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Evaluation of Closed Stress Corrosion Cracks in Nickel Based Alloy Weld Metal Using Subharmonic Phased Array

Ni 基合金溶接金属中の閉口応力腐食割れの
サブハーモニック超音波フェーズドアレイによる評価

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1. Introduction

Ultrasonic inspection of stress corrosion cracks (SCCs) in Ni-based alloy weld metal (NBAWM) of nuclear power plants is difficult because of crack closure. For the application of new inspection methods to solve this problem and training/educating of workers for inspection, realistic closed SCC specimens similar to those in actual atomic power plants are required. SCCs similarly to that in actual plants can be generated in high temperature pressurized water (HTPW). However, the method requires several years[1,2]. On the other hand, an acceleration method which uses chemical solution requires only several months. However, the SCCs are open[3,4].

Here, we form a closed SCC in NBAWM by combining chemical solution and HTPW. Then, we evaluate the SCC using subharmonic phased array for crack evaluation (SPACE).[5,6]

2. Single array SPACE

A schematic illustration of single array SPACE is shown in **Fig. 1**. By inputting a focused ultrasound from a PZT array transducer, the scatterings of fundamental and subharmonic waves occur at the open and closed parts of cracks, respectively. The scattered waves are received by the same array and digitally filtered at fundamental and subharmonic frequencies. They are then summed after a shift following the delay law. Finally, the root-mean-square (RMS) value is calculated as the intensity at each imaging point. Fundamental array (FA) and subharmonic array (SA) images can indicate the open and closed parts of a crack, respectively.

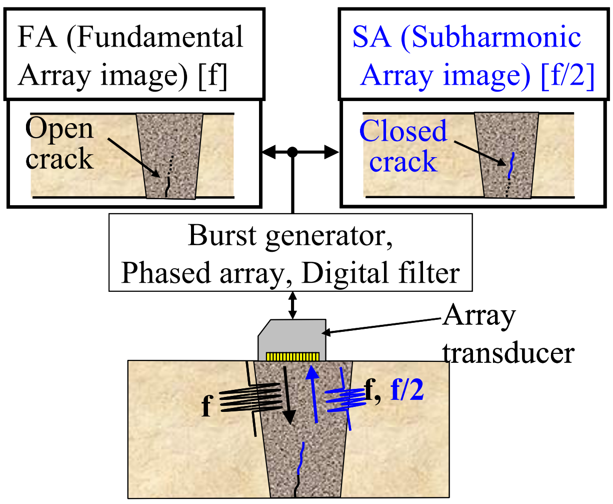

Fig. 1 Schematic of single array SPACE.

3. Fabrication of specimen

Fabrication process of specimen is shown in **Fig. 2**. The first step is to weld AISI 316L stainless steel plates with NBAWM, which is commercially available as Alloy 600 (Fig. 2(a)). The NBAWM was then partly bored by electric discharge machining (EDM), and the bored part was molded with a Ni-based alloy of higher carbon content for an easier SCC extension. A starting notch was fabricated in the molded part. Then, the SCC was extended from the notch in $K_2S_4O_6$ solution at room temperature under thermal tensile stress, which was applied by cooling after welding a thermally expanded specimen into a fixed jig, as shown in (b). It took a few weeks to form an SCC of about 9 mm depth.

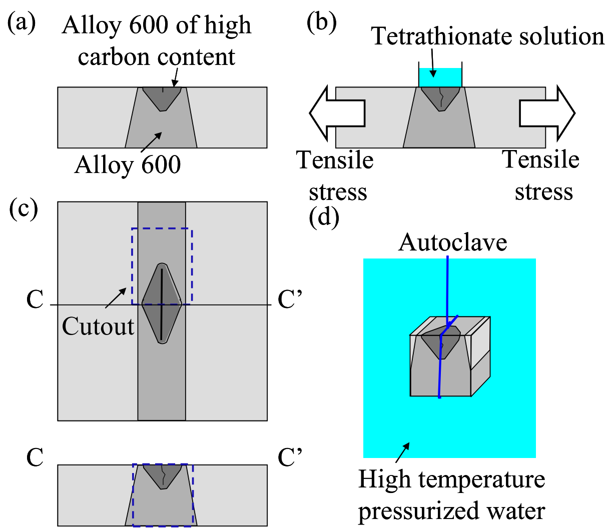

Fig. 2 Fabrication process of specimen.

To close the SCC by filling oxide films between crack faces, the SCC specimen was immersed in HTPW in an autoclave at 288 °C for 1321 h, as shown in (d). Here, to effectively interpenetrate not only the root but also the tip with the HTPW, the specimen was cut at the center in the length direction, as shown in (c).

