

Contents

1	Origin of Polymer Materials	1
1.1	History of Polymers	1
1.1.1	Examples of Polymers	4
1.2	Types of Polymers	5
1.2.1	Based on Applications	5
1.2.2	Classification Based on Temperature Effect	6
1.2.2.1	Thermosetting Polymers	6
1.2.2.2	Thermoplastic Polymers	6
1.3	Properties of Polymers	6
1.3.1	Molecular Weight	7
1.3.2	Structural Aspects	7
1.3.3	Copolymers in Sequence	9
1.3.4	Crystallinity of Polymers	10
1.3.4.1	Solid-State Crystallinity	10
1.3.4.2	Factors Favoring Crystallinity	10
1.3.5	Morphology of the Polymeric Crystals	10
1.3.5.1	Solid-State Thermal Transitions	11
1.3.6	Mechanical Behavior	11
1.3.7	Polymer Rheology and Processing	13
1.3.7.1	Polymer Processing Techniques	13
1.3.7.2	Rheology of Nanocomposites	14
1.3.7.3	Theory and Modeling of Nanocomposites Rheology	15
1.3.8	Polymer Viscoelasticity	15
1.4	Physicochemical Properties of Polymers	17
1.4.1	Polymers are Very Resistant to Chemicals	17
1.4.2	Polymers are Both Thermal and Electrical Insulators	17
1.4.3	Polymers are Very Light in Weight with Significant Degrees of Strength	17
1.4.4	Polymers are Processed in Various Ways	17
1.4.5	Polymers are Materials With a Seemingly Limitless Range of Characteristics and Colors	18
1.4.6	Polymers are Usually Made of Petroleum, but not Always	18

1.4.7	Polymers are Used to Make Items That Have no Alternatives to Other Materials	18
	References	18
2	Synthesis of Polymers	21
2.1	Features of the Polymerization Reactions	21
2.2	Chain Polymerization	22
2.3	Ring-Opening Polymerization	22
2.4	Polycondensation	24
2.5	Polyaddition	24
2.6	Step-Growth Polymerization	24
2.7	Dendrimers	25
2.8	Anionic Polymerization	27
2.9	Cationic Polymerization	28
2.10	Controlled Radical Polymerization	29
2.11	Atom Transfer Radical Polymerization (ATRP)	30
2.12	Reversible Addition Fragmentation Chain Transfer (RAFT)	31
2.13	Supramolecular Polymerization	32
2.14	Bulk Polymerization	32
2.15	Solution Polymerization	33
2.16	Suspension Polymerization	33
2.17	Methods for the Synthesis of Functional Polymers	34
2.17.1	Direct Copolymerization	34
2.17.2	End-Functionalization	34
2.17.3	Functionalization-Grafting	34
2.17.4	Click Chemistry in Polymerization	35
2.18	Polymer Nanoparticles	36
2.19	Synthesis Techniques of Polymer Nanoparticle	37
2.19.1	Solvent Evaporation	37
2.19.2	Salting-Out	38
2.19.3	Nanoprecipitation	39
2.19.4	Dialysis	40
2.19.5	Supercritical Fluid Technology	40
2.19.6	Rapid Expansion of Supercritical Solution (RESS)	40
2.19.7	Rapid Expansion of Supercritical Solution into a Liquid Solvent (RESOLV)	41
2.19.8	Polymerization of Monomers	41
2.19.9	Emulsion Polymerization	42
2.19.10	Conventional Emulsion Polymerization	42
2.19.11	Surfactant-Free Emulsion Polymerization	42
2.19.12	Mini-Emulsion Polymerization	42
2.19.13	Micro-Emulsion Polymerization	43
2.19.14	Interfacial Polymerization	43
	References	44

