1P2-12

Imaging of Branched Stress Corrosion Cracks by Subharmonic Phased Array for Crack Evaluation (SPACE)

サブハーモニック超音波フェーズドアレイ SPACE による枝分かれ応力腐食割れの映像化

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1. Introduction

To measure closed cracks, we have developed a novel imaging method, subharmonic phased array for crack evaluation (SPACE),[1,2] which uses a lithium niobate transmitter for large-amplitude incidence required for subharmonic generation and an array receiver for imaging. Furhermore, we proposed a confocal SPACE approach[3] with a single array transducer for both transmissions and receptions, where the large-amplitude incidence is realized by focusing. As an option of confocal SPACE, a radarlike display that predominately shows the information along the beam direction was also proposed. This is useful in precise investigations of scattering behaviors. However, the confocal SPACE has yet to demonstrate the capablity to image a complexly branched SCC, which is considered to be a critical issue in aging nulcear power plants.

In this study, we formed a complexly branched SCC in an acceleration method[2], and applied the confocal SPACE to image the SCC specimen to demonstrate its usefulness.

2. Confocal SPACE

A schematic of the confocal SPACE is shown in **Fig. 1**. It can define multiple transmission focal points (TFPs) at multiple angles θ and distances r. To focus ultrasound at each TFP, an array transducer is excited with appropriate delay laws. After receiving the scattered waves using the array, they are filtered at fundamental and subharmonic frequencies, respectively. Subsequently, by focusing on receptions, agian with the appropriate delay laws, single-focus fundamental array (FA) and subharmonic array (SA) images are created. Open and closed cracks are imaged in the single-focus FA and SA images, respectively.

For the observation of linear and nonlinear scattering behaviors, a radarlike display was introduced. It is a display method that shows single-focus images of different incidence angles with a line indicating the incidence direction. The linear and nonlinear scattering behaviors can be observed in details by arranging some still images or displaying these images successively as a movie like a radar.

Furthermore, the single-focus FA and SA images in the vicinity of TFPs are merged into one image; thereby, merged FA and SA images are obtained. Thus, cracks over the entire region of interest can be visualized in these merged images.

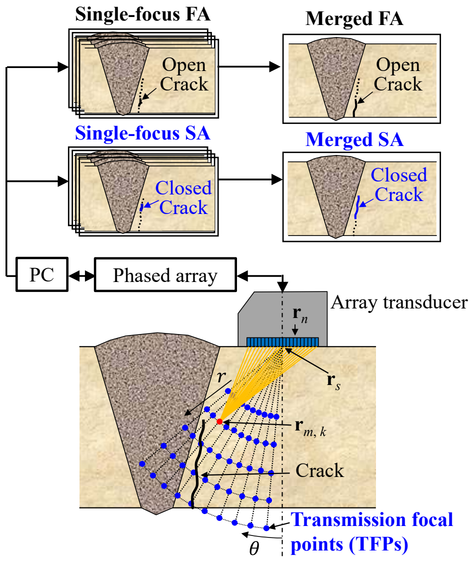

Fig. 1 Schematic illustration of confocal SPACE.

3. Experimental conditions

We formed a complexly branched SCC in a sensitized austenitic stainless-steel (SUS304 sensitized at 600 ℃ for 4 h) specimen in an acceleration method.[2] The SCC was extended from the tip of a deep fatigue crack. The corrosive environment was a solution of 30 wt % $MgCl_2$ at 90℃, [2] and a nominal bending stress of 124 MPa was applied to the crack for 1800 h. Note that the time for the SCC extension was selected to be longer than Ref. 2).

The experimental configuration is shown in **Fig. 2**. The PZT array transducer (Imasonic) used has 128 elements with a center frequency of 5 MHz. Considering the directivity of scattering waves, the central 64 elements of the array were used for

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receptions, whereas the full aperture (128 elements) was used for transmissions to increase the incidence amplitude. The array was driven by an open phase array research platform (Verasonics). The excitation voltage was three-cycle burst with 7 MHz and 150 V. To image the SCC precisely, we selected TFPs with $\theta = -20 \sim 20°$ ($0.5°$ step) and $r = 24 \sim 30$ mm (0.5 mm).

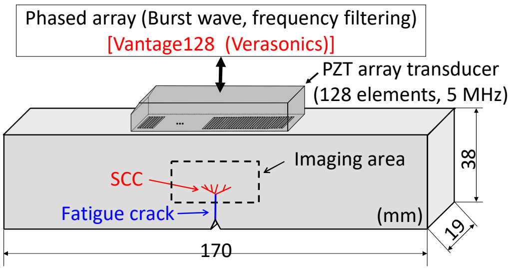

Fig. 2 Experimental configuration.

