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Higher Harmonic Imaging of Crack Tip Plastic Zone
疲労き裂先端塑性域の高調波画像化

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1. Introduction

Crack growth in ductile metals is accompanied by local plastic zone in front of the crack tip. The size of the crack tip plastic zone and plastic strain magnitude are measure of material degradation.

Applicable NDE (Nondestructive Evaluation) techniques for fatigue cracks are summarized in **Fig. 1**[1)], where Meyendorf et al. say that the nonlinear acoustic/ultrasonic techniques is most promising for detection of fatigue damage in early stage.

The present authors have reported that small non-metallic inclusions, which could be nuclei of micro cracks or micro voids preceding fatigue crack, can be visualized by immersion higher harmonic method[2)], therefore we added it by the red marks. In addition, they [3, 4)] also have imaged local plastic zone around a hole in steel plate deformed by tension by using a local resonance harmonic imaging.

In this study, we demonstrate that the plastic zone in front of fatigue crack in steel is clearly visualized by the immersion higher harmonic imaging method.

2. Experimental

Fatigue samples of low carbon steel (SM500) plate have a central hole of 4mm in diameter and EDM notch of 0.25mm in width and 3.4mm in length. The plate width, length in parallel area and thickness are 40, 10 and 3.2mm, respectively. Crack was introduced by tension-tension fatigue test with different ΔK values. After fatigue test, samples of 20×20mm with the fatigue crack were cut out as shown in **Fig. 2**, thereafter both surfaces were ground by 0.2 mm to remove thickness variation due to local plastic deformation. The sample thickness after grinding is 3.6mm, and thickness variation is less than 0.005mm.

For imaging crack tip plastic zone, we used the immersion higher harmonic imaging system shown in **Fig. 3**. The main components are sine burst wave pulser of 100MHz in frequency(RITEC RAM-5000), high-pass filters, amplifier (RITEC RPR-4000) and imaging software (InsightScan and InsightAnalysis).

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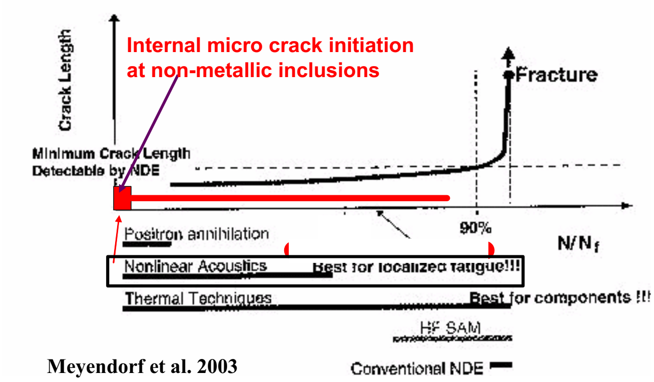


Fig. 1 NDE techniques applicable for fatigue crack[1)].

Fig. 2 Cut-out sample with a fatigue before surface grinding.

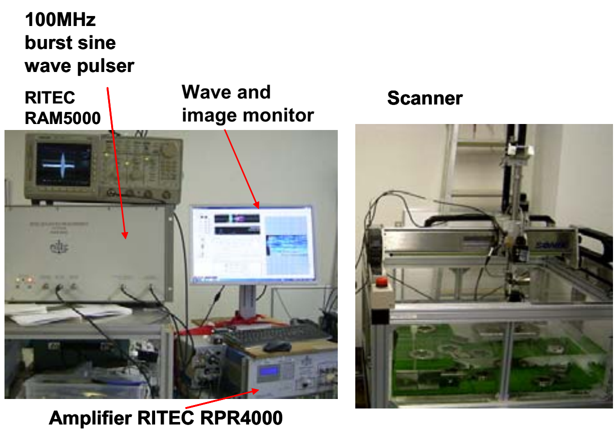
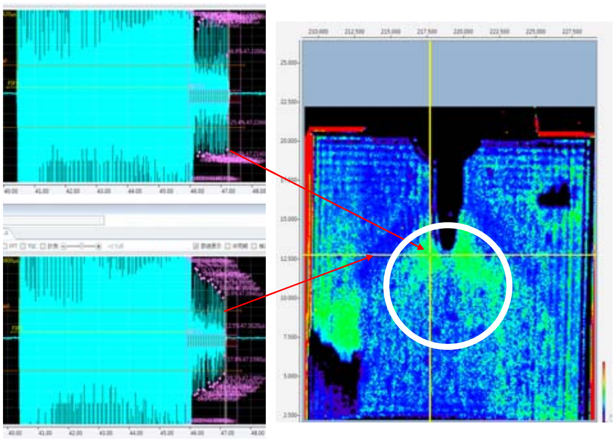


Fig. 3 Experimental setup for immersion higher harmonic imaging.



