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Second Harmonic Components Generation for Size and Number of Micro-Cracks Using Finite Element Method
有限要素法による微細き裂の大きさや数に伴う
２次高調波発生量の検討

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1. Introduction

Ultrasonic waves have been widely used in nondestructive evaluation (NDE) of various materials. Recently, nonlinear ultrasonic (second-harmonic or subharmonic) pulse waves have been studied for use in NDE [1, 2]. The second-harmonic frequency component is generated by the nonlinear vibration when the larger amplitude ultrasonic waves with a fundamental frequency component are transmitted into materials having micro-cracks. We have carried out several studies on second-harmonic ultrasonic wave properties and their application [2].

In the tensile test, second-harmonic components were increased as the strain was increased, because plastic deformation was ocuured. On the other hand, second-harmonic components were decreased when the strain was near the tensile fracture. If the measurement is carried out for only second-harmonic components, we might misjudge that the material is still sustainable. It is necessary to consider those results theoretically.

In this study, second-harmonic components generation from the material having micro-cracks was carried out using finite element method (FEM). This simulated results will be discussed.

2. Simulation model

FEM software ComeWAVE™ [3] was used. Simulation model was shown in **Fig. 1**. The material was iron. Wavelet waves (8 cycles and 3 MHz) were used as transmitted waves. From (*x*, *z*) = (0 mm, 0 mm) in Fig. 1, the ultrasonic waves were transmitted toward *z* axis.

Models are shown in **Fig. 2(a) – (f)**. In Fig. 2(a) – (d) micro-crack size and its number were increased. In Fig. 2(e) and (f), open cracks were put. In the model, since micro-cracks are smaller crack-width compared to ultrasonic amplitude, nonlinear vibration is occurred and second-harmonic components are generated, while open cracks are much larger crack-width compared to ultrasonic amplitude.

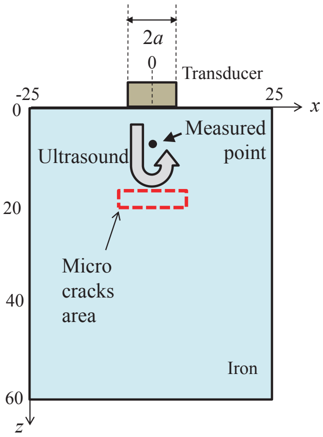

Fig. 1 FEM model for micro-cracks

Vibration velocities at the measured point (*x*, *z*) = (0 mm, 8 mm) and its spectra were calculated.

In pattern 1, one small micro-crack (the length *L*= 0.1 mm, the width *W* = 1.0 nm) was located (*x*, *z*) = (0 mm, 20 mm).

In pattern 2, five small micro-cracks and one large micro-cracks (*L*= 0.2 mm, *W* = 5.0 nm) were located (*x*, *z*) = (±2 mm, 20 mm), where *x* = ±2 mm was -3 dB ultrasonic waves beam width.

In pattern 3, six large micro-cracks were located (*x*, *z*) = (±2 mm, 20 mm) and six small micro-cracks were located (*x*, *z*) = (±2 mm, 18 mm).

In pattern 4, all crack length was increased. A small micro-crack was *L*=0.2 mm, a large micro-crack was *L*= 0.5 mm.

In pattern 5, crack located area was enlarged by *x* = ± 5 mm, where was a diameter of the transducer. Three small cracks were located each side. Moreover, open cracks were also located, which was assumed that the micro-cracks were grown.

Finally, in pattern 6, cracks of 80 % were open cracks.

3. Results and discussion

A calculated vibration velocity waveform and its spectrum in pattern 4 are shown in **Fig. 3(a)** and

