2Pa4-4

Drying of wet cloth by aerial intense ultrasound field formed by stripe-mode transverse vibrating plate

縞モードたわみ振動板によって形成した空中強力音場による水を含んだ布の乾燥

Tomoya Nakamura‡, Takuya Asami, Hikaru Miura (Coll. of Sci. & Tech., Nihon Univ.)
中村友哉‡，淺見拓哉，三浦　光（日大・理工）

1. Introduction

Recently, Peng et al. studied the removal of moisture from a wet cloth by direct contact with an ultrasonic vibration source[1]. In the present study, we investigated the noncontact drying of wet cloth using high-intensity aerial ultrasound. A wet cloth that is sufficiently larger than the wavelength of the sound wave and almost totally reflects the sound wave was installed in the antinode position in the standing-wave sound field formed by a stripe-mode transverse vibrating plate. We found that a high drying effect can be obtained by irradiation with ultrasonic waves[2]. In this study, to investigate the drying effect of ultrasound on a cloth placed at the node of sound pressure in the standing-wave field, the dry water content and drying rate were measured.

2. Stripe-mode transverse vibrating plate ultrasonic source

Figure 1 shows the outline of the ultrasonic source composed of a bolt-clamped Langevin-type transducer for 20 kHz, an exponential horn for amplitude expansion, a resonance rod, and a rectangular stripe-mode transverse vibrating plate (A 2017, length 103 mm, width 54 mm, thickness 1 mm). When the plate vibrated at its resonance frequency of 20.5 kHz, the mode in which 10 nodes of transverse vibration were generated almost parallel to the width was used. To form a strong standing-wave field, two sets of ultrasonic sources with the same characteristics were used. The two sets of sources were installed so that the stripe-mode transverse vibrating plates were parallel and faced each other. The distance between the vibrating plates was set at 28 mm, and a vertical reflector was set at about 2 mm (corresponding to 1/4 wavelength from the position of the node of transverse vibration closest to the end of the vibration) from the short side of the vibraton. Both sources were driven in phase. The sound pressure formed a standing-wave sound field measuring 1 wavelength in the z-axis direction and 5 wavelengths in the x-axis direction. When the input power was 20 W, the sound pressure at the antinode of the sound pressure was about 7 kPa (sound pressure level of 169 dB).

3. Drying experiment

In this study, drying sample were placed in the standing-wave field described in section 2, and drying experiments were carried out using ultrasonic waves.

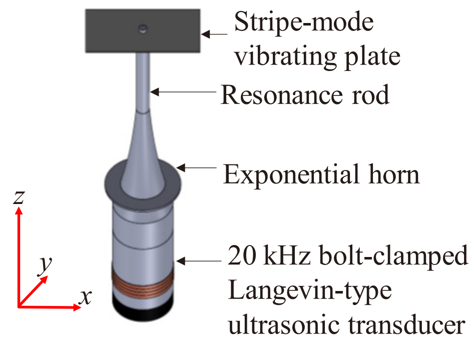

Fig. 1. Ultrasonic source.

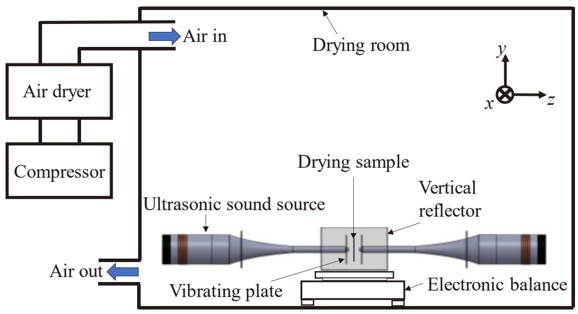

Fig. 2. Outline of the drying room.

3.1. Apparatus and drying method

Figure 2 shows an outline of the drying experiment apparatus. As shown in the figure, dry air from an air-cooled air dryer was supplied to the drying chamber. The weight of the dried samples in the drying experiment was measured using an electronic balance. The measurement conditions were as follows: the temperature of the drying chamber was 28 °C, the relative humidity was 20 – 25 %, the frequency was constant at 20.5 kHz, and the total power to the two sets of ultrasonic sources was 0 or 50 W. Because the electronic balance cannot read the weight during ultrasonic irradiation, the ultrasonic source was intermittently driven (alternating irradiation for 30 s and non-irradiation for 4 s).

E-mail: csto19026@g.nihon-u.ac.jp
asami.takuya@nihon-u.ac.jp
miura.hikaru@nihon-u.ac.jp

3.2. Drying sample

The drying sample used in the experiment was Kanakin 3 (size 80 × 30 mm, thickness 0.2 mm, dry weight 0.23 g, and 100 % cotton). To keep the sample parallel to the vibration, it was sandwiched between two sheets of stainless steel netting (SUS 304, wire diameter 0.5 mm, clearance 2.9 mm, porosity 64%). The sample was placed parallel to the diaphragm at the position of the antinode or node of the sound pressure of the standing-wave field between the vibrating plates.

