

## Table of Contents

<b>Preface</b> . . . . .	xiii
<b>Chapter 1. An Introduction to Failure Mechanisms and Ultrasonic Inspection</b> . . . . .	1
Kumar V. JATA, Tribikram KUNDU and Triplicane A. PARTHASARATHY	
1.1. Introduction. . . . .	1
1.2. Issues in connecting failure mechanism, NDE and SHM . . . . .	2
1.3. Physics of failure of metals . . . . .	4
1.3.1. High level classification . . . . .	4
1.3.1.1. Deformation . . . . .	5
1.3.1.2. Fracture. . . . .	5
1.3.1.3. Dynamic fatigue . . . . .	6
1.3.1.4. Material loss . . . . .	7
1.3.2. Second level classification . . . . .	7
1.3.2.1. Deformation due to yield . . . . .	7
1.3.2.2. Creep deformation and rupture . . . . .	9
1.3.2.3. Static fracture . . . . .	12
1.3.2.4. Fatigue . . . . .	13
1.3.2.5. Corrosion. . . . .	18
1.3.2.6. Oxidation. . . . .	20
1.4. Physics of failure of ceramic matrix composites . . . . .	21
1.4.1. Fracture. . . . .	23
1.4.1.1. Mechanical loads and fatigue. . . . .	23
1.4.1.2. Thermal gradients. . . . .	24
1.4.1.3. Microstructural degradation. . . . .	25
1.4.2. Material loss . . . . .	25
1.5. Physics of failure and NDE . . . . .	26

1.6. Elastic waves for NDE and SHM . . . . .	26
1.6.1. Ultrasonic waves used for SHM . . . . .	26
1.6.1.1. Bulk waves: longitudinal and shear waves . . . . .	27
1.6.1.2. Guided waves: Rayleigh and Lamb waves, bar, plate and cylindrical guided waves . . . . .	28
1.6.2. Active and passive ultrasonic inspection techniques . . . . .	30
1.6.3. Transmitter-receiver arrangements for ultrasonic inspection . . . . .	30
1.6.4. Different types of ultrasonic scanning. . . . .	31
1.6.5. Guided wave inspection technique. . . . .	32
1.6.5.1. One transmitter and one receiver arrangement. . . . .	32
1.6.5.2. One transmitter and multiple receivers arrangement . . . . .	35
1.6.5.3. Multiple transmitters and multiple receivers arrangement . . . . .	36
1.6.6. Advanced techniques in ultrasonic NDE/SHM . . . . .	36
1.6.6.1. Lazer ultrasonics . . . . .	36
1.6.6.2. Measuring material non-linearity . . . . .	37
1.7. Conclusion . . . . .	38
1.8. Bibliography . . . . .	38
<b>Chapter 2. Health Monitoring of Composite Structures Using Ultrasonic Guided Waves</b> . . . . .	43
Sauvik BANERJEE, Fabrizio RICCI, Frank SHIH and Ajit MAL	
2.1. Introduction. . . . .	43
2.2. Guided (Lamb) wave propagation in plates . . . . .	46
2.2.1. Lamb waves in thin plates. . . . .	51
2.2.2. Lamb waves in thick plates . . . . .	55
2.3. Passive ultrasonic monitoring and characterization of low velocity impact damage in composite plates . . . . .	60
2.3.1. Experimental set-up . . . . .	60
2.3.2. Impact-acoustic emission test on a cross-ply composite plate. . . . .	64
2.3.3. Impact test on a stringer stiffened composite panel . . . . .	71
2.4. Autonomous active damage monitoring in composite plates. . . . .	75
2.4.1. The damage index . . . . .	76
2.4.2. Applications of the damage index approach . . . . .	77
2.5. Conclusion . . . . .	85
2.6. Bibliography . . . . .	86
<b>Chapter 3. Ultrasonic Measurement of Micro-acoustic Properties of the Biological Soft Materials</b> . . . . .	89
Yoshifumi SAIJO	
3.1. Introduction. . . . .	89
3.2. Materials and methods . . . . .	91

