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Investigation of cleaning effect by micro bubbles under ultrasonic irradiation
超音波駆動気泡による洗浄効果の実験的検討

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1. Introduction

Using ultrasonic cleaning, eco-friendly cleaning system is expected to be constructed. Previously, the ultrasonic cleaning have been used with chemical action of cleaning solution to achive a high cleaning effect. However, it will be abolished totally the use of CFC's substitute solvent as cleaning solution untill 2020 [1]. Therefore, the cleaning effect induced by physical forces of ultrasonic should be improved. One of physical forces results from cavitaion phenomena. Cavitaion is generation of microbubbles by caused the extremely decreased pressure. However, the cleaning mechanism is still unknown in detail, because it is difficult to observe rapid vibration of microbubbles under ultrasonic field.

In order to clarify relationship between the cleaning effect and bubble behaviors in ultrasound, we investigate how microbubbles induce cleaning effect by means of the high-speed video camera.

2. Experimental procedure

2.1. Preparation of sample

We use a slide glass (Size: 76×26 mm, Thickness: 0.8~1.0 mm) as cleaning object to observe clearly the cleaning effect by caused bubble behaviors. A thin film of pigment ink is removal object on the slide glass with the use with spin coater. The sample is heat-treatmented in order to prevent the ink from dissoluting to water in following experiments.

2.2. Observation of bubble behaviors

Focusing on the relationship between cleaning effect and bubble behaviors, we observe the cleaning process using high-speed video camera (HPV-1, Shimazu). The observation system is described in Ref. [2].

Figure 1 shows the structure of experimental cell. The experimental cell consists of acrylic container and a bolt-on Langevin typed transducer. The sample is set horizontally to the sound propagation axis. Initial bubble is adhered on the sample surface to facilitate the generation of cavitaion. The electrical signal into the transducer is 500 cycles sinusoidal wave with center frequency of 28 kHz. In this cell, the acoustic standing wave is formed during ultrasound irradiating .

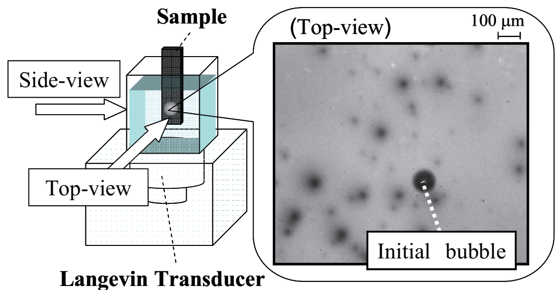

Fig. 1 The structure of experimental cell.

3. Results

3.1. Observation of cleaning process

Observation results showed that a bubble cluster was formed after the collapse of the initial bubble. The bubble cluster consisted of a main bubble and many small bubbles [see Fig.2]. We observed that vibrations of these microbubbles removed the ink from the slide glass. **Figure 2** shows images of typical cleaning process during one period of ultrasound. These images were observed from top-view. In Fig. 2(1), we can see significant removal of the ink. It is confirmed that the ink is removed around main bubble. We consider that the violent vibration of main bubble results in the considerable detachment of ink. On the other hand, many small bubbles were generated around main bubble as shown in Fig. 2(2). We can confirm that a portion of ink was removed [see Fig. 2(3)].

Observed small bubbles observed around main bubble were not real cavitaion bubble. However, small bubbles were repeated to generate and disappear while vibrating, this characteristic is similar with cavitation bubble. Therefore, the cleaning effect of small bubbles is discussed in the following sections.

3.2. Relationship between bubble behabiors and cleaning effect

It is known that violent bubble vibration

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generates the shock wave and rapid flow of ambient fluid. We conseider that these forces relate to removal of ink. Therefore, we investigate relationship between small bubble vibration and removal effect. Here, the bubble vibration was evaluated using maximum bubble volume during the expansion. This is because the contracted bubble could not be confirmed in observed images. **Figure 3** shows the relationship of maximum bubble volume and cleaning area. In Fig. 3, it can be confirmed that the cleaning area increases with an increase in the bubble volume. However, there was low close correlation between bubble volume and cleaning area.

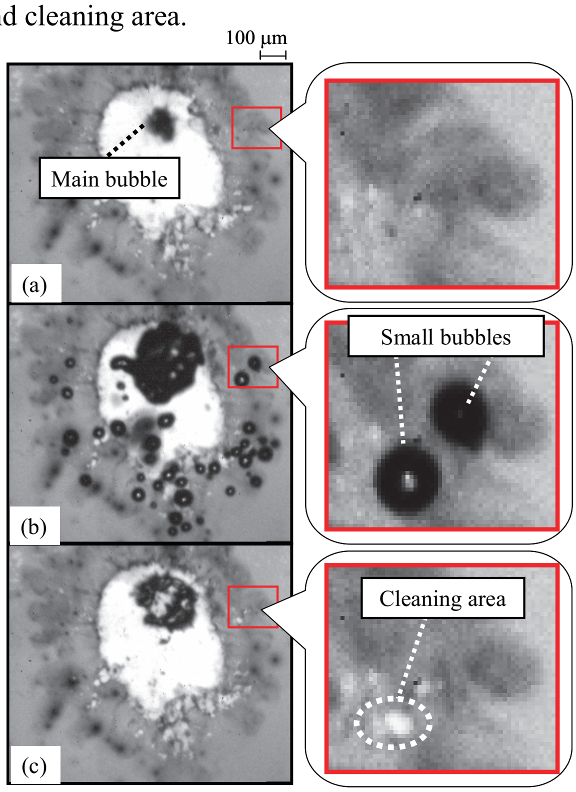

Fig. 2 Cleaning process by microbubbles(Top-view).

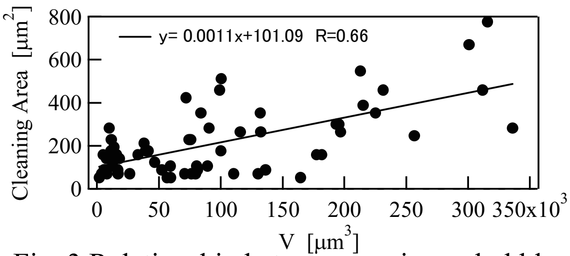

Fig. 3 Relationship between maximum bubble volume and cleaning area.

4. Discussions

We consider the low close correlation in Fig.3. This result is related to the distance between bubble and sample surface. The flow speed and pressure amplitude of shock-wave become decreased with an increase of distance from bubble. Therefore, we consider that cleaning effect depends on the distance between bubble and wall. To investigate how far small bubbles generated from the wall We observed bubble behaviors from side-view.

Figure 4 showed images of typical bubble behaviors. it was confirmed small bubbles were generated across a wide area from the upper of main bubble to the sample surface. Focusing on small bubbles nearby wall, bubble behaviors which contributes to removal of ink was observed. In Fig. 4(a)-(c), small bubbles contracted toward the wall. Thus, this is possible to influence generation of ambient fluid flow toward wall. On the other hand, micro-jet was observed clearly in Fig. 4(d)-(f). Above behavior could not be confirmed at far distance from the wall.

Aboved observed results suggested that bubble behaviors depended on the distance between the bubble and wall. This change of bubble behaviors affects the force acting on the wall surface. Although, it is possible that in the short distance bubble behaviors can give impacts on the wall, in the long distance they can not. Therefore, cleaning effect of microbubbles seems to be associated with this distance.

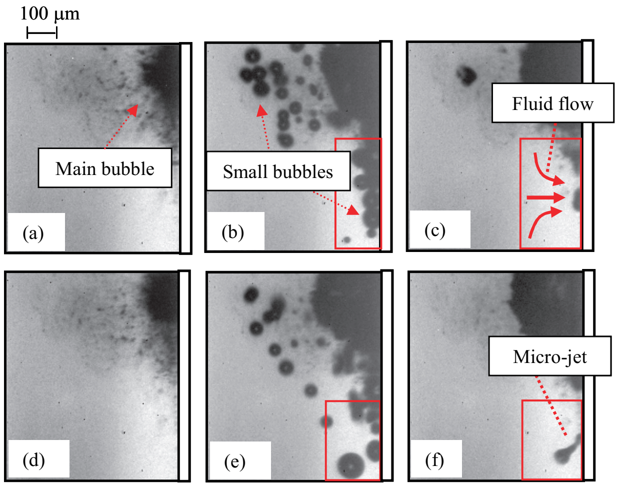

Fig. 4 Bubbles-behavior during two periods of ultrasound (Side-view).

5. Conclusion

In this paper, the cleaning process and bubble behaviors were opyically observed with the use of high-speed video camera. As the results, it is suggested that bubble vibration contributed cleaning effect. Further studies are necessary in order to investigate how the cleaning effect depend on the distance between microbubbles and sample surface.

References

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