

Contents

1	Introduction	1
1.1	Lessons from Nature	2
1.2	Industrial Significance	6
1.3	Research Objective and Approach.....	6
1.4	Organization of the Book	7
	References.....	7
2	Roughness-Induced Superomniphobic Surfaces: Lessons from Nature	11
2.1	Definitions and Applications	11
2.2	Natural Superhydrophobic, Self-Cleaning, Low Adhesion/Drag Reduction Surfaces with Antifouling	13
2.3	Natural Superoleophobic, Self-Cleaning, and Low-Drag Surfaces with Antifouling	15
2.4	Natural Superhydrophobic and High-Adhesion Surfaces	15
2.5	Summary.....	16
	References.....	16
3	Modeling of Contact Angle for a Liquid in Contact with a Rough Surface	19
3.1	Contact Angle Definition	19
3.2	Homogenous and Heterogeneous Interfaces and the Wenzel and Cassie–Baxter Equations	20
3.2.1	Limitations of the Wenzel and Cassie Equations	26
3.2.2	Range of Applicability of the Wenzel and Cassie Equations.....	28
3.3	Contact Angle Hysteresis	32
3.4	Stability of a Composite Interface and Role of Hierarchical Structure	34
3.5	The Cassie–Baxter and Wenzel Wetting Regime Transition	38
3.6	Summary.....	42
	References.....	43

Part I Lotus Effect

4	Lotus Effect Surfaces in Nature	49
4.1	Plant Leaves	49
4.2	Characterization of Superhydrophobic and Hydrophilic Leaf Surfaces	51
4.2.1	Experimental Techniques	51
4.2.2	SEM Micrographs	52
4.2.3	Contact Angle Measurements	53
4.2.4	Surface Characterization Using an Optical Profiler	54
4.2.5	Surface Characterization, Adhesion, and Friction Using an AFM	57
4.2.6	Role of the Hierarchical Roughness	62
4.3	Summary	64
	References	64
5	Fabrication Techniques Used for Structures with Superhydrophobicity, Self-Cleaning, Low Adhesion/Low Drag with Antifouling Properties	67
5.1	Roughening to Create One-Level Structure	67
5.2	Coating to Create One-Level Hydrophobic Structures	72
5.3	Methods to Create Two-Level (Hierarchical) Structures	73
	References	75
6	Fabrication and Characterization of Micro-, Nano-, and Hierarchical Structured Surfaces	79
6.1	Introduction	79
6.2	Experimental Techniques	81
6.2.1	Contact Angle, Surface Roughness, and Adhesion	81
6.2.2	Droplet Evaporation Studies	82
6.2.3	Bouncing Droplet Studies	82
6.2.4	Vibrating Droplet Studies	82
6.2.5	Microdroplet Condensation and Evaporation Studies Using ESEM	83
6.2.6	Generation of Submicron Droplets	83
6.2.7	Waterfall/Jet Tests	86
6.2.8	Wear and Friction Tests	87
6.3	Micro- and Nanopatterned Polymers	88
6.3.1	Contact Angle	89
6.3.2	Effect of Submicron Droplet on Contact Angle	91
6.3.3	Adhesive Force	91
6.3.4	Summary	92
6.4	Micropatterned Si Surfaces	93
6.4.1	Cassie–Baxter and Wenzel Transition Criteria	96
6.4.2	Effect of Pitch Value on the Transition	98

- 6.4.3 Observation of Transition During the Droplet Evaporation 100
- 6.4.4 Another Cassie–Baxter and Wenzel Transition for Different Series 104
- 6.4.5 Contact Angle Hysteresis and Wetting–Dewetting Asymmetry 106
- 6.4.6 Contact Angle Measurements During Condensation and Evaporation of Microdroplets on Micropatterned Surfaces 110
- 6.4.7 Observation of Transition During the Bouncing Droplet 113
- 6.4.8 Summary 118
- 6.5 Ideal Surfaces with Hierarchical Structure 119
- 6.6 Hierarchical Structured Surfaces with Wax Platelets and Tubules Using Nature’s Route 120
 - 6.6.1 Effect of Nanostructures with Various Wax Platelet Crystal Densities on Superhydrophobicity 125
 - 6.6.2 Effect of Hierarchical Structure with Wax Platelets on the Superhydrophobicity 129
 - 6.6.3 Effect of Hierarchical Structure with Wax Tubules on Superhydrophobicity 133
 - 6.6.4 Self-Cleaning Efficiency of Hierarchical Structured Surfaces 140
 - 6.6.5 Observation of Transition During the Bouncing Droplet 142
 - 6.6.6 Observation of Transition During the Vibrating Droplet 146
 - 6.6.7 Measurement of Fluid Drag Reduction 152
 - 6.6.8 Summary 152
- 6.7 Mechanically Durable Hierarchical Structured Surfaces 153
 - 6.7.1 CNT Composites 154
 - 6.7.2 Nanoparticle Composites 163
- 6.8 Summary 169
- References 171

