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Method of Determining Effect of Heat on Mortar by Using Aerial Ultrasonic Waves with Finite Amplitude

Osumi, Ayumu (1), Sato, Yasufumi (1), and Ito, Youichi (1)

(1) Faculty of Science and Technology, Nihon University; 1-8-14, Kanda Surugadai, Chiyoda-ku, Tokyo, 101-8308, Japan; oosumi@ele.cst.nihon-u.ac.jp

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ABSTRACT

We developed a method of determining the effect of heat on mortar samples by analyzing the vibrations of mortar samples that were exposed to high temperatures of about 500°C to 1,000°C and excited in a non-contact manner by using a high-intensity aerial ultrasonic wave with finite amplitude (at a fundamental frequency of 20 kHz). If a high-intensity aerial ultrasonic wave is emitted onto the surface of an acryl resin or metallic plate, the plate may be excited by the ultrasonic wave in a non-contact manner and vibrate at the same frequency as the emitted ultrasonic wave. If the ultrasonic wave has finite amplitude, it contains harmonic components specific to the ultrasonic wave. If the plate is irradiated with the ultrasonic wave, therefore, it may produce vibrations at frequencies corresponding to the frequency components of the ultrasonic wave. By using such a high-intensity aerial ultrasonic wave with finite amplitude (at a fundamental frequency of 20 kHz, and a sound pressure of 6 to 10 kPa), we attempted to determine the variation in the properties of an object that was exposed to and affected by the high heat of a fire for example. The target object used for this paper was an object made of mortar, which is a material typically used in construction. Mortar samples irradiated with an ultrasonic wave were vibrated at frequencies corresponding to the fundamental frequency (20 kHz) and plural harmonic components (40 kHz to 100 kHz) of the ultrasonic wave. It was found that the mortar samples influenced by the heat had clearly different vibration velocity rates respectively produced by the ultrasonic emission at each frequency. Thus, we could determine the effects that heat had on the mortar samples exposed to it.

1. INTRODUCTION

If liquid droplets and solid particles on the surface of an object are irradiated with a high-intensity aerial ultrasonic wave, they will be excited by the ultrasonic wave in a non-contact manner, and be instantaneously detached and removed from the surface of the object. In this case, it can be considered that the ultrasonic wave excites not only the liquid droplets and solid particles, but also the object itself. The ultrasonic waves directed onto the surface of the object converge to a point at a frequency of about 20 kHz. These ultrasonic waves have finite amplitudes and contain harmonic components at frequencies that are integral times higher than the fundamental frequency. By using such a high-intensity aerial ultrasonic wave with finite amplitude (at a fundamental frequency of 20 kHz), we attempted to determine the variation in the properties of an object, which was exposed to and affected by the high heat of a fire for example. The target object used for this study was an object made of mortar, which is a material typically used in construction. The method, which determines the properties or internal defects of mortar and concrete materials by contacting an ultrasonic transducer with the surfaces of the materials, has already been used. However, this method has to meet the requirements that the surface of any target object must be sufficiently smooth to be measured, and that a medium for improving acoustic coupling must be inserted between the measured surface of the target object and the ultrasonic transducer. However, the method using an aerial ultrasonic wave does not need to meet such requirements and it is expected that the method may be used to make a wide range of measurements in a relatively easy way. Moreover, in our research, we used ultrasonic waves focused onto a point, which may be used to determine a narrow range of variations in the properties of the object.

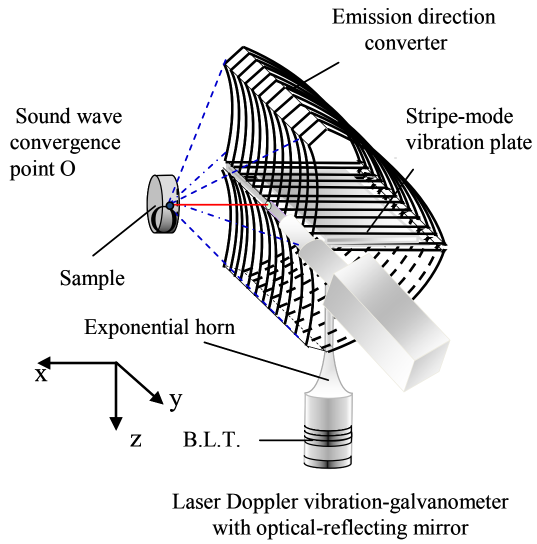
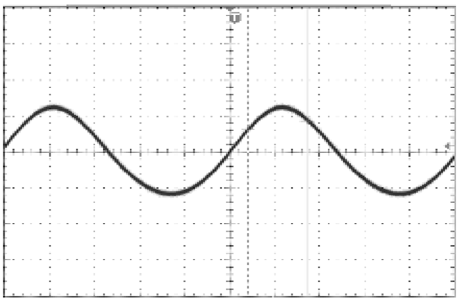


