RAYLEIGH WAVE VELOCITY MAPPING USING SCANNING ACOUSTIC MICROSCOPE

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INTRODUCTION

In a Scanning Acoustic Microscope (SAM) amplitude of focused acoustic beam reflected by a sample is utilized to produce acoustic images and to measure local elastic property for effective nondestructive characterization of materials. The most important acoustic rays involved in both imaging and quantitative measurements in an acoustic lens are shown in Fig. 1. The extra contribution to the reflected signal from the Rayleigh waves generated at the interface between water and the sample surface enhances the contrast in acoustic images. Amplitude acoustic images produced at a defocus are very effective in revealing the microstructure structure, surface and near surface defects, flaws, micro cracks etc. On the other hand an interference between the direct reflected ray (PO) and the Rayleigh ray (AB-BC-DE-EF) [see Fig.1] produces a V(z) curve which displays periodic minima as the distance between the lens and the sample is varied. The periodicity in the V(z) curve is directly related to the Rayleigh wave velocity. This makes an acoustic microscope a quantitative tool for measurement of local elastic property. Several methodologies have been developed to analyze the V(z) curve to obtain high accuracy in the measurement of Rayleigh wave velocity. A computationally intensive procedure with additional experimental data on a sample that doesn’t support Rayleigh waves has been utilized to analyze the V(z) curves by Kushibiki et al.[1] to measure the Rayleigh wave velocity with an accuracy of 1 part in 10^4 m/s. Although this tedious and time consuming procedure is very useful for high accuracy single location measurements, time necessary to produce an image of the variation Rayleigh wave velocity over an area becomes forbiddingly too large.

An alternative methodology is to utilize a measurement of difference in propagation time between the direct reflected signal and the Rayleigh wave signal[2,3,4,5,6,7]. This procedure can not be implemented in SAM working with tone bust signals because the width of the burst will encompass both the direct and Rayleigh wave signal, more over only in this situation V(z) curve can be generated. On the other hand many of the commercial acoustic microscopes that operate in the frequency range of 10 to 100 MHz utilize impulse excitation. Since the impulses have a very narrow width it is possible to separate in time domain the direct reflected signal and the Rayleigh wave signal. In this case the Rayleigh wave velocity can be determined by measuring the time separation between the two signals as a function of defocus. Though several researchers
Fig. 1. Acoustic rays in an acoustic lens involved in the Rayleigh wave velocity measurements (Rayleigh ray - AB-BC-DE-EF and Direct ray - PO).

Fig. 2. Description of Rayleigh wave velocity measurement using time difference.
have utilized this approach to measure Rayleigh wave velocity the accuracy and precession of the method has not been analyzed. Moreover to extend the technique for mapping the Rayleigh wave velocity, performing measurements at several defocuses to determine the velocity can increase the time. For this purpose we have adopted a method of measuring at two convenient defocuses to determine the Rayleigh wave velocity. Results of measurements at a single location and over an area on an isotropic sample has been used for analyzing the precession and accuracy of the velocity measurements. Images of the Rayleigh wave velocity in samples of Ti-6Al-4V obtained using this methodology are presented.

EXPERIMENTAL METHODOLOGY

The High Precision Scanning Acoustic Microscope used for Rayleigh wave velocity measurements has been described in the literature [8]. Essentially the difference between the commercial acoustic microscopes and HIPSAM is the capability to acquire the full digitized wave form of the reflected signal from the sample and utilization of software gating of the important portion of the wave form. In all the measurements presented here a spherical focus lens (Panametrics, Model No V3330. Nominal frequency: 50 MHz ) has been used. The transducer is excited by an impulse from a Panametrics pulser (Model 5900 PR) and the digitized wave form is acquired at a defocus \(z_1 = 400 \text{ } \mu\text{m}\). Using software gating option the peak position of the direct reflected signal (\(t_{w1}\)) and the Rayleigh wave signal (\(t_{R1}\)) are detected [ See Fig.2] and stored in the computer. The lens is further defocused to \(z_2= 900 \text{ } \mu\text{m}\) and the procedure is repeated to obtain \(t_{w2}\) and \(t_{R2}\). The Rayleigh wave velocity is computed using the equation (1)

\[
V_R = \frac{2 (z_1 \cdot z_2)}{[(t_{w1} - t_{w2})^2 - (t_{R1} - t_{R2})^2]^{1/2}}
\]

