

Contents

Preface	v
About the Editors	xvii
List of Contributors	xxi

CHAPTER 1. Melt Processing of Polymer/Montmorillonite Layered Silicates (MLS): Nanocomposite Films for Flexible Food Packaging

J. A. Ratto, D. Froio, C. Thellen, J. Lucciarini

1. Flexible Packaging	1
2. Permeability of Polymers	2
3. Barrier Polymers	3
4. Polymer Nanocomposites	3
4.1. Structure of Montmorillonite Layered Silicate	3
4.2. Morphology of Polymer/Montmorillonite Layered Silicate Nanocomposites	4
4.3. Tortuous Path	4
4.4. Preparation of Nanocomposites	5
5. Processing of Nanocomposites	5
5.1. Extrusion	5
5.2. Modified Extrusion Techniques	12
6. Melt Processed Nanocomposites for Food Packaging	16
6.1. Recyclable Polymers/MLS Nanocomposites	16
6.2. Biodegradable Polymers/MLS Nanocomposites	22
6.3. Multilayered Structures	29
7. Summary and Future of Nanocomposites for Packaging	29
References	29

CHAPTER 2. Transport Properties of Nanocomposites Based on Polymers and Layered Inorganic Fillers

D. Nordqvist, M. S. Hedenqvist

1. Introduction	34
2. Layered Inorganic Fillers	35
3. Theory of Geometrical Impedance and Constraint	42
4. Elastomer Composites	46
4.1. Silicon Rubber (SR)	46
4.2. Natural Rubber (NR)	46
4.3. Styrene Butadiene Rubber (SBR)	46
4.4. Nitrile Rubber (NBR)	46
4.5. Styrene Acrylonitrile/Ethylene Vinylacetate (SAN/EVA) Polymer Blends	47
4.6. Butyl Rubber (IIR)	47

4.7.	Fluororubber (FR)	48
4.8.	Poly(urethane urea) (PUU)	48
4.9.	Crosslinked Polypropylene Glycol (PPGda) and Polyethylene Glycol (PEGda) Diacrylates	48
5.	Semicrystalline Polymer Composites	48
5.1.	Polyethylene (PE)	48
5.2.	Isotactic (iPP) and Syndiotactic Polypropylene (sPP)	49
5.3.	Paraffins	50
5.4.	Poly(ethylene-co-vinyl alcohol) (EVOH)	51
5.5.	Poly(vinyl alcohol) (PVOH)	51
5.6.	Modified PVOH	52
5.7.	Polyesteramide	52
5.8.	Polyamide-6 (PA-6)	53
5.9.	Poly(ethylene terephthalate) (PET)	54
5.10.	Poly(ethylene terephthalate-co-ethylene naphthalate) (PETN)	54
6.	Glassy Polymer Composites	55
6.1.	Poly(methyl methacrylate) (PMMA)	55
6.2.	PET (Amorphous)	55
6.3.	Polyethersulfone (PES)	55
6.4.	Sulphonated Poly(ether ketone) (sPEK) and Poly(etherether ketone) (sPEEK)	56
6.5.	Polyimide (PI)	56
6.6.	Polyurethane (PU)	56
6.7.	Acrylic Resin Emulsion	56
6.8.	Polybenzimidazole (PBI)	56
7.	Thermoset Composites	56
7.1.	Vinyl Ester Thermoset	56
7.2.	Multilayers Based on Polyallylamine Hydrochloride (PAH) and Polyacrylic Acid (PAA)	57
7.3.	Epoxy	57
8.	Renewable and/or Biodegradable Composites	58
8.1.	Starch	59
8.2.	Poly(lactic Acid) (PLA)	59
8.3.	Poly- ϵ -Caprolactone (PCL)	60
8.4.	Other Polymers	60
9.	Conclusions	61
	References	61

CHAPTER 3. Semiaromatic Polyester/Layered Silicate Nanocomposite Materials for Packaging Application

Y. Imai

1.	Introduction	65
1.1.	Semiaromatic Polyesters for Packaging Application	65
1.2.	Polymer/Layered Silicate Nanocomposites	66
1.3.	Layered Silicates for Nanocomposites	67
2.	PET/Layered Silicate Nanocomposites	68
2.1.	Factors Affecting the Synthesis of PET/Layered Silicate Nanocomposites	68
2.2.	PET/Layered Silicate Nanocomposites Prepared by Polycondensation	69