3.3. Moisture content on a dry basis

To quantify the moisture content of the dry sample, the moisture content on dry basis was used:

$$\text{Moisture content on a dry basis} = \frac{W_W - W_D}{W_D} \times 100\ \%$$

where W_W represents the weight of samples containing moisture and W_D represents the weight of the sample after drying (no moisture). In the drying experiment, the initial moisture content on dry basis was assumed to be 150 %.

3.4. Experimental results

The experimental results are shown in **Figure 3**. In the figure, the vertical axis represents the moisture content on a dry basis, and the horizontal axis represents the ultrasonic irradiation time. The results for two installation positions of the cloth are shown. The broken purple line marks 20% moisture content on dry basis. It can be seen from the figure that the moisture content on dry basis decreased over time. The figure also shows that the drying time was shortened by the irradiation of the ultrasonic wave in comparison with the case of 0 W.

3.5. Drying rate relative to the location of the drying sample

The drying rate was defined as the change in water content per unit time in the drying sample to distinguish the difference in drying rate from the two installation positions of the drying sample. The drying rate was calculated from the results in Fig. 3. The results are shown in **Figure 4**. The vertical axis represents the drying rate, and the horizontal axis represents the ultrasound irradiation time. As shown in the figure, the drying rate increased from the beginning of the drying process when the drying sample was placed at the antinode of the sound field, and then decreased as it dried. When the sample was placed at the node of the sound field, the drying process was slow in the early stage, fast after about 50 s or more, and then slow again, with a decreasing rate as the sample dried. It was also found that the drying rate without the ultrasonic wave was slower than that with the ultrasonic wave regardless of the position of the drying sample.

4. Conclusion

In this study, a standing-wave sound field was formed using a stripe-mode transverse vibrating plate, and an experiment on cloth drying was carried out at the antinode and node positions of the sound field. The results showed that the drying rate of the cloth was faster at the antinode position of the sound field in the early stage of the drying process, and faster at the nodal position of the sound field during the middle stage of drying.

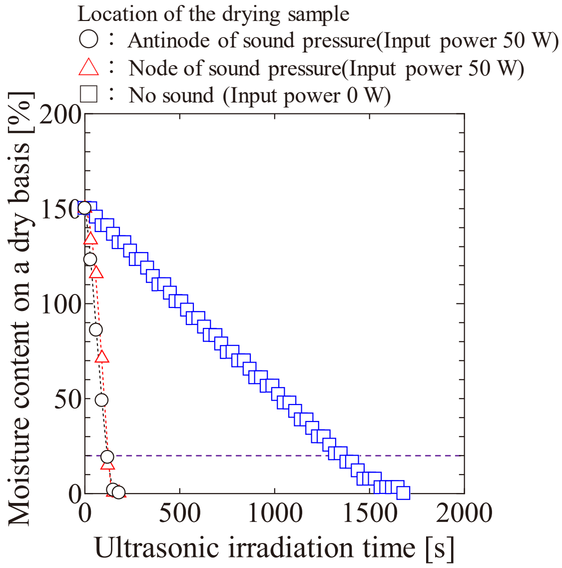

Fig. 3. Moisture content on a dry basis during ultrasound irradiation.

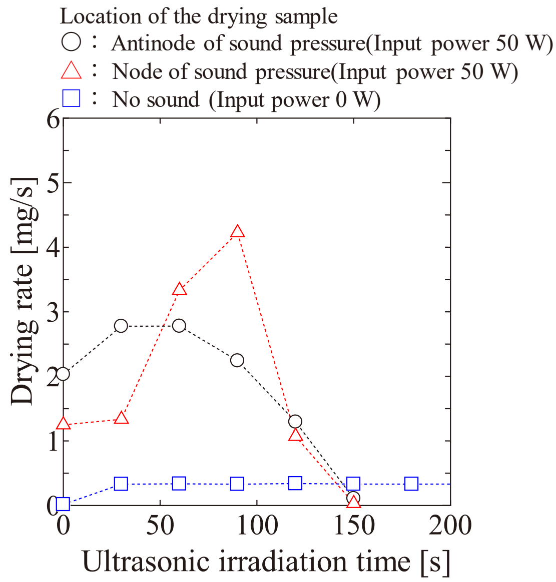

Fig. 4. Drying rate during ultrasound irradiation.

Acknowledgment

Part of this work was supported by JSPS KAKENHI Grant Number 18K11700.

References

1. C. Peng, etc., Energy, 125(2017), p. 498-508.
2. T. Nakamura, T. Asami, H. Miura: IEICE, US2019-74, 2020. 1. [in Japanese].