2Pb2-8

Diagnosis of Fire Damage inside Mortar Using Aerial Ultrasound Wave Source Scanning Method

空中超音波波源走査法を用いたモルタルの火害診断

Ayumu Osumi[1†], Tomohide Iketani[1], and Youichi Ito[1] ([1]Coll.Sci. and Tech., Nihon Univ.)
大隅 歩 [1†]，池谷 友秀 [1]，伊藤 洋一 [1]（[1]日大・理工）

1. Introduction

A fire damage diagnosis[1-3] inside concrete structures remaining after the fire is extremely important for identifying the fire source and determining the repair scale to reuse.

In this study, we experimentally investigated a method using a wave source scanning method with using aerial ultrasonic waves as a new method for diagnosing the penetration depth of the fire damage inside concrete structures.

2. Measurement principle

When surface acoustic waves (SAWs) at a low-frequency propagates in the concrete, the concrete can be regarded as an isotropic medium, and its propagation velocity C_R can be shown by Equation 1.

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

Here, E is the Young's modulus, ρ is the density, ν is the Poisson's ratio. In general, when the concrete exposed to high temperatures above 500 ℃ reduces the Young's modulus to about 70%, the density to about 10%, and the Poisson's ratio to about 0.1.[4,5] At this time, the propagation velocity of SAWs is about 40% lower than that in the healthy state from Eq. (1).

In this study, the state in which the propagation speed of SAWs propagating through the concrete decreases to the above speed (40 % decrease) is defined as a fire damage state. In addition, the penetration depth from the concrete surface that can be diagnosed as being in a state of the fire damage state is defined as a fire damage depth. By the way, as shown in **Fig. 1**, SAWs propagate in a range of about one wavelength from the surface layer of the concrete. In the event of a fire, the concrete is heated from the surface layer, so the area around the surface layer is in a state of fire damage. Considering the above conditions, the fire damage depth can be estimated by the following procedure.

(1) It measures the propagation velocity of SAWs when SAWs from low frequency to high frequency are propagated in the fire damaged concrete.

(2) The propagation velocity of SAWs in the concrete of a healthy sample is compared with SAWs measured above, and the state of the fire damage is determined from the attenuation rate.

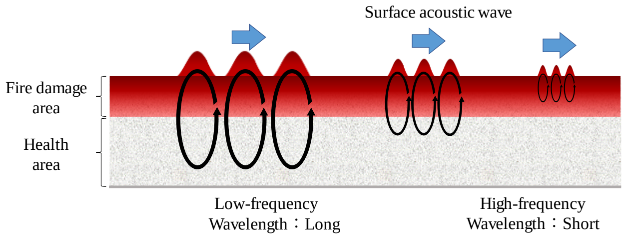

Fig.1 Measurement principle.

3. Experimental devices and procedure

Fig. 2 show the experimental devices. These devices comprised an aerial ultrasonic sound source, a receiving piezoelectric element, a data logger, other peripheral devices, and a PC to control them.

This sound source was a point-focused sound source with a spherical arrangement of 335 aerial ultrasonic transducers and a focal length of 150 mm. To avoid the influence of the side rope of the radiated sound wave, an acoustic guide (acryl plate: thickness 3 mm; acryl pipe: diameter 6 mm, length 30 mm) was installed at the sound-wave focal point and the sound wave propagated through the sound guide. The sound source was excited by a 10-burst cycle with a frequency of 40 kHz and an input voltage of 24 V. Experimental conditions were a sampling frequency of 2 MHz and a sampling time of 1 ms. Furthermore, in order to excite the target surface at multiple frequencies, the measurement was performed by changing the drive frequency in 10 kHz steps in the range of 30-60 kHz. Since the sound wave to be irradiated is extremely strong, a harmonic sound wave of integer order is generated in addition to the drive frequency due to the non-linearity.