2.3. PET/Layered Silicate Nanocomposites Prepared by Ring-Opening Polymerization	71
2.4. PET/Layered Silicate Nanocomposites Prepared by Melt Intercalation	72
3. Other Semiaromatic Polyester/Layered Silicate Nanocomposites	73
3.1. Poly(butylene terephthalate) (PBT)	73
3.2. Poly(trimethylene terephthalate) (PTT)	74
3.3. Poly(ethylene naphthalate) (PEN)	74
3.4. Other Aromatic Polyesters	74
4. Related Topics	74
4.1. Application of Layered Silicate Nanocomposite Materials for Multilayered PET Bottles	74
4.2. Biodegradable PET/Layered Silicate Nanocomposites	77
5. Summary	77
References	77

CHAPTER 4. Nylon Nanocomposites for Packaging Applications

J. K. Pandey, S. A. S. Alariqi, D. R. Saini, S. H. Ahn, M. Misra

1. Introduction	81
2. Synthesis and Preparation Methods for Nylon Nanocomposites	82
2.1. <i>In Situ</i> Polymerization	82
2.2. Melt Blending	83
3. Properties of Nanocomposites	84
3.1. Morphology and Crystallinity	84
3.2. Barrier Properties	87
3.3. Mechanical Properties	91
3.4. Durability	94
4. Applications	96
5. Commercial Products of Nylon Nanocomposites for Packaging	96
6. Future Prospects	96
7. Conclusions	97
References	97

CHAPTER 5. Nanocomposites of Polyolefin

*J. K. Pandey, J. W. Lee, W. S. Chu, D. R. Saini,
A. K. Mohanty, M. Misra, T. Lan, S. H. Ahn*

1. Introduction	100
1.1. Components of Polymer Nanocomposites	100
1.2. Synthetic Routes	101
2. Nanocomposites of Polypropylene (PP)	103
2.1. Preparation of PP Nanocomposites	103
2.2. Structure and Crystallinity of PP Nanocomposites	107
2.3. Barrier Properties of PP Nanocomposites	112
2.4. Thermal Properties of PP Nanocomposites	114
2.5. Mechanical Properties of PP Nanocomposites	116
2.6. Other Properties	118
2.7. Degradation of PP Nanocomposites	119
3. Nanocomposites of Polyethylene (PE)	119
3.1. Preparation of PE Nanocomposites	120
3.2. Structure and Crystallinity of PE Nanocomposites	122

3.3. Barrier Properties of PE Nanocomposites	125
3.4. Mechanical Properties of PE Nanocomposites	126
3.5. Thermal Properties of PE Nanocomposites	128
3.6. Other Properties	129
3.7. Degradation of PE Nanocomposites	132
4. Nanocomposites of Ethylene Propylene Copolymers	132
5. Applications and Commercial Manufacturers of Polyolefin Nanocomposites	135
6. Conclusion	136
References	136

CHAPTER 6. Microcellular Polymer Nanocomposites for Packaging and Other Applications

S. Gong, L.-S. Turng, C. B. Park, L. Liao

1. Microcellular Plastics	144
1.1. Background	144
1.2. Rationale	144
2. Microcellular Processes	145
2.1. Batch Process	145
2.2. Microcellular Extrusion Process	146
2.3. Microcellular Injection Molding Process	147
2.4. Microcellular Blow Molding Process	148
2.5. Microcellular Process Challenges	148
3. Polymer Nanocomposites	149
3.1. Overview	149
3.2. Polymer/Clay Nanocomposites	149
4. Microcellular Polymer Nanocomposites	151
4.1. The Benefits of Microcellular Polymer Nanocomposites	151
4.2. Microcellular Polyamide-6 (PA-6)/Clay Nanocomposites	151
4.3. Microcellular Biobased Polylactide (PLA)/Clay Nanocomposites	155
4.4. Microcellular Polystyrene (PS)/Clay Nanocomposites	158
4.5. Microcellular Polystyrene (PS)/Carbon Nanofiber Nanocomposites	159
4.6. Microcellular Polyethylene (PE)/Clay Nanocomposites	159
4.7. Other Microcellular Polymer Nanocomposites	161
5. Applications of Microcellular Plastics and Nanocomposites	161
5.1. Microcellular Injection Molded Components	161
5.2. Microcellular Extrusion Molded Components	162
5.3. Microcellular Blow Molded Components	162
References	162

