

Table of Contents

Chapter 1. Introduction	1
Dominique FRANÇOIS	
Chapter 2. Constitutive Equations	5
Jean-Louis CHABOCHE	
2.1. Introduction.	5
2.2. Fundamental concepts	6
2.2.1. Domain of elasticity	6
2.2.2. Hardening	8
2.2.3. Normality rules	11
2.3. Unified theory of viscoplasticity	13
2.3.1. General form of the constitutive law	13
2.3.2. Choice of viscosity law	14
2.3.3. Isotropic hardening laws.	16
2.3.4. Kinematic hardening laws.	18
2.3.5. Cyclic hardening and softening.	20
2.3.6. Static recovery	20
2.3.7. Time-independent limit case	21
2.3.8. Methods of determination	22
2.3.8.1. Determination of hardening laws within independent time-scheme	22
2.3.8.2. Determination of the viscosity law.	23
2.3.8.3. Determination of static recovery effects	24
2.3.9. Other unified approaches	24
2.4. Other types of modeling	25
2.4.1. Plasticity-creep partition.	25
2.4.2. Methods by means of micro-macro transposition	27
2.4.3. More advanced hardening laws.	30
2.4.4. Aging	32

2.4.5. Damage	33
2.5. Conclusion	34
2.6. Bibliography	35
Chapter 3. Measurement of Elastic Constants	41
Pascal GADAUD	
3.1. Elastic constants	42
3.1.1. The perfect crystal – elastic constants	42
3.1.2. Isotropic solid – elastic moduli	44
3.1.3. From isotropic solid to real material	47
3.1.4. Dynamic modulus	48
3.2. Quasi-static mechanical tests	50
3.2.1. Uni-axial tensile and compression tests	51
3.2.2. Torsion and bending tests	52
3.2.3. Hydrostatic compression tests	54
3.3. Ultrasonic methods	55
3.3.1. Principle	55
3.3.2. Measurement error sources	56
3.3.3. Measurements at high temperatures	57
3.3.4. Immersion-bath ultrasound interferometry	59
3.4. Resonant methods	60
3.4.1. Introduction to resonant methods	60
3.4.2. Various experimental methods	60
3.4.3. Bar and disk tests	61
3.4.4. Bending tests on foil	63
3.4.5. Torsion tests	64
3.4.6. Other tests	65
3.5. Modulus measurements of coatings	65
3.5.1. Vibratory methods	66
3.5.2. Instrumented indentation	67
3.6. Bibliography	69
Chapter 4. Tensile and Compression Tests	73
Dominique FRANÇOIS	
4.1. Introduction	73
4.2. Description of the tensile test	73
4.2.1. Test piece	73
4.2.2. Gripping	74
4.2.3. Tensile testing machine	74
4.2.3.1. Arrangements	74
4.2.3.2. Stiffness	76

4.3. Standard data	77
4.4. Determination of constitutive equations	79
4.4.1. True stress and strain	79
4.4.2. Empirical expressions of the work hardening curve	80
4.4.3. Necking.	83
4.4.3.1. Condition with no strain rate effect	83
4.4.3.2. Strain rate sensitivity.	84
4.4.3.3. Yield drops.	85
4.5. Damage determination	85
4.6. Compression test.	87
4.7. Conclusion	87
4.8. Notations	88
4.9. Bibliography	88
Chapter 5. Hardness Tests	89
Sylvie POMMIER	
5.1. Introduction.	89
5.2. Standard hardness tests	90
5.2.1. Vickers hardness tests	91
5.2.2. Micro-hardness	92
5.2.3. Nano-hardness (Berkovich type indenter)	92
5.2.4. Brinell and Rockwell ball tests	93
5.3. Analytical approaches of hardness tests	96
5.3.1. Identification of the modulus of elasticity (Hertz contact).	96
5.3.2. Identification of the yield strength (Hill's analysis).	100
5.4. Finite element analysis of hardness test	103
5.4.1. Finite element method	103
5.4.2. Effect of work-hardening amplitude.	105
5.4.3. Effect of the type of hardening	106
5.4.4. Pile-up method	107
5.4.5. Viscous material	109
5.4.6. Porous materials	110
5.4.7. Films and surface coatings	111
5.4.8. Measurement of fracture toughness of brittle materials	112
5.5. Conclusion	112
5.6. Appendices	113
5.6.1. Appendix 1: formulary (Hertz contact)	113
5.6.2. Appendix 2: slip line method (Hill)	118
5.6.3. Appendix 3: equivalences between tensile and hardness tests.	121
5.7. Bibliography	121