3	Characterization of Polymer Materials	49
3.1	Introduction	49
3.2	UV-Visible Spectroscopy	50
3.3	Elemental Analysis	51
3.4	Infrared Spectroscopy	52
3.5	Qualitative Analysis of Polymers	52
3.6	Spectral Analysis for Polyethylene and Polystyrene	53
3.7	Determination of Molecular Weight and Thermodynamic Properties	55
3.8	Differential Scanning Colorimetry (DSC) Analysis	56
3.9	Thermogravimetric Assays (TGAs)	57
3.10	Gel Permeation Chromatography (GPC)	57
3.11	High-Performance Liquid Chromatography (HPLC)	57
3.12	Size Exclusion Chromatography (SEC)	58
3.13	Raman Spectroscopy	59
3.13.1	Polyethylene Density	60
3.13.2	Polybutadiene Microstructure	60
3.14	Mechanical Testing and Rheometry	61
3.15	Nuclear Magnetic Resonance Spectroscopy	62
3.16	X-ray Diffraction	63
3.17	Molar Mass and Molar Mass Distribution	64
3.18	Osmometry	64
3.19	Mass Spectrometry	65
3.20	Scanning Electron Microscopy (SEM)	65
3.21	Transmission Electron Microscopy (TEM)	66
3.22	Atomic Force Microscopy (AFM)	66
3.23	Optical Microscopy (OM)	66
	References	67
4	Diverse Applications of Polymer Materials	71
4.1	Board Area of Polymer Applications	71
4.2	Polymers in Biotechnology	73
4.3	Polymer Dielectrics for Electronics	74
4.3.1	Luminescent Layers in Light-Emitting Diodes	75
4.4	Smart and Self-healing Coatings	76
4.5	Polymeric Biocides and Herbicides	76
4.6	Polymers for Soil Remediation	77
4.7	Benefits of Polymers in Fabric and Home Care Formulations	77
4.8	Polymeric Materials for Photonics	78
4.9	Polymers for Electrophotography	78
4.10	Polymers in Energy Applications	79
4.11	Polymers in Construction Applications	82
4.12	Polymers in Automobile Applications	82
	References	83

5	Introduction to Nanomaterials	87
5.1	Nanotechnology	87
5.2	Nanomaterials	87
5.3	Types of Nanomaterials	89
5.3.1	Quantum Dots	89
5.3.2	Organic Materials	89
5.3.3	Metal Oxides	90
5.3.4	Carbon Nanotubes	90
5.3.5	Polymeric Nanomaterials	91
5.4	Synthesis of Nanoparticles	91
5.4.1	Coprecipitation	91
5.4.2	Hydrothermal Technique	92
5.4.3	Inert Gas Condensation	92
5.4.4	Sonochemical	93
5.4.5	Microemulsion	93
5.4.6	Microwave-Assisted	94
5.4.7	Laser Ablation	95
5.4.8	Sol-Gel	95
5.4.9	Spark Discharge	95
5.4.10	Template Synthesis	97
5.4.11	Biological Synthesis	97
5.5	Applications of Nanotechnology	98
5.5.1	Nanotechnology in Energy Sector	98
5.5.2	Nanotechnology in Textile	98
5.5.3	Nanotechnology in Agriculture	99
5.5.4	Nanotechnology in Electronics	100
5.5.5	Nanotechnology in Cosmetics	100
5.5.6	Nanotechnology in Medical Field	100
	References	101
6	Introduction to Polymer Nanocomposites	105
6.1	Classes of Nanocomposites	105
6.2	Different Types of Nanocomposites	105
6.2.1	Polymer-Based and Non-Polymer-Based Nanocomposites	106
6.2.1.1	Polymer/Ceramic Nanocomposite	106
6.2.1.2	Inorganic/Organic Polymer Nanocomposites	106
6.2.1.3	Inorganic/Organic Hybrid Nanocomposite	107
6.2.1.4	Polymer/Layered Silicate (PLS) Nanocomposites	107
6.2.1.5	Polymer/Polymer Nanocomposites	107
6.2.1.6	Biocomposites	107
6.2.1.7	Ceramic Matrix Nanocomposites	107
6.2.1.8	Metal Matrix Nanocomposites	107
6.2.1.9	Polymer Matrix Nanocomposites	108
6.3	Synthesis Methods of Nanocomposite	108
6.3.1	Solution Casting Method	108
6.3.2	Melt Blending Method	108

6.3.3	In situ Polymerization Method	108
6.3.4	Exfoliation Adsorption Method	109
6.3.5	Template Synthesis Method	109
6.4	Characterization Techniques for Nanocomposite	110
6.5	Applications of Nanocomposite Materials	111
6.5.1	Automotive Industry	111
6.5.2	Packaging Industry	111
6.5.3	Catalysis	111
6.5.4	Solid Polymer Electrolyte	111
6.5.5	Water Treatment Applications	111
6.5.6	Aircrafts	112
6.5.7	Electronics	112
6.5.8	Environmental Protection	112
	References	113
7	Polymer Nanocomposites in Energy Storage System	115
7.1	Introduction	115
7.2	Batteries	115
7.3	Thermal	115
7.4	Mechanical Storage	116
7.5	Hydrogen	116
7.6	Pumped Hydropower	116
7.7	Flywheels	116
7.8	Role of Polymer Nanocomposites in Energy Storage Applications	119
7.9	Properties of Polymer Nanocomposites	120
7.9.1	Physical Properties	120
7.9.2	Rheological Properties	120
7.9.3	Mechanical Properties	121
7.9.4	Thermal Properties	121
7.9.5	Barrier and Chemical Resistance	122
7.9.6	Flame Retardancy	122
7.9.7	Optical Properties	122
7.9.8	Electrical Properties	123
7.9.9	Dielectric Properties	123
7.9.10	Biological Properties	123
	References	124
8	Polymer Nanocomposites for Renewable Energy Storage System	127
8.1	Renewable Energy	127
8.2	Renewable Energy Storage	127
8.3	Polymers for Energy Storage	128
8.4	Carbon-Based Storage Materials	129
8.5	Energy Storage Capability of Polymer Nanocomposites	132
	References	134

9	High-Performance Inorganic Polymer Nanocomposites-Based Solar Cells	137
9.1	Introduction	137
9.2	Organic–Organic Composites	137
9.3	Inorganic Nanocomposites	138
9.4	Nanocomposites in Perovskite Solar Cells	139
9.5	Polymeric Nanocomposites in Dye-Sensitized Solar Cells (DSSCs)	140
	References	142
10	Polymer Nanocomposites for Magnetic Energy and Thermal Energy Storage	145
10.1	Background of Polymer Nanocomposites for Energy Storage	145
10.2	Energy Density	145
10.3	Superconducting Magnetic Energy Storage (SMES)	146
10.4	Thermal Energy Storage (TES)	148
10.4.1	Sensible Heat Storage (SH-TES)	149
10.4.2	Latent Heat Storage (LH-TES)	149
10.4.3	Thermochemical Heat Storage (TH-TES)	149
10.5	Thermoplastic Composites for TES	151
	References	153
11	Polymer Nanocomposites for Triboelectricity and Hydrogen Storage	157
11.1	Polymer Nanocomposites for Triboelectricity	157
11.1.1	Energy Harvesting Application	158
11.2	Polymer Nanocomposites for Hydrogen Storage	160
11.3	Hydrogen-Based Energy Storage System	161
11.3.1	Liquid Hydrogen Storage	161
11.3.2	Compressed and Stored in a Pressure Tank	162
11.3.3	Physical Adsorption in Carbon	162
11.3.4	Complex Compounds-Microsphere Hydrogen Storage	162
11.3.5	Metal Hydrides	162
	References	164
12	Polymer Nanocomposites for Supercapacitors and Battery Application	167
12.1	Battery-Based Energy Storage System	167
12.2	Types of Battery	168
12.2.1	Lead-Acid Battery	168
12.2.2	Nickel-Based Battery	169
12.2.3	Sodium–Sulfur Battery (NaS)	169
12.2.4	Lithium-Based Battery	169
12.2.5	Flow Battery Energy Storage (FBES)	170
12.3	Conducting Polymer Nanocomposites	170

12.4	Fuel Cells	171
12.5	Capacitor and Supercapacitor Energy Storage	174
	References	176
13	Electrochemical Energy Storage System	181
13.1	Introduction	181
13.2	Need for Energy Storage System	185
13.2.1	Energy Reality and Increasing Renewable Penetration	185
	References	187
14	Electrical Energy Storage System	189
14.1	Introduction	189
	References	194
15	Real-Time Applications of Polymer Nanocomposites	195
15.1	Introduction	195
15.2	Polymer–Graphene/Carbon Nanotube	199
	References	210
16	Modeling and Simulation Techniques	213
16.1	Introduction	213
16.2	Modeling and Simulation of Polymer Nanocomposites	213
16.2.1	Nanocomposite thermodynamics	213
16.2.2	Atomistic MD Simulation of Graphene-Based PMMA Nanocomposites	218
16.3	Systems Simulated and Simulation Strategy	220
16.4	Interface and Interfacial Polarization	225
16.5	Simulation Techniques Based on Hydrogen Storage	226
16.6	Finite Element Modeling of a Composite Hydrogen Storage vessel	230
	References	232
17	Life Cycle Analysis of Polymer Nanocomposites for Energy Storage	235
17.1	Scope of a Life Cycle Analysis	235
17.2	Techno-Economic Evaluations of Energy Storage Systems	236
17.3	Energy and Power Density	237
17.4	Self-Discharge	237
17.5	Response Time	237
17.6	Cost and Economies of Scale	237
17.7	Lifetime	237
17.8	Storage Capacity	237
17.9	Monitoring and Control Equipment	238
17.10	Efficiency	238
17.11	Operating Constraints	238
	References	238

- 18 Future Research and Case Study on Energy Storage System 241**
- 18.1 Introduction 241
- 18.2 Case Study 1: Pumped Storage Hydropower (PSH) in France 241
- 18.3 Case Study 2: Battery Storage 243
- 18.4 Case Study 3: Solar PV Storage and Energy Shift 244
- 18.5 Case Study 4: Solar and Battery Storage for Customers and Ancillary Services 244
- References 246

- Index 247**