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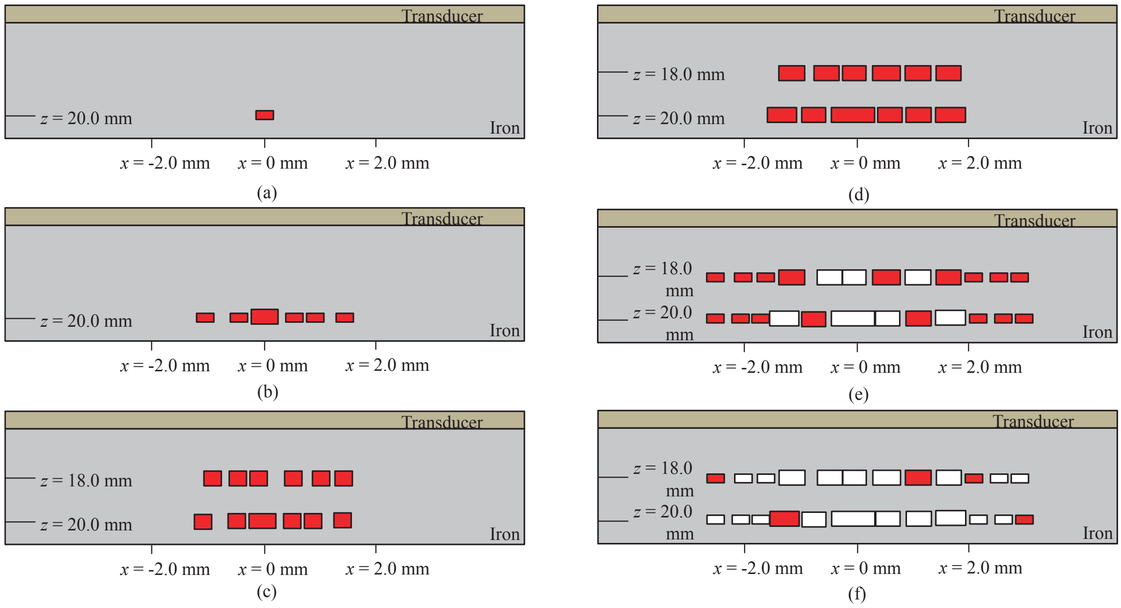

Fig. 2 Model pattern. (a) Pattern 1, (b) Pattern 2, (c) Pattern 3, (d) Pattern 4, (e) Pattern 5, and (f) Pattern 6. Red blocks are micro cracks and white blocks are open cracks.

3(b). Furthermore, the detected second-harmonic components in pattern 1 - 6 are shown in **Fig. 4**. In pattern 1, a reflected wave was almost not detected. Since reflected wave from small reflection object was very small, reflected wave might be scattered. In pattern 2 - 4, second harmonic components were increased, while they were decreased in pattern 5 and 6. Second-harmonic components should be influenced to not open cracks but to micro-crack..

4. Conclusions

Second-harmonic components generation from the material having micro-cracks was carried out using finite element method (FEM). The 6 models referred to the material applied tensile load which had been observed by the SEM were calculated. As the results, second harmonic components were increased as micro-cracks and were decreased as open cracks.

In the future, the calculation of the second harmonic components detection in a surface as they detect using the transducer will be carried out.

Acknowledgment

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References

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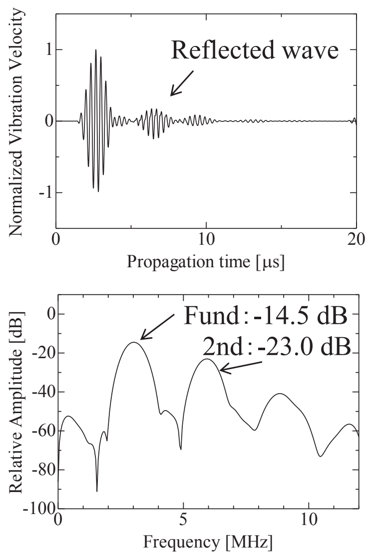

Fig. 3 (a) Calculated waveform and (b) its spectrum in pattern 4.

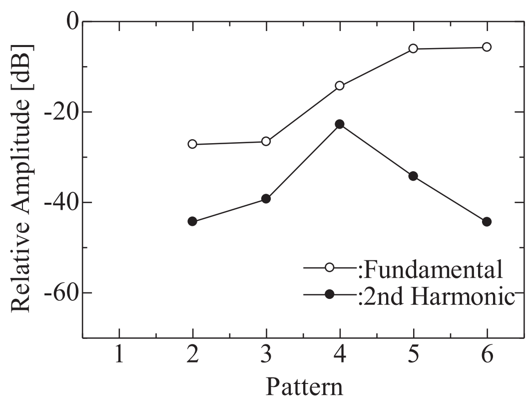

Fig. 4 Calculated fundamental and second-harmonic components for each pattern.