## Contents

Foreword xvii Preface xix

#### 1 Fundamentals of Smart Corrosion Protection Coatings 1

۱v

- 1.1 Introduction of Corrosion Protection Coatings 1
- 1.1.1 Mechanisms of Corrosion Protection Coatings 2
- 1.1.2 Failure Type and Failure Mechanism of Corrosion Protection Coatings *3*
- 1.2 Smart Self-healing Coatings 5
- 1.2.1 Intrinsic Self-healing Coating 5
- 1.2.1.1 Self-healing Based on Dynamic Bonds 6
- 1.2.1.2 Self-healing Based on Shape Memory Effect 6
- 1.2.2 Extrinsic Self-healing Coating 8
- 1.2.2.1 Self-healing Coating Based on Defect Filling 10
- 1.2.2.2 Self-healing Coating Based on Corrosion Inhibitors 11
- 1.2.3 Characterization Methods of Self-healing Properties 14
- 1.3 Smart Self-reporting Coatings 16
- 1.4 Superhydrophobic Coatings 17
- 1.5 Conclusions 20 References 20

### 2 Development of Thermally Activated Self-healing Coating 29

- 2.1 Introduction 29
- 2.2 Thermally Activated Self-healing Coatings to Simultaneously Recover the Corrosion-resistance and Adhesion Strength 29
- 2.2.1 Materials and Methods 30
- 2.2.1.1 Materials 30
- 2.2.1.2 Preparation of Dispersant Cerium Oleate 30
- 2.2.1.3 Preparation of Ce(NO<sub>3</sub>)<sub>3</sub>-EVA Microcapsules 31
- 2.2.1.4 Characterization of Microcapsule 31
- 2.2.1.5 Preparation of Coatings 31
- 2.2.1.6 Self-healing Tests 31
- 2.2.1.7 Molecular Dynamic Simulation 32

- vi Contents
  - 2.2.2 Characterization of Microcapsules 32
  - 2.2.3 Thermal Properties and Self-healing Behavior of Coatings 33
  - 2.2.4 Healing Mechanisms of Coatings at Different Curing Temperatures 34
  - 2.2.5 Electrochemical Analysis of the Coatings *34*
  - 2.2.6 Multiple Self-healing Mechanisms 38
  - 2.2.7 Adhesion Recovery Mechanism of the Coating 40
  - 2.3 Thermally Activated Self-healing Coatings Based on Dual Actions 43
  - 2.3.1 Materials and Methods 44
  - 2.3.1.1 Materials 44
  - 2.3.1.2 Preparation of PCL/8HQ Microcapsules 44
  - 2.3.1.3 Preparation of Coatings 44
  - 2.3.1.4 Morphology Observation 45
  - 2.3.1.5 Corrosion Inhibitor Loading and Releasing Test 45
  - 2.3.1.6 Focused Ion Beam Microscopy 45
  - 2.3.1.7 Electrochemical Measurement 45
  - 2.3.2 Characterization of PCL/8HQ Microcapsules 46
  - 2.3.2.1 SEM Images of PCL/8HQ Microcapsules 46
  - 2.3.2.2 Loading Rate of 8HQ in PCL/8HQ Microcapsules 46
  - 2.3.2.3 Corrosion Inhibitor Release Process from Microcapsules 48
  - 2.3.2.4 Corrosion Inhibitor Release Process from Coatings 49
  - 2.3.3 Characterization of Self-healing Coatings 50
  - 2.3.3.1 The Influence of Microcapsule Content on the Coating Property 50
  - 2.3.3.2 Macroscopic Electrochemical Tests of Self-healing Coatings 54
  - 2.3.3.3 Microscopic Electrochemical Tests of Self-healing Coatings 57
  - 2.3.3.4 Characterization of Scratched Coatings After Immersion 60
  - 2.4 Chapter Summary 63 References 64

