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Surface Acoustic Wave-based Characterization of Randomly Distributed Surface Cracks

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Abstract

In this paper we present an approach to characterize surface breaking cracks by analayzing propagation of surface acoustic waves. We generate surface acoustic waves with plane wave fronts using a line-focused pulsed-laser to study scattering of SAWs on surface microcracks. A homogenized behavior of the randomly scattered and interferometrically detected field, i.e. the coherent waveform, is gained by spatially averaging the measurements. The data is studied in the time and frequency domain. The experimental results show the attenuation of the coherent SAWs due to scattering and the strongly distorted shape indicates the presence of dispersion. These parameters can be used to characterize the density and depth distribution of the cracks.

Keywords: Surface Acoustic Waves; Surface Crack; Homogeneous Medium; dispersion

1. Introduction

The characterization of surface cracks by elastic waves is of significant practical interest in the quality control of steel products (where non–destructive testing methods are applicable). In an ideal elastic material surface acoustic waves (SAWs) propagate without geometrical damping along a free surface [Achenbach (1999); Landau and Lifschitz (1987)]. Theoretical treatments for one crack, i. e. the determination of the scattered wave for a given crack geometry and the incident wave, are well known [Achenbach et al. (1980)]. To treat this problem one needs to solve semi–analytically singular integral equations, and an extension to multiple cracks seems to be not a straightforward task. Generally spoken the modeling of SAW–scattering becomes involved due to the fact that the wave propagates along a boundary, whereas a stress–singularity exists at the crack tip. So different models are elaborated and numerically implemented. A 2D/3D finite element method to model single scatterer embedded in a homogeneous medium are investigated [Wilcox and Velichko (2010)]. This approach is related to the scattering matrix (S–matrix) theory, where S connects linearly the incident and the scattered wave fields in the far–field limit [Velichko and Wilcox (2010)]. To

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our knowledge a theoretical description of SAW–scattering in inhomogeneous media (e.g. coated steel plates) up to now is missing completely.

An effective medium approach replaces the cracked region by a material with different elastic properties [Pecorari (1998); Pinfield and Challis (2011); Pinfield et al. (2011); Pinfield and Challis (2012); Saenger (2008)]. The difficulties of the true scattering problem for many cracks with different depths and relative orientations obviously does not vanish but are shifted to the computation of the effective elastic modules [for a comparison of effective medium approaches in suspensions and bubble swarms in liquids see Dubois et al. (2011)]. An experimentally application of the effective medium approach for a uniform distribution of cracks was already investigated by Burke et al. (1994).

2. Problem statement

The main objective of our work is to characterize mean depth and density distributions of surface breaking cracks as they exist in steel samples.

For theoretical descriptions, we consider a half-space with homogeneously distributed surface-breaking cracks. The cracks are perpendicular to the traction-free surface and arise between the grains, i.e. the cracks are randomly orientated. The number of surface-breaking cracks per unit free surface area is denoted by n. The velocity and attenuation of surface waves depend on n and also on the depth of the cracks. Therefore, it should be possible to correlate these parameters and consequently relate ultrasonic surface-wave measurements with crack distribution characteristics.

We recall the classical theoretical approach [see Achenbach (1999)] relating the usual features of surface-wave propagation such as the coefficient $\alpha(\omega)$ of attenuation of the Rayleigh wave to the parameters defining the distribution of the surface-breaking cracks. The dispersion of the Rayleigh wave can be described using the complex wave number

$$k_R = \omega/c_R(\omega) + i\alpha(\omega), \tag{1}$$

where $c_R(\omega)$ is the phase velocity. The incident Rayleigh wave propagating along the surface is reflected by the cracks causing multiple scattering. Accordingly the power flow of the incident wave along the surface is reduced by wave scattering. The intensity of the incident wave is diminished and accordingly its amplitude decreases by propagating through the cracked zone.

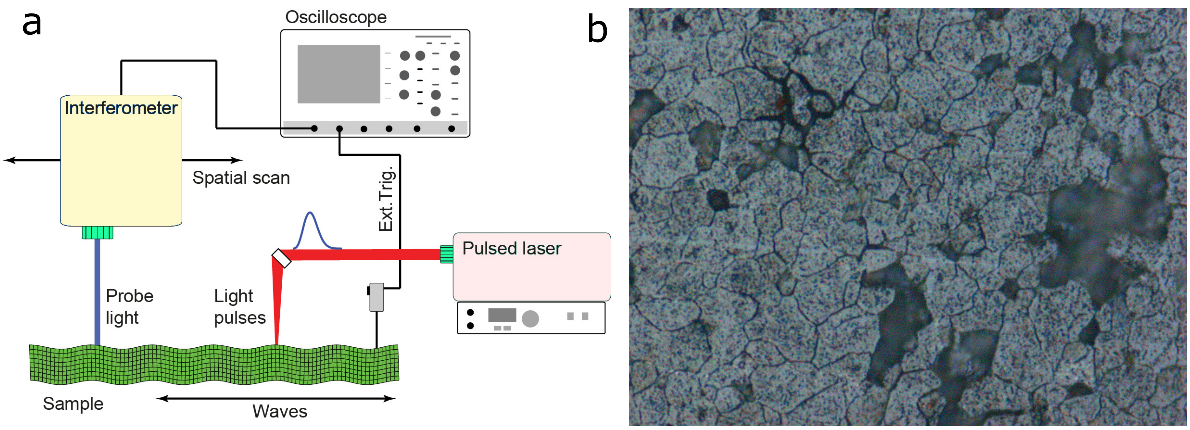

Fig. 1. (a) Experimental setup consisting of a pulsed excitation laser, line focused with a cylindrical lens, an interferometric detection unit and an oscilloscope for measurement data recording, triggered by a photo diode (b) Micrograph showing the grain structure of a typical sample