4. Experimental results

To investigate the change in linear and nonlinear scattering behaviors at the branched SCC, the radarlike display of single-focus FA and SA images with different incidence angles are shown in **Fig. 3**. For $\theta = 5°$, a strong response appeared in the single-focus FA image, whereas the response was weak in the single-focus SA image. For $\theta = 0°$, multiple strong responses showed up aside the incident angle in the FA image, whereas only a single strong response was seen in the SA image right along the incident angle. For $\theta = -6°$, strong responses appeared at the different depths along the incident direction in the FA and SA images.

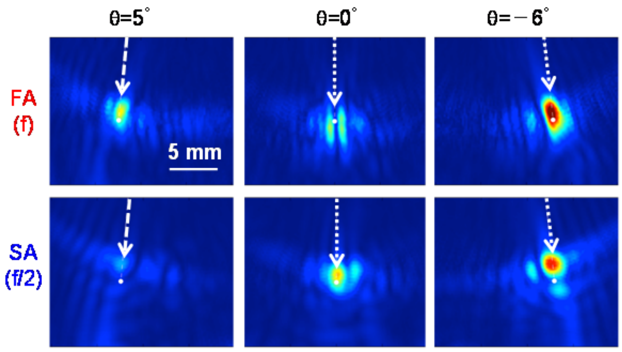

Fig. 3 Radarlike display of the branched SCC.

To image the SCC over a wide area, merged FA and SA images were created on the basis of single-focus FA and SA images, as shown in **Figs. 4(a) and 4(b)**, respectively. In the merged FA and SA image, multiple linear and nonlinear responses, showing open and closed parts, respectively, were imaged over a wider area than the single-focus images. To precisely examine those responses, the merged FA and SA images were superimposed (**Fig. 4(c)**). As a result, it turned out that the linear and nonlinear responses appeared at different positions. Note that the nonlinear responses were deeper than the linear responses. This is useful in terms of accurate crack depth measurement.

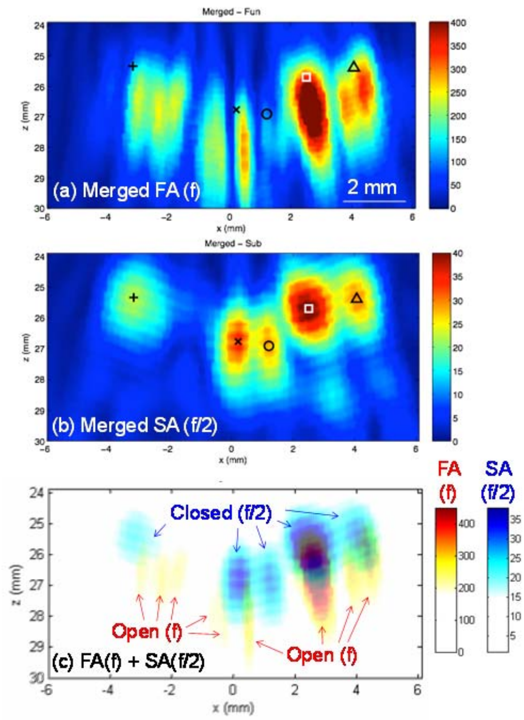

Fig. 4 Merged images of the branched SCC.

5. Conclusions

We applied confocal SPACE to the complexly branched SCC formed in the acceleration method. In the radalike display, various linear and nonlinear scattering behaviors were observed in detail. In the merged images, the open and closed parts of branched SCC were successfully visualized. These results suggest that confocal SPACE is useful not only in accurate crack depth measurement but also in optimizing inspection condtions and contributing to the progress of fracture mechanics and corrosion engineering.

Acknowledgment

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References

1. Y. Ohara, T. Mihara, R. Sasaki, T. Ogata, S. Yamamoto, Y. Kisihimoto and K. Yamanaka: Appl. Phys. Lett. **90** (2007) 011902.
2. Y. Ohara, H. Endo, T. Mihara and K. Yamanaka: Jpn. J. Appl. Phys. **48** (2009) 07GD01.
3. A. Sugawara, K. Jinno, Y. Ohara and K. Yamanaka: Jpn. J. Appl. Phys. **54** (2015) 07HC08.