#### 3 Development of Photothermally Activated Self-healing Coating 75

- 3.1 Introduction 75
- 3.2 Self-healing Coating Based on GO–CeO<sub>2</sub> Photothermal Fillers 75
- 3.2.1 Materials and Methods 76
- 3.2.1.1 Materials 76
- 3.2.1.2 Instruments 76
- 3.2.1.3 Preparation of GO–CeO<sub>2</sub> 76
- 3.2.1.4 Morphological and Structural Characterization of GO–CeO<sub>2</sub> 78
- 3.2.1.5 Surface Treatment of the Substrates 78
- 3.2.1.6 Preparation of Composite Coatings 78
- 3.2.1.7 Characterization of Coatings 79
- 3.2.1.8 Photothermal Conversion of GO–CeO<sub>2</sub>/Epoxy Coating 79
- 3.2.2 Characterization and Property of GO–CeO<sub>2</sub> Composites 79
- 3.2.2.1 Morphological and Structural Characterization of GO–CeO<sub>2</sub> 79
- 3.2.2.2 Dispersion Properties of GO–CeO<sub>2</sub> 82
- 3.2.3 Characterization and Properties of the GO–CeO<sub>2</sub>/Epoxy Coating 84

Contents vii

- 3.2.3.1 Dispersion Properties of GO–CeO<sub>2</sub> in Epoxy Coating 84
- 3.2.3.2 Mechanical Properties of GO–CeO<sub>2</sub>/Epoxy Coating 85
- 3.2.3.3 Photothermal Conversion Properties of GO–CeO<sub>2</sub>/Epoxy Coating 86
- 3.2.3.4 Self-healing Properties of the GO–CeO<sub>2</sub>/Epoxy Coating 87
- 3.3 Self-healing Coating Based on TiN-BTA@MSN Photothermal Filler *89*
- 3.3.1 Materials and Methods 90
- 3.3.1.1 Materials 90
- 3.3.1.2 Instruments 90
- 3.3.1.3 Preparation of TiN-BTA@MSN 92
- 3.3.1.4 Morphology and Structure Characterization of TiN-BTA@MSN 92
- 3.3.1.5 Photothermal Conversion Performance of TiN-BTA@MSN 92
- 3.3.1.6 Inhibitor Release Behavior of TiN-BTA@MSN 92
- 3.3.1.7 Corrosion Inhibition Properties of TiN-BTA@MSN 93
- 3.3.1.8 Preparation of Photothermal Composite Coating 93
- 3.3.1.9 Photothermal Conversion Property of Epoxy/TBS Coating 93
- 3.3.1.10 Corrosion Protection of Epoxy/TBS Coating 94
- 3.3.2 Preparation and Characterization of TiN-BTA@MSN 94
- 3.3.2.1 Morphology and Structure of TiN-BTA@MSN 94
- 3.3.2.2 Photothermal Conversion Properties of TiN-BTA@MSN 98
- 3.3.2.3 Inhibitor Release Behavior of TiN-BTA@MSN 98
- 3.3.2.4 Corrosion Inhibition Property of TiN-BTA@MSN 101
- 3.3.3 Preparation and Characterization of Epoxy/TBS Coatings 102
- 3.3.3.1 Photothermal Conversion Properties of Epoxy/TBS Coating 103
- 3.3.3.2 Corrosion Protection Property of Intact Coatings 105
- 3.3.3.3 Self-healing Property of Scratched Coatings 106
- 3.4 Self-healing Coating Based on PCL@TiN Photothermal Fillers 109
- 3.4.1 Materials and Methods 110
- 3.4.1.1 Materials 110
- 3.4.1.2 Instruments 110
- 3.4.1.3 Preparation of PCL Microspheres 110
- 3.4.1.4 Preparation of PCL@TiN Composite Microspheres 110
- 3.4.1.5 Morphological and Structural Characterization of PCL@TiN 112
- 3.4.1.6 Photothermal Conversion Performance of PCL@TiN 112
- 3.4.1.7 Preparation of Photothermal Composite Coating *112*
- 3.4.1.8 Characterization of Epoxy/PT Coating 112
- 3.4.1.9 Photothermal Conversion Property of Epoxy/PT Coating 113
- 3.4.1.10 Corrosion Resistance and Self-healing Property of Epoxy/PT Coating 113
- 3.4.2 Preparation and Characterization of PCL@TiN 113
- 3.4.2.1 Morphology and Structure Characterization of PCL@TiN 113
- 3.4.2.2 Photothermal Conversion Properties of PCL@TiN 115
- 3.4.3 Preparation and Characterization of Epoxy/PT Photothermal Coatings *117*
- 3.4.3.1 Characterization of Epoxy/PT Coating *117*

3.4.3.2	Photothermal Conversion Property of Epoxy/PT Coating 118
3.4.3.3	Self-healing Properties of Scratched Coatings 119
3.4.3.4	Photothermal-induced Water Evaporation on Epoxy/PT Coatings 121
3.4.3.5	Outdoor Application Performance of Epoxy/PT Coatings 121
3.5	Self-healing Coating Based on $Fe_3O_4$ -MBT Photothermal Fillers 123
3.5.1	Materials and Methods 124
3.5.1.1	Materials 124
3.5.1.2	Instruments 124
3.5.1.3	Preparation of $Fe_3O_4$ Hollow Nanoparticles 124
3.5.1.4	Preparation of $Fe_3O_4$ Nanoparticles Loaded with 2-MBT 125
3.5.1.5	Preparation of Fe <sub>3</sub> O <sub>4</sub> /2-MBT Containing Epoxy Coatings 125
3.5.1.6	Characterization of $Fe_3O_4$ Hollow Nanoparticles 126
3.5.1.7	Characterization of $Fe_3O_4/2$ -MBT Nanoparticles 126
3.5.1.8	Characterization of Corrosion Protection and Photothermal Properties of
	Coatings 126
3.5.2	Preparation and Characterization of Fe <sub>3</sub> O <sub>4</sub> /2-MBT Nanoparticles 127
3.5.2.1	Composition and Structural Characterization of Fe <sub>3</sub> O <sub>4</sub> Hollow
	Nanoparticles 127
3.5.2.2	Composition and Structural Characterization of Fe <sub>3</sub> O <sub>4</sub> /2-MBT
	Nanoparticles 128
3.5.2.3	Corrosion Inhibition Properties of Fe <sub>3</sub> O <sub>4</sub> /2-MBT Nanoparticles 130
3.5.3	Preparation and Characterization of $Fe_3O_4/2$ -MBT-epoxy Coating 133
3.5.3.1	Photothermal Response of Fe <sub>3</sub> O <sub>4</sub> /2-MBT Nanoparticle Containing Epoxy
	Coatings 133
3.5.3.2	Characterization of Corrosion Resistance of Intact Coatings 134
3.5.3.3	Characterization of the Self-healing Properties of Scratched
	Coatings 135
3.6	Chapter Summary 138
	References 139
4	Development of pH- and Redox-activated Self-healing
	Coating 153
4.1	Introduction 153
4.2	pH Responsive Self-healing Coating Based on the Synergistic Effect of
	Two Corrosion Inhibitors 153
4.2.1	Materials and Methods 155
4.2.1.1	Materials 155
4.2.1.2	Instruments 155
4.2.1.3	Preparation of Corrosion Inhibitor-loaded SiO <sub>2</sub> Nanocapsules 156
4.2.1.4	Corrosion Inhibitor Release Behavior from MBT-BTA@mSiO <sub>2</sub> 157
4.2.1.5	Preparation of Self-healing Coatings 157
4.2.1.6	Electrochemical Measurements 158
4.2.2	Characterization of MBT-BTA@mSiO <sub>2</sub> 158
4.2.2.1	Morphology and Structure Characterization of MBT-BTA@mSiO <sub>2</sub> 158
4222	Inhibitor Loading Canacity of MBT-BTA@mSiO 162

