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# Fire Damage Diagnosis of Locally Heated Mortar Using Airborne Ultrasound

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## 1. Introduction

In many cases when a fire occurs in a concrete structure, it is very important to diagnose the fire damage of the remaining structure to determine scientifically the location of the fire source and the deterioration of the building in order to determine the scale of repair and reuse. We have studied a noncontact fire-damage diagnosis method that uses the propagation characteristics of surface acoustic waves excited by nonlinear airborne ultrasound irradiation [1]. In this report, we investigate experimentally the spatial resolution of the fire-damage diagnosis for a locally heated area of a concrete wall, assuming that the wall was subjected to nondestructive strong localized fire damage.

## 2. Wall fire-damage model

In our previous work, we performed fire-damage diagnosis experimentally and theoretically on a specimen when the entire surface of the structure had been heated to a high temperature, as shown in **Fig. 1**(a), assuming that the entire wall surface of the structure was uniformly damaged by fire. However, in an actual fire scene, the distribution of fire damage on the wall surface is likely to be uneven because of the influence of furniture and other objects. Therefore, it is necessary to study the spatial resolution of fire-damage diagnosis by this measurement method using a sample with localized fire damage as shown in Fig. 1(b). In this report, we investigated experimentally the spatial resolution of fire damage by preparing mortar samples that were locally heated to high temperatures.

## 3. Outline of experiment

3.1. Experimental devices and methods

**Figure 2** shows a schematic of the experimental system, which comprised a high intensity airborne ultrasound source, an acoustic emission (AE) sensor (PICO; Physical Acoustics Corporation), and peripheral equipment. The ultrasound source comprises 335 airborne ultrasound transducers with a diameter of 10 mm arranged along a hemispherical dome with a radius of 150 mm, and the emitted sound waves were focused at a point on the central axis of the hemisphere. The sound waves were irradiated to the sample surface through an acoustic guide comprising a pipe (inner diameter: 6 mm) and an acoustic window to reduce the influence of side lobes characteristic of focused sound waves. The sound source was driven with a driving frequency of 40 kHz, an applied voltage of 20 V, and 10 cycles. Because the irradiated sound waves were extremely powerful, strong nonlinearities generate harmonic sound waves of integer order in addition to the driving frequency. By actively using this feature, vibration information of many frequencies can be obtained. In addition, the scanning elastic-wave source technique [2,3] which is based on the reciprocity theorem of acoustic fields was used in this measurement. In this method, the receiver was placed at a fixed position, and the excitation position of the sound-wave irradiation was scanned two-dimensionally; using this method makes it possible to obtain stable measurements that are less affected by the surface properties of the fire-damaged object. In the experiment, a 100 mm × 100 mm area in the center of the sample was irradiated with sound waves in 1-mm steps, and surface acoustic waves including harmonics were measured using an ultrasound probe at a fixed position on the sample surface. The measurement timing was triggered by the rising edge of the applied voltage signal to the transducer, and the vibration waveform was acquired at a sampling frequency of 2 MHz.

3.2. Experimental sample

**Figure 3** shows the mortar sample used in the experiment, which was made of instant cement (Toyo Matelan) to eliminate the influence of the aggregate on the sound waves. The water-to-cement ratio was 25%, and the dimensions were 220 mm × 150 mm × 50 mm. To simulate localized heating of a portion of the wall surface, a 50 mm × 50 mm area in the center of the specimen surface was heated directly, while the other areas were covered with fireproof fabric; the heating conditions were an electric furnace with an internal temperature of 900°C for 10 min. To obtain the temperature history, thermocouples were placed inside the sample at a depth of 1 mm from the sample surface in the

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directly heated area and in the area with suppressed heating, as shown in Fig. 3. **Table 1** gives the results after 10 min of heating. The surface temperature of the directly heated area reached about 400°C, while the area covered by the refractory cloth showed an average temperature increase of only about 200°C.

