Contents

Preface xiii

1 Tribological Characterization of Biocomposites: An Overview 1

Manickam Ramesh, Thangamani Vinitha, and Manickam Tamil Selvan

۱v

- 1.1 Introduction 1
- 1.2 Tribological Characterization 2
- 1.2.1 Flax Reinforcement 3
- 1.2.2 Coconut Coir Reinforcement 4
- 1.2.3 Banana Reinforcement 4
- 1.2.4 Hemp Reinforcement 4
- 1.2.5 Ramie Reinforcement 5
- 1.2.6 Calotropis gigantea Reinforcement 5
- 1.2.7 Kenaf Reinforcement 6
- 1.2.8 Betel Nut Fibers 7
- 1.3 Parameters Influencing the Tribological Characteristics *8*
- 1.3.1 Impact of Reinforcement Orientation on Wear Behavior 8
- 1.3.2 Effect of Reinforcement Volume Fraction on Wear Behavior 9
- 1.3.3 Effect of Fillers on Wear Behavior 11
- 1.3.4 Influence of Surface Modification on Wear Behavior 11
- 1.4 Morphology Analysis of Tribological Characteristics 12
- 1.5 Conclusion 14 References 15

2 Tribological Properties of the Natural Fiber-Reinforced Epoxy Composites 19

Lin Feng Ng and Mohd Yazid Yahya

- 2.1 Introduction 19
- 2.2 Fiber-Reinforced Composites 20
- 2.3 Cellulosic Natural Fibers 22
- 2.4 Impact of Tribology on the Environment and Industry 23

vi Contents

2.5	Tribological Properties of FRPs 25
2.5.1	Tribological Properties of Natural Fiber-Reinforced Epoxy
	Composites 25
2.5.2	Tribological Properties of Natural Fiber-Reinforced Epoxy Hybrid
	Composites 30
2.6	Conclusion 33
	References 34
3	Wear Properties of Flax/Epoxy-Based Composites With
	Different Machining Parameters 39
	K.R. Sumesh, Petr Spatenka, and G. Rajeshkumar
3.1	Introduction 39
3.2	Materials and Methods 40
3.2.1	Method 40
3.2.2	Wear Testing 40
3.3	Results and Discussion 41
3.3.1	Wear Results 41
3.4	Conclusions 43
	References 43
4	Polyester-Based Biocomposites for Tribological
	Applications 47
	Anand Gobiraman Santhosh Nagaraja and Vishvanathperumal
	Sathivamoorthi
41	Introduction: Background and Driving Forces 47
4.2	Materials and Methods 49
421	Natural Fibers 49
422	Polvester–Natural Fiber Composites 49
423	Hybrid Polyester—Composites 50
424	Methods of Production of Biocomposites 51
4241	Stratification 51
4242	Hand Lay-Un Method 52
4243	Vacuum Bagging Technique 52
4244	Tribological Tests on Natural Fiber-Reinforced Polyester-Based
7.2.7.7	Riocomposites 52
13	Tribological Characteristics of Polyester-Based Biocomposites 53
н.) Л.Л	Polyester-Based Biocomposites for Tribological Applications 59
4.4	Conclusions 60
4.5	Pafarances 61
	Kelefences 01
5	Tribological Properties of the Natural Fiber-Reinforced Vinyl
	Ester Composites 65
	Krushna Gouda, Muthukumar Chandrasekar, Vellaichamy Parthasarathy,
	Senthilkumar Krishnasamy, and Senthil Muthu Kumar Thiagamani
5.1	Introduction 65
5.2	Natural Fiber-Based VE Composite 70
	*

- 5.3 Problems Associated with Natural Fiber-Based Composite 71
- 5.4 Conclusion 71 References 71

6 Friction and Sliding Wear Properties of the Natural Fiber-Reinforced Polypropylene Composites 75

Emel Kuram

- 6.1 Introduction 75
- 6.2 Polypropylene 76
- 6.3 Natural Fibers 76
- 6.4 Natural Fiber-Reinforced PP Composites 80
- 6.5 Tribological Properties of Natural Fiber-Reinforced PP Composites 83
- 6.5.1 Friction Coefficient of Natural Fiber-Reinforced PP Composites 86
- 6.5.2 Wear Behavior of Natural Fiber-Reinforced PP Composites 90
- 6.6 Conclusions 94 Acknowledgments 94 References 95