Contents ix

- 4.2.2.3 Release Behavior of MBT-BTA@mSiO<sub>2</sub> 163
- 4.2.2.4 Corrosion Inhibition Performance of MBT-BTA@mSiO<sub>2</sub> 167
- 4.2.3 Characterization and Property of MBT-BTA@mSiO<sub>2</sub>/Epoxy Coating *169*
- 4.2.3.1 Electrochemical Performance of Scratched Coatings 170
- 4.2.3.2 Surface Morphology Analysis of Scratched Coatings 170
- 4.2.3.3 Composition of Scratch Coatings 170
- 4.2.3.4 Long-term Protective Performance of Intact Coatings 173
- 4.3 pH Responsive Self-healing Coating Based on rGO@MS-P-BTA 176
- 4.3.1 Materials and Methods 176
- 4.3.1.1 Materials 176
- 4.3.1.2 Preparation of rGO@MS-P-BTA 176
- 4.3.1.3 Preparation of Self-healing Coating with rGO@MS-P-BTA Microcapsules 177
- 4.3.1.4 Characterization of rGO@MS-P-BTA 178
- 4.3.1.5 Characterization of Self-healing Coatings 178
- 4.3.2 Preparation and Characterization of rGO@MS-P-BTA 178
- 4.3.2.1 Morphology and Structure of rGO@MS-P-BTA Microcapsules 178
- 4.3.2.2 pH-Controlled Corrosion Inhibitor Release 181
- 4.3.3 Self-healing Performance of rGO@MS-P-BTA Containing Coatings *183*
- 4.3.3.1 Photothermal Effect of Coatings 183
- 4.3.3.2 Electrochemical Performance of Coatings with rGO@MS-P-BTA 184
- 4.3.3.3 Corrosion Monitoring of Coatings with rGO@MS-P-BTA 185
- 4.3.3.4 Mechanical Properties of Coating with rGO@MS-P-BTA 187
- 4.3.3.5 Corrosion Protection Mechanism of Coatings with rGO@MS-P-BTA 187
- 4.4 Redox and Saline Responsive Self-healing Coating Based on PANI/BTA Nanocapsules 188
- 4.4.1 Materials and Methods 189
- 4.4.1.1 Materials 189
- 4.4.1.2 Preparation and Characterization of PANI/BTA Nanocapsules 189
- 4.4.1.3 Preparation of Self-healing Coatings with PANI/BTA 190
- 4.4.1.4 Self-healing Coating Performance Test 190
- 4.4.2 Preparation and Characterization of PANI/BTA Nanocapsules 192
- 4.4.2.1 Morphology and Structure of PANI/BTA Nanocapsules 192
- 4.4.3 Characterization of PANI/BTA-Based Epoxy Coating 193
- 4.4.3.1 Contact Angle Analysis of PANI/BTA Nanocapsule Coating 193
- 4.4.3.2 Electrochemical Analysis of Scratched PANI/BTA Nanocapsule Coating 193
- 4.4.3.3 SMP Performance of PANI/BTA Nanocapsule Coating 196
- 4.4.3.4 Electrochemical Analysis of Healed PANI/BTA Coatings 196
- 4.4.3.5 Corrosion Monitoring of PANI/BTA Nanocapsule Coatings 198
- 4.4.3.6 Passivation of PANI 199
- 4.4.3.7 Mechanical Properties of PANI/BTA Nanocapsule Coatings 200

