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Non-contact Diagnosis of Fire Damage of Mortar using Surface Acoustic Waves
弾性表面波を利用したモルタル火害の非接触診断

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1. Introduction

Our purpose is a practical application of a non-contact method for diagnosing fire damage to concrete by using high-intensity aerial ultrasonic waves and optical equipment [1-3]. This is a method for diagnosing fire damage by using the vibration characteristics of an object to estimate the change of elastic modulus of concrete exposed to high temperatures during a fire. However, it is difficult at present to diagnose fire damage in the depth direction. To solve this problem, we propose a method for estimating the change of elastic modulus in the depth direction by using the relationship between the propagation speed and frequency of surface acoustic waves. In this report, as a basic study, we attempt non-contact measurements of changes in the propagation speed of acoustic waves on the surface of mortar that expose to high temperatures.

2. Measurement Principle

The elastic modulus and density of concrete decrease at temperatures above 570 °C, depending on the material and structure [4]. Generally, in the case of mortar that expose to high temperatures, change of its density is less than that of its elastic modulus. Therefore, as described by Eq. (1), the propagation speed of the surface acoustic waves is decreased substantially by fire damage:

$$C_R = \frac{0.87 + 1.12\nu}{1+\nu}\sqrt{\frac{E}{\rho}\cdot\frac{1}{2(1+\nu)}} \qquad (1)$$

Here, C_R is the propagation speed of acoustic waves, ν is Poisson’s ratio, E is Young’s modulus, and ρ is the density [5].

In addition, the surface acoustic waves propagate in a surface layer whose depth (approximately one wavelength of the propagating wave) depends on frequency [6]. Above the mention, it is expected that the propagation speed of acoustic waves at high frequency decreases due to elastic modulus decreases by fire damage because the acoustic surface waves of short wavelength at high frequency propagate in shallow layer of object. In contrast, it is expected that the propagation speed of acoustic waves at low frequency does not decreases substantially even if elastic modulus decreases by fire damage because the acoustic surface waves of long wavelength at low frequency propagate from the surface to the deep part of the object integrally [7].

Our research group proposes estimating the extent of fire damage to concrete in the depth direction by measuring the change of propagation speed of acoustic waves based on the above phenomenon. Furthermore, the proposed method involves irradiating the sample simultaneously with the harmonics of integral multiples because very high-intensity aerial ultrasonic waves exhibit strong nonlinearity. Therefore, it is also possible to measure the propagation speed of multiple the frequency components of the surface acoustic waves simultaneously.

3. Experimental Method

Fig.1 shows an outline of the experimental device based on the measurement principle. The device includes a sound source that can emit high-intensity aerial ultrasonic waves, and a laser Doppler vibrometer (LDV) that measures the vibration of the surface of the sample. In this study, we use a focus sound source. As shown in Fig.1, the point-convergent sound source consists of 263 transducers (drive frequency: 40 kHz) that are distributed evenly inside a hemisphere (diameter: 150 mm). In this sound source, a sound pressure of 5700 Pa is generated at the focus point (supply power: 10 W), and integer-order harmonic sound waves are generated in addition to the fundamental (i.e., driving) frequency.