3.2.1. Acoustic microscopy between 100 and 200 MHz . . . . .	91
3.2.2. Sound speed acoustic microscopy . . . . .	95
3.2.3. Acoustic microscopy at 1.1 GHz . . . . .	98
3.3. Results . . . . .	99
3.3.1. Gastric cancer . . . . .	99
3.3.2. Renal cell carcinoma . . . . .	103
3.3.3. Myocardial infarction . . . . .	104
3.3.4. Heart transplantation . . . . .	106
3.3.5. Atherosclerosis . . . . .	107
3.4. Conclusion . . . . .	112
3.5. Bibliography . . . . .	112
<b>Chapter 4. Corrosion and Erosion Monitoring of Pipes by an Ultrasonic Guided Wave Method . . . . .</b>	<b>115</b>
Geir INSTANES, Mads TOPPE, Balachander LAKSHMINARAYAN, and Peter B. NAGY	
4.1. Introduction . . . . .	115
4.2. Ultrasonic guided wave monitoring of average wall thickness in pipes . . . . .	118
4.2.1. Guided wave inspection with dispersive Lamb-type guided modes . . . . .	119
4.2.2. Averaging in CGV inspection . . . . .	123
4.2.3. The influence of gating, true phase angle. . . . .	129
4.2.4. Temperature influence on CGV guided wave inspection . . . . .	132
4.2.5. Inversion of the average wall thickness in CGV guided wave inspection. . . . .	134
4.2.6. Additional miscellaneous effects in CGV guided wave inspection. . . . .	136
4.2.6.1. Fluid loading effects on CGV inspection . . . . .	136
4.2.6.2. Surface roughness effects on CGV inspection . . . . .	139
4.2.6.3. Pipe curvature effects on CGV inspection . . . . .	141
4.3. Experimental validation . . . . .	145
4.3.1. Laboratory tests . . . . .	145
4.3.2. Field tests . . . . .	151
4.4. Conclusion . . . . .	153
4.5. Bibliography . . . . .	155
<b>Chapter 5. Modeling of the Ultrasonic Field of Two Transducers Immersed in a Homogenous Fluid Using the Distributed Point Source Method . . . . .</b>	<b>159</b>
Rais AHMAD, Tribikram KUNDU and Dominique PLACKO	
5.1. Introduction. . . . .	159
5.2. Theory . . . . .	160

5.2.1. Planar transducer modeling by the distribution of point source method . . . . .	160
5.2.2. Computation of ultrasonic field in a homogenous fluid using DPSM. . . . .	161
5.2.3. Matrix formulation . . . . .	163
5.2.4. Modeling of ultrasonic field in a homogenous fluid in the presence of a solid scatterer . . . . .	165
5.2.5. Interaction between two transducers in a homogenous fluid . . . . .	169
5.3. Numerical results and discussion . . . . .	171
5.3.1. Interaction between two parallel transducers. . . . .	172
5.3.2. Interaction between an inclined and a flat transducer. . . . .	184
5.3.3. Interaction between two inclined transducers . . . . .	185
5.4. Conclusion . . . . .	186
5.5. Acknowledgments. . . . .	186
5.6. Bibliography . . . . .	187
<b>Chapter 6. Ultrasonic Scattering in Textured Polycrystalline Materials . .</b>	<b>189</b>
Liyong YANG, Goutam GHOSHAL and Joseph A. TURNER	
6.1. Introduction. . . . .	189
6.2. Preliminary elastodynamics . . . . .	191
6.2.1. Ensemble average response . . . . .	191
6.2.2. Spatial correlation function . . . . .	195
6.3. Cubic crystallites with orthorhombic texture . . . . .	197
6.3.1. Orientation distribution function . . . . .	197
6.3.2. Effective elastic stiffness for rolling texture . . . . .	199
6.3.3. Christoffel equation . . . . .	201
6.3.4. Wave velocity and polarization. . . . .	202
6.3.5. Phase velocity during annealing . . . . .	207
6.3.6. Attenuation . . . . .	210
6.4. Attenuation in hexagonal polycrystals with texture . . . . .	215
6.4.1. Effective elastic stiffness for fiber texture . . . . .	216
6.4.2. Attenuation . . . . .	220
6.4.3. Numerical simulation . . . . .	223
6.5. Diffuse backscatter in hexagonal polycrystals . . . . .	229
6.6. Conclusion . . . . .	232
6.7. Acknowledgments. . . . .	233
6.8. Bibliography . . . . .	233

