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Subharmonic Phased Array for Crack Evaluation Using Refraction and/or Mode Conversion at an Interface

界面での屈折・モード変換を用いたき裂評価のための分調波フェーズドアレイ

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1. Introduction

Accurate measurement of crack depth and length is required for the evaluation of structures. For the crack depth measurement from the anti-crack opening side, we have developed an imaging method, subharmonic phased array for crack evaluation using bulk wave (Bulk SPACE).[1)] For the crack length measurement from the crack opening side, focusing of surface acoustic wave (SAW) using an array transducer is promising. Thus far, the generation and detection of SAW by an array transducer through a wedge was proposed,[2,3)] where a surface defect was detected with a high sensitivity by using time reversal process. However, imaging and/or nonlinear ultrasound has not been realized. In this study, we propose SPACE using SAW (SAW SPACE) to measure closed crack length. We formulate delay law considering refraction and/or mode conversion at the interface, and demonstrate its performance in a closed-crack specimen.

2. Principle of SAW SPACE

Figure 1 shows an implementation of SAW SPACE. An array transducer is used for transmission and reception. SAW is focused from the array transducer through a wedge with a critical angle of Rayleigh wave, following the delay law formulated based on Fermat's principle. By large-amplitude incident SAW, linear and nonlinear scattering occurs at the open and closed parts of a crack, respectively. After filtering the received signals at the fundamental and subharmonic frequencies, they are shift-summed to create fundamental array (FA) and subharmonic array (SA) images. This process is repeated for multiple transmission focal points (TFPs) and thereafter the images in the vicinity of TFPs are merged to image cracks over a large area. As an option, the interaction between SAW and crack can be directly observed using a laser interferometer, because SAW propagates on the free surface.

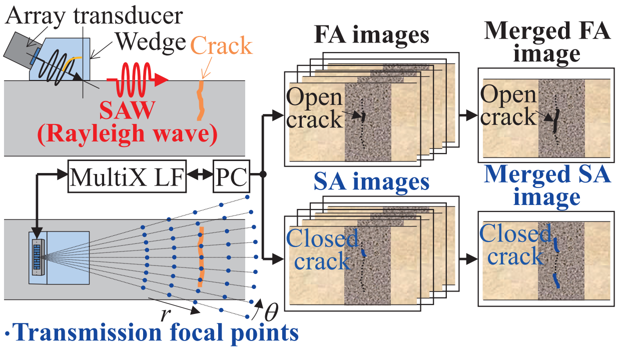

Fig. 1. Implementation of SAW SPACE.

3. Formulation of delay law

Figure 2 shows coordinates to formulate a delay law. Assuming that a longitudinal wave velocity in the wedge and a Rayleigh wave velocity are V_{W} and V_{R}, respectively, propagation time from the n th element $\mathbf{r}_{\mathrm{E}}$ to the TFP $\mathbf{r}_{\mathrm{F}}$ is given by

$$\tau(n) = |\mathbf{r}_{\mathrm{E}} - \mathbf{r}_{\mathrm{I}}|/V_{\mathrm{W}} + |\mathbf{r}_{\mathrm{I}} - \mathbf{r}_{\mathrm{F}}|/V_{\mathrm{R}}\ , \tag{1}$$

where an incident point $\mathbf{r}_{\mathrm{I}}$ is determined by minimizing the propagation time $\tau(n)$ based on Fermat's principle. Propagation time difference $\Delta\tau(n)$ between the 1st and the nth elements is given by

$$\Delta\tau(n) = \tau(n) - \tau(1)\ . \tag{2}$$

The delay law is used to focus SAW at each TFP. FA and SA images are created by applying a delay law similar to eq. (1), where the TFP $\mathbf{r}_{\mathrm{F}}$ is replaced by the position vector $\mathbf{r}(x, y)$ of each pixel.

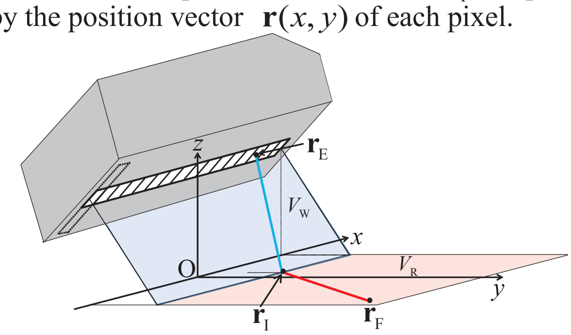

Fig. 2. Coordinates to formulate a delay law.

4. Experimental conditions

We used an aluminum-alloy (A7075) fatigue crack specimen[1] (K_{max}=5.3, K_{min}=0.6 MPa·m$^{1/2}$) and a stainless-steel (SUS304) stress corrosion crack (SCC) specimen[4]. The measurement configurations are shown in Fig. 3. PZT array transducer (5 MHz, 32 el.) was excited by 3-cycle burst wave with 2 MHz and 150 V. TFPs were selected to be 60 points (θ=−29°～30° with a step of 1°, r =42.6 mm).

