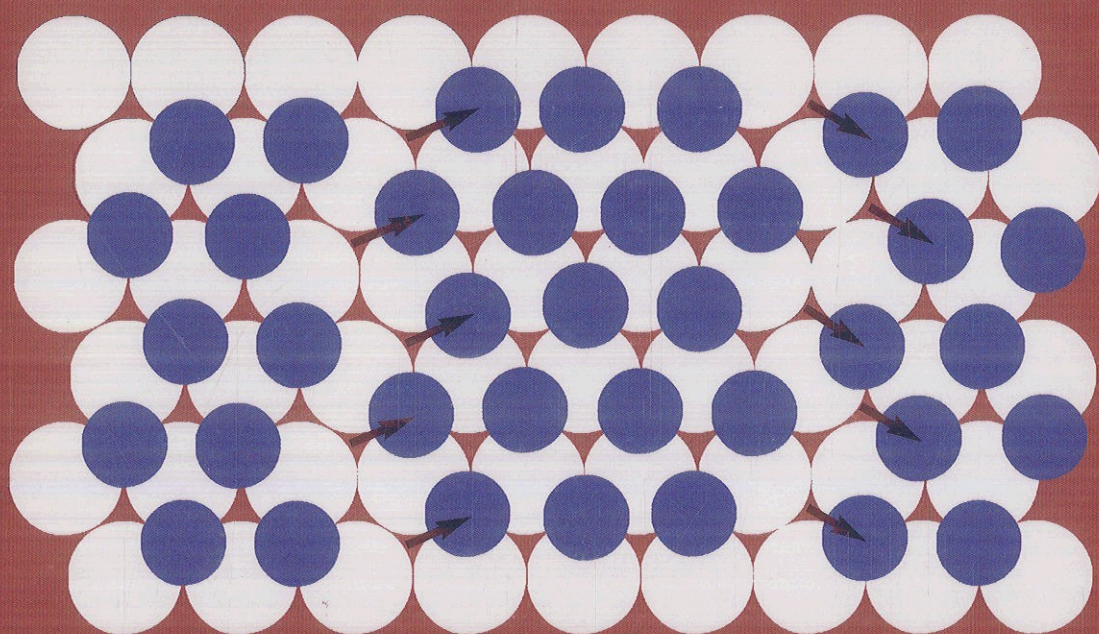


MECHANICAL BEHAVIOR OF MATERIALS

SECOND EDITION



WILLIAM F. HOSFORD

Contents

<i>Preface</i>	<i>page xiii</i>
1 Stress and Strain	1
Introduction	1
Stress	2
Sign Convention	3
Transformation of Axes	4
Principal Stresses	6
Mohr's Stress Circles	6
Strains	9
Small Strains	11
Transformation of Axes	12
Mohr's Strain Circles	13
Force and Moment Balances	14
Boundary Conditions	16
Note	17
Problems	17
2 Elasticity	20
Introduction	20
Isotropic Elasticity	20
Variation of Young's Modulus	22
Isotropic Thermal Expansion	24
Elastic Anisotropy	25
Orientation Dependence of Elastic Response	27
Orientation Dependence in Cubic Crystals	28
Orientation Dependence in Noncubic Crystals	30
Orientation Dependence in Materials Other Than Single Crystals	31
Anisotropic Thermal Expansion	31
References	32
Notes	32
Problems	33

3 Mechanical Testing	36
Introduction	36
Tensile Specimens	36
Stress–Strain Curves	37
Ductility	40
True Stress and Strain	41
The Bridgman Correction	43
Temperature Rise	43
Sheet Anisotropy	44
Measurement of Force and Strain	45
Axial Alignment	46
Special Problems	47
Compression Test	47
Plane–Strain Compression	50
Plane–Strain Tension	51
Biaxial Tension (Hydraulic Bulge Test)	51
Torsion Test	53
Bend Tests	54
Hardness Tests	56
Mutual Indentation Hardness	59
References	60
Notes	60
Problems	61
4 Strain Hardening of Metals	65
Introduction	65
Mathematical Approximations	65
Power Law Approximation	67
Necking	68
Work Per Volume	70
Localization of Strain at Defects	70
Notes	71
Problems	72
5 Plasticity Theory	74
Introduction	74
Yield Criteria	74
Tresca (maximum shear stress criterion)	75
Von Mises Criterion	76
Flow Rules	78
Principle of Normality	79
Effective Stress and Effective Strain	80
Other Isotropic Yield Criteria	82
Anisotropic Plasticity	84
Effect of Strain Hardening on the Yield Locus	86
References	87

Notes	87
Problems	88
6 Strain Rate and Temperature Dependence of Flow Stress	92
Introduction	92
Strain Rate Dependence of Flow Stress	92
Superplasticity	95
Combined Strain and Strain Rate Effects	99
Strain Rate Sensitivity of bcc Metals	100
Temperature Dependence	103
Combined Temperature and Strain Rate Effects	103
Hot Working	108
References	109
Notes	109
Problems	110
7 Slip and Crystallographic Textures	113
Introduction	113
Slip Systems	113
Schmid's Law	113
Strains Produced by Slip	116
Strain Hardening of fcc Single Crystals	117
Tensile Deformation of fcc Crystals	118
Slip in bcc Crystals	120
Slip in hcp Crystals	121
Lattice Rotation in Tension	121
Lattice Rotation in Compression	123
Texture Formation in Polycrystals	124
Approximate Calculations of R Values	125
Deformation of Polycrystals	126
Texture Strengthening	127
Effects of Texture on Microstructure	128
References	132
Notes	132
Problems	133
8 Dislocation Geometry and Energy	137
Introduction	137
Theoretical Strength of Crystals	137
The Nature of Dislocations	139
Burgers Vectors	141
Energy of a Screw Dislocation	142
Reactions between Parallel Dislocations and Frank's Rule	144
Stress Fields around Dislocations	144
Forces on Dislocations	146
Partial Dislocations in fcc Crystals	147
Stacking Faults	149

References	152
Notes	152
Problems	153
9 Dislocation Mechanics	155
Introduction	155
Frank-Read Sources	155
Dislocation Pile-Ups	158
Cross-Slip	158
Dislocation Intersections	159
Climb	163
References	163
Note	163
Problems	164
10 Mechanical Twinning and Martenitic Shear	166
Introduction	166
Formal Notation	167
Twinning Shear	167
Twinning in fcc Metals	169
Twinning in bcc Metals	169
Twinning in hcp Metals	171
Shapes of Twins	173
Mechanism of Twinning	175
Martensite Transformation	178
Shape Memory and Superelasticity	178
References	181
Note	181
Problems	181
11 Hardening Mechanisms in Metals	184
Introduction	184
Crystal Structure	184
Grain Size	184
Strain Hardening	186
Solid Solution Strengthening	187
Dispersion Strengthening	188
Yield Points and Strain Aging	191
Combined Effects	192
References	195
Notes	195
Problems	196
12 Discontinuous and Inhomogeneous Deformation	199
Stick-Slip Phenomena	199
Dynamic Strain Aging	200
Other Causes of Serrated Stress–Strain Curves	205

Strain Localization	205
Reference	206
Notes	206
Problems	206
13 Ductility and Fracture	208
Introduction	208
Ductile Fracture	210
Brittle Fracture	216
Impact Energy	218
References	221
Notes	221
Problems	223
14 Fracture Mechanics	225
Introduction	225
Theoretical Fracture Strength	225
Stress Concentration	227
Griffith Theory	227
Orowan Theory	229
Fracture Modes	229
Irwin's Fracture Analysis	229
Plastic Zone Size	231
Thin Sheets	233
Temperature and Loading Rate	234
Metallurgical Variables	235
Fracture Mechanics in Design	235
Compact Tensile Specimens	236
Strain-Energy Release	237
The J Integral	238
References	240
Notes	240
Problems	241
Appendix. Size and Shape of the Plastic Zone at the Crack Tip	243
15 Viscoelasticity	244
Introduction	244
Rheological Models	244
Series Combination of Spring and Dashpot	245
Parallel Combination of Spring and Dashpot	246
Combined Series Parallel Model	246
More Complex Models	248
Damping	248
Natural Decay	249
Elastic Modulus – Relaxed versus Unrelaxed	250
Thermoelastic Effect	251
Snoek Effect in bcc Metals	253