CHAPTER 7. Bio-Nanotechnology in Bio-Packaging

A. Alemdar, M. Sain

1. Introduction	167
2. Renewable Resources for Bio-Packaging	168
2.1. Biobased Polymers	168
2.2. Cellulose-Based Nano-Reinforcements for Bio-Packaging	169
3. Design and Manufacturing of Bio-Packaging Materials	173
3.1. Bioplastics for Bio-Packaging	173
3.2. Developing Novel Biodegradable Nanocomposites for Bio-Packaging	174

4. Material Properties of Nanocomposites for Bio-Packaging	174
4.1. Thermal and Mechanical Properties	174
4.2. Water Vapor Transmittance and Gas Barrier Properties	176
5. Environmental Impact of Biobased Materials	177
5.1. Biodegradability	177
5.2. Compostability	178
6. Current Applications and Future Trends in Bio-Packaging	178
References	179

CHAPTER 8. Starch Nanocomposites for Packaging

*D. Ray, J. K. Pandey, M. Das, A. K. Mohanty, S. H. Ahn,
L. T. Drzal, M. Misra*

1. Introduction	183
1.1. Starch	185
1.2. Microcomposites and Nanocomposites	187
2. Composites of Starch	189
2.1. With Natural Polymers	189
2.2. With Synthetic Polymers	189
2.3. Composites of Starch After Chemical Modification	193
3. Nanocomposites of Starch	193
3.1. With Layered Silicates	193
3.2. With Cellulose Whiskers	195
3.3. With Carbon Nanotubes	195
3.4. With Starch Nanocrystals	196
4. Applications in Packaging	196
5. Ecofriendly Behavior of Starch-Based Nanocomposites	198
6. Limitations of Starch-Based Nanocomposites	200
7. Future Directions	201
References	201

CHAPTER 9. Proteinous Nanomaterials for Packaging Applications

R. Kumar, Q. Wu, L. Wang, L. Zhang

1. Introduction	205
2. Structure of Proteins	207
3. Commercially Available Protein	209
3.1. Soy	209
3.2. Zein	210
3.3. Collagen	210
3.4. Whey	211
3.5. Wheat Gluten	211
3.6. Casein	211
3.7. Keratin	212
4. Protein Based Nanomaterials	212
4.1. SPI/Clay	213
4.2. SPI/Whiskers	213
4.3. Nanocrystals/Nanoparticles	214
4.4. Nanofibers	215

5. Promising Applications in Packaging	215
5.1. Films/Foils	215
5.2. Functional Materials	222
5.3. Foams	223
5.4. Capsules	224
References	225

CHAPTER 10. Silver Nanocomposites for Antimicrobial Packaging

*S. Vivekanandhan, M. Venkateswarlu, N. Satyanarayana,
A. K. Mohanty, M. Misra*

1. Introduction	230
2. Antimicrobial Active Packaging	231
2.1. Active Packaging	231
2.2. Antimicrobial Packaging Concepts	232
2.3. Limitations of Conventional Methods	232
2.4. Need for Novel Methods with Reliable Properties	233
3. Antimicrobial Activity of Silver Nanostructures	233
3.1. Science Behind the Antimicrobial Activity of Silver Nanostructures	233
3.2. Common Synthesis Process	234
4. Silver Nanocomposites	236
4.1. Types of Silver Nanocomposites	236
4.2. Advantages of Silver–Polymer Nanocomposites for Packaging	238
5. Preparation of Silver Nanocomposites	238
5.1. Physical Method	238
5.2. Chemical Method	239
5.3. Physicochemical Method Metal–Polymer Nanocomposites	239
6. Characterization of Silver Nanocomposites	240
6.1. X-ray Diffraction	240
6.2. FTIR	240
6.3. UV-Visible Spectroscopy	241
6.4. Thermal Analysis (DSC and TG/DTA)	241
6.5. Scanning Electron Microscope	242
6.6. Transmission Electron Microscope	243
6.7. Atomic Force Microscope	243
6.8. Antimicrobial Activity	243
6.9. Toxicity Studies	244
7. Silver Nanocomposites for Antimicrobial Packaging	244
7.1. Food Packaging	244
7.2. Antimicrobial Wear	245
7.3. Construction Products	245
7.4. Medical Packaging with Antimicrobial Finish	245
8. Other Applications of Silver Nanocomposites	245
8.1. Sensor	246
8.2. Catalysis	246
8.3. Optics and Electrical	246
9. Conclusions	246
References	246

CHAPTER 11. The Use of Nanotechnology to Improve the Performance of Plant Oil-Based Coatings for Military Use and Applications in Packaging

*J. J. L. Scala, P. Smith, J. A. Orlicki, F. Levine,
A. M. Rawlett, J. Escarsega*

