

Contents

<i>Preface</i>	vii
<i>Authors</i>	ix
<i>Acknowledgement</i>	x

Part I Overview and review of composite materials

F. L. MATTHEWS

1	Overview	3
1.1	Composite materials	3
1.2	Structural analysis	4
2	Fundamentals of composites	6
2.1	Basic characteristics	6
2.2	Fibres and matrices	11
2.3	Summary	16
2.4	Reference	16
3	Stiffness and strength of composites	17
3.1	Stiffness of unidirectional composites and laminates	17
3.2	Micromechanics of unidirectional composites	27
3.3	Strength of unidirectional composites and laminates	30
3.4	Application to structures	34
3.5	Summary	36
3.6	References	37

Part II Fundamentals of finite element analysis

G. A. O. DAVIES

4	Fundamentals of finite element analysis	41
4.1	Basic theoretical foundations	41
4.2	Principle of virtual displacements	45

4.3	An arbitrary structure	46
4.4	Finite element approximations	49
4.5	Brick, beam, plate and shell elements	56
4.6	Model generation	61
4.7	Solution procedures	63
4.8	Results verification	65
4.9	Summary	67
4.10	Reference	68

Part III Finite elements applied to composite materials

D. HITCHINGS

5	Composites and finite element analysis	71
5.1	Elements used for composite laminate analysis	71
5.2	Accuracy of the finite element solution	78
5.3	Other modelling techniques useful for composite analysis	79
5.4	Changes of mesh density	82
5.5	Modelling of composite materials	84
5.6	Examples of finite element composite analysis	87
5.7	Effect of lay-up on plate response	90
5.8	Summary	93
6	Definition of composite materials in finite element analysis	94
6.1	Introduction	94
6.2	Geometry and topology	94
6.3	Fibre orientation	96
6.4	Volume fraction and ply thickness variations	99
6.5	Laminate ply drop-off	100
6.6	Modelling real structures	101
6.7	Non-linearities in composite analysis	104
6.8	Failure models	107
6.9	Determination of energy release rates	110
6.10	Crack propagation modelling	112
6.11	Micromechanical models using finite element analysis	113
6.12	Smart composites: the inclusion of piezo-electric effects	116
6.13	Summary	118
6.14	References	119

Part IV Analytical and numerical modelling

C. SOUTIS

7	Interlaminar stresses and free edge stresses	123
7.1	Introduction	123
7.2	Development of classical analysis	126
7.3	Finite element analysis of straight edges	129
7.4	Finite element analysis of curved edges	130
7.5	Summary	135
7.6	References	136
8	Fracture and fracture mechanics	139
8.1	Introduction	139
8.2	Crack tip behaviour in homogeneous solids	140
8.3	Crack extension in composites	142
8.4	Application of fracture mechanics to composites	146
8.5	Progressive failure models	155
8.6	Summary	156
8.7	References	157
9	Delamination	158
9.1	Introduction	158
9.2	A continuum model	159
9.3	Two-dimensional finite element analysis	164
9.4	Discussion of VCC results	168
9.5	Finite element analysis using interface elements	171
9.6	Summary	172
9.7	References	173
10	Joining	175
10.1	Introduction	175
10.2	Adhesively bonded joints	175
10.3	Mechanically fastened joints	183
10.4	Summary	190
10.5	References	191
11	Fatigue	194
11.1	Introduction	194
11.2	Damage modes in composite laminates	194
11.3	Fatigue of unidirectional laminates	196
11.4	Fatigue of multidirectional laminates	198
11.5	Fatigue damage effects on mechanical properties	201

vi	Contents	
11.6	Fatigue damage modelling	203
11.7	A finite element model for fatigue life prediction of CFRP components	204
11.8	Summary	207
11.9	References	208
	<i>Index</i>	211