Chapter 6. Fatigue Tests	125
Henri-Paul LIEURADE, Suzanne DEGALLAIX, Gérard DEGALLAIX and Jean-Pierre GAUTHIER	
6.1. Principles	125
6.1.1. Definition	125
6.1.2. Objective of fatigue tests	126
6.1.3. Classification of fatigue tests	127
6.1.4. Classification of loading modes	127
6.1.5. Test pieces	128
6.1.5.1. Shape	128
6.1.5.2. Dimensions	128
6.1.5.3. Machining of test pieces	128
6.1.6. Calibration of testing machines	130
6.1.6.1. Definition of a dynamometric bar	130
6.1.6.2. Determination of cyclic loads	130
6.1.6.3. Dynamic calibration of testing machines by axial load	130
6.2. High-cycle fatigue tests – endurance limit	131
6.2.1. Classification of loadings	131
6.2.2. Stress-number of cycles to failure curve (Wöhler curve)	132
6.2.3. Nature and dispersion of fatigue test results	133
6.2.4. Determination of endurance limit of metallic materials	135
6.2.4.1. Estimation of fatigue resistance, σ_D	135
6.2.4.2. Statistical methods	135
6.2.5. Expression of the S-N curve	139
6.2.6. Estimation of the number of cycles N_{50} by the Henry straight line method	140
6.2.6.1. Field of application	140
6.2.6.2. Principle of the method	140
6.2.6.3. Implementation of the method	141
6.2.7. Accounting for the main parameters of influence	141
6.2.7.1. Mechanical parameters	141
6.2.7.2. Geometric parameters	144
6.2.7.3. Parameters of material processing	146
6.2.7.4. Environmental parameters	146
6.2.8. Examination of the fracture facies of the test pieces	146
6.3. Low-cycle fatigue tests	147
6.3.1. Introduction	147
6.3.2. Physical mechanisms of low-cycle fatigue	149
6.3.3. Methods for low-cycle fatigue tests	152
6.3.4. Experimental apparatus	153
6.3.4.1. Machines	153
6.3.4.2. Test pieces	154

6.3.4.3. Instrumentation	154
6.3.5. Data processing	156
6.3.5.1. Stress response: cyclic hardening/softening curves	156
6.3.5.2. Stress-strain hysteresis loops	163
6.3.5.3. Resistance to low-cycle fatigue curves	165
6.3.6. Ratcheting effect	167
6.4. Measurement of the crack propagation rate in fatigue	168
6.4.1. Introduction	168
6.4.1.1. Fatigue crack initiation and propagation	168
6.4.1.2. Recalling the notion of plastic zone at the crack tip.	170
6.4.1.3. The Paris law	171
6.4.1.4. Crack closure phenomenon	172
6.4.2. Implementation of crack propagation rate measurements	173
6.4.2.1. Principle of the test.	173
6.4.2.2. Test pieces	174
6.4.2.3. Equipment	176
6.4.2.4. Performing the test	183
6.4.2.5. Processing and presentation of results.	185
6.4.2.6. Main information to deliver after the test.	188
6.4.3. Other types of tests	188
6.4.3.1. Devices for testing outside ambient environment	188
6.4.3.2. Variable loading tests	188
6.4.3.3. Tests on non-metallic materials	188
6.5. Bibliography	189
Chapter 7. Impact Tests	193
Jean-Michel FRUND	
7.1. Introduction.	193
7.2. Some history	193
7.3. Description of the impact test	194
7.3.1. Test piece	194
7.3.2. Charpy impact pendulum	196
7.3.3. Charpy instrumented impact pendulum	196
7.3.3.1. Measurement of the load	196
7.3.3.2. Measurement of the displacement	197
7.3.3.3. Different time-displacement curves	198
7.3.3.4. Determinations of the characteristic values of the load.	198
7.3.3.5. Determination of the global fracture energy	198
7.3.3.6. Determination of the percentage of brittle appearance from the load-time curve	200
7.4. Determination of transition curves	200