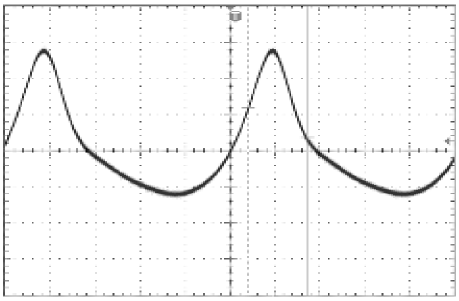
Figure 1. Ultrasonic source for producing aerial convergentultrasonic wave with finite amplitudeand schematic view of system used for experiment

2. EXPERIMENTAL DEVICE

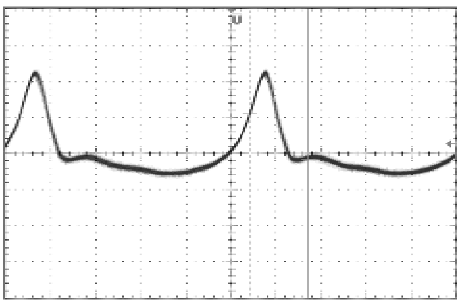
Figure 1 shows a schematic view of the experimental device that we used. A point-converging acoustic source of the stripe-mode vibration plate type (at a frequency of 20 kHz) was used to generate high-intensity aerial ultrasonic waves. This ultrasonic source comprised an ultrasonic transducer, a stripe-mode vibration plate, and an emission direction converter. The ultrasonic waves emitted by the vibration plate were focused on a point by the emission direction converter that comprised insulation plates and parabolic reflecting plates. The ultrasonic waves radiated by this acoustic source were converged on a circular section 10 mm in diameter which was placed 140 mm from the opening of the acoustic source, and the source thus provided intensive ultrasonic waves of about 4000 Pa at the supplied power of 50 W. In the experiment, the center of each sample was made to coincide with the convergence point O of the radiated ultrasonic waves, as shown in Figure 1. The sample was continuously irradiated with ultrasonic waves, and vibration displacements on the sample face irradiated with the ultrasonic waves were measured by using a laser Doppler displacement meter. Because direct incidence of laser light on the surface of a sample was difficult to achieve due to the construction of the acoustic source, a 90º-deflectable optical probe was used to measure the laser light, as shown in the figure.



(a) 0.5W



(b) 20W



(c) 50W

Figure 2. Sound pressure waveforms of focused ultrasonic waves with finite amplitude

3. CHARACTERISTICS OF CONVERGED ULTRASONIC WAVES FOR IRRADIATION

Figure 2 shows a waveform example of the high-intensity aerial ultrasonic wave radiated onto the surface of a sample for different electric powers of the sound source (the electric powers supplied to the sound source are 0.5, 20, and 50 W). In the case of the ultrasonic wave with finite amplitude, the ultrasonic wave propagation velocity is high if the sound pressure is plus and low if the sound pressure is minus. Therefore, as shown Fig. 2, on the time axis, the maximum amplitude of a wave moves to the left according to propagation, and the minimum amplitude moves to the right. Moreover, the waveform is distorted, as the amplitude grows with an increase in the supplied electrical power. In the frequency domain, the transformation of the shape of the wave due to distortion is observed as generation of a higher harmonic wave. Therefore, these ultrasonic waves consisted of the component at the fundamental frequency (20 kHz) as well as the harmonic components at frequencies that are integral times higher than the fundamental frequency.

Figure 3 shows the relationship between the sound pressure and the power supplied to the sound source, measured on the face of the sample (at Point O) when the sample plate was placed at the convergence point O of ultrasonic waves, as shown in Fig. 1.