# **x** Contents

4.4.4	Self-healing Mechanism of PANI/BTA Nanocapsule Coatings 200
4.5	Chapter Summary 201
	References 203
5	Development of Ion Exchange Activated Self-healing
	Coating 217
5.1	Introduction 217
5.2	Ion Exchange Activated Self-healing Coating Using GO-LDH
	Fillers 217
5.2.1	Materials and Methods 218
5.2.1.1	Materials 218
5.2.1.2	Preparation of GO-LDH Composites 218
5.2.1.3	Coating Preparation 219
5.2.1.4	Morphology Characterization 220
5.2.1.5	Chemical Structure Characterization 220
5.2.1.6	Electrochemical Measurement 221
5.2.1.7	Neutral Salt Spray Test 221
5.2.1.8	Analysis of the Corrosion Inhibitor Film 221
5.2.2	Characterization of GO-LDH 221
5.2.2.1	Structure and Morphology Analysis 221
5.2.2.2	Analysis of Corrosion Inhibitor Release 225
5.2.2.3	Evaluation of the Corrosion Inhibition of GO-LDH 226
5.2.3	Barrier and Self-healing Performance of Waterborne Epoxy Coatings
	Containing GO-LDH-V 227
5.2.4	Protection Mechanism of GO-LDH-V Waterborne Epoxy Coating 238
5.2.4.1	Electron Probe Microanalysis 238
5.2.4.2	Scratch Morphology and EDS Spectrum Analysis 238
5.2.4.3	Raman Analysis of the Scratched Coating Surface 239
5.2.4.4	Cross Section Morphology of Coating 240
5.2.5	Coating Protection Mechanism 240
5.3	Chapter Summary 242
	References 244
6	Development of pH-responsive and Metal Ion-responsive
	Self-reporting Coating 251
6.1	Introduction 251
6.2	pH-responsive Self-reporting Coatings Based on PhPh Indicator 252
6.3	Metal Ion-responsive Self-reporting Coatings Based on CDs 253
6.3.1	Materials and Methods 254
6.3.1.1	Materials 254
6.3.1.2	Instruments 254
6.3.1.3	Preparation and Characterization of Carbon Dots 254
6.3.1.4	Corrosion Inhibition Performance of CDs 256
6.3.1.5	Preparation and Characterization of CDs–SSA 256
6.3.1.6	Corrosion Inhibition and Corrosion Sensitivity of CDs–SSA 256

- 6.3.1.7 Self-reporting Performance of Coatings 257
- 6.3.2 Characterization of CDs 257
- 6.3.2.1 Structure and Morphology Analysis 257
- 6.3.2.2 Electrochemical Analysis 258
- 6.3.2.3 Surface Corrosion Morphology Characterization 261
- 6.3.3 Preparation and Properties of CDs-SSA 261
- 6.3.3.1 Morphology and Structural Characterization of CDs-SSA 263
- 6.3.3.2 Analysis of Electrochemical Results of CDs-SSA 264
- 6.3.3.3 Surface Corrosion Morphology Characterization 269
- 6.3.3.4 Corrosion Sensitivity of CDs-SSA 274
- 6.3.4 Self-reporting and Self-healing Properties of CDs–SSA-Based Epoxy Coating 276
- 6.4 Metal Ion-responsive Self-reporting Coatings Based on UF/Phen Microcapsules 279
- 6.4.1 Materials and Methods 281
- 6.4.1.1 Materials 281
- 6.4.1.2 Preparation of UF/Phen Microcapsules 281
- 6.4.1.3 Characterization of UF/Phen Microcapsules 282
- 6.4.1.4 Preparation of Self-reporting and Self-healing Coating Based on UF/Phen Microcapsules 282
- 6.4.1.5 Self-reporting and Self-healing Performance Analysis 282
- 6.4.1.6 Corrosion Sensing Behavior of Coatings Based on UF/Phen Microcapsules 282
- 6.4.2 Characterization of UF/Phen Microcapsules 283
- 6.4.2.1 Morphology of UF/Phen Microcapsules and Release of Corrosion Inhibitors 283
- 6.4.2.2 Thermal Performance and Shape-Memory Effect of Coating Based on UF/Phen Microcapsules 287
- 6.4.2.3 Electrochemical Analysis of Self-healing Coating Based on UF/Phen Microcapsules 288
- 6.4.2.4 Corrosion Sensing of Coating Based on UF/Phen Microcapsules 291
- 6.4.3 Self-reporting and Self-healing Mechanism of UF/Phen Microcapsule Coating 292
- 6.5 Chapter Summary 294 References 296

#### 7 Development of Mechanically Responsive Self-reporting Coating 305

- 7.1 Introduction *305*
- 7.2 Mechanically Responsive Self-reporting Coating Based on DCF 306
- 7.2.1 Materials and Methods 307
- 7.2.1.1 Materials 307
- 7.2.1.2 Instruments 307
- 7.2.1.3 Preparation of DCF@PU/UF Microcapsules 307
- 7.2.1.4 Fabrication of SMEP Coating Containing DCF@PU/UF 309

xii Contents

7.2.1.5	Characterization of DCF@PU/UF Microcapsules 309
7.2.1.6	Characterization of Coatings 309
7.2.1.7	Characterization of Self-reporting and Self-healing Performance 310
7.2.2	Characterization of DCF@PU/UF Microcapsules 310
7.2.3	Characterization of EP Coatings 311
7.2.4	Self-reporting Performance of DCF@PU/UF-EP Coatings 313
7.2.5	Self-healing Performance of DCF@PU/UF-EP coatings 316
7.2.6	Dual Self-reporting and Self-healing Mechanisms 318
7.3	Chapter Summary 320
	References 322
8	Development of Aging-Resistant Coating with Self-healing
	and Self-reporting Properties 329
8.1	Introduction 329
8.2	Aging-Resistant, Self-healing, and Self-reporting Smart Coatings Based
	on TA Additives 332
8.2.1	Materials and Methods 333
8.2.1.1	Materials 333
8.2.1.2	Instruments 333
8.2.1.3	Coloration Test of TA 333
8.2.1.4	Corrosion Inhibition Performance of TA 334
8.2.1.5	Preparation of TA-MSNs 334
8.2.1.6	Coloration Test of TA-MSNs 335
8.2.1.7	Corrosion Inhibition Test of TA-MSNs 336
8.2.1.8	Preparation of TA-MSNs-Based Coatings 336
8.2.1.9	Coloration Properties of Coatings 337
8.2.1.10	Self-healing Property of Coatings 337
8.2.1.11	Aging-Resistant Property of Coatings 337
8.2.2	Color Development and Corrosion Inhibition Properties of TA 338
8.2.2.1	Chromogenic Properties of TA 338
8.2.2.2	Corrosion Inhibition Performance of TA 339
8.2.3	Characterization and Property of TA-MSNs 344
8.2.3.1	Morphology and Structure of TA-MSNs 344
8.2.3.2	Release Behavior of TA-MSNs 347
8.2.3.3	Coloration Properties of TA-MSNs 349
8.2.3.4	Corrosion Inhibition Performance of TA-MSNs 350
8.2.3.5	Radical Scavenging Activity of TA-MSNs 352
8.2.4	Characterization and Property of TA-MSNs/Epoxy Coating 353
8.2.4.1	Self-reporting Property of Coatings 353
8.2.4.2	Corrosion Resistance of Coatings 354
8.2.4.3	Self-healing Property of Damaged Coatings 361
8.2.4.4	Aging Resistance of Coatings 368
8.3	Aging-Resistant Anticorrosion Coatings Based on TP Additives 369
8.3.1	Materials and Methods 369
8.3.1.1	Materials 369

- 8.3.1.2 Instruments 369
- 8.3.1.3 Selection of Antioxidant 369
- 8.3.1.4 Preparation of TP-MSNs 370
- 8.3.1.5 Characterization of TP-MSNs 370
- 8.3.1.6 Preparation of TP-MSNs-Based Anti-aging Coating 371
- 8.3.1.7 Characterization of TP-MSNs-Based Anti-aging Coating 371
- 8.3.2 Preparation and Oxidation Resistance of TP-MSNs 371
- 8.3.2.1 Oxidation Resistance of Different Polyphenols 371
- 8.3.2.2 Morphology and Oxidation Resistance of TP-MSNs 372
- 8.3.3 Preparation and Aging Resistance of TP-MSNs-Loaded Coatings 376
- 8.3.3.1 Corrosion Resistance of TP-MSNs-Loaded Coatings 376
- 8.3.3.2 Aging Resistance of TP-MSNs-Loaded Coatings 378
- 8.4 Chapter Summary 381