Other Damping Mechanisms	254
References	255
Notes	255
Problems	256
16 Creep and Stress Rupture	259
Introduction	259
Creep Mechanisms	259
Temperature Dependence of Creep	263
Deformation Mechanism Maps	264
Cavitation	265
Rupture versus Creep	266
Extrapolation Schemes	266
Alloys for High-Temperature Use	269
References	271
Notes	271
Problems	272
17 Fatigue	275
Introduction	275
Surface Observations	275
Nomenclature	276
<i>S-N</i> Curves	278
Effect of Mean Stress	279
The Palmgren-Miner Rule	281
Stress Concentration	282
Surfaces	284
Design Estimates	285
Metallurgical Variables	286
Strains to Failure	286
Crack Propagation	289
Cyclic Stress–Strain Behavior	292
Temperature and Cycling Rate Effects	292
Fatigue of Polymers	295
Fatigue Testing	297
Design Considerations	297
Summary	298
References	298
Notes	298
Problems	299
18 Residual Stresses	302
Introduction	302
Small-Scale Stresses	302
Bauschinger Effect	305
Nonuniform Cooling	306
Nonuniform Material	307

Stresses from Welding	307
Stresses from Mechanical Working	308
Consequences of Residual Stresses	310
Measurement of Residual Stresses	311
Relief of Residual Stresses	313
References	314
Notes	314
Problems	315
19 Ceramics and Glasses	318
Introduction	318
Elastic Properties	318
Slip Systems	319
Hardness	319
Weibull Analysis	321
Testing	322
Porosity	323
High-Temperature Behavior	324
Fracture Toughness	324
Toughening of Ceramics	326
Fatigue	329
Silicate Glasses	329
Strength of Glasses	332
Thermally Induced Stresses	333
Delayed Fracture	334
Glassy Metals	334
References	336
Notes	336
Problems	337
20 Polymers	339
Introduction	339
Elastic Behavior	339
Rubber Elasticity	344
Damping	345
Yielding	347
Effect of Strain Rate	348
Effect of Pressure	350
Crazing	354
Yielding of Fibers in Compression	356
Fracture	356
Deformation Mechanism Maps	357
Shape-Memory Effect	357
References	360
Notes	360
Problems	361

21 Composites	363
Introduction	363
Fiber-Reinforced Composites	363
Elastic Properties of Fiber-Reinforced Composites	363
Strength of Fiber-Reinforced Composites	367
Volume Fraction of Fibers	368
Orientation Dependence of Strength	369
Fiber Length	369
Failure with Discontinuous Fibers	372
Failure under Compression	373
Typical Properties	374
Particulate Composites	375
Brick Wall Model	376
Lamellar Composites	378
Morphology of Foams	379
Mechanical Properties of Foams	379
Metal Foams	379
Flexible Foams – Open Cell	381
Flexible Foams – Closed Cell	381
References	381
Notes	382
Problems	382
22 Mechanical Working	385
Introduction	385
Bulk-Forming Energy Balance	385
Deformation Zone Geometry	389
Friction in Bulk Forming	392
Formability	393
Deep Drawing	394
Stamping	396
References	401
Notes	401
Problems	402
APPENDIX I: Miller Indices	407
APPENDIX II: Stereographic Representation of Orientations	412
<i>Index</i>	415