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Nonlinear Ultrasonic Imaging of Closed Cracks by Load Difference Phased Array with Global Pre-Heating and Local Cooling

全体加熱・局所冷却による荷重差分を用いた閉じたき裂の非線形超音波映像法

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1. Introduction

The crack closure causes the underestimation and missdetection Thus far, we have developed a closed-crack imaging method, subharmonic phased array for crack evaluation (SPACE), on the basis of subharmonic waves and phased array technique with frequency filtering.[1)] However, since SPACE used short-burst input waves to attain high temporal resoultion, strong linear scatterers such as back surfaces appeared in the subharmonic images as filtering leakage.[1)] To solve this problem, we proposed a load difference phased array (LDPA), which is based on the subtraction between PA images at different loads. The principle of LDPA was verified in the fundamental experiment by using a servohydraulic testing machine.[2)] However, the servohydraulic testing machine is not practical because of its big size and heavy weight.

On the other hand, the method for opening cracks by thermal stress was proposed.[3,4)] In this method, the specimen is locally cooled to generate the temperature gradient. This results in tensile thermal stress. However, the tensile thermal stress cannot be controlled since the cooling temperature is fixed by the cooling medium.

Here, we propose the LDPA with global pre-heating and local cooling which can control the tensile thermal stress, and verify it in a closed fatigue crack specimen.

2. Principle of LDPA with Global Pre-Heating and Local Cooling

The schematics of LDPA with global pre-heating and local cooling is illustrated in Fig. 1. Here, we assume that the crack with closed tip around the weld with a weld defect is imaged by linear phased array (PA). After global pre-heating, the open crack, the back surface and the weld defect are imaged in PA image [Fig. 1(a)], whereas the closed crack is not imaged because the ultrasound is transparent through the closed tip. Then, the top surface of specimen is locally cooled by cooling spray such as air duster, which can ideally cool the specimen until -55°C. The vicinity of top surface is contracted, and thereby, the tensile thermal stress is applied to the closed crack on the similar principle as three-point bending test. Here, the tensile thermal stress applied can be controled by varying the temperature of global pre-heating since the tensile thermal stress depends on the temperature gradient between the top surface and the crack area. In this way, the crack tip becomes open, and thereby, the crack tip is imaged in the PA image [Fig. 1(b)], whereas the other linear scatterers are not changed. Therefore, by subtracting the PA images before and after the onset of local cooling, only the crack can be extracted with canceling the other linear scatterers, as illustrated in Fig. 1(c).

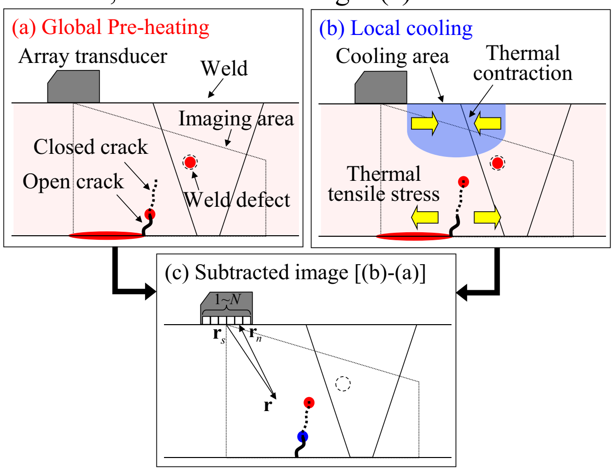

Fig. 1 Principle of LDPA with global pre-heating and local cooling.

3. Experimental Conditions

The closed fatigue crack specimen made of an aluminum alloy A7075 (Fig. 2) was used.[5)] The tensile thermal stress applied to the crack depends on the temprature gradient and cooling area. Here, the temperature of global pre-heating was selected to be 50°C. The part of top surface illustrated in the top of Fig. 2 was cooled by the two cooling spray (HFC-125a) during 15 s. During the local cooling, the crack was monitored by PA with a PZT array transducer (5 MHz, 32 elements) and input pulse wave with high temporal resolution.