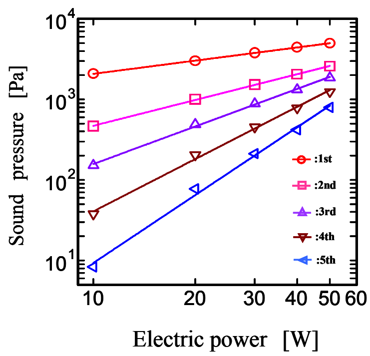


Figure 3. Relationship between electric power supplied to sound source and sound pressure atfundamental frequency of soundwaves and harmonic component

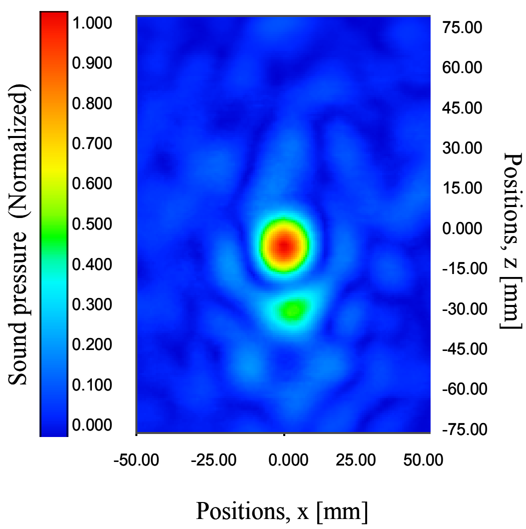


Figure 4. Sound pressure distribution on samples

In the figures, the vertical axis represents the sound pressure of the emitted ultrasonic wave, while the horizontal axis represents the electric power supplied to the ultrasonic source. The sound pressure was measured by a 1/8 condenser microphone (Model 4138 by B&K). The frequency of the measured sound pressure was analyzed by a fast Fourier transform spectrum analyzer. The figure shows that the sound pressure at the fundamental frequency (20 kHz) increases at a rate of about 1/2 power depending on the supplied power, while that for harmonics increases at the rate of a higher power depending on the supplied power as the frequency is higher.

Figure 4 shows the sound pressure distribution of ultrasonic waves radiated (at the supplied power of 30 W) on the plane x-z around the convergence point O. The ultrasonic waves are converged to a small and circular range around the point O.

4. NON-CONTACT EXCITATION OF OBJECT

First, we carried out basic experiments to determine the possibility of exciting an object in a non-contact manner by using the converged high-intensity aerial ultrasonic wave. Acryl and duralumin samples were used in these experiments. Table I gives detailed data of these samples. A paint for reflecting the laser light was applied to the surfaces of the acryl samples. As described above, vibration velocity was measured by radiating ultrasonic waves on the surface of a sample plate in such a manner that the center of the plate coincided with the convergence point O.

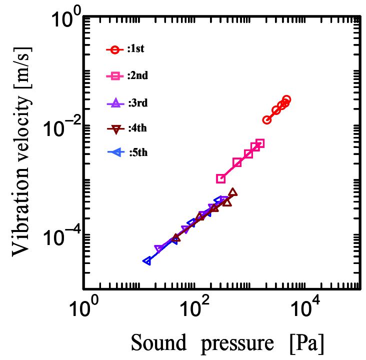
Table Ⅰ Details of samples

Material	Dimension [mm]	Thickness [mm]
Acryl 1	150×100	2.0
Acryl 2	150×100	5.0
Acryl 3	150×100	10.0
Duralumin	150×100	5.0

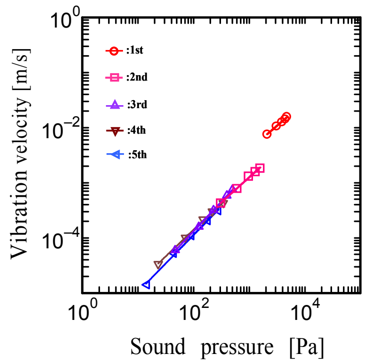
Figures 5 (a) to (d) show the results. As shown in these figures, in the case of 10-mm-thick acryl samples, the profiles showing the relationships between sound pressure and vibration velocity at the fundamental (first) to fifth frequencies are almost on the same line. This means that the relationships between the sound pressure of the radiated ultrasonic waves and the vibration velocity of a sample at different frequencies were almost the same. In the case of 5-mm-thick acryl samples, the profiles showing the relationships between sound pressure and vibration velocity at the second to fifth frequencies are almost on the same line, though the profile for the ultrasonic wave at the fundamental (first) frequency is deviated from this line. In the case of 2-mm-thick samples, the profiles for the ultrasonic wave at the first and second frequencies are largely deviated from those for the ultrasonic waves at the higher frequencies. This means that a sample is more liable to vibrate if the wavelength of the ultrasonic waves is greater than the thickness of the sample. The 5-mm-thick duralumin samples showed almost the same tendency as the 5-mm-thick acryl samples.

