
CONTENTS

Preface	xi
List of symbols	xiv
1 Background and overview	1
1.1 Introduction	1
1.1.1 Inertial effects in fracture mechanics	2
1.1.2 Historical origins	3
1.2 Continuum mechanics	13
1.2.1 Notation	13
1.2.2 Balance equations	16
1.2.3 Linear elastodynamics	22
1.2.4 Inelastic materials	29
1.3 Analytic functions and Laplace transforms	30
1.3.1 Analytic functions of a complex variable	30
1.3.2 Laplace transforms	33
1.4 Overview of dynamic fracture mechanics	37
1.4.1 Basic elastodynamic solutions for a stationary crack	38
1.4.2 Further results for a stationary crack	40
1.4.3 Asymptotic fields near a moving crack tip	42
1.4.4 Energy concepts in dynamic fracture	44
1.4.5 Elastic crack growth at constant speed	47
1.4.6 Elastic crack growth at nonuniform speed	49
1.4.7 Plasticity and rate effects during crack growth	52
2 Basic elastodynamic solutions for a stationary crack	55
2.1 Introduction	55
2.2 Suddenly applied antiplane shear loading	60
2.3 Green's method of solution	65

2.4	Suddenly applied crack face pressure	72
2.5	The Wiener-Hopf technique	77
2.5.1	Application of integral transforms	78
2.5.2	The Wiener-Hopf factorization	84
2.5.3	Inversion of the transforms	91
2.5.4	Higher order terms	96
2.6	Suddenly applied in-plane shear traction	97
2.7	Loading with arbitrary time dependence	100
3	Further results for a stationary crack	104
3.1	Introduction	104
3.2	Nonuniform crack face traction	106
3.2.1	Suddenly applied concentrated loads	107
3.2.2	Fundamental solution for a moving dislocation	110
3.2.3	The stress intensity factor history	112
3.3	Sudden loading of a crack of finite length	117
3.4	Three-dimensional scattering of a pulse by a crack	123
3.5	Three-dimensional stress intensity factors	131
3.6	Fracture initiation due to dynamic loading	140
3.6.1	The Irwin criterion	140
3.6.2	Qualitative observations	141
3.6.3	Experimental results	144
4	Asymptotic fields near a moving crack tip	152
4.1	Introduction	152
4.2	Elastic material; antiplane shear	155
4.3	Elastic material; in-plane modes of deformation	160
4.3.1	Singular field for mode I	161
4.3.2	Higher order terms for mode I	169
4.3.3	Singular field for mode II	170
4.3.4	Supersonic crack tip speed	171
4.4	Elastic-ideally plastic material; antiplane shear	175
4.4.1	Asymptotic fields for steady dynamic growth	178
4.4.2	Comparison with equilibrium results	182
4.5	Elastic-ideally plastic material; plane strain	184
4.5.1	Asymptotic field in plastically deforming regions	187
4.5.2	A complete solution	190
4.5.3	Other possible solutions	194
4.5.4	Discontinuities	197
4.5.5	Elastic sectors	202
4.6	Elastic-viscous material	206