At each defocus the wave form is averaged several times and the measurement of the timings are also repeated to increase the accuracy in the measurement of timings. A detailed description of the methodology can be found in Martin et al[9].

MEASUREMENTS ON STANDARD SAMPLE

To analyze the precision and accuracy of the Rayleigh wave velocity measurements using HIPSAM two types of measurements were performed on an elastically isotropic sample of E6 glass ( Dia. 50 mm and thickness 25 mm). Measurements of Rayleigh wave velocity at a single location were performed one hundred times to check the repeatability, and the results are shown in Fig.3. The average Rayleigh wave velocity for a single location is \((3038 \pm 5) \text{ } \text{m/s}\). Fig 4 shows the variation in the Rayleigh wave velocity measured over an area of 2mm x 2mm. The average velocity over this area is \((3039 \pm 5) \text{ } \text{m/s}\). These measurements is in good agreement with the Rayleigh wave velocity \((3026 \pm 0.25)\) determined from experimentally measured longitudinal and shear wave velocities on the same sample as reported by Sathish et al.[10]. Hence, the Rayleigh wave velocity measurement has an accuracy and precision of better than 0.5%. The measurement over an area has a low background and hence variations higher than 0.5% can be mapped to produce an image.
Fig 3. Rayleigh wave velocity measurement at a single location on E6 glass sample.

Fig. 4. Rayleigh wave velocity variation in E6 glass. Area: 2mmx2mm, (100x100) Points

RAYLEIGH WAVE VELOCITY MAPPING IN Ti-6Al-4V SAMPLES

Plastically Deformed Region

When a material is plastically deformed a small change in elastic constants is observed. Hence this should lead to changes in the Rayleigh wave velocity. Utilization of an acoustic microscope to measure and map the variation in local regions will be useful for characterizing elastic properties near crack tips, welded regions etc. To test the feasibility Rayleigh wave velocity has been measured in a plastically deformed region in a sample. The sample is a disc of Ti-6Al-4V (Dia. 50mm and thickness 5mm), into this a radial notch (15 mm long) was created. A wedge was forced into the notch until the region around the tip of the notch was plastically deformed. The sample along with the wedge was metallographically polished (3μm) to remove surface topography developed during the forcing of the wedge and to obtain a flat specimen. Rayleigh wave velocity measurements were performed in an area (5mmx5mm) covering the plastically deformed region near the tip of the notch. An image is shown in Fig.5 which clearly shows about 2% increase in Rayleigh wave velocity in the plastically deformed region.
Colonies in Textured Samples

During the processing of Ti-6Al-4V texture is formed. In this microstructure, groups of grains with similar crystallographic orientation “colonies” will be observed together. Although this can be observed optically and the crystallographic orientation can be determined using Electron Back Scatter Pattern (EBSP) it is difficult to identify the differences in their elastic properties. This information can be readily obtained by performing a mapping of the Rayleigh wave velocity. For this purpose a sample was metallographically polished and the Rayleigh wave velocity measurements were

Fig 5. Rayleigh wave velocity variation in the plastically deformed zone.

Fig 6. Rayleigh wave velocity variation in colonies in a sample of Ti-6Al-4V.
performed over an area of 3 mm x 3mm. An image of the Rayleigh wave velocity variation is shown in Fig 4. The groups of grains with similar crystallographic orientation can be observed and the differences in the velocities can be measured.

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