental Force-Displacement Curves	278
6	Modeling the Manufacture of the Reinforcement Architecture	278
6.1	Model Set-Up	279
6.2	Model Input: Knitting Machine Parameters	280
6.3	Model Input: Material Property Parameters	280
6.4	Model Input: Non-Physical Parameters	282
6.5	Simulating the Mechanics of the Knitting Process	283
7	Concluding Remarks	284
8	Acknowledgements	286
9	References	286
Chapter 16 Impact Damage in Composite Laminates		289
1	Introduction	289
2	Deformation and Energy Release Rate of Axisymmetric Plates with Multiple Delaminations	291

2.1	Axisymmetric Plate with Multiple Delaminations of the Same Size	291
2.2	A Delamination is Larger or Smaller than the Rest	293
2.3	Effect of geometrical nonlinearity	295
2.4	Finite Element Analysis	296
2.5	Some Derived Relationships	297
3	Effect of the Stacking Sequence	300
4	Simulation of Delamination Growth in Composite Laminates	304
5	Conclusion	305
6	References	306

Chapter 17 Discontinuous Basalt Fiber-Reinforced Hybrid Composites

	309	
1	Introduction	309
2	Basalt Fibers	310
2.1	Characteristics, Applications	310
2.2	Production and Properties of Melt-Blown Basalt Fibers	313
3	Hybrid Composites	314
3.1	Concept and Realization	314
3.2	Property Prediction	316
3.3	Applications	317
4	Thermoplastic Hybrid Composites	317
4.1	Polypropylene with Hybrid Reinforcement Containing Basalt Fibers	317
4.2	Basalt Fiber-Reinforced Polymer Blends	319
5	Thermoset Hybrid Composites	321
5.1	Basalt Fiber Mat-Reinforced Hybrid Thermosets	321
5.2	Hybrid Fiber Mat-Reinforced Hybrid Thermosets	323
6	Conclusions and Outlook	324
7	Acknowledgement	325
8	References	325

Chapter 18 Accelerated Testing Methodology for Polymer Composite Durability

	329	
1	Introduction	329
2	Prediction Procedure of Fatigue Strength	330
3	Some Experimental Details and Relationships Obtained	330
3.1	Experimental Procedure	330
3.2	Failure Mechanism	331
3.3	Master Curve for the CSR Strength	333
3.4	Master Curve for Creep Strength	334

3.5 Master Curve for the Fatigue Strength at Zero Stress Ratio	335
3.6 Prediction of Fatigue Strength for Arbitrary Stress Ratios	337
4 Applicability of the Prediction Method	338
5 Conclusion	339
6 References	340
Contributing Authors	343
List of Acknowledgements	357
Author Index	361
Subject Index	363