7 Wear Behavior of the Natural Fiber-Reinforced Thermoplastic

Composites 105

Ramu Sundaramoorthy, Vellaichamy Parthasarathy, Jeyanthi Subramanian, Lin Feng Ng, and Naveen Jesuarockiam

- 7.1 Introduction 105
- 7.2 Wear Testing Methods 105
- 7.3 Factors Affecting Wear Behavior of the Composite 107
- 7.4 Motion Type 107
- 7.5 Load 107
- 7.6 Velocity 107
- 7.7 Temperature 108
- 7.8 Test Duration 108
- 7.9 Performance Metrics From the Wear Test 108
- 7.10 Wear Studies on Natural Fiber-Reinforced Thermoplastic Composites *109*
- 7.11 Conclusion 113
 - References 113
- 8 Tribological Characterization of the Natural Fiber-Reinforced Polyimide Composites 115

Anand Gobiraman, Santhosh Nagaraja, and Vishvanathperumal Sathiyamoorthi

- 8.1 Introduction: Background and Driving Forces 115
- 8.2 Materials and Methods *117*
- 8.2.1 Natural Fibers 118
- 8.2.2 Methods of Production of Natural Fiber-Reinforced Polymer Composites *119*

8.2.2.1	Stratification 120
8.2.2.2	Hand Layup 120
8.2.2.3	Vacuum Bagging Technique 121
8.3	Polyimides 121
8.4	Natural Fibers/Polyimides Composites 121
8.5	Tribological Applications of Natural Fibers/Polyimides
	Composites 122
8.6	Conclusions 124
	References 125
9	Investigations of the Friction and Wear Resistance of the
	Natural Fiber-Reinforced Polyamide Composites 129
	İbrahim Can Kaymaz, Alperen Doğru, Miray Batıkan Kandemir,
	and Mehmet Özgür Seydibeyoğlu
9.1	Introduction 129
9.1.1	Thermosetting 130
9.1.2	Thermoplastics 130
9.1.3	Thermoplastic Composites 131
9.1.4	Thermoplastic Polymer Matrix 132
9.1.5	Fibers 133
9.2	Natural Fiber-Reinforcement Polyamide 134
9.2.1	Polyamide 134
9.2.2	Natural Fibers 135
9.2.2.1	Animal Fiber 135
9.2.2.2	Plant Fiber 135
9.2.3	Mineral Fiber 141
9.2.4	Production 141
9.3	Friction and Wear Resistance at Natural Fiber-Reinforcement
	Polyamide 142
9.3.1	Friction 142
9.3.2	Wear 145
9.3.3	Testing and Measurement 148
9.3.3.1	Friction Test Methodologies 148
9.3.3.2	Wear Test Methodologies 148
9.3.4	Applications 149
	References 150
10	Friction and Wear Resistance of the Natural Fiber-Reinforced
	Polymer Composites With Metal Oxide Fillers 159
	Niket Suresh Powar and Mariyappan Shanmugam
10.1	Introduction 159
10.2	Oil Palm Fiber 160
10.3	Jute Fiber 161
10.4	Bamboo Fiber 162

viii

- 10.5 Coconut Fiber 164
- 10.6 Conclusion 164 References 165
- 11 Investigation of Sliding Wear Properties of Nanofiller-Based Biocomposites 167

Ajish Babu, Anusree Thilak, Harikrishnan Pulikkalparambil, Sandhya Alice Varghese, Sanjay Mavinkere Rangappa, Kuruvilla Joseph, and Suchart Siengchin

- 11.1 Introduction 167
- 11.2 Wear General Aspects 168
- 11.3 Methods to Measure Wear 170
- 11.4 Sliding Wear in Polymer Composites 171
- 11.5 Sliding Wear in Biocomposites, General 173
- 11.5.1 Sliding Wear Property of Biofiller Incorporated Biopolymer Composite *173*
- 11.5.2 Sliding Wear Property of Synthetic/Inorganic Filler Incorporated Biopolymer Composite 175
- 11.6 Conclusion 177 Acknowledgment 177 References 177
- 12Friction and Wear Properties of Biocomposites for Dental,
Orthopedic, and Biomedical Applications185