## 4. Measurement results of surface acoustic wave propagation

**Figure 4** shows an example of surface acoustic wave propagation measurements at 80 kHz (second harmonic). The area indicated by the black dotted line in the figure is the area directly heated. The measurement results are normalized by the maximum vibration velocity during the measurement time. The results show that surface acoustic waves propagated spherically from the excitation source. It can also be seen that as the surface acoustic waves propagated through the directly fire-damaged area, the sound velocity changed. The propagation velocity was calculated from the wavelengths and frequencies of the propagation waveforms obtained at the locations where the effect of the fire damage was suppressed and at the directly heated locations. **Table 2** gives the calculated propagation velocities. The propagation velocity where the fire damage was suppressed, was about 1470 m/s, while that at the directly heated location decreased to about 1090 m/s. The results show that the proposed measurement method can detect locally heated areas with a spatial resolution of at least 50 mm × 50 mm.

## 5. Conclusion

The spatial resolution of fire-damage diagnosis for locally heated areas was investigated experimentally assuming that a concrete wall was subjected to strong local fire damage. Consequently, it was confirmed that the local heating area can be detected with a spatial resolution of at least 50 mm × 50 mm using the surface acoustic wave propagation characteristics in the mortar sample with the temperature difference of about 200°C between the locally heated area with the maximum temperature of 400°C and the area with less heating.

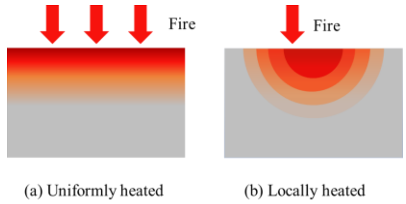

Fig. 1. Wall fire-damage model.

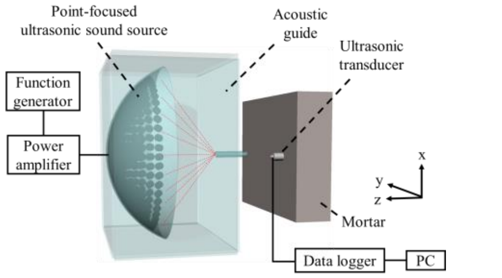

Fig. 2. Experimental system.

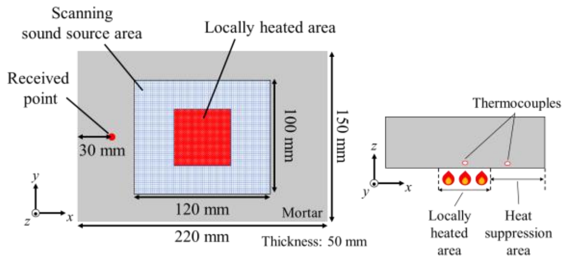

Fig. 3. Experimental sample.

Table 1. Temperature history.

| Position of thermocouple from surface [mm] | Heat suppression area [°C] | Locally heated area [°C] |
|---|---|---|
| 1 | 212 | 403 |

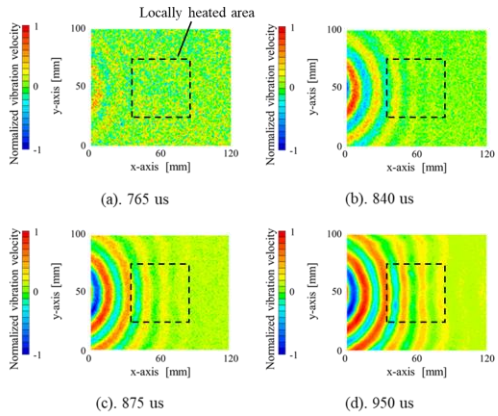

Fig. 4. Elastic surface-wave propagation results (second harmonic).

Table 2. Calculated propagation velocities.

| Heat suppression area [m/s] | Locally heated area [m/s] |
|---|---|
| 1469 | 1093 |


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### References


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