Contents

Preface *xi*

PART ONE
ADHESIVES AND ADHESION

1 Introduction 3
1.1 Definitions and bonding 3
1.2 Structure of the book 5
Part 1 – Adhesives and adhesion 5
Part 2 – Applications 7
1.3 Historical development 7
1.4 Engineering applications of adhesives 9
Aerospace 9
Building 12
Civil engineering 14
Marine and offshore 19
Railway 21
Vehicle and automotive 22
1.5 Relevance to civil engineering 25
1.6 Closing remarks 28
1.7 Further reading 28

2 Adhesive classification and properties 30
2.1 Engineering and non-engineering adhesives 30
2.2 Generic classification of adhesives 33
Epoxy resins 33
Epoxy hardeners 37
Epoxy additives 39
Polyesters 42
Acrylics 44
Polyurethanes 45
Polymer bonding aids 45
2.3 Adhesive properties 47
Unmixed state 48
Freshly mixed state 48
During cure 54
Hardened state 54
2.4 Concluding remarks 75

3	**Adhesion and surface pretreatment**	76
3.1	Introduction	76
3.2	Interfacial contact and intrinsic adhesion	77
	Preliminaries	77
	Interfacial contact	79
	Wetting equilibria and contact angles	80
	Surface and interfacial free energies	82
	Mechanisms of adhesion	85
3.3	Surface pretreatment	88
	Opening remarks	88
	Methods of surface pretreatment	88
	Pretreatment for metals	92
	Pretreatments for concrete	101
	Pretreatments for polymer composites	104
	Priming layers and coupling agents	105
	The bonding operation	111
3.4	Methods to study pretreatments	112
	Mechanical test procedures	112
	Surface analysis	112
3.5	Summary and concluding remarks	113
4	**Adhesive joints**	116
4.1	Introduction	116
4.2	Factors affecting joint strength	119
4.3	Joint design	121
	General considerations	121
	Stress analysis and design philosophies	125
4.4	Test procedures	132
	General remarks	132
	Structural analysis requirements	133
	Durability evaluation requirements	138
	Test joints versus real joints	138
	Joint tests in shear	140
	Joint tests in tension	147
	Joint tests for peel	149
	Joint tests for fracture	150
4.5	Joint behaviour	156
	Creep	157
	Fatigue	158
	Fracture	160
	Environmental conditions	160
4.6	Durability and performance in service	162
	Effect of water	163
	Techniques for increasing interfacial stability	171
	Climatic exposure trials	172
	Summary of durability aspects	173
4.7	Concluding remarks	177

5 Specification, fabrication and quality control 180
5.1 Introduction 180
5.2 Specification considerations 183
Elementary concepts 183
Adhesive selection 183
Surface pretreatment 185
Joint design 186
Fabrication procedures 187
5.3 Quality control and non-destructive testing 188
Adhesion control 189
Cohesion control 190
5.4 Safety 193

PART TWO
APPLICATIONS

6 Applications in repair and strengthening 197
6.1 Concrete repair 197
Resin injection 197
Patches 199
Coatings and sealants 203
Property mismatch 205
6.2 Concrete strengthening 215
Concrete overlays 215
Externally bonded reinforcement 217
6.3 Steel structures 231
6.4 Timber structures 236
6.5 Masonry structures 238

7 Applications in new construction 243
7.1 Bearings and expansion joints for bridges 243
7.2 Skid resistant surfacings 245
7.3 Resin bonded fixings to concrete, masonry and rocks 247
7.4 Wire and strand anchors 253
7.5 Composite steel–concrete construction 254
7.6 Segmental concrete construction 255
7.7 Epoxy coated rebars 260
7.8 Glued laminated timber 262

8 Potential future developments 267
8.1 Introduction 267
8.2 Sandwich construction 267
Open sandwich construction 268
Precast open sandwich panels for bridge decks 269
Closed sandwich construction 277
8.3 Composite construction 279
Steel/concrete 279
Other material combinations 279

8.4 Compound structural elements 280
Aluminium extrusions 281
Composite pultrusions 281
8.5 Steelwork fabrication 281
Bonded stiffeners 283
Tension splices, beam splices and cover plates 285
Hollow sections and truss connections 287
8.6 Connections between metals 288
Light-gauge materials 288
Aluminium connections 288
Rebar connections 290
8.7 Connections between plastics 290
Pultruded sections 291
Cladding attachments 291
Externally bonded reinforcement 293
Plastic bridges 293
8.8 Miscellaneous connections 294
8.9 Closing remarks 296

APPENDIX
COMPLIANCE SPECTRUM FOR A TWO-PART COLD-CURE ADHESIVE FOR STRUCTURAL BONDING OF STEEL TO CONCRETE

A.1 Purpose 297
A.2 Form of material 297
A.3 Working characteristics 299
A.4 Mechanical properties of hardened adhesive and steel-to-steel joints 299
A.5 Quality control data 306
A.6 Packaging 306
A.7 Instruction sheet 307

References 309

Index 326