Contents

vii

4.6.1	Antiplane shear crack tip field	207
4.6.2	Plane strain crack tip field	214
4.7	Elastic-viscoplastic material; antiplane shear	215
5	Energy concepts in dynamic fracture	221
5.1	Introduction	221
5.2	The crack tip energy flux integral	224
5.2.1	The energy flux integral for plane deformation	224
5.2.2	Some properties of $F(\Gamma)$	227
5.3	Elastodynamic crack growth	231
5.3.1	Dynamic energy release rate	231
5.3.2	Cohesive zone models of crack tip behavior	235
5.3.3	Special forms for numerical computation	240
5.4	Steady crack growth in a strip	243
5.4.1	Strip with uniform normal edge displacement	243
5.4.2	Shear crack with a cohesive zone in a strip	247
5.5	Elementary applications in structural mechanics	250
5.5.1	A one-dimensional string model	250
5.5.2	Double cantilever beam configuration	254
5.5.3	Splitting of a beam with a wedge	257
5.5.4	Steady crack growth in a plate under bending	261
5.5.5	Crack growth in a pressurized cylindrical shell	262
5.6	A path-independent integral for transient loading	264
5.6.1	The path-independent integral	264
5.6.2	Relationship to stress intensity factor	269
5.6.3	An application	271
5.7	The transient weight function method	274
5.7.1	The weight function based on a particular solution	274
5.7.2	A boundary value problem for the weight function	280
5.8	Energy radiation from an expanding crack	289
6	Elastic crack growth at constant speed	296
6.1	Introduction	296
6.2	Steady dynamic crack growth	298
6.2.1	General solution procedure	299
6.2.2	The Yoffe problem	300
6.2.3	Concentrated shear traction on the crack faces	305
6.2.4	Superposition and cohesive zone models	306
6.2.5	Approach to the steady state	310

6.3	Self-similar dynamic crack growth	313
6.3.1	General solution procedure	314
6.3.2	The Broberg problem	318
6.3.3	Symmetric expansion of a shear crack	330
6.3.4	Nonsymmetric crack expansion	334
6.3.5	Expansion of circular and elliptical cracks	336
6.4	Crack growth due to general time-independent loading	340
6.4.1	The fundamental solution	342
6.4.2	Arbitrary initial equilibrium field	350
6.4.3	Some illustrative cases	353
6.4.4	The in-plane shear mode of crack growth	355
6.4.5	The antiplane shear mode of crack growth	356
6.5	Crack growth due to time-dependent loading	356
6.5.1	The fundamental solution	358
6.5.2	Arbitrary delay time with crack face pressure	362
6.5.3	Incident plane stress pulse	365
7	Elastic crack growth at nonuniform speed	367
7.1	Introduction	367
7.2	Antiplane shear crack growth	369
7.3	Plane strain crack growth	378
7.3.1	Suddenly stopping crack	379
7.3.2	Arbitrary crack tip motion	387
7.3.3	In-plane shear crack growth	392
7.4	Crack tip equation of motion	393
7.4.1	Tensile crack growth	395
7.4.2	Fine-scale periodic fracture resistance	401
7.4.3	Propagation and arrest of a mode II crack	407
7.4.4	A one-dimensional string model	410
7.4.5	Double cantilever beam: approximate equation of motion	421
7.5	Tensile crack growth under transient loading	426
7.5.1	Incident plane stress pulse	426
7.5.2	An influence function for general loading	431
7.6	Rapid expansion of a strip yield zone	432
7.7	Uniqueness of elastodynamic crack growth solutions	437
8	Plasticity and rate effects during crack growth	442
8.1	Introduction	442
8.2	Viscoelastic crack growth	442
8.3	Steady crack growth in an elastic-plastic material	448

Contents

ix

8.3.1	Plastic strain on the crack line	451
8.3.2	A growth criterion	459
8.3.3	A formulation for the complete field	461
8.3.4	The toughness–speed relationship	465
8.3.5	The steady state assumption	467
8.4	High strain rate crack growth in a plastic solid	469
8.4.1	High strain rate plasticity	470
8.4.2	Steady crack growth with small-scale yielding	474
8.4.3	An approximate analysis	477
8.4.4	Rate effects and crack arrest	481
8.5	Fracture mode transition due to rate effects	485
8.5.1	Formulation	486
8.5.2	A rate-dependent cohesive zone	488
8.5.3	The crack growth criteria	494
8.6	Ductile void growth	498
8.6.1	Spherical expansion of a void	500
8.6.2	A more general model	506
8.7	Microcracking and fragmentation	508
8.7.1	Overall energy considerations	509
8.7.2	Time-dependent strength under pulse loading	512
Bibliography		521
Index		559