1. Introduction	250
2. Plant Oil Functionality	251
2.1. Plant Oil Composition	251
2.2. Polymerization of Plant Oils	252
2.3. Distribution of Functionality in Plant Oils	254
2.4. Genetic Engineering of Plant Oils	256
3. Plant Oil-Based Coatings	256
3.1. Oxidative Drying Oils	256
3.2. Alkyd Resins	258
3.3. Military Applications of Alkyd Resins	259
3.4. Epoxies	261
3.5. Polyurethanes	263
3.6. Acrylics	263
3.7. Latexes	265
3.8. Hybrid Coatings	265
4. Nanotechnology to Improve Coating Performance	265
4.1. Dendrimers and Hyperbranched Polymers—Polyfunctional Scaffolds for New Materials	265
4.2. Fluorinated Additives	268
4.3. Low Solar Loading Pigments	273
4.4. Polymeric Flattening Agents	274
4.5. Other Nano-Additives	274
5. Nano-Additives and Plant Oil-Based Packaging Coatings	276
5.1. Packaging Coatings	276
5.2. Uses of Plant Oils for Packaging Coatings	277
5.3. Application of Nano-Additives in Packaging Coatings	278
6. Summary and Conclusions	278
References	279

CHAPTER 12. Nanomaterial Enhanced Scaffolds for Tissue Engineering

A. Menner, L. Safinia, A. Bismarck

1. Introduction	283
2. Nano-Structured Surfaces	284
2.1. Creation of Nano-Structured Surfaces	285
2.2. Nano-Hydroxyapatite Compacts	286
2.3. Carbon Nanomaterials	286
2.4. Helical Rosette Nanotubes	288
3. Emulsion Templating	288
3.1. The Emulsion Template	289
3.2. Tailoring PolyHIPE Morphology	289
3.3. PolyHIPEs in Tissue Engineering	291

4. Thermally Induced Phase Separation	292
4.1. Thermally Induced Liquid–Liquid Phase Separation	293
4.2. Tailoring Morphology and Physical Properties of Polymer Foams Produced Using TIPS	294
4.3. Tissue Engineering Applications of 3D Scaffolds Fabricated via TIPS	295
References	295

CHAPTER 13. Commercial Development of Nanocomposite Packaging

T. Lan, Y. Liang

1. Introduction	299
2. Nanoclay Chemistry and Nanocomposite Formation	300
3. Design and Performance Benefit of Nanocomposite Packaging	302
4. Economical and Environmental Benefits of Nanocomposite Packaging	303
5. Regulation of Nanocomposites for Food Packaging Applications	304
References	304

CHAPTER 14. Environmental and Social Impacts of Nanotechnology in Packaging

S. E. Selke, N. Nordin

1. Introduction	306
2. Concerns Associated with Nanotechnology	307
2.1. Precautionary Principle	308
2.2. Grey Goo and Green Goo	308
2.3. Nanoparticles	308
2.4. Privacy and Related Concerns	309
3. Overview of Organizations Involved with Societal and/or Scientific Concerns about Nanotechnology	310
3.1. Government Organizations	310
3.2. Non-Government Groups	311
4. Evaluations of the Safety of Nanotechnologies	315
4.1. Royal Society Report	316
4.2. Swiss Re	317
4.3. ETC Group Reports	317
4.4. EC Health and Consumer Protection Directorate General	318
4.5. Institute of Occupational Medicine Report	319
4.6. Defra Report	319
4.7. EU Particle Risk Project	319
4.8. Nanosafe 2	319
4.9. Nanotox	319
4.10. Technologiezentrum	319
4.11. Allianz	319
4.12. EC Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)	320
4.13. Nanologue Background Paper	320
4.14. Nanoforum and the Institute for Environment and Sustainability	320
4.15. Nanomaterials in the Workplace	321

- 5. Public Perceptions of Nanotechnology 321
 - 5.1. Public Opinions in the United States 321
 - 5.2. Public Opinion in the UK 322
- 6. Regulations, Standards, Decision Making, and Public Involvement 322
 - 6.1. Recommendations for Regulatory Approaches 322
 - 6.2. Government Organizations in the United States 324
 - 6.3. Regulatory and Standards Organizations in the European Union 326
 - 6.4. International Risk Governance Council (IRGC) Reports 326
 - 6.5. Role of the Social Sciences 327
 - 6.6. Public Information and Participation 327
- 7. Summary and Conclusions 328
 - References 329

- Index 333