5. EXPERIMENTS ON HEATED MORTAR SAMPLES

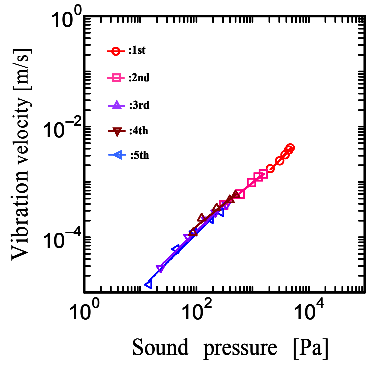
After obtaining the above results, we carried out experiments on heated mortar samples. Table Ⅱ gives detailed data of these samples. We used a mortar sample (MS20) that was not subjected to any heat (ambient temperature) and mortar samples that were exposed to atmospheres at temperatures of about 500℃ (MS500) and 1000℃ (MS1000), respectively, f-



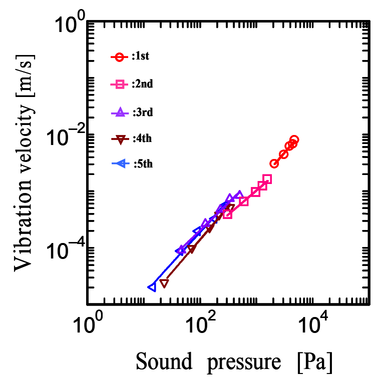
(a) 2-mm-thick acryl



(b) 5-mm-thick acryl



(c) 10-mm-thick acryl



(d) 5-mm-thick duralumin

Figure 5. Relationship between sound pressure and vibration velocity atconvergence point of samplesshown in Table Ⅰ

-or 30 minutes.

Table Ⅱ Details of samples

Mortar	Normal (MSA20)	500℃ (MSA500)	1000℃ (MSA1000)
Diameter [mm]	49.96	50.46	50.50
Thickness [mm]	21.42	19.84	19.52
Weight [g]	91.08	76.88	71.48
Volume [m^3]	4.197× 10-5	3.966× 10-5	3.908× 10-5
Density [kg/m^3]	2170	1939	1829

Figures 6, 7 and 8 show the vibration profiles of the mortar samples MS20, MS500 and MS1000 respectively. In the figures, the vertical axis represents the vibration velocity, while the horizontal axis represents the sound pressure of the emitted ultrasonic waves, and the striated dotted lines are the gradient of vibration velocity at the (second to fifth) harmonic frequencies. The figures show that the 3 samples produced vibrations at frequencies corresponding to the fundamental and harmonic frequencies of the emitted ultrasonic wave with finite amplitude (Fig. 3). They also show that the vibration velocities increased as the sound pressure of the emitted ultrasonic wave increased. For the sample MS1000 as shown in Fig. 8, the vibration profiles at the fundamental frequency and each harmonic frequency almost fit the straight dotted lines as shown in the figure. For the sample MS20 (Fig. 6), however, the vibration profile for the fundamental frequency is largely shifted up from that for the harmonic frequencies. This means that the ratios of the vibration velocities at the harmonic frequencies to the sound pressure of the emitted ultrasonic wave were lower than the ratio of the vibration velocity at the fundamental frequency to the sound pressure.

Figure 9 shows the ratio (in percent) of the total vibration velocity at the (second to fifth) harmonic frequencies to the vibration velocity at the fundamental frequency, calculated from the results shown in Figs. 6 to 8. In the figure, the vertical axis represents the ratio (in percent) of total vibration velocity at the (second to fifth) harmonic frequencies to the vibration velocity at the fundamental frequency, while the horizontal axis represents the electric power supplied to the ultrasonic source.

This figure shows that the ratio (in percent) of harmonic components in the ultrasonic wave increased for each sample as the sound pressure of the ultrasonic waves emitted to the sample increased, and as heat had a larger effect on the sample exposed to it. If the same power was supplied to the ultrasonic source, that is, if ultrasonic waves of the same intensity were emitted onto mortar samples, the ratio (in percent) of of harmonic components in the ultrasonic wave was higher as heat had a stronger effect on the sample exposed to it. This means that the profiles of samples were clearly different, and that it is possible to determine the presence of heat in each sample as well as the effect of heat on each sample exposed to it, if a variable power in the range of 10 W to 50 W is supplied to the ultrasonic source.

