

Contents

Preface *xi*

1	Benefits, Limitations, and Applications of Adhesive Bonding	1
1.1	Definition of Basic Concepts	2
1.2	Historical Context on Adhesive Bonding	3
1.3	Benefits and Limitations of Adhesive Bonding	4
1.4	Examples of Current Applications of Adhesive Bonding	8
1.4.1	Transportation	8
1.4.1.1	Aeronautical Industry	8
1.4.1.2	Road Transport and Rail Industry	11
1.4.1.3	Naval Industry	13
1.4.2	Civil Engineering	15
1.4.2.1	Tiling	15
1.4.2.2	Floor and Wall Covering	15
1.4.2.3	Anchoring Systems	15
1.4.2.4	Building Facades	16
1.4.2.5	Wooden Construction	17
1.4.3	Labelling and Packaging Industry	18
1.4.3.1	Labelling of Consumable Products	18
1.4.3.2	Packaging	18
1.4.4	Medical Applications and Devices	19
1.4.5	Electronic Devices	23
1.4.6	Sport Equipment	23
1.4.7	Footwear	24
2	Principles of Adhesion	27
2.1	Forces Associated with Adhesion	28
2.2	Surface Roughness	31
2.3	Wettability	32
2.4	Adhesion and Cohesion Work	35
2.5	Spreading	36

2.6	Adhesion Theories	37
2.6.1	Adsorption Theory	37
2.6.2	Mechanical Theory	38
2.6.3	Diffusion Theory	41
2.6.4	Electrostatic Theory	41
2.7	Defects and Weak Spots in Adhesive Joints	42
3	Surface Preparation	45
3.1	Objectives of Surface Preparation	45
3.2	Classes of Substrate Materials	47
3.2.1	Metals	47
3.2.2	Polymers	47
3.2.3	Composites	48
3.2.4	Other Materials	49
3.3	Surface Preparation Processes	49
3.3.1	Passive Processes	51
3.3.1.1	Passive Chemical Processes	51
3.3.1.2	Passive Mechanical Processes	55
3.3.2	Active Processes	59
3.3.2.1	Active Chemical Processes	59
3.3.2.2	Physical–Chemical Processes	62
3.3.3	Primers and Adhesion Promoters	65
3.4	Conservation of the Post-treatment Surface	67
4	Main Families of Adhesives and Adhesive Selection	69
4.1	Typical Composition of a Modern Adhesive	69
4.2	Methods for Adhesive Classification	70
4.2.1	Molecular Structure	70
4.2.1.1	Thermosets	71
4.2.1.2	Thermoplastics	71
4.2.1.3	Elastomers	72
4.2.1.4	Hybrid Materials	72
4.2.2	Physical Form	74
4.2.3	Mechanical Properties	74
4.2.4	Hardening and Implementation Method	75
4.2.4.1	Hardening by Chemical Reaction	75
4.2.4.2	Hardening via Physical Processes	76
4.2.4.3	Pressure-Sensitive Adhesives	76
4.2.5	Chemical Composition	77
4.3	Main Structural Adhesives	77
4.3.1	Epoxy Adhesives	77
4.3.2	Polyurethane Adhesives	78
4.3.3	Acrylic Adhesives	79
4.3.4	Phenolic Adhesives	80
4.3.5	Aromatic Adhesives	81

4.4	Main Non-structural Adhesives	81
4.4.1	Elastomeric Adhesives	81
4.4.2	Polyester Adhesives	82
4.4.3	Hot Melt Adhesives	82
4.4.4	Inorganic Adhesives	83
4.5	How to Select an Adhesive	83
4.5.1	Case Study: Adhesive Selection for the Automotive Industry	84
4.6	How to Test and Characterise an Adhesive	88
4.6.1	Mechanical Testing	88
4.6.1.1	Strength Tests	89
4.6.1.2	Fracture Tests	93
4.6.1.3	Testing Under Severe Environmental and Loading Conditions	98
4.7	Mechanical Properties of Adhesives	102
5	Manufacture	107
5.1	Adhesive Storage	107
5.1.1	Storage Time	108
5.1.2	Humidity	109
5.1.3	Temperature	109
5.1.4	Light and UV Radiation	110
5.2	Adhesive Metering and Mixing	110
5.2.1	Adhesive Metering	111
5.2.2	Adhesive Mixing	111
5.3	Adhesive Forms and Application	114
5.3.1	Liquid Adhesives	114
5.3.2	Paste Adhesives	115
5.3.3	Film Adhesives	116
5.3.4	Tapes	117
5.4	Joint Assembly and Fixturing	117
5.4.1	Moulds and Fixtures	117
5.4.2	Adhesive Thickness Control	119
5.4.3	Joint Assembly	119
5.5	Adhesive Hardening	120
5.5.1	Heat Curing Processes	121
5.5.2	Evaporation-Based Processes	125
5.6	Finishing Steps	126
6	Quality Control	127
6.1	Quality Control of the Incoming Materials	128
6.1.1	Control of Adhesive Quality	128
6.1.1.1	Mechanical Properties	128
6.1.1.2	Viscosity	128
6.1.2	Control of Adherend Quality	129
6.1.2.1	Mechanical Properties	129
6.1.2.2	Wettability, Contact Angle, and Surface Energy	129