Part II Salvinia Effect

- 7 Fabrication and Characterization of Micropatterned Structures Inspired** 179
 - 7.1 Introduction 179
 - 7.2 Characterization of Leaves and Fabrication of Inspired Structural Surfaces 181

7.3 Measurement of Contact Angle and Adhesion..... 182

7.3.1 Observation of Pinning and Contact Angle 182

7.3.2 Adhesion 184

7.4 Summary..... 184

References..... 186

Part III Rose Petal Effect

8 Characterization of Rose Petals and Fabrication and Characterization of Superhydrophobic Surfaces with High and Low Adhesion 189

8.1 Introduction..... 189

8.2 Characterization of Two Kinds of Rose Petals and Their Underlying Mechanisms 190

8.3 Fabrication of Surfaces with High and Low Adhesion 196

8.4 Summary..... 205

References..... 206

Part IV Oleophobic/Oleophilic Surfaces

9 Modeling, Fabrication, and Characterization of Oleophobic/Oleophilic Surfaces..... 209

9.1 Introduction..... 209

9.2 Modeling of Contact Angle for Various Surfaces..... 210

9.3 Experimental Techniques 211

9.4 Fabrication and Characterization of Oleophobic Surfaces 213

9.4.1 Wetting Behavior on Flat and Micropatterned Surfaces 214

9.4.2 Wetting Behavior on Flat and Micropatterned Surfaces with C₂₀F₄₂ 218

9.4.3 Wetting Behavior on Nano- and Hierarchical Structures and Sharkskin Replica..... 220

9.5 Summary..... 222

References..... 223

Part V Shark skin Effect

10 Shark skin Surface for Fluid-Drag Reduction in Turbulent Flow 227

10.1 Introduction..... 227

10.2 Mechanisms of Fluid Drag..... 229

10.3 Role of Riblets in Drag Reduction 232

10.4 Studies with Various Riblet Geometries..... 234

10.4.1 Studies with 2D Riblets 239

10.4.2 Studies with 3D Riblets 242

10.4.3 Riblet Trends in Pipe Flow 246

10.5	Riblet Fabrication and Applications	246
10.5.1	Riblet Dimension Selection	248
10.5.2	Application of Riblets for Drag Reduction and Antifouling	248
10.5.3	Riblet Fabrication Methods for Study and Applications	251
10.6	Effect of Fluid Slip and Polymer Additives on Fluid Drag.....	252
10.6.1	The Effect of Fluid Slip on Drag Reduction	253
10.6.2	Effect of Fish Mucus and Polymers on Fluid Drag	256
10.7	Summary.....	258
	References	262

Part VI Gecko Adhesion

11	Gecko Adhesion	269
11.1	Introduction.....	269
11.2	Hairy Attachment Systems.....	270
11.3	Tokay Gecko.....	272
11.3.1	Construction of Tokay Gecko	272
11.3.2	Adhesion Enhancement by Division of Contacts and Multilevel Hierarchical Structure	274
11.3.3	Peeling	277
11.3.4	Self-Cleaning	280
11.4	Attachment Mechanisms.....	283
11.4.1	van der Waals Forces	285
11.4.2	Capillary Forces	286
11.5	Adhesion Measurements and Data	287
11.5.1	Adhesion Under Ambient Conditions	288
11.5.2	Effects of Temperature	290
11.5.3	Effects of Humidity.....	291
11.5.4	Effects of Hydrophobicity	292
11.6	Adhesion Modeling of Fibrillar Structures.....	292
11.6.1	Single Spring Contact Analysis.....	294
11.6.2	The Multilevel Hierarchical Spring Analysis	295
11.6.3	Adhesion Results of the Multilevel Hierarchical Spring Model	298
11.6.4	Capillary Effects	305
11.7	Adhesion Database of Fibrillar Structures	310
11.7.1	Fiber Model.....	310
11.7.2	Single Fiber Contact Analysis	310
11.7.3	Constraints	311
11.7.4	Numerical Simulation	316
11.7.5	Results and Discussion	316

11.8 Fabrication of Gecko Skin-Inspired Structures 321

 11.8.1 Single-Level Roughness Structures..... 321

 11.8.2 Multilevel Hierarchical Structures 328

11.9 Summary..... 331

References..... 333

12 Outlook 339

Index 341

Biography 349