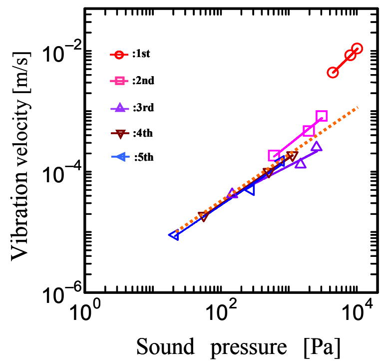


Figure 6. Relationship between sound pressure and vibration velocity at convergence point of mortar sample MS20

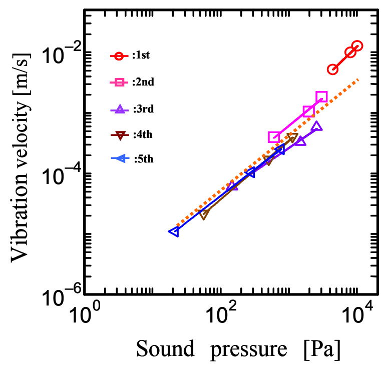


Figure 7. Relationship between sound pressure and vibration velocity at convergence point of mortar sample MS500

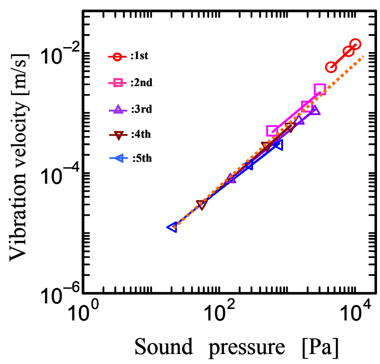


Figure 8. Relationship between sound pressure and vibration velocity at convergence point of mortar sample MS1000

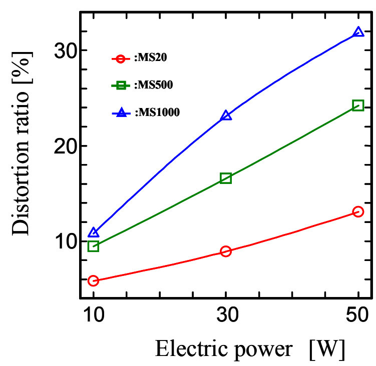


Figure 9. Ratio (in percent) of total vibration velocity at (second to fifth) harmonic frequencies to vibration velocity at fundamental frequency

6. CONCLUSIONS

The mortar samples exposed to high temperatures of about 500°C to 1000°C were excited in a non-contact way by using a high-intensity aerial convergent ultrasonic wave (at a fundamental frequency of 20 kHz) with finite amplitude. As a result, it was found that the mortar samples vibrated at frequencies corresponding to the fundamental frequency and the second to fifth harmonic frequencies (40 kHz to 100 kHz). It was also found that the vibration velocity of each sample depended on the intensity of the emitted ultrasonic wave, and that the vibration characteristic of each sample depended on the effect that heat had on the sample exposed to it. This means that it is possible to determine the heat received by a sample by measuring the ratio of the vibration velocity at a harmonic frequency to that at the fundamental frequency. To measure the ratio of vibration velocity, it was found that the appropriate range of intensities was 2000 to 4000 Pa for the emitted ultrasonic wave.

REFERENCES

1 Y. Ito, A. Oosumi, and N. Asakura: "Examination of Noncontact Excitation of Acrylic Board Using High-Intensity Aerial Ultrasonic Waves Having Finite Amplitude" Japanese Journal of Applied Physics **47,** 4292-4295 (2008)

2 Y. Ito: "The Motion of High-Intensity Aerial Ultrasonic Waves (20 kHz) Entering a Perforation" Japanese Journal of Applied Physics **41,** 3228-3231 (2002)

3 L. Tao, Y. Mpri, and S. Motooka: "Evaluation of Strength of Concrete by Linear Predictive Coefficient Method" Japanese Journal of Applied Physics **44,** 4358-4363 (2005)

4 M. Watanabe, M. Nishihira, and K. Imano: "Detection of Defects on Reverse Side of Metal Plate Using MHz-Range Air-Coupled Lamb Wave" Japanese Journal of Applied Physics **45,** 4565-4568 (2006)

5 D. D. Sukumana and Ihara: "Application of Air-Coupled Ultrasound to Noncontact Surface Roughness Evaluation" Japanese Journal of Applied Physics **44,** 4417-4420 (2005)