6.1.2.3	Surface Roughness	131
6.2	Quality Control of the Manufacturing Process	133
6.3	Quality Control on Bonded Structures	137
6.3.1	Types of Defects Present in Bonded Joints	137
6.3.2	Destructive Tests	138
6.3.2.1	Proof Tests	139
6.3.2.2	Fractography Analysis	139
6.3.3	Non-destructive Tests	141
6.3.3.1	Visual Inspection	141
6.3.3.2	Tap Test	142
6.3.3.3	Ultrasonic Test	143
6.3.3.4	Acoustic Emission Test	143
6.3.3.5	Radiography Test	144
6.3.3.6	Eddy Current Test	145
6.3.3.7	Thermal Infrared Method	146
6.3.3.8	Lamb Wave-Based Testing	146
6.3.3.9	Electromechanical Impedance Spectroscopy	146
6.3.3.10	Laser-Based Testing	149
7	Environment, Health, and Safety	151
7.1	Toxicity of Adhesives: Are Adhesives Really Toxic?	153
7.2	General Precautions for Handling Adhesives	153
7.2.1	Pictograms	154
7.2.2	Training for Handling Adhesives	157
7.2.3	Safety Eyewear	158
7.2.4	Hand Protection – Gloves	158
7.2.5	Safety Shoes	159
7.2.6	Lab Coat	159
7.2.7	Ventilation Systems	159
7.3	Hazardous Characteristics of the Most Common Adhesives	160
7.3.1	Structural Adhesives	160
7.3.1.1	Epoxies	160
7.3.1.2	Polyurethanes	161
7.3.1.3	Acrylic Adhesives	161
7.3.1.4	Phenolic Adhesives	161
7.3.1.5	Aromatic Adhesives	161
7.3.2	Non-structural Adhesives	162
7.3.2.1	Synthetic Rubbers	162
7.3.2.2	Polyesters	162
7.3.2.3	Hot Melt Adhesives	162
7.3.2.4	Inorganic Adhesives	162
7.4	Surface Preparation Precautions	162
7.5	Adhesive Application Precautions	164
7.6	Environmental Protection	164
7.6.1	Air	165

7.6.2	Water	165
7.6.3	Soil	166
8	Design of Bonded Joints	167
8.1	Main Loading Modes on Adhesive Joints	168
8.2	Main Adhesive Joint Geometries	169
8.3	Joint Strength Prediction Using Analytical Methods	171
8.3.1	Determination of Stresses Acting on an Adhesive Joint	172
8.3.2	Failure Criteria for Bonded Joints	175
8.3.2.1	Failure in the Adhesive	176
8.3.2.2	Failure in the Adherends	177
8.4	Joint Strength Prediction Using Numerical Methods	180
8.5	Parameters That Affect Joint Performance	183
8.5.1	Effect of Adhesive Thickness	183
8.5.2	Effect of Overlap Length	184
8.5.2.1	Overlap Length and Adhesive Behaviour	185
8.5.2.2	Overlap Length and Adherend Strength	186
8.5.2.3	Overlap Length and Composite Adherends	187
8.5.3	Effect of Temperature and Thermal Stresses	187
8.6	Methods to Improve Joint Strength	189
8.6.1	Adhesive Fillet	189
8.6.2	Mixed Adhesive Joints	190
8.6.3	Functionally Graded Joints	190
8.6.4	Hybrid Joints	191
8.7	Case Studies	192
8.7.1	Case Study 1 – Effect of Adhesive Type on the Strength of Adhesive Joints	192
8.7.2	Case Study 2 – Effect of Overlap Length and Adherend Type on the Strength of Adhesive Joints	194
8.7.3	Case Study 3 – Effect of Adhesive Thickness on the Strength of Adhesive Joints	197
8.7.4	Case Study 4 – Strength Prediction of Adhesive Joints with Composite Adherends	201
8.7.5	Case Study 5 – Strength Prediction of an SLJ with Cohesive Zone Modelling	205
8.7.6	Case Study 6 – Effect of Thermal Stresses on Adhesive Joints	208
9	Durability of Adhesively Bonded Joints	213
9.1	Environmental Effects	214
9.1.1	Hygrothermal Ageing	214
9.1.2	Temperature	220
9.2	Loading Conditions	221
9.2.1	Fatigue	221
9.2.1.1	Total Fatigue Life (S–N) Approach	223
9.2.1.2	Fatigue Crack Growth Approach	225
9.2.2	Creep	229

10	Case Studies	235
10.1	Vehicle Construction	235
10.2	Seat Fixation in Passenger Trains	237
10.3	Aeronautical Applications	239
10.4	Flexible Cooling Circuits	241
10.5	Glass to Metal Bonding in Appliances	243
10.6	Roof Coverings	245
10.7	Shoe Manufacture	246
10.8	Food Packaging	248
	Recommended Bibliography	251
	Referenced Bibliography	251
	Index	253