

Contents

Preface	<i>XI</i>
List of Contributors	<i>XV</i>
Abbreviations	<i>XVII</i>

1	Introduction	<i>1</i>
	<i>Raju Francis, Geethy P. Gopalan, and Anjaly Sivadas</i>	
1.1	Introduction	<i>2</i>
1.1.1	Why Recycling?	<i>2</i>
1.1.2	Sources of Waste	<i>2</i>
1.1.3	Plastics	<i>3</i>
1.1.4	Recycling of Plastics	<i>3</i>
1.1.5	Municipal Solid Waste	<i>4</i>
1.1.6	Various Stages of Recycling Plastic Wastes	<i>6</i>
1.1.7	Additives	<i>6</i>
1.1.8	Mixed Plastics	<i>8</i>
1.1.9	Composites	<i>8</i>
1.2	Conclusion	<i>8</i>
	References	<i>9</i>
2	Common Additives used in Recycling of Polymers	<i>11</i>
2.1	Review on Different Additives Used in Polymer Recycling	<i>11</i>
	<i>Sivasankarapillai Vishnu Sankar and Sivasankarapillai Anil Kumar</i>	
2.1.1	Introduction	<i>11</i>
2.1.1.1	Challenges in Recycling – Need for Additives	<i>11</i>
2.1.1.2	Equipment for Additive Processing	<i>12</i>
2.1.2	Different Types of Additives	<i>12</i>
2.1.2.1	Stabilizing Agents	<i>14</i>
2.1.2.2	Compatibilizers	<i>19</i>
2.1.2.3	Antioxidants	<i>21</i>
2.1.2.4	Impact Modifiers	<i>23</i>
2.1.2.5	Fillers and Modifiers	<i>25</i>
2.1.2.6	Antistatic Agents	<i>26</i>
2.1.2.7	Coloring Agents	<i>26</i>

2.1.2.8	Flame Retardants	27
2.1.2.9	Lubricants	28
2.1.2.10	Plasticizers	28
2.1.2.11	Antibacterial or Antimicrobial Additives	29
2.1.2.12	Coupling Agents	29
2.1.3	Conclusion	30
	References	30
2.2	Recent Trends and Future of Polymer Additives in Macromolecular Recycling Technology: A Brief Overview	31
	<i>Sivasankarapillai Vishnu Sankar and Sivasankarapillai Anil Kumar</i>	
2.2.1	Introduction	31
2.2.2	Miscellaneous Additives	32
2.2.2.1	Nucleating Agents	32
2.2.2.2	Reinforcing Agents or Fillers	33
2.2.2.3	Optical Brighteners	36
2.2.2.4	Surface Improvers	37
2.2.2.5	Antiblocking Additives	39
2.2.2.6	Blowing Agents (Foaming Agents)	39
2.2.2.7	Antifogging Agents	41
2.2.3	New Trends in Additives Technology	43
2.2.3.1	Advances in Stabilizers	46
2.2.3.2	Advances in Flame Retardants (FRs)	46
2.2.3.3	Advances in Plasticizers	47
2.2.3.4	Advances in Coloring Agents	47
2.2.3.5	Advances in Fillers	48
2.2.3.6	Advances in Other Additive Classes	48
2.2.3.7	Multifunctional Additives	49
2.2.4	Conclusion	49
	References	50
3	Methods of Recycling	55
3.1	Methods of Recycling of Polymers: Addition Polymers	55
	<i>Beena Sethi</i>	
3.1.1	Introduction	55
3.1.2	Primary Recycling	58
3.1.3	Mechanical Recycling (or Secondary Recycling)	58
3.1.4	Chemical or Feedstock Recycling (Tertiary Recycling)	59
3.1.5	Energy Recovery (Quaternary Recycling)	60
3.1.6	Chemical Recycling of Polyethylene (LDPE and HDPE)	62
3.1.6.1	Introduction	62
3.1.6.2	Thermolysis Schemes and Technologies	63
3.1.6.3	Reactor Types	65
3.1.7	Polyolefin Thermal Cracking	66
3.1.7.1	Catalytic Degradation	66
3.1.8	Chemical Recycling of Polypropylene	67

3.1.8.1	Introduction	67
3.1.8.2	Pyrolysis	69
3.1.8.3	Co-pyrolysis	70
3.1.8.4	Catalytic Cracking	71
3.1.9	Chemical Recycling of Polystyrene	75
3.1.9.1	Introduction	75
3.1.9.2	Recycling Methods for Polystyrene Products	76
3.1.9.3	Future Prospects	83
3.1.10	Chemical Recycling of Poly(vinyl chloride)	83
3.1.10.1	Introduction	83
3.1.10.2	Mixed Plastic Recycling Processes	86
3.1.10.3	Mixed PVC Wastes World Initiatives	88
3.1.10.4	The BASF Feedstock Recycling Process	88
3.1.10.5	Veba Combi Cracking Process	90
3.1.11	Chemical Recycling of Poly(methyl methacrylate)	90
3.1.11.1	Introduction	90
3.1.11.2	Dissolution/Reprecipitation	91
3.1.11.3	Chemical/Feedstock Recycling	92
	References	93
3.2	Methods of Recycling of Polymers: Condensation Polymers	101
	<i>Beena Sethi</i>	
3.2.1	Introduction	101
3.2.2	Chemical Recycling of Nylon	101
3.2.2.1	Introduction	101
3.2.2.2	Recycling Methods	101
3.2.3	Chemical Recycling Involving Depolymerization of Nylons Which Can Be Carried Out by Hydrolysis or Ammonolysis of Nylon 6,6 and Nylon 6	102
3.2.3.1	Hydrolysis of Nylon 6	102
3.2.3.2	Hydrolysis of Nylon 6,6 and Nylon 4,6	103
3.2.3.3	Ammonolysis of Nylon 6,6	103
3.2.3.4	Recovery of Nylon 6,6 Monomers	104
3.2.3.5	Catalytic Pyrolysis	105
3.2.3.6	Applications of Depolymerized Nylon 6	105
3.2.4	Chemical Recycling of Polycarbonate	105
3.2.4.1	Introduction	105
3.2.4.2	Recycling Techniques	106
3.2.5	Advantages of Recycling and Reuse of Polymers	110
	References	112
4	Recycling of Plastics	115
	<i>Preetha Balakrishnan and Meyyappallil Sadasivan Sreekala</i>	
4.1	Introduction	115
4.2	Plastic Waste Management Scenario	117
4.3	Ways of Recycling	119

