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Removal of extraneous matter by ultrasonic washing in running water

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ABSTRACT

Fused deposition modeling (FDM) is a fabrication method used in additive manufacturing. In FDM, support materials that act as splints can be required depending on the shape of the object, and the support material must be removed after the object is completed. The support material can be removed cleanly by using a water-soluble support material, but this method is lengthy. Ultrasonic washing with running water can remove the support materials locally and quickly by using the cavitation or acoustic flow generated by irradiating the water with strong ultrasonic waves. In this study, ultrasonic washing with running water was investigated using polyvinyl alcohol as a model of soiling. Running water irradiated with ultrasonic waves gave a substantially higher washing rate than unirradiated running water.

Keywords: Ultrasonic, Low frequency, Washing, Support material removal

1. INTRODUCTION

Three-dimensional printers (1, 2) use additive manufacturing technology; for example, the fused deposition modeling (FDM) method, in which a molded product is formed by laminating a plastic, such as acrylonitrile butadiene styrene or polylactic acid resin. For some objects, a temporary support material is required to form splints to support the resin; however, the support material must be removed after the object is completed. There are various methods for removing the support material, including using tools, water-soluble support material, washing liquid and an ultrasonic cleaner(3), and high-pressure water. However, there are problems with these removal methods. Removing the support material using tools is labor-intensive, small parts cannot be removed completely, and the object can be damaged. Water-soluble support materials take a long time to dissolve completely and the washing solution must be replaced many times. High-pressure water may also the damage the object and splash the surrounding area. To solve these problems, we have examined washing support materials in running water irradiated with low-frequency ultrasonic vibrations. Because The washing time was shorter and the object was cleaned uniformly irrespective of its size and shape.

In this study, the washing effect of the ultrasonic waves in running water in our ultrasonic washing device was evaluated quantitatively at various input powers. Polyvinyl alcohol (PVA)(4) was used as the support material.

2. ULTRASONIC WASHING DDEVICE AND EXPERIMENTAL METHOD

2.1 Ultrasonic Vibration Source

Figure 1 shows a schematic of the flow-through ultrasonic cleaner used in this study. The ultrasonic vibration source is composed of a bolt-clamped Langevin vibration transducer (D4427PC, Honda Electronics; 27 kHz, 40 mm in diameter, and 90 mm in length) and an exponential horn (diameter of thick end face: 40 mm; diameter of thin end face: 8 mm; material: duralumin) with an overall length of 111 mm.

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2.2 Washing Apparatus and Washing Method

The exponential horn is covered with an acrylic pipe from the flange to the thin end. The distance between the horn and the acrylic pipe is 1 mm. Water is supplied to the ultrasonic vibration surface at the tip of the horn from the water inlet and outlet attached to the acrylic pipe. Water flows in from the water inlet (indicated by the blue arrow in Figure 1), ultrasonic waves are applied through the ultrasonic vibration plane, which has a structure corresponding to the washed item. Water is supplied by a pump (NP-50, NAKASA) and the flow rate is adjusted with a valve.

The sample for washing is attached to the tip of the bar of a rod-shaped push solenoid (CH 12840250, Takaha Kiko) to control the position of the sample in the water and the washing time. Before and after washing, the water does not come into contact with the sample, because the solenoid rod is raised. During washing, the rod is lowered and the sample is placed in front of the water outlet.

2.3 Frequency Characteristics of Ultrasonic Vibration Sources

To investigate the vibration characteristics of the ultrasonic vibration source, the admittance was measured using an impedance analyzer (ZGA 5920, NF). The measurements were performed with a fixed driving voltage of 1 V_{rms} with no load (air) and with a load (water flowing through the pipe at a flow rate of 1 L/min).