Piyush Gaur, Chandrasekar Muthukumar, and V. Parthasarathy

- 12.1 Introduction 185
- 12.2 Desired Properties and Classification of Biomaterials 188
- 12.2.1 Desired Properties of Biomaterials 188
- 12.2.2 Classification of Biomaterials 189
- 12.2.2.1 Metallic Biomaterials 189
- 12.2.2.2 Ceramic Biomaterials 193
- 12.2.2.3 Composite Biomaterials 193
- 12.3 Wear of Biomaterials 194
- 12.3.1 Wear Testing Methods 195
- 12.3.2 Friction and Wear Characterization Techniques for Biomaterials 196
- 12.4 Friction and Wear Properties of Biocomposites Used in Different Biomedical Applications *197*
- 12.4.1 Dental Applications 197
- 12.4.1.1 Friction and Wear of Dental Resins 199
- 12.4.2 Orthopedic Applications 200
- 12.4.2.1 Friction and Wear of Biocomposites in Orthopedics Applications 203
- 12.5 Conclusion 207
 - References 207

x Contents

13	Wear and Friction Behavior of Biocomposites Fabricated
	Through Additive Manufacturing 219
	Manickam Ramesh, Kanagaraj Niranjana, and Manickam Tamil Selvan
13.1	Introduction 219
13.2	Additive Manufacturing of Biocomposites 220
13.3	Fabrication of Biocomposites Using AM 222
13.4	Types of Wear Behavior Based on Its Processes, Effects, and
	Environment 222
13.4.1	Adhesion Wear 223
13.4.2	Abrasive Wear 224
13.4.3	Erosive Wear 225
13.4.4	Fatigue Wear 226
13.4.5	Corrosive or Oxidative Wear 226
13.4.6	Fretting Wear 226
13.5	Determining the Level of Specimen Deterioration 227
13.6	Wear and Frictional Characteristics of AM Products 228
13.7	Method of Testing the Wear and Friction in the AM Parts 228
13.7.1	Pin-on-Disk or Tribometer 239
13.7.2	Pin-on-Drum 239
13.7.3	Repeated Impact Wear Test 240
13.7.4	Acoustic Emission Monitoring Test 241
13.7.5	Rubbing Test 241
13.8	Conclusion 241
	References 242
14	Influence of Fiber Treatment on the Wear Properties of
	Biocomposites 247
	Anthony Chidi Ezika, Emmanuel Rotimi Sadiku, Raphael Stone Odera,
	Uzoma Ebenezer Enwerem, Victor Ugochukwu Okpechi,
	Martin Emeka Ibenta, and Shadrack Chukwuebuka Ugwu
14.1	Introduction 247
14.2	Fibers 248
14.2.1	NF Reinforcement 249
14.2.2	Treatments of NFs 250
14.2.2.1	Types of NF Treatment 250
14.3	Biocomposites 254
14.3.1	Classification of Biocomposites 254
14.3.2	Natural Fiber-Polymer Composites 254
14.3.3	Tribological Properties of NF-Reinforced Composites 255
14.4	Influence of Fiber Treatment on the Wear Properties of NF-Filled
	Polymer 256

- 14.4.1 Influence of Fiber Treatment on the Wear Properties of NF-Reinforced Epoxy Composites 257
- 14.4.2 Influence of Fiber Treatment on the Wear Properties of NF- Reinforced Polyester Composites 260

- 14.4.3 Influence of Fiber Treatment on the Wear Behavior of NF Reinforced Vinyl Ester Composite 262
- 14.4.4 Influence of Fiber Treatment on the Wear Properties of NF- Reinforced Polypropylene Composites *263*
- 14.4.5 Influence of Fiber Treatment on the Wear Properties of NF-Reinforced Polylactic Acid Composites 265
- 14.4.6 Influence of Fiber Treatment on the Wear Properties of NF-Reinforced High-Density Polyethylene Composites 267
- 14.4.7 Influence of Fiber Treatment on the Wear Properties of NF- Reinforced Low-Density Polyethylene Composites 267
- 14.4.8 Influence of Fiber Treatment on the Wear Properties of NF- Reinforced PET Composites 269
- 14.4.9 Influence of Fiber Treatment on the Wear Properties of NF- Reinforced Polyamide Composites 269
- 14.4.10 Influence of Fiber Treatment on the Wear Properties of NF-Reinforced Hybrid Biocomposites (Fiber Blending + Polymer Blending) Composites 270
- 14.5 Conclusion 273 References 273

Index 285