

Contents

1	Introduction	1
1.1	General background	1
1.2	Why apply fracture mechanics principles to wood?	2
1.3	Why apply knowledge of fatigue processes to wood?	3
1.4	Arrangement of this book	4
2	Structure and properties of wood	7
2.1	The nature of wood	7
2.1.1	Tree growth and wood formation	7
2.1.2	Gross growth features in wood	11
2.1.3	Chemical components	12
2.1.4	Microfibrils and cell walls	13
2.1.5	Microstructure	14
2.1.6	Macrostructure	16
2.1.7	Variation of wood	17
2.2	Pre-service damage in wood	19
2.2.1	Damage in standing trees	19
2.2.2	Damage due to harvesting and processing	20
2.2.3	Damage due to biological agents	21
2.3	Physical and mechanical properties of wood	21
2.3.1	Density and porosity	22
2.3.2	Moisture content	23
2.3.3	Dimensional changes in wood	25
2.3.4	Mechanical properties of wood	25
2.3.5	Key factors affecting mechanical properties of wood	27
2.4	References	34
	Appendix: Notation	34
3	Mechanical behaviour of wood: concepts and modelling	37
3.1	Material complexity and modelling levels	37
3.2	Micro scale: cell level	39
3.3	Meso scale: growth ring level	41
3.4	Macro scale: clear wood	43

3.4.1	General considerations	43
3.4.2	Elastic response	47
3.4.3	In-elastic response	50
3.4.4	Strength criteria	52
3.4.5	Rheological behaviour	53
3.5	Massive scale: structural wood	58
3.5.1	General considerations	58
3.5.2	Representation of mechanical behaviour	59
3.6	References	60
	Appendix: Notation	63
4	Principles of fracture mechanics	67
4.1	The failure stress-based strength theory — motivation for fracture mechanics	67
4.2	Griffith theory	68
4.2.1	Stress concentrations	68
4.2.2	Condition for crack growth	68
4.3	Linear elastic fracture mechanics (LEFM)	71
4.3.1	Strain energy release rate	71
4.3.2	The stress intensity factor	76
4.3.3	Reconciliation of K and G	81
4.3.4	Mixed mode fracture	82
4.3.5	Fatigue in a fracture mechanics context	83
4.4	Nonlinear fracture mechanics	84
4.4.1	The fracture process zone	85
4.4.2	R -curves	86
4.4.3	Fictitious/effective crack models	88
4.4.4	The J-integral	91
4.5	Relevance of material morphology	92
4.6	Continuum damage mechanics	94
4.7	Issues affecting applications of fracture mechanics to wood	95
4.8	References	96
	Appendix: Notation	97
5	Fracture and failure phenomena in wood	99
5.1	Fracture and failure	99
5.2	LEFM-based fracture toughness measurements of wood	100
5.2.1	Mode I fracture	101
5.2.2	Mode II fracture	106
5.2.3	Mixed mode fracture	109
5.2.4	Mode III fracture	111

5.3	Nonlinear fracture characterisation	111
5.3.1	Other fracture characterisations	116
5.4	Material issues affecting fracture properties	116
5.4.1	Microstructural issues	116
5.4.2	Other issues affecting fracture toughness	118
5.5	Issues for material modelling	119
5.6	References	119
	Appendix: Notation	121
6	Fatigue in wood	123
6.1	The phenomenon	123
6.2	State of experimentally based knowledge	124
6.2.1	Overview	124
6.2.2	Effect of loading variables	127
6.2.3	Residual mechanical properties	133
6.2.4	Density effect	134
6.2.5	Massive wood	134
6.2.6	Wood-based panel products	141
6.3	Failure mechanisms in clear wood	142
6.3.1	Axial load parallel to grain	142
6.3.2	Flexure parallel to grain	144
6.3.3	Axial stress perpendicular to grain	146
6.3.4	Shear	148
6.3.5	Summary	150
6.4	References	151
	Appendix: Notation	153
7	Fracture modelling in wood	155
7.1	The modelling problem	155
7.2	Statistical fracture models	156
7.3	Nonlinear fracture mechanics modelling	161
7.3.1	Fictitious crack models	161
7.3.2	Bridging model	164
7.3.3	Applications	165
7.4	Other modelling paradigms	166
7.4.1	Finite element models	166
7.4.2	Morphology-based models	168
7.4.3	Lattice models	168
7.4.4	Damage models	172
7.5	Which model to use?	173
7.6	References	174
	Appendix: Notation	175

8	Fatigue modelling in wood	177
8.1	General considerations	177
8.2	Empirical models	177
8.3	Phenomenological models	189
8.4	Mechanics models	190
8.5	Concluding remarks and recommendations	192
8.6	References	195
	Appendix: Notation	197
9	Application of information and concepts	199
9.1	Overview	199
9.2	Problem 1: Brittle failure in multiple bolt joints	199
9.3	Problem 2: Continuum failure models applied to slotted plates	203
9.4	Problem 3: Critical load levels for end-notched members	207
9.5	Problem 4: Critical crack length in a reinforced glulam girder	210
9.6	Problem 5: Static fatigue in roof joists	213
9.7	Problem 6: Static fatigue in bolted truss joints	215
9.8	Problem 7: Fatigue in bridge stringers	219
9.9	Problem 8: Cyclic fatigue in nailed joints	223
9.10	References	227
	Index	229