<b>Chapter 7. Embedded Ultrasonic NDE with Piezoelectric Wafer Active Sensors</b> . . . . .	237
Victor GIURGIUTIU	
7.1. Introduction to piezoelectric wafer active sensors . . . . .	237
7.2. Guided-wave ultrasonic NDE and damage identification . . . . .	240
7.3. PWAS ultrasonic transducers . . . . .	242
7.4. Shear layer interaction between PWAS and structure . . . . .	244
7.5. Tuned excitation of Lamb modes with PWAS transducers . . . . .	246
7.6. PWAS phased arrays . . . . .	249
7.7. Electromechanical impedance method for damage identification . . . . .	255
7.8. Damage identification in aging aircraft panels . . . . .	258
7.8.1. Classification of crack damage in the PWAS near-field . . . . .	259
7.8.2. Classification of crack damage in the PWAS medium-field . . . . .	260
7.8.2.1. Impact detection with piezoelectric wafer active sensors . . . . .	263
7.8.2.2. Acoustic emission detection with piezoelectric wafer active sensors . . . . .	266
7.9. PWAS Rayleigh waves NDE in rail tracks . . . . .	268
7.10. Conclusion . . . . .	268
7.11. Acknowledgments . . . . .	269
7.12. Bibliography . . . . .	269
<b>Chapter 8. Mechanics Aspects of Non-linear Acoustic Signal Modulation due to Crack Damage</b> . . . . .	273
Hwai-Chung WU and Kraig WARNEMUENDE	
8.1. Introduction. . . . .	273
8.1.1. Passive modulation spectrum . . . . .	274
8.1.2. Active wave modulation. . . . .	275
8.2. Damage in concrete . . . . .	275
8.3. Stress wave modulation. . . . .	280
8.3.1. Material non-linearity in concrete . . . . .	281
8.3.2. Generation of non-linearity at crack interfaces . . . . .	282
8.3.3. Unbonded planar crack interface in semi-infinite elastic media. . . . .	289
8.3.4. Unbonded planar crack interface with multiple wave interaction. . . . .	295
8.3.5. Plane crack with traction . . . . .	301
8.3.6. Rough crack interface . . . . .	307
8.4. Summary and conclusion. . . . .	314
8.5. Bibliography . . . . .	315

<b>Chapter 9. Non-contact Mechanical Characterization and Testing of Drug Tablets</b> . . . . .	319
Cetin CETINKAYA, Ilgaz AKSELI, Girindra N. MANI, Christopher F. LIBORDI and Ivin VARGHESE	
9.1. Introduction. . . . .	319
9.2. Drug tablet testing for mechanical properties and defects . . . . .	321
9.2.1. Drug tablet as a composite structure: structure of a typical drug tablet . . . . .	321
9.2.2. Basic manufacturing techniques: cores and coating layers. . . . .	322
9.2.3. Tablet coating . . . . .	323
9.2.4. Types and classifications of defects in tablets . . . . .	325
9.2.5. Standard tablet testing methods . . . . .	327
9.2.6. Review of other works. . . . .	330
9.3. Non-contact excitation and detection of vibrational modes of drug tablets. . . . .	332
9.3.1. Air-coupled excitation via transducers . . . . .	334
9.3.2. LIP excitation via a pulsed lazer . . . . .	336
9.3.3. Vibration plate excitation using direct pulsed lazer irradiation . . . . .	338
9.3.4. Contact ultrasonic measurements . . . . .	340
9.4. Mechanical quality monitoring and characterization . . . . .	341
9.4.1. Basics of tablet integrity monitoring. . . . .	341
9.4.2. Mechanical characterization of drug tablet materials . . . . .	356
9.4.3. Numerical schemes for mechanical property determination. . . . .	361
9.5. Conclusions, comments and discussions. . . . .	365
9.6. Acknowledgments. . . . .	367
9.7. Bibliography . . . . .	367
 <b>Chapter 10. Split Hopkinson Bars for Dynamic Structural Testing</b> . . . . .	 371
Chul Jin SYN and Weinong W. CHEN	
10.1. Introduction . . . . .	371
10.2. Split Hopkinson bars . . . . .	372
10.3. Using bar waves to determine fracture toughness . . . . .	374
10.4. Determination of dynamic biaxial flexural strength . . . . .	380
10.5. Dynamic response of micromachined structures . . . . .	381
10.6. Conclusion . . . . .	383
10.7. Bibliography . . . . .	384
 <b>List of Authors</b> . . . . .	 387
 <b>Index</b> . . . . .	 391