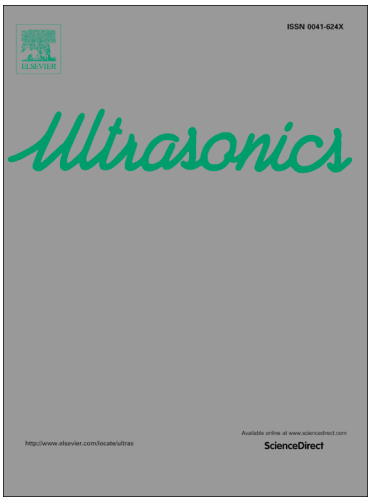

Nonlinear effects of micro-cracks on long-wavelength symmetric Lamb waves

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Nonlinear effects of micro-cracks on long-wavelength symmetric Lamb waves

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Abstract

For an elastic medium containing a homogeneous distribution of micro-cracks, an effective one-dimensional stress-strain relation has been determined with finite element simulations. In addition to flat micro-cracks, voids were considered that contain a Hertzian contact, which represents an example for micro-cracks with internal structure. The orientation of both types of micro-cracks was fully aligned or, for flat micro-cracks, totally random. For micro-cracks with Hertzian contacts, the case of random orientation was treated in an approximate way. The two types of defects were found to give rise to different degrees of non-analytic behavior of the effective stress-strain relation, which governs the nonlinear propagation of symmetric (S0) Lamb waves in the long-wavelength limit. The presence of flat micro-cracks causes even harmonics to grow linearly with propagation distance with amplitudes proportional to the amplitude of the fundamental wave, and gives rise to a static strain. The presence of the second type of defects leads to a linear growth of all harmonics with amplitudes proportional to the square of the fundamental amplitude, and to a strain-dependent velocity shift. Simple expressions are given for the growth rates of higher harmonics of S0 Lamb waves in terms of the parameters occurring in the effective stress-strain relation. They have partly been determined quantitatively with the help of the FEM results for different micro-crack concentrations.

Keywords: micro-cracks, effective material properties, FEM, penny-shaped cracks, Hertzian contact, nonlinear ultrasound, harmonic generation, perturbation theory, non- destructive evaluation, Lamb waves

1. Introduction

Nonlinear phenomena of acoustic waves can be efficiently applied to the detection of pre-fatigue in an early stage. In this context, guided waves, especially Rayleigh and Lamb waves, have moved more and more into the focus [1]. In

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