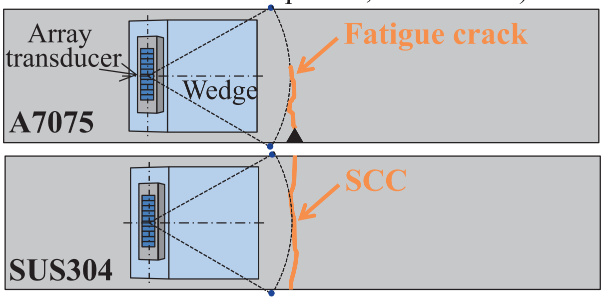

Fig. 3. Measurement configurations.

5. Experimental results

Figure 4 shows the imaging results of the fatigue crack. The fatigue crack was imaged as bright spots in FA (a) and SA (b) images. In particular, the response at the crack tip was strong in the SA image. This suggests that crack tip was closed. The crack lengths measured in both images were almost the same as the true ones.

Figure 5 shows the imaging results of the SCC. The SCC was imaged in a different distribution in FA (a) and SA (b) images. Scattering at grain boundary was also imaged in the FA image. The crack lengths measured in both images were almost the same as the true ones. Thus it was verified that SAW SPACE is useful in measuring closed crack length and distribution of the open and closed parts.

Furthermore, we directly observed the interaction between SAW and the cracks by measuring the waveforms with a scanning laser interferometer (Fig. 6). As a result, the reflected wave from the fatigue crack and several scattered waves at the SCC were observed. The transmission coefficient of SAW was higher in the fatigue crack than in the SCC. This suggests the difference in crack closure.

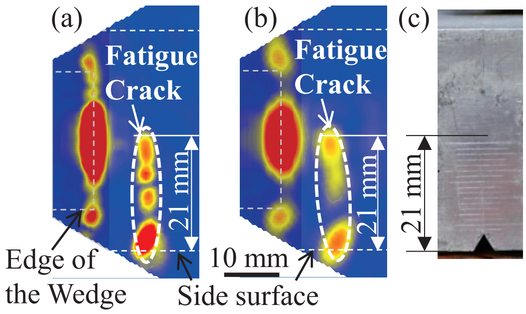

Fig. 4. Imaging results of fatigue crack: (a) FA and (b) SA images, (c) photograph.

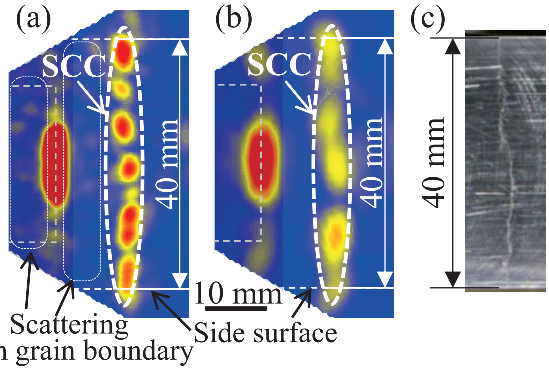

Fig. 5. Imaging results of SCC: (a) FA and (b) SA images, (c) photograph.

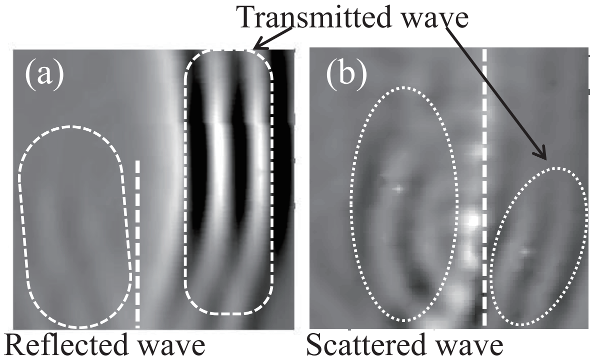

Fig. 6. Visualization of the interaction between SAW and cracks: (a) fatigue crack, (b) SCC.

6. Conclusions

We proposed SAW SPACE to measure closed crack length. A delay law considering refraction and/or mode conversion at the interface was formulated. By applying it, a fatigue crack and SCC were imaged and their length was correctly measured. Furthermore, the scattering/reflection behaviors and the difference in transmission were observed by a scanning laser interferometer. This is useful in understanding the interaction between SAW and cracks.

By replacing the wedge with water, an immersion SAW SPACE is realized with improved flexibility, which will be included in the poster.

References

1) Y. Ohara, T. Mihara, R. Sasaki, T. Ogata, S. Yamamoto, Y. Kishimoto, and K. Yamanaka: Appl. Phys. Lett. **90** (2007) 011902.
2) R. K. Ing, M. Fink, and O. Casula: Appl. Phys. Lett. **68** (1996) 161.
3) W. A. K. Deutsch, A. Cheng, and J. D. Achenbach: Res. Nondestr. Eval. **9** (1997) 81.
4) Y. Ohara, S. Horinouchi, Y. Shintaku, R. Shibasaki, Y. Yamaguchi, M. Tagami, and K. Yamanaka: Hihakai Kensa **60** (2011) 658 [in Japanese].