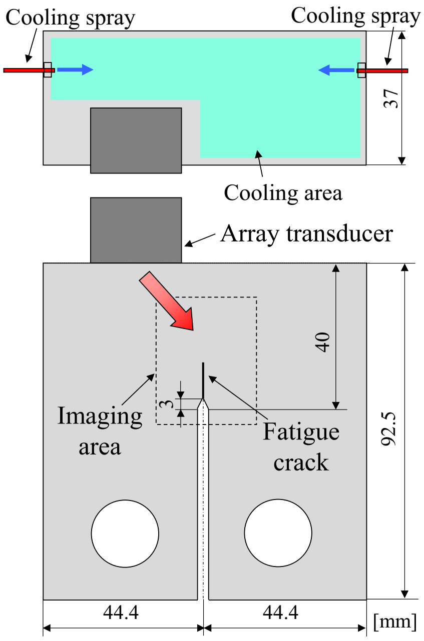

Fig. 2 Experimental configuration.

4. Experimental Results

The PA images before and after the onset of local cooling are shown in Fig. 3. The crack was not imaged in Fig. 3(a) before local cooling. This shows that the crack was closed. After the onset of local cooling, the crack appeared in the PA images. The maximum crack depth was 11.3 mm in Fig. 3(c) at 4 s after the onset of local cooling. This is the same as the true crack depth which was confirmed in the preliminary test by a servohydraulic testing machine. On the other hand, the crack depth was 9.6 mm in a conventional way[4] where the specimen was cooled from room temperature by the cooling spray. This shows that the tensile stress was insufficient to open the closed crack only by local cooling and the combination of global pre-heating and local cooling is effective in opening the tightly closed crack. Then, as the cooling time progressed from 4 s, the crack appeared at shallower part. Finally, it diminished in Fig. 3(e) at 15 s. This is because the tensile thermal stress was decreased since the temperature distribution gradually became uniform. This also shows that the short cooling time of approximately 4 s is sufficient in this specimen.

To extract only the crack response, the LDPA was applied to Figs. 3(c) and 3(a). In the subtracted image [Fig. 3(f)], the tip and root of crack was successfully extracted with canceling the strong linear scatterer such as the left edge of notch. Here, the selectivity is defined by the intensity ratio between a closed crack and a linear scatterer.[2] We assumed the other linear scatterer to be the left edge of notch, which is independent of crack opening/closing behavior. As a result, the selectivity was enhanced by 27.5dB by LDPA.

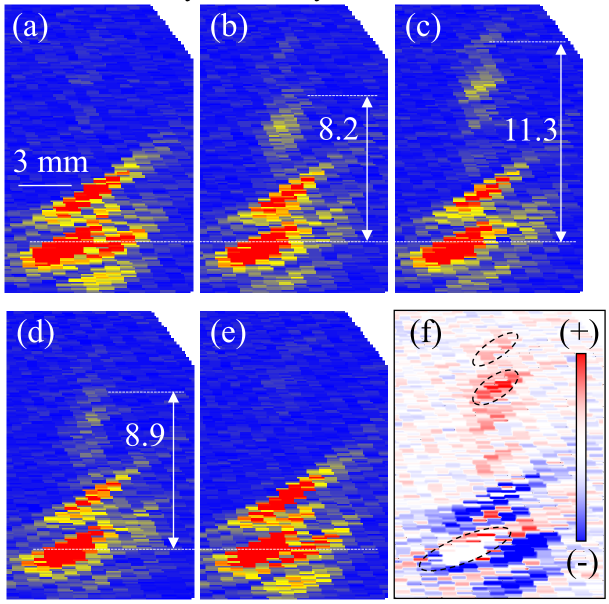

Fig. 3. Snapshots of PA images with global pre-heating (50℃) and local cooling: (a) PA image before cooling, (b), (c), (d), and (e) PA images at 2 s, 4 s, 10 s, and 15 s after the onset of local cooling, (f) Subtracted image.

5. Conclusions

We proposed a practical closed-crack imaging method with high selectivity and high resolution, load difference phased array (LDPA) with global pre-heating and local cooling. The method was verified in a closed fatigue crack specimen. This method would enable us to estimate the crack closure stress by combining the numerical analysis of thermal stress.

Acknowledgment

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