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Nondestructive Evaluation of Plane Crack Tip Using Laser Induced Pulse Wave and Vibration

レーザ励起パルス超音波と低周波加振を用いたクラック先端の非破壊検査

Ryosuke Nakase[1‡] and Mami Matsukawa[1] ([1]Doshisha Univ.)
中瀬了介 [1‡]，松川真美 [1] ([1] 同志社大)

1. Introduction

Precise measurement of small cracks is an important issue for nondestructive evaluation. Especially, reliable and quantitative evaluation of cracks is necessary for the assessment of structure, because small cracks possibly cause the decrease of strength. These cracks, however, remain difficult to be detected because they are often closed at the tips. One interesting procedure for evaluating the closed cracks is the nonlinear techniques [1-3]. They are based on the detection of nonlinear components, such as superharmonics or subharmonics of the incident wave, which are generated by the interaction of a large-amplitude ultrasonic wave with the closed crack tips [1-3]. These methods still have comparatively poor spatial resolution. Ohara et al. has proposed an array sensor to overcome this problem [2].

In this study, we propose a simple system for detecting the spatial distribution of small cracks, especially, the distribution of crack tips. Here, we combine two techniques. One is a laser ultrasonic method under thermo-elastic regime; the other is the crack vibration by low frequency and large-amplitude Lamb wave. Using this technique, we have tried to detect the position of crack tips.

2. Experiment

2.1 Sample

Figure 1 shows an acrylic sample (27.0 × 22.0 × 5.0 mm^3) with a plane crack. The crack ran almost parallel to the sample surface. In order to generate a short ultrasonic pulse by the thermo-elastic effect, a thin aluminum film was deposited on the sample surface.

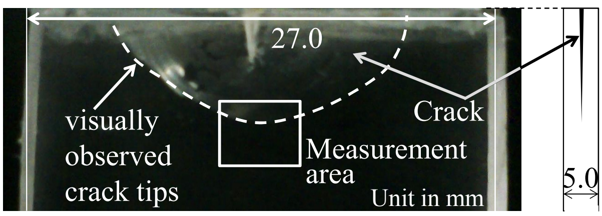

Fig. 1 Sample figure.

mmatsuka@mail.doshisha.ac.jp

2.2 Excitation of Lamb wave S0 mode

A PZT transducer (Fuji ceramics) was attached on one sample side as shown in **Fig. 1**. 3 cycles sinusoidal burst wave at 200 kHz and 100 Vpp was applied to the PZT transducer. The displacement of sample surface was observed by a laser doppler vibrometer (Ono sokki, LV-1610). Here S0 mode Lamb wave was generated and the displacement of the sample surface was about 30 nm.

2.3 Irradiation timing of pulse laser

The crack tips are fluctuated by the Lamb wave. The timing of laser irradiation is expected to match the effect of displacement to the crack tips. We then irradiated short pulse laser on the sample surface at the positive or negative peaks of the Lamb wave. We defined the laser induced wave which passed through the crack during positive peak as P(t) and negative peak as N(t).

2.4 Experimental system

Figure 2 shows the experimental system. We used Nd-YLF pulse laser (wave length 1047 nm, pulse energy 80 μJ, pulse width 5 ns, reception time 1 ms; Spectra-Physics, R2-VS5-104Q). This laser beam was focused on the sample surface. We constrained sample surface by the transparent gel to improve the directivity of the laser induced wave [4]. The laser induced waves propagated in the sample and were observed by a hand-made PVDF transducer (ϕ 5.0 mm). After an amplification of 46 dB by a pre-amplifier, the signal passed a high pass filter (cutoff frequency: 1 MHz) before measurement by an oscilloscope. We observed the waves which passed the area of clack tips.

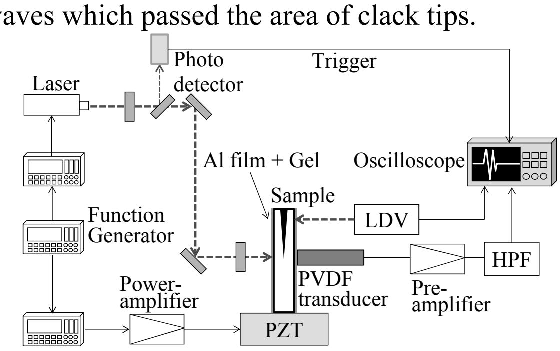

Fig. 2 Experimental system.