References 383

9 Development of Superhydrophobic Coating with Good Mechanical Durability and Self-healing Effect 393

- 9.1 Introduction 393
- 9.2 Preparation and Evaluation of Modified Nano SiO<sub>2</sub>/Epoxy Resin Superhydrophobic Coating 394
- 9.2.1 Materials and Methods 395
- 9.2.1.1 Materials 395
- 9.2.1.2 Modification of nSiO<sub>2</sub> 395
- 9.2.1.3 Preparation of Modified nSiO<sub>2</sub>/Epoxy Resin Composite Coating 396
- 9.2.1.4 Structure Analysis of Modified nSiO<sub>2</sub> 396
- 9.2.1.5 Hydrophobic Property of Modified nSiO<sub>2</sub>/Epoxy Coating 396
- 9.2.1.6 Mechanical Durability and Stability Analysis of Coating 396
- 9.2.2 Characterization of nSiO<sub>2</sub> and nSiO<sub>2</sub>/Epoxy Coating 397
- 9.2.2.1 Characterization of nSiO<sub>2</sub> 397
- 9.2.2.2 Structure and Hydrophobicity of nSiO<sub>2</sub>/Epoxy Coating 398
- 9.2.2.3 Stability and Anti-icing Ability of nSiO<sub>2</sub>/Epoxy Coating 401
- 9.3 Preparation and Evaluation of CNTs/Epoxy Resin Superhydrophobic Coating 402
- 9.3.1 Materials and Methods 403
- 9.3.1.1 Materials 403
- 9.3.1.2 Preparation of CNTs/Epoxy Resin Composite Coating 403
- 9.3.1.3 Surface Characterization of CNTs/Epoxy Composite Coatings 404
- 9.3.1.4 Anti-icing Property of CNTs/Epoxy Composite Coatings 404
- 9.3.1.5 Mechanical Durability Test 404
- 9.3.1.6 Electrochemical Analysis 405
- 9.3.2 Characterization of CNTs/Epoxy Coating 405
- 9.3.2.1 Surface Characterization of CNTs/Epoxy Coating 405
- 9.3.2.2 Surface Hydrophobicity of CNTs/Epoxy Coatings with Different CNT Content 406
- 9.3.2.3 Anti-Icing Properties of CNTs/Epoxy Composite Coatings 407