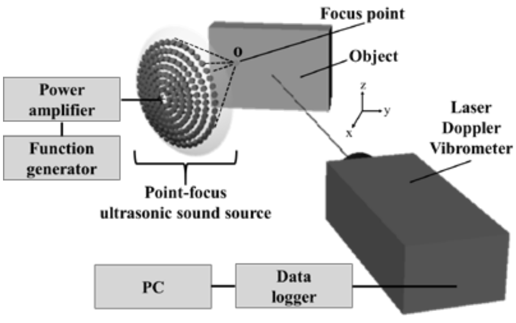

Fig.1 Schematic view of experiment system

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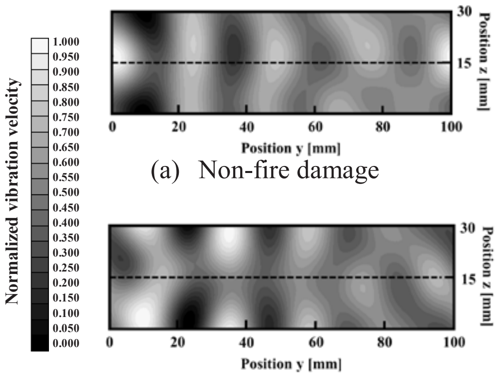
The vibration velocity of the mortar surface is excited by irradiation with the high-intensity acoustic wave is measured in a non-contact way by the LDV. In addition, the LDV can move accurately by a three-axis precision stage. Each measurement is made 1 s after movement is complete, whereupon the vibration information of the measurement point is acquired with the rising of an oscillator-applied voltage signal as a trigger. Furthermore, the fundamental frequency and each harmonic component are extracted using a bandpass filter (center frequency: ±1 kHz), and imaging is performed from the distribution of instantaneous vibration velocity of each frequency component.

The sample used in the experiment is mortar of dimensions 220 × 150 × 50 mm. In addition, its sample was heated in an electric furnace until the surface temperature reaches 900 °C.

4. Result and Discussion

In the experiment, the measurement area (100 mm × 30 mm) is around the center of the sample surface and is measured in 1-mm intervals. In addition, the sound source is driven at 20 cycles and an applied voltage of 10 V, and the waveform is acquired over a measurement time of 1 ms. As an example, **Fig. 2** shows the state of the surface wave propagation (second harmonic: 80 kHz) in the measurement area at a certain time. The results are extracted waveform with 2D FFT and are normalized by the measured maximum value of vibration velocity during the measurement time.

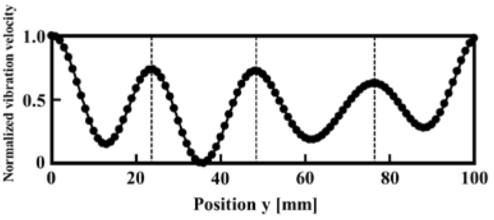
Comparing before and after fire damage, the intervals between the acoustic sound waves length in the surface of the burnt sample are clearly shorter, which expects that the propagation speed is decreased. Here, we calculate the propagation speed of the surface acoustic waves based on the vibration's velocity distribution along the dotted line (*y* = 15 mm) in **Fig.2**. **Fig.3** shows the extraction results of the vibration's velocity distribution. From this figure, the propagation speed is calculated by averaging the distance between some amplitude peaks of the surface acoustic waves. The calculated results are given in **Table I**. The propagation speed of the surface acoustic waves is decreased by approximately 500 m/s, which is sufficient to be able to detect the influence of the fire damage. From the above results, we confirm that mortar has fire damage can be diagnosed by measuring the difference in propagation speed of surface acoustic waves that is caused by heating to high temperatures.



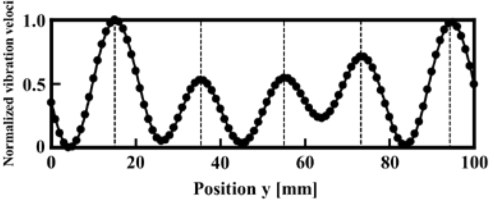
(a) Non-fire damage

(b) Fire damage

Fig.2 Distribution of vibration velocity by instantaneous value



(a) Non-fire damage



(b) Fire damage

Fig.3 Normalized vibration velocity by instantaneous value

Table I Speed of surface wave

Non-fire damage	(m/s)	2111.2
Fire damage	(m/s)	1603.7

5. Conclusion

We attempted to measure in a non-contact way a change in the propagation speed of acoustic waves in the surface of mortar that was exposed to high temperatures. As a result, we showed that mortar has fire damage can be diagnosed by measuring the difference in propagation speed of surface acoustic waves that is caused by heating to high temperatures.

References

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