

Contents

<i>From the preface to First Edition</i>	xiii
<i>Preface to Second Edition</i>	xiv
1 General introduction	1
1.1 Types of composite material	1
1.2 Design of composite materials	5
1.3 The concept of load transfer	6
References and further reading	8
2 Fibres and matrices	9
2.1 Reinforcements	9
2.1.1 Carbon fibres	9
2.1.2 Glass fibres	14
2.1.3 Organic fibres	16
2.1.4 Silicon carbide	17
2.1.5 Alumina and aluminosilicates	21
2.2 The strength of reinforcements	22
2.2.1 Thermal stability	22
2.2.2 Compressive strength	23
2.2.3 Fibre fracture and flexibility	24
2.2.4 A statistical treatment of fibre strength	27
2.3 Matrices	30
2.3.1 Polymer matrices	30
2.3.2 Metal matrices	34
2.3.3 Ceramic matrices	35
References and further reading	36
3 Fibre architecture	39
3.1 General considerations	39

viii	<i>Contents</i>	
3.1.1	Volume fraction and weight fraction	39
3.1.2	Fibre packing arrangements	40
3.1.3	Clustering of fibres and particles	42
3.2	Long fibres	43
3.2.1	Laminates	43
3.2.2	Woven, braided and knitted fibre arrays	46
3.2.3	Characterisation of fibre orientations in a plane	48
3.3	Short fibres	49
3.3.1	Fibre orientation distributions in three dimensions	49
3.3.2	Fibre length distributions	53
3.4	Voids	55
3.5	Fibre orientation during processing	59
	References and further reading	59
4	Elastic deformation of long-fibre composites	60
4.1	Axial stiffness	60
4.2	Transverse stiffness	62
4.3	Shear stiffness	69
4.4	Poisson contraction effects	71
	References and further reading	77
5	Elastic deformation of laminates	78
5.1	Elastic deformation of anisotropic materials	78
5.1.1	Hooke's law	78
5.1.2	Effects of symmetry	80
5.2	Off-axis elastic constants of laminae	83
5.2.1	Calculation procedure	83
5.2.2	Engineering constants	87
5.3	Elastic deformation of laminates	93
5.3.1	Loading of a stack of plies	93
5.3.2	Predicted behaviour	95
5.4	Stresses and distortions	97
5.4.1	Balanced laminates	97
5.4.2	Stresses in individual plies of a laminate	98
5.4.3	Coupling stresses and symmetric laminates	101
	References and further reading	104
6	Stresses and strains in short-fibre composites	105
6.1	The shear lag model	105
6.1.1	Stress and strain distributions	107
6.1.2	The stress transfer length	109

	<i>Contents</i>	ix
6.1.3	Transfer of normal stress across fibre ends	114
6.1.4	Prediction of stiffness	115
6.1.5	Onset of inelastic behaviour	118
6.2	The Eshelby method	121
6.2.1	A misfitting ellipsoid	123
6.2.2	The equivalent homogeneous ellipsoid	123
6.2.3	The background stress	126
6.2.4	Composite stiffness	127
	References and further reading	131
7	The interface region	133
7.1	Bonding mechanisms	133
7.1.1	Adsorption and wetting	133
7.1.2	Interdiffusion and chemical reaction	135
7.1.3	Electrostatic attraction	137
7.1.4	Mechanical keying	137
7.1.5	Residual stresses	138
7.2	Experimental measurement of bond strength	138
7.2.1	Single-fibre pull-out test	140
7.2.2	Single-fibre push-out and push-down tests	143
7.2.3	Other tests	146
7.3	Control of bond strength	147
7.3.1	Coupling agents and environmental effects	147
7.3.2	Toughness-reducing coatings	151
7.3.3	Interfacial chemical reaction and diffusion barrier coatings	152
7.3.4	The interphase region	153
	References and further reading	155
8	Strength of composites	158
8.1	Failure modes of long-fibre composites	158
8.1.1	Axial tensile failure	159
8.1.2	Transverse tensile failure	171
8.1.3	Shear failure	177
8.1.4	Failure in compression	178
8.2	Failure of laminae under off-axis loads	184
8.2.1	Maximum stress criterion	185
8.2.2	Other failure criteria	186
8.2.3	Experimental data for single laminae	188
8.3	Strength of laminates	191

x	<i>Contents</i>	
	8.3.1 Tensile cracking	192
	8.3.2 Interlaminar stresses	194
	8.3.3 Edge effects	195
8.4	Failure of tubes under internal pressure	197
	8.4.1 Pure hoop loading	199
	8.4.2 Combined hoop and axial loading	201
	8.4.3 Netting analysis	203
	References and further reading	205
9	Toughness of composites	208
9.1	Fracture mechanics	208
	9.1.1 Basic concepts	208
	9.1.2 Interfacial fracture and crack deflection	213
9.2	Contributions to work of fracture	217
	9.2.1 Matrix deformation	217
	9.2.2 Fibre fracture	218
	9.2.3 Interfacial debonding	219
	9.2.4 Frictional sliding and fibre pull-out	220
	9.2.5 Effects of microstructure	223
9.3	Sub-critical crack growth	226
	9.3.1 Fatigue	227
	9.3.2 Stress corrosion cracking	233
	References and further reading	234
10	Thermal behaviour of composites	237
10.1	Thermal expansion and thermal stresses	237
	10.1.1 Thermal stresses and strains	237
	10.1.2 Thermal expansivities	240
	10.1.3 Thermal cycling of unidirectional composites	244
	10.1.4 Thermal cycling of laminates	247
10.2	Creep	251
	10.2.1 Basics of matrix and fibre behaviour	251
	10.2.2 Axial creep of long-fibre composites	253
	10.2.3 Transverse creep and discontinuously reinforced composites	255
10.3	Thermal conduction	259
	10.3.1 Heat transfer mechanisms	259
	10.3.2 Conductivity of composites	260
	10.3.3 Interfacial thermal resistance	264
	References and further reading	269

<i>Contents</i>		xi
11	Fabrication	271
11.1	Polymer composites	271
11.1.1	Liquid resin impregnation routes	272
11.1.2	Pressurised consolidation of resin pre-pregs	274
11.1.3	Consolidation of resin moulding compounds	276
11.1.4	Injection moulding of thermoplastics	278
11.1.5	Hot press moulding of thermoplastics	279
11.2	Metal composites	280
11.2.1	Squeeze infiltration	281
11.2.2	Stir casting	282
11.2.3	Spray deposition	283
11.2.4	Powder blending and consolidation	285
11.2.5	Diffusion bonding of foils	285
11.2.6	Physical vapour deposition (PVD)	286
11.3	Ceramic composites	286
11.3.1	Powder-based routes	288
11.3.2	Reactive processing	290
11.3.3	Layered ceramic composites	291
11.3.4	Carbon/carbon composites	291
	References and further reading	293
12	Applications	295
12.1	Minesweeper hull	295
12.2	Sheet processing rolls	297
12.3	Helicopter rotor blade	299
12.4	Golf driving club	301
12.5	Racing bicycle	303
12.6	Diesel engine piston	303
12.7	Microelectronics housing	305
12.8	Gas turbine combustor can	307
12.9	Aircraft brakes	308
	References and further reading	309
	<i>Appendix</i> Nomenclature	311
	<i>Author index</i>	315
	<i>Subject index</i>	320