(a) (b)

Fig. 4 Image of crack tip plastic zone (b) and received waveforms (a). Resonance frequency: 21.26MHz.

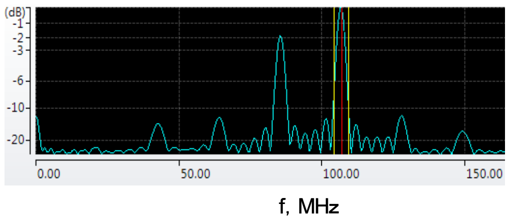


Fig. 5 Spectrum of received wave in crack tip plastic zone (right green area in Fig. 4).

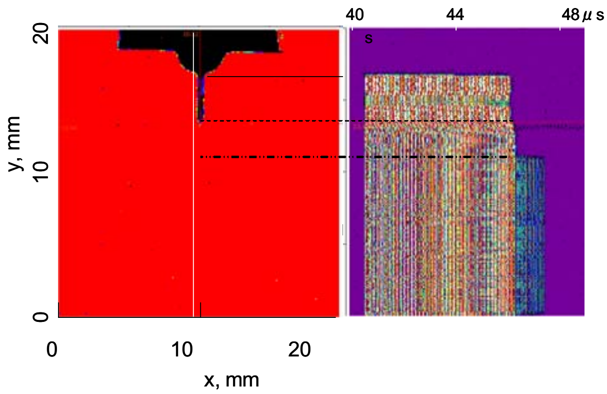
Sine burst wave of 21.26 MHz in resonant frequency and 80 cycles was normally transmitted for samples and a high-pass filter of 80MHz was inserted in the receiving circuit to extract 5th harmonic. A point focus transducer of 30MHz in frequency and 30mm in focal length was used.

3. Higher Harmonic Image of Crack Tip Plastic Zone

The 5th harmonic images of the crack tip plastic zone are shown in **Figs. 4** and **6**. The crack length is about 2.5mm. In Fig. 4 (b), the plastic zone is clearly imaged in the white circle. As shown in Fig. 4 (a), the delayed wave amplitude is higher in plastic zone. The spectrum shown in **Fig. 5** is highest at 106 MHz, 5th harmonic.

Figures 6(a) and **(b)** show the EDM slit and the duration of the received wave, respectively. The duration is shortest in the EDM slit and longest in crack free area. In the cracked area, the duration is slightly longer than in EDM slit. The crack lengths in Figs. 4 and 6 are about 2.5 mm, which is the same as direct observation.

Figures 7 shows the harmonic image of the crack tip plastic zone by resonance frequency 16.41 MHz and 40 MHz high-pass filter. Due to higher



(a) I (b)

Fig. 6 Harmonic image of top surface (a) and amplitude time variation (b).

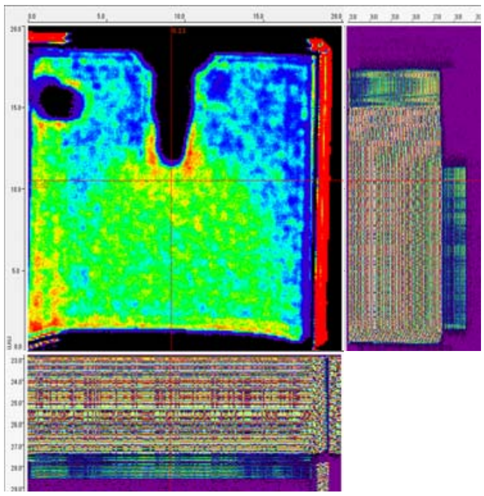


Fig. 7 Image of crack tip plastic zone. Resonance frequency: 16.41MHz, 40MHz high-pass filter.

input energy, the plastic zone is clearly imaged.

4. Concluding Remarks

By the immersion local resonance harmonic imaging technique, we visualized the plastic zone in front of fatigue crack tip in a steel plate.

Acknowledgment

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