4.3.1	Reuse	120
4.3.2	Mechanical Recycling	121
4.3.3	Chemical Recycling	121
4.4	Poly(Lactic Acid)	122
4.5	Poly(Vinyl Chloride)	125
4.6	Polyethylene	126
4.7	Polypropylene	128
4.8	Polystyrene	129
4.9	Poly(Ethylene Terephthalate) (PET)	129
4.10	Applications	134
	References	135

5 Recycling of Rubber 141

Valiya Parambath Swapna and Ranimol Stephen

5.1	Introduction	141
5.2	Rubber	142
5.3	Recycling of Rubber Products	143
5.3.1	Chemical Process	143
5.3.2	Physical Methods	145
5.3.2.1	Mechanochemical Techniques	145
5.3.2.2	Microwave Technique	146
5.3.2.3	Ultrasonic Technique	146
5.3.2.4	Twin-Screw Extruder	148
5.3.3	Biological Process	148
5.4	Applications of Recycled Rubber	152
5.4.1	Sound-Insulation Materials	152
5.4.2	Civil Engineering Applications	153
5.4.3	Oil Absorbent	154
5.4.4	Energy Production	154
5.4.5	Zinc Fertilizer	155
5.5	Concluding Remarks	155
	References	156

6 Fibers 163

Raju Francis, Nidhin Joy, Anjaly Sivadas, and Geethy P. Gopalan

6.1	Introduction	163
6.2	Natural Fibers	164
6.2.1	Kenaf	165
6.2.2	Cotton	167
6.2.3	Sisal	170
6.2.4	Asbestos	174
6.3	Synthetic Fibers	176
6.3.1	Nylon	177
6.3.2	Polyester	182
6.3.3	Glass Fiber	187

6.3.3.1	Glass Fiber-Reinforced Plastics	188
6.3.3.2	Mechanical Process	188
6.3.3.3	Thermal Process	188
6.3.3.4	Chemical Recycling	190
6.3.4	Carbon Fiber	192
6.3.4.1	Mechanical Recycling	192
6.3.4.2	Thermal Recycling	193
6.3.4.3	Chemical Recycling	195
6.4	Conclusion	198
	References	198
7	Recycling of Polymer Blends and Composites (Epoxy Blends)	209
	<i>Jyothi V. Sunny</i>	
7.1	Introduction	209
7.2	Polymer Blends and Composites	209
7.2.1	Methods of Recycling	213
7.2.1.1	Mechanical Recycling	213
7.2.1.2	Chemical Recycling	215
7.2.1.3	Thermal Recycling	216
7.3	Characterization and Application of Recyclates	218
7.4	Conclusions	219
	References	219
8	Recycling of Other Layered Mixed Plastics or Resins: Polyurethanes	223
	<i>Jyothi V. Sunny</i>	
8.1	Introduction	223
8.2	Mechanical Recycling	226
8.3	Chemical Recycling	227
8.3.1	Glycolysis	228
8.3.2	Hydrolysis	229
8.3.3	Aminolysis	229
8.4	Thermochemical methods	230
8.4.1	Pyrolysis	230
8.4.2	Gasification	230
8.4.3	Hydrogenation	230
8.5	Energy Recovery by Incineration	231
	References	232
9	Ecoprofiles of Recycled Polymers at a Glance	235
9.1	Advantages of Recycled Polymers on the Environment	235
	<i>Raju Francis and Anjaly Sivasadas</i>	
9.1.1	Introduction	235
9.1.2	Poly(ethylene terephthalate) (PET)	236
9.1.3	High-Density Polyethylene (HDPE)	237

9.1.4	Poly(vinyl chloride) (PVC)	239
9.1.5	Polypropylene (PP)	240
9.1.6	Polystyrene (PS)	241
9.1.7	Other Polymers	242
9.1.8	Conclusion	245
	References	245
9.2	Toxic or Environmental Effects of Recycled Polymers	248
	<i>Raju Francis, Nidhin Joy, and Anjaly Sivasdas</i>	
9.2.1	Introduction	248
9.2.2	Will Recycling Reduce the Amount of Waste?	249
9.2.2.1	Recycling of Waste Electrical and Electronic Equipment (WEEE)	250
9.2.2.2	Recycling of Tires	251
9.2.2.3	Recycling of Plastics	251
9.2.2.4	Recycling of Polymers	251
9.2.2.5	Health Problems	252
9.2.2.6	Recycling by Polymer Incineration	252
9.2.3	Conclusion	253
	References	253
	Index	257