3. Results and Discussion

Figure 3 shows examples of laser induced waves under Lamb wave excitation. The continuous line (P(t)) is the wave which passed at the maximum displacement, whereas the broken line (N(t)) is the wave which passed at the minimum displacement. The signal around 2.0 μs is the wave propagated in sample. The signal around 2.3 μs is a reflection in the surface gel.

As shown in **Fig. 3**, the wave amplitude changed due to the measured points. The amplitude clearly decreased at the area of crack tips. However, the amplitude of laser induced wave depends on condition of sample surface or sample thickness. Therefore, we focused on the difference between P(t) and N(t), especially, on the phase spectra of the laser induced wave around 2.0 μs. **Figure 4** shows the phase difference between P(t) and N(t), waves at an identical measurement point. As shown in **Fig. 4**, phase difference around 23 MHz increased near the crack tips. **Figure 5** shows the relation between the maximum value of phase difference and the distance from the crack tips. As shown in **Fig. 5**, at the area without crack, phase difference was small (Average value: 0.23 radian). On the other hand, phase difference tends to increase at the crack area.

By focusing phase difference between P(t) and N(t), the detection of crack tips become possible. One good threshold for the evaluation in this case seems to be the phase difference of 0.5 radian. The phase difference between P(t) and N(t) mainly happens at the crack tips because of the fluctuation of crack tips by Lamb wave excitation. One possible explanation is the changes of wave properties near the crack, which is induced by the possible opening or closing of crack tips.

Of course, we should also consider the changes of amplitude of spectra in detail, which seems to give us more information of the crack tips.

4. Conclusions

We proposed a new procedure for detecting crack tips. We evaluated crack tips by combining a laser ultrasonic method and vibration of crack by Lamb wave. Making use of the phase difference of observed laser induced wave, the area of crack tips was confirmed. This system is very simple and compact, which seems to be applicable for the nondestructive evaluations.

References

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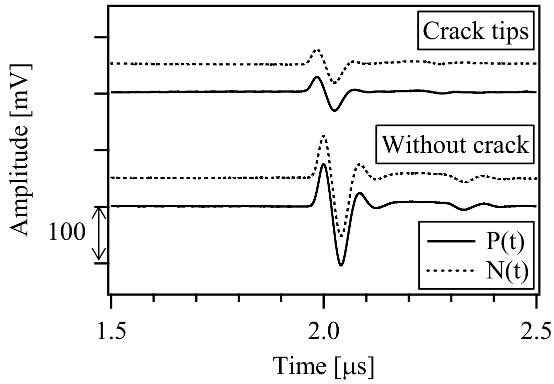

Fig. 3 Transmitted laser induced waves.

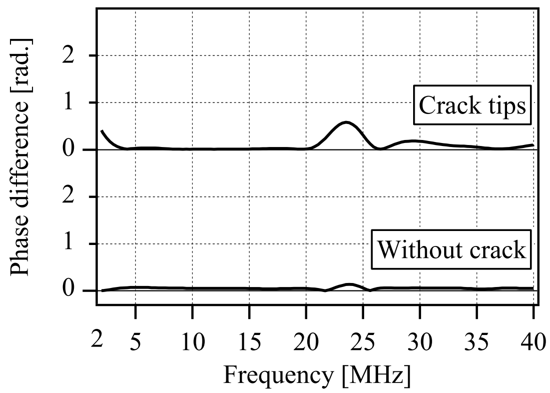

Fig. 4 Phase difference between P(t) and N(t).

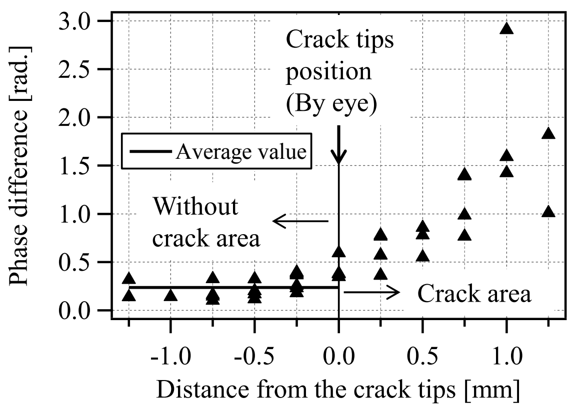

Fig. 5 Phase difference as a function of distance from the crack tips.