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Surface hardness monitoring of object during hardening by high-intensity aerial ultrasonic waves
強力空中超音波による物体硬化過程の表面硬さモニタリング

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1. Introduction

We have developed a method for determining the surface hardness of cement during hardening by measuring the vibration on the surface with high-intensity aerial ultrasonic waves. In this study, we measure the displacement and vibration velocity of the material surface under aerial ultrasonic irradiation to evaluate the surface hardness of cement as the surface hardness characteristics change from that of a liquid just after placement to that of a solid.

2. Measurement principle

Fig. 1 shows the principle of the measurement method. Two measurement models are used to evaluate the surface hardness by sound wave irradiation. One model is used when the surface is liquid or soft and the other is used when the surface is solid.

Equation (1) is used when the object is liquid or soft.

$$\sigma = \frac{F}{E} \tag{1}$$

Here, surface displacement σ is acoustic radiation force F divided by modulus of elasticity E [1]. Therefore, this equation is used to measure the surface displacement when it is assumed surface hardness is chiefly represented by the modulus of elasticity.

Equation (2) is used when the object is a solid.

$$V(\omega) = \frac{P(\omega)}{Z(\omega)} \tag{2}$$

Here, vibration velocity V(ω) is the sound pressure of the object surface P(ω) divided by mechanical impedance Z(ω) [2]. Therefore, this equation is used to measure the vibration velocity when it is assumed the surface hardness is chiefly represented by mechanical impedance [3].

3. Experimental apparatus and method

Fig. 2 shows an outline of the experimental apparatus. It uses a point-converging acoustic source

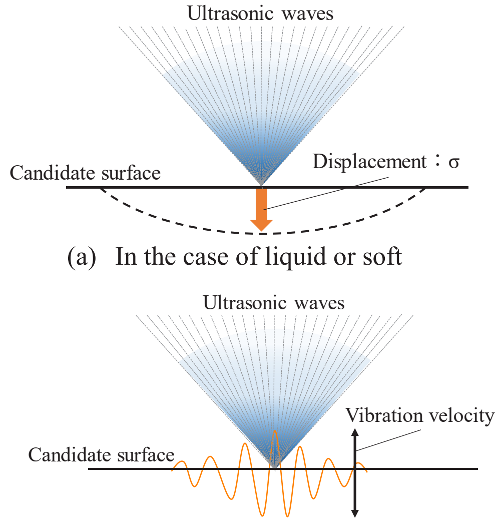

Fig. 1 The principle of the measurement method

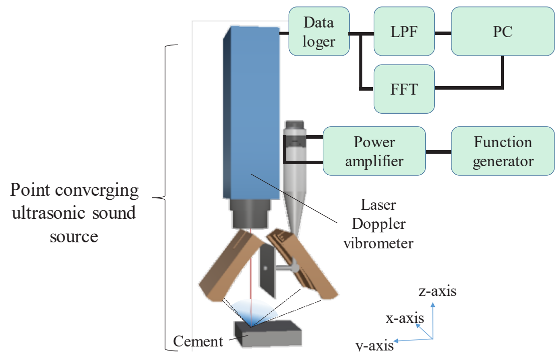

Fig. 2 Experimental apparatus

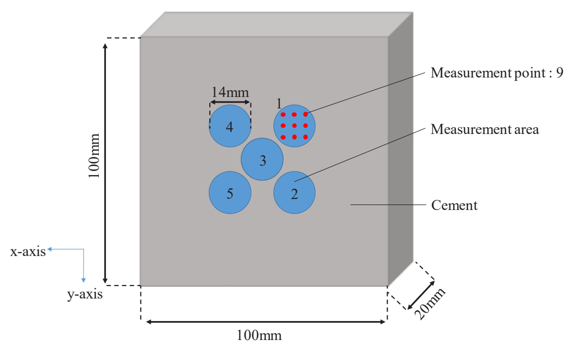

Fig. 3 Overview of sample used in the experiment

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with a stripe-mode vibration plate (drive frequency: 28 kHz) to generate high-intensity aerial ultrasonic waves (focusing distance: 130 mm, focal circular area: 8 mm) with a sound pressure of about 2200 Pa in the focus area [4]. The displacement and vibration velocity of the surface of the cement under ultrasonic wave irradiation are measured with a laser Doppler vibrometer (LDV). The LDV signal is divided into two signals (**Fig. 2**). Displacement is measured by passing one signal through a low-pass filter (cutoff frequency: 10 Hz). Vibration velocity is obtained by fast Fourier transform of the other signal.

Fig. 3 shows an overview of sample used in the experiment. The samples were 100 × 100 × 20 mm (width × length × thickness), and the water-cement ratio was about 40%. The measurements were performed at nine points in each of five circular areas (diameter: 12 mm) including the central part of the sample. It took 6 min to complete the measurements in all the areas, and the measurements were taken at various times over 4 h.

4. Experimental results

4.1. Displacement of the material surface

Fig. 4 shows the displacement measurements from area 3 as an example. The displacement of the surface decreases sharply immediately after cement placement and converges to nearly 0 after 1 h, indicating the change in the surface hardness of liquid cement.

4.2. vibration velocity of material surface

Fig. 5 shows the vibration velocity median in each area, and each characteristic curve is normalized. The vibration velocity increases slightly for 1 h after cement placement, whereas the vibration velocity decreases slightly after 1 h, sharply after 2 h, and gradually after 3 h. These results show that the mechanical impedance of the cement increased with the cement curing. The characteristic curve of stress in the figure shows the surface hardness of the material measured with a hardness meter. The hardness meter measurements could only be taken after the cement had solidified after 2 h. The surface hardness increased for 1 h, and then increased slightly after 3 h. The surface hardness and impedance results showed an inverse relationship with the characteristic curve of the vibration velocity. Our results demonstrate that it is possible to monitor the hardening of cement by measuring the vibration velocity.

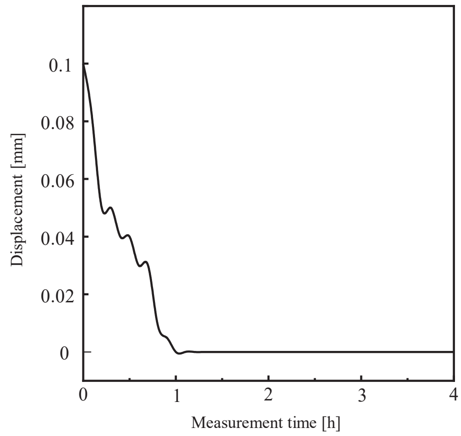

Fig. 4 Displacement measurements from area 3

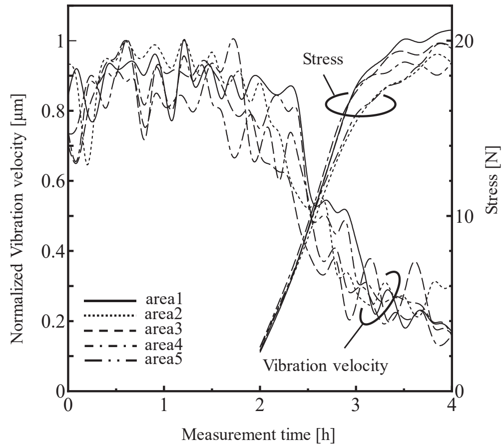

Fig. 5 vibration velocity median and stress in each area

5. Conclusion

We monitored cement during hardening immediately after cement placement by using high-intensity aerial ultrasonic waves and optical equipment to measure the displacement and vibration velocity.

Acknowledgment

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References

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