9.3.2.4	Mechanical Durability of CNTs/Epoxy Composite Coatings 409
9.3.2.5	Electrochemical Test of CNTs/Epoxy Composite Coatings 411
9.4	Shape Memory Self-healing Superhydrophobic Coating Based on
	SiO <sub>2</sub> –CNT Hybrids 413
9.4.1	Materials and Methods 414
9.4.1.1	Materials 414
9.4.1.2	Preparation of SiO <sub>2</sub> -CNT Hybrid/Epoxy Shape Memory Coating 414
9.4.1.3	Glass Transition Temperature $(T_g)$ Test of Coatings 415
9.4.1.4	Surface Characterization of Coatings 415
9.4.1.5	Electrothermal Performance Test 415
9.4.1.6	Surface Mechanical Durability 415
9.4.1.7	Electrochemical Analysis 415
9.4.2	Characterization of SiO <sub>2</sub> –CNTs/Epoxy Composite Coating 415
9.4.2.1	$T_{g}$ of SiO <sub>2</sub> -CNTs/Epoxy Composite Coating 415
9.4.2.2	Surface Hydrophobicity of SiO <sub>2</sub> -CNTs/Epoxy Composite Coating 416
9.4.2.3	Electrothermal Property of SiO <sub>2</sub> -CNTs Hybrid/Epoxy Coatings 418
9.4.2.4	Mechanical Durability of SiO <sub>2</sub> –CNTs Hybrid/Epoxy Coatings 421
9.4.2.5	Electrochemical Test of SiO <sub>2</sub> -CNTs Hybrid/Epoxy Coatings 422
9.5	Superhydrophobic Self-healing Coating Based on CNTs/LDH
	Nanocontainers Loaded with Corrosion Inhibitors 424
9.5.1	Materials and Methods 425
9.5.1.1	Materials 425
9.5.1.2	Preparation of CNTs/LDH/VO <sub>3</sub> <sup><math>-</math></sup> 425
9.5.1.3	Preparation of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Epoxy Coating $426$
9.5.1.4	Characterization of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Epoxy Coating 427
9.5.1.5	Water Contact Angle Measurement 427
9.5.1.6	Release Behavior of Corrosion Inhibitors From CNTs/LDH/VO <sub>3</sub> <sup>-</sup> 427
9.5.1.7	Electrochemical Analysis 427
9.5.2	Characterization of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Epoxy Composite Coating 427
9.5.2.1	Characterization of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> 427
9.5.2.2	Superhydrophobic Property of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Based Coatings 431
9.5.2.3	Electrochemical Performance of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Based Coatings 432
9.5.3	Corrosion Protection Mechanism of CNTs/LDH/VO <sub>3</sub> <sup>-</sup> Based
	Coating 434
9.6	Chapter Summary 435
	References 437
10	Investigation of the Self-healing Performance of Coatings
	Using Atmospheric Corrosion Monitor Technique 445
10.1	Introduction 445
10.2	Characterization Methods for Corrosion Protection Coatings 446
10.2.1	Experimental Characterization Methods for Corrosion Protection
	Coatings 446
10.2.1.1	Salt Spray Test 446
10.2.1.2	Immersion Test 447

- 10.2.1.3 Wet-Dry Alternating Cycle Test 447
- 10.2.1.4 Atmospheric Exposure Test 447
- 10.2.2 Experimental Testing Methods for Corrosion Protection Coatings 448
- 10.2.2.1 Electrochemical Methods 448
- 10.2.2.2 Surface Analysis Methods 449
- 10.2.3 Research Progress in Atmospheric Corrosion Monitor Technique 449
- 10.3 Study of the Self-healing Behavior of Coatings Using ACMTechnique 450
- 10.3.1 Materials and Methods 450
- 10.3.1.1 Materials 450
- 10.3.1.2 Preparation of Galvanic Corrosion Sensors 450
- 10.3.1.3 Preparation of Coatings 452
- 10.3.1.4 Accelerated Corrosion Test 454
- 10.3.1.5 Characterization of Coatings 454
- 10.3.2 Self-healing Performance of Coatings in Room Temperature Immersion Environment 454
- 10.3.2.1 Determination of Corrosion Inhibitor Amount in Coatings 455
- 10.3.2.2 Corrosion Morphology on Coating Surfaces 455
- 10.3.2.3 Electrochemical Analysis 457
- 10.3.2.4 ACM Measurement 461
- 10.3.3 Self-healing Performance of Coatings in Alternating Wet–Dry Environment 463
- 10.3.3.1 Corrosion Morphology on Coating Surfaces 463
- 10.3.3.2 Electrochemical Analysis 465
- 10.3.3.3 ACM Measurement 467
- 10.3.4 Self-healing Performance of Coatings in Outdoor Exposure Environment 471
- 10.3.4.1 ACM Measurement 471
- 10.4 Chapter Summary 475 References 478
- 11
   Future Development Direction of Smart Anticorrosive

   Coatings
   485
- 11.1 Introduction 485
- 11.2 Smart Self-healing Coatings 485
- 11.2.1 Application of Self-healing Coatings in Marine Corrosion 486
- 11.2.2 Application of Self-healing Coatings in Nuclear Corrosion 488
- 11.2.3 Application of Self-healing Coatings in Oil Gas Corrosion 489
- 11.3 Smart Self-reporting Coatings 490
- 11.4 Superhydrophobic Coatings 491
- 11.5 Application of Atmospheric Corrosion Monitor Technology in Smart Coating Design 493

**Index** 495