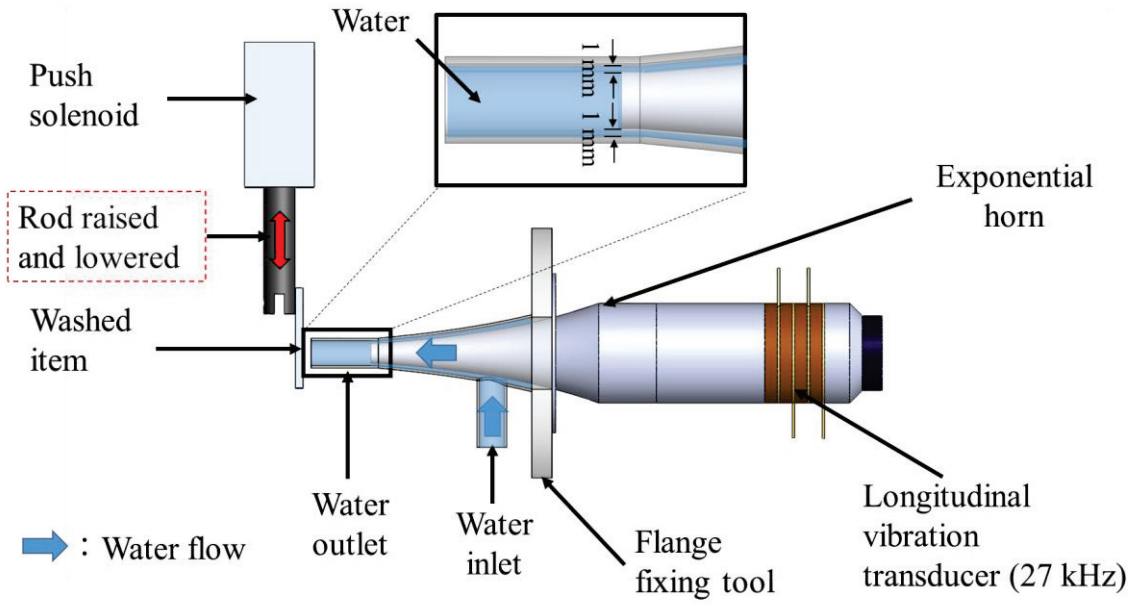


Figure 1 – Experimental device.

Figure 2 shows the conductance as a function of frequency. The results for no load are shown in black and the results for water flowing through the pipe are shown in red. With no load, the resonance frequency was 25.2 kHz, the conductance was 26.3 mS, and the Q value was 813. With the water flow, the resonance frequency was 25.1 kHz, the conductance was 6.75 mS, and the factor was 200.

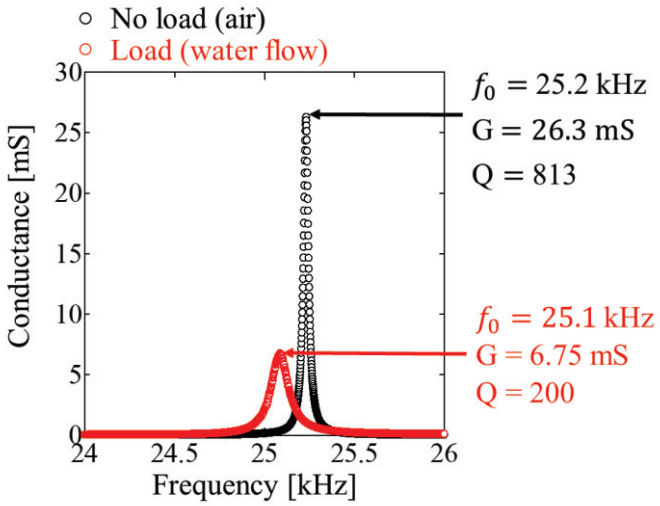


Figure 2 – Conductance as a function of frequency.

3. RESULTS OF WASHING EXPERIMENTS

3.1 Washing Effect on Paint

Figure 3 shows the appearance of a paint sample, which consisted of an acrylic plate (40 × 40 mm) with an area covered with black water-based paint (0.25 g) to model dirt. The sample was placed about 2 mm away from the water outlet parallel to the vibrating surface of the ultrasonic vibration source and was cleaned at various input powers.

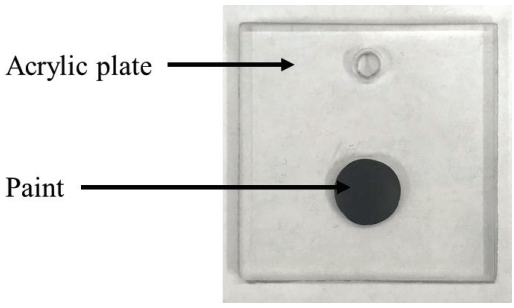


Figure 3 – Photograph of a paint sample consisting of paint on an acrylic plate.

The washing time was 60 s, the flow rate was 1 L/min, the input power was changed from 0 to 12 W in 2 W intervals, and 10 samples were cleaned for each input power. The washing rate was measured to determine the effect of changing the input power on the washing and was calculated by the gravimetric method using equation (1).

$$\text{Washing rate} = \frac{(W_s - W_w)}{W_s} \times 100\ [\%] \tag{1}$$

Here, W_s is the amount of dirt before washing and W_w is the amount of dirt after washing. Before washing, the samples were dried at 50 °C in an oven (DRE 320 DA, ADVANTEC), and then weighed. After the experiment, the samples were allowed to air dry for 24 h and were weighed. All samples were weighed using a universal electronic balance (MC 1000, Kensei Kogyo Co., Ltd.).

Figure 4 shows the washing rate as a function of input power for the paint sample. The washing rate is shown on the vertical axis and the input power is shown on the horizontal axis. The black circles represent the values of the washing rates of 10 samples, and the open circles represent the average washing rates. The average washing rate at 0 W (without ultrasonic irradiation) in running water was 28.7%, whereas that at 6 W was 92.1%. Thus, the washing rate with ultrasonic radiation was a maximum of about 3 times higher than that without. The washing rate increased from 0 to 6 W,

decreased from 6 to 10 W, and was constant from 10 to 12 W. These results could be explained by the increase in cavitation and the generation of microbubbles in the pipe as the input power was increased, and the sound field in the pipe was disturbed. Therefore, the ultrasonic vibration did not propagate readily through the water, and the washing rate is lower than that at input powers higher than 6 W (5).

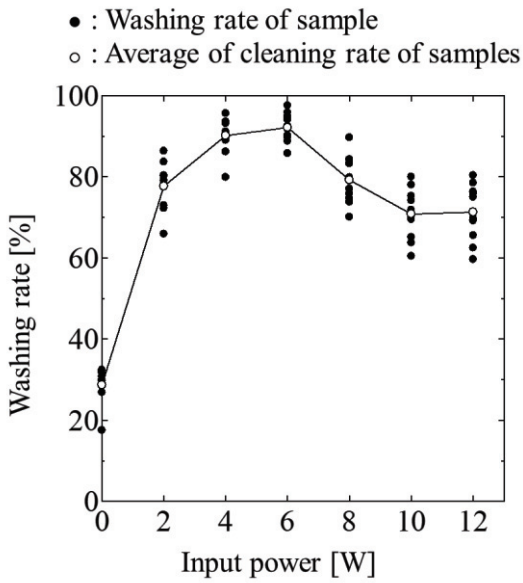


Figure 4 – Relationship between washing rate and input power for the paint samples.

3.2 Washing Effect on Water-soluble Support Materials

Figure 5 shows a photograph of the PVA sample used to investigate the washing effect on water-soluble support materials. Acrylic plates similar to those in Section 3.1 were used for the base to which 0.12 g of water-soluble PVA (PVA 175 N05KG, eSUN) support material was attached. The sample was placed about 2 mm from the water outlet parallel to the vibrating surface of the ultrasonic vibration source.

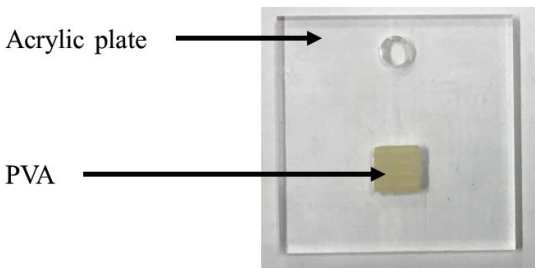


Figure 5 – Photograph of a PVA sample consisting of PVA on an acrylic plate.

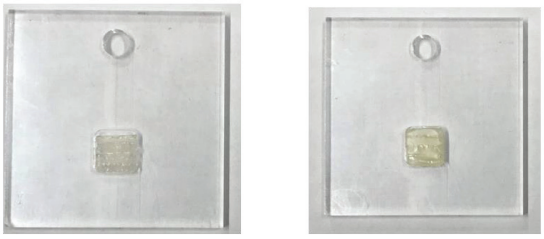
PVA samples were used to determine the washing rate with a washing time of 180 s, a constant flow rate of 1 L/min, and input powers of 0 and 6 W. The washing rate was calculated with equation (1) using the same method as for the paint samples in Section 3.1. The PVA samples were dried at 197 °C in the oven, and weighed. After washing, the samples were allowed to air dry for 24 h and weighed. All samples were weighed with the electronic balance.

Table 1 shows the washing rates before and after washing with and without ultrasound. Ultrasonication increased the washing rate by about 5 times compared with no ultrasonication.

Figure 6 (a) and (b) show photographs of the PVA samples after washing with ultrasonication and without ultrasonication, respectively. After washing with ultrasonication, the surface of the PVA was uneven and dissolved, whereas without ultrasonication the surface was flat.

Table 1 – Effect of ultrasound on weight and washing rate of PVA samples.

In running water	With ultrasonication	Without ultrasonication
Before washing (g)	0.120	
After washing (g)	0.055	0.109
Washing rate (%)	54.2	9.17



(a) With ultrasonication. (b) Without ultrasonication.
Figure 6 – Photographs of PVA samples after washing.

4. CONCLUSIONS

We examined the washing effect of ultrasonication in running water quantitatively by changing the input power. Paint samples were cleaned at input powers from 0 to 12 W, and the washing rate was highest at 6 W and was about 3 times that at 0 W. PVA support material was used for the PVA samples, and the washing rate at 6 W was about 5 times that at 0 W, demonstrating the effectiveness of ultrasonication for washing in running water.

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