Contents

Preface  XI
List of Contributors  XV
Abbreviations  XVII

1 Introduction  1
Raju Francis, Geethy P. Gopalan, and Anjaly Sivadas
1.1 Introduction  2
1.1.1 Why Recycling?  2
1.1.2 Sources of Waste  2
1.1.3 Plastics  3
1.1.4 Recycling of Plastics  3
1.1.5 Municipal Solid Waste  4
1.1.6 Various Stages of Recycling Plastic Wastes  6
1.1.7 Additives  6
1.1.8 Mixed Plastics  8
1.1.9 Composites  8
1.2 Conclusion  8
References  9

2 Common Additives used in Recycling of Polymers  11
Sivasankarapillai Vishnu Sankar and Sivasankarapillai Anil Kumar
2.1 Review on Different Additives Used in Polymer Recycling  11
2.1.1 Introduction  11
2.1.1.1 Challenges in Recycling – Need for Additives  11
2.1.2 Equipment for Additive Processing  12
2.1.2.1 Stabilizing Agents  14
2.1.2.2 Compatibilizers  19
2.1.2.3 Antioxidants  21
2.1.2.4 Impact Modifiers  23
2.1.2.5 Fillers and Modifiers  25
2.1.2.6 Antistatic Agents  26
2.1.2.7 Coloring Agents  26
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
Sivasankarapillai Vishnu Sankar and Sivasankarapillai Anil Kumar

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
Beena Sethi
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
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
Jyothi V. Sunny
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
Jyothi V. Sunny
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
Raju Francis and Anjaly Sivadas
9.1 Advantages of Recycled Polymers on the Environment 235
9.1.1 Introduction 235
9.1.2 Poly(ethylene terephthalate) (PET) 236
9.1.3 High-Density Polyethylene (HDPE) 237