4. Experimental Results

We selected the array position by mechanical scan to image crack tip, as shown in **Fig. 3(a)**. Here, the input wave emitted from a PZT array transducer with 16 element of 0.5 mm pitch was 3-cycle burst waves with a center frequency of 7 MHz. The exciting voltage was 150 V. As a result, the SCC was not visualized in the FA image (Fig. 3(b)) because of strong linear scattering at the coarse grains. In contrast, in the SA image (Fig. 3(c)), the crack tip was imaged at 11 mm depth. This shows that the part of the SCC was closed by the generation of the oxide film between crack faces, and the contact vibration occurred at the interface of oxide films.

To confirm the subharmonic generation, we performed frequency analyses of shift-summation waveforms at points A and B of Fig. 3. As shown in **Fig. 4 (a)**, the shift-summation waveform at A was not distorted. Subharmonic component was not observed in power spectrum (b) and wavelet analysis (c). This is reasonable because the response at A is linear scattering at coarse grain. On the other hand, the shift-summation waveform at B in (d) was distorted. Subharmonic component separated from fundamental component was observed in power spectrum (e) and wavelet analysis (f). Thus, we confirmed the subharmonic generation at closed SCC.

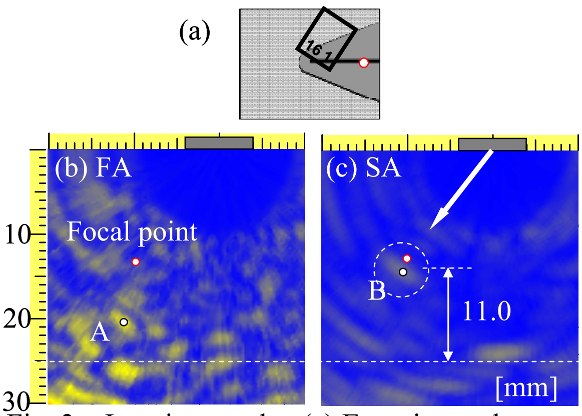

Fig. 3 Imaging results: (a) Experimental configuration, (b) FA image, (c) SA image.

5. Discussion

Oxide film generation between crack faces in Alloy 600 in HTPW has yet to be reported. However, an oxide film growth on external surface of Alloy 182 was reported[7]. This shows that the thickness of oxide film was more than 150 nm for immersion time similar to that of this study. Interestingly, the thickness is almost the same in the order of magnitude as that of incident waves. This suggests that oxide film generation between crack faces in HTPW is useful for fabrication of closed SCCs.

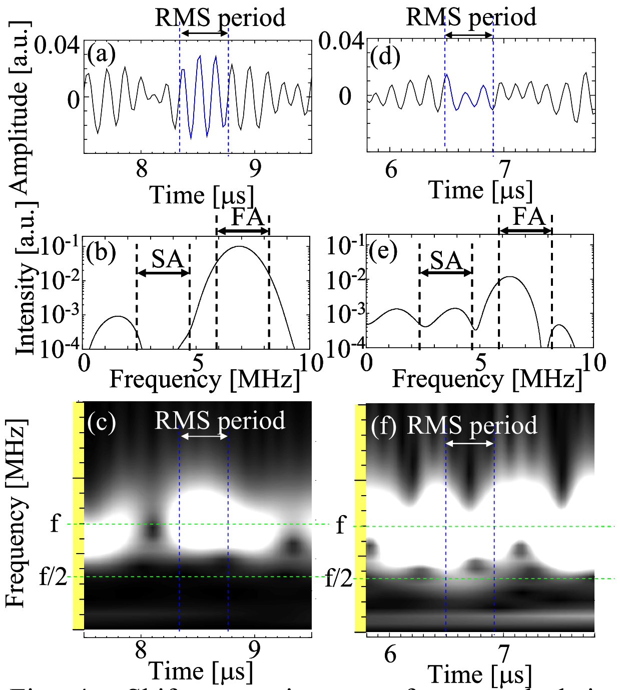

Fig. 4 Shift-summation waveforms and their frequency analyses: (a) and (d) Shift-summation waveforms, (b) and (e) Power spectrum, (c) and (f) Wavelet analysis at A and B, respectively.

6. Conclusion

We fabricated a SCC specimen by combining chemical solution and HTPW. Then, we evaluated the SCC by single array SPACE, and found that the SCC was closed. The result will significantly contribute to the improvement of nondestructive evaluation methods and the training/education of workers for inspection.

Acknowledgment

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