7.5. Transition temperature and upper shelf	201
7.6. Impact fracture energy-fracture toughness empirical correlations	202
7.7. Bibliography	205
Chapter 8. Fracture Toughness Measurement	207
Dominique FRANÇOIS	
8.1. Introduction.	207
8.2. Fracture mechanics bases.	209
8.2.1. Rice Cherepanov J integral	209
8.2.2. Stress intensity factor K	210
8.2.3. Plastic zone at the crack tip	211
8.2.3.1. Plastic zone correction	211
8.2.3.2. Plane stress plastic zone	212
8.2.3.3. Plane strain plastic zone	213
8.3. Implementation of fracture toughness tests	213
8.3.1. Test pieces	213
8.3.2. Data processing	215
8.3.3. Validity of measurements	216
8.4. Measurement of fracture toughness J_{Ic}	217
8.4.1. Basis of elastoplastic fracture mechanics	217
8.4.2. J_{Ic} testing	217
8.4.2.1. Interrupted loadings method	218
8.4.2.2. Partial unloading method	218
8.4.2.3. Potential drop method	219
8.4.2.4. Other methods	219
8.4.2.5. Crack tip blunting	219
8.4.3. Data processing	219
8.4.4. Conditions of validity	220
8.5. CTOD measurement	221
8.6. Conclusion	221
8.7. Notations	222
8.8. Bibliography	222
Chapter 9. Dynamic Tests	225
Jean-Luc LATAILLADE	
9.1. Introduction.	225
9.2. Test methods relying on propagation techniques and on the Hopkinson bar	226
9.2.1. Compression device and uni-dimensional theory	228
9.2.1.1. Radial inertia	229
9.2.1.2. Calculation of applied load and of displacement	230
9.2.1.3. Dynamic compression Hopkinson test	231

9.2.2. Torsion with Hopkinson bars	246
9.2.2.1. Overall considerations	246
9.2.2.2. Case of very ductile materials	249
9.2.3. Tension with Hopkinson bars	251
9.2.3.1. Low resistance specimen adaptation.	251
9.2.3.2. Adaptation of a tensile test bench line for interrupted tests	255
9.2.3.3. Brittle material case: alternatives.	256
9.2.4. Taylor test	258
9.2.4.1. Overall considerations	258
9.2.4.2. Principle	259
9.3. Dynamic fracture mechanics tests	259
9.3.1. Introduction	259
9.3.2. Charpy test analysis according to the Kishimoto method	260
9.3.3. Charpy test with Hopkinson bars.	262
9.4. Plate against plate test.	264
9.4.1. Principle	264
9.4.1.1. Traveling diagram	265
9.4.1.2. Rankine-Hugoniot conservation equation	267
9.4.1.3. Lagrangian analysis	270
9.4.1.4. Application to the characterization of an elastomer.	271
9.5. Collision tests	277
9.5.1. Inertia wheel instrumented impacting device	277
9.5.1.1. Overall considerations	277
9.5.1.2. Discussion and application to an adhesive joint	278
9.5.1.3. Application to an adhesive joint	281
9.5.2. Drop weight tests	284
9.5.2.1. Introduction: the critical mass-velocity couple	284
9.6. Bibliography	289
Chapter 10. Notched Axi-symmetric Test Pieces	293
Jacques BESSON	
10.1. Introduction	293
10.2. Geometry and notations.	294
10.3. Notch test piece testing	296
10.3.1. Mechanical test	296
10.3.2. Observation of damage.	297
10.4. Specimen elastic analysis.	297
10.5. Plastic analysis of specimens.	299
10.5.1. Bridgman analysis.	299
10.5.2. Finite element analysis.	303
10.5.3. Small deformations analysis.	304

10.5.4. Large deformations analysis	305
10.5.4.1. Necked tensile specimen	305
10.5.4.2. AE_{χ} specimens	305
10.5.4.3. Plastic anisotropy	306
10.6. Damage analysis	308
10.6.1. Case study: brittle fracture	310
10.6.2. Case study: uncoupled ductile fracture	313
10.6.3. Case study: coupled ductile fracture	316
10.7. Viscoplasticity and creep damage	319
10.8. From notch to crack?	320
10.9. Bibliography	321
List of Authors	325
Index	327