

Contents

- Abstract 3
- Acronyms 5
- 1 Introduction 9
 - 1.1 Short overview of available methods for surface treatment evaluation 10
 - 1.1.1 Existing procedures: production, destructive and laboratory methods 11
 - 1.1.2 Development of the in-situ NDT methods 11
 - 1.1.3 Comparison of the methods and objectives of current work 14
 - 1.2 Ultrasonic testing: an overview 16
 - 1.2.1 Conventional ultrasonic testing 16
 - 1.2.2 Nonlinear UT measurements 18
 - 1.2.3 Existing limitations and challenges 21
- 2 Theoretical Framework: elements of the theory of elasticity 23
 - 2.1 Linear model (Elastic moduli, infinitesimal displacements, plastic deformation region) 23
 - 2.2 Elastic waves in isotropic solids 25
 - 2.2.1 Bulk waves 25
 - 2.2.2 Surface acoustic waves (Rayleigh waves) 25
 - 2.3 Reflection and refraction of elastic waves 26
 - 2.4 Nonlinear theory of elasticity: account of third-order terms 29
 - 2.5 Acoustoelastic effect 30
 - 2.5.1 BW AEC 30
 - 2.5.2 RW AEC definitions and calculation from TOEC 31
 - 2.6 Rayleigh wave velocity dispersion inversion for stress measurement 31
 - 2.7 Nonlinear interaction of elastic waves in solids 32
- 3 Methodology 39
 - 3.1 AEC measurements 39
 - 3.1.1 TOEC/BW AEC measurements using contact ultrasonic measurements 40
 - 3.1.2 RW AEC measurements using laser interferometry 41
 - 3.2 Immersed measurements of RW dispersion using the ultrasonic goniometer HUGO 42
 - 3.3 Design of in-situ method of nonlinear elastic parameters estimation 43
 - 3.4 Algorithms 49
 - 3.4.1 Automated strain extraction from raw extension data 49
 - 3.4.2 Comparison of the group velocity evaluation methods for the BW AEC measurements 50
 - 3.4.3 Group velocity evaluation using the iterative algorithm for the low SNR data 54
 - 3.4.4 Phase velocity extraction 55

3.4.5	Multidimensional phase unwrapping and wave vectors/phase velocity extraction	59
3.4.6	Extraction of the radiation direction of elastic wave and its polarisation for sparse multidimensional data	66
3.4.7	Local scattering efficiency by perturbation theory for wide-band primary pulses	68
3.5	Supplementary study of applicability of contactless laser ultrasonics	69
4	Results	71
4.1	Third-Order Elastic Constant (TOEC) values for relevant superalloys	71
4.2	RW AEC values for relevant superalloys	72
4.3	Rayleigh wave dispersion measurements	74
4.4	Nonlinear interaction of elastic waves and its potential for AEC estimation	75
4.4.1	Perturbation model	75
4.4.2	Experimental results	77
4.4.3	Extraction of propagation direction and dominant polarization from multidimensional data	79
4.4.4	Sensitivity of local scattering efficiency to TOEC variation	79
5	Discussion	81
5.1	Key parameters for the accuracy of the BW AEC and RW AEC measurements	81
5.2	Nonlinear interaction of Rayleigh waves as a prospective in-situ method for evaluation of surface layer nonlinear elastic constants	82
5.3	Design of future setups for AEC determination	83
6	Conclusion	87
7	References	89
8	Appendix	99
8.1	Calculation of bulk waves acoustoelastic constants	99
8.2	Algebraic expressions for RW AEC mapping from BW measurements	100
8.3	Parameters of Rayleigh wave dispersion inversion	100
8.4	Polarization restrictions for nonlinear bulk wave interactions	101
8.5	Ordinary least squares fit	102
8.6	Supplementary graphics of perturbation model simulation results	103
	List of publications	112