In this report, we measured at frequency from the fundamental wave to the third harmonic. In this measurement, a wave source scanning method using the reciprocity theorem of the sound field was used. In this method, the receiver was fixedly

osumi.ayumu@nihon-u.ac.jp

arranged and a sound wave irradiation position was scanned two-dimensionally, enabling stable measurement without being affected by the properties of the object surface that has been damaged by the fire. In the experiment, sound waves were radiated with 1 mm steps in the irradiation sound wave scanning area shown in **Fig. 3**, and the excited SAW was measured with an ultrasonic probe fixed at a fixed position on the sample surface.

In addition, the propagation speed was calculated by measured propagation images of SAWs at each frequency.

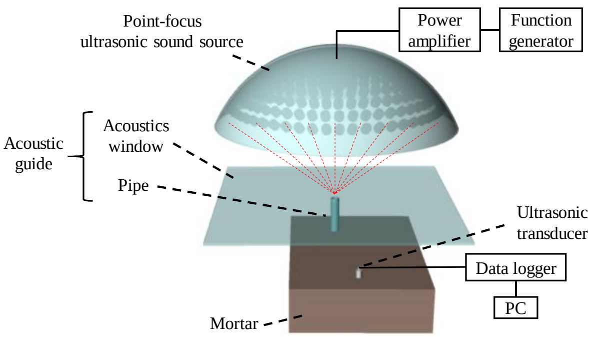

Fig.2 Schematic view of experimental devices.

Fig.3 shows the outline of the mortar sample (W/C : 25%, 150 × 220 × 50 mm) used in the experiment. The fire damage sample was prepared by heating in an electric furnace with an internal temperature of 850 ℃ for 10 minutes. In order to form the fire damaged area from the surface layer to the deep layer, the side surface and back surface of the sample were covered with a heat-resistant cloth during heating.

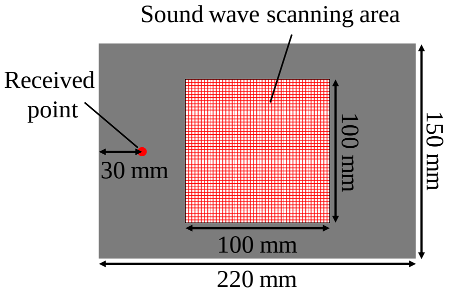

Fig.3 Schematic view of sample detail.

4. Result

Table 1 shows the result of the measured mortar propagation velocity.

From the result, it can be confirmed that the propagation velocity of the healthy sample was constant with respect to the frequency. On the other hand, the propagation speed of fire damaged samples decreases as the frequency increases. From the result, the frequency was 50 kHz when SAWs propagation velocity of the fire damaged sample drops to about 40% of that of the healthy sample. Therefore, the region where SAWs with a frequency of 50 kHz propagates (wavelength 23 mm) was estimated to be the depth of the fire damage.

Table 1 Propagation speed of SAWs at each frequency.

Frequency [kHz]	Normal Model [m/s]	Fire damage Model [m/s]	Speed reduction rate [%]
30	1990	1230	38.19
40	1940	1200	38.14
50	1950	1150	41.02
60	1920	1020	46.87
80	1840	880	52.17
90	1980	900	54.54
100	1900	900	52.63
110	1870	880	52.94
120	1920	840	56.25
150	1950	900	53.84
180	1980	900	54.54

5. Conclusion

We conducted an experimental verification of the fire damage depth diagnosis inside the fire damage mortar using the wave source scanning method using aerial ultrasonic waves. As the result, it was clarified that this method can estimate the depth of the fire damaged area inside the mortar in a non-contact manner.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 19K04931.

References

1. T. Saito, A. Osumi and Y. Ito: International Congress on Ultrasonics. 32 (2017) 030017.
2. T. Saito, A. Osumi and Y. Ito: Symposium on Ultrasonic Electronics. 38 (2017) p.25-28.
3. A. Osumi, M. Enomoto and Y. Ito: Jpn. J. Appl. Phys. 53 (2014) 07KC16.
4. N. Kakae, K. Miyamoto, T. Momma, S. Sawada, H. Kumagai, Y. Ohga, H. Hirai, T. Abiru: ACT. **15** (2017) P.190-212.
5. M. Li, C. Qian, W. Sun, Cement and Concrete Research, **34** (2004) P.1001-1005.