INSTANTANEOUS BEHAVIOR OF CAVITATION CLOUDS AT IMPINGEMENT OF CAVITATING WATER-JET

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ABSTRACT

It is known that water-jet with cavitation clouds shows unsteady behavior and causes high impact. It is useful for not only the water jet technology but also various engineering fields. The unsteadiness of cavitation clouds is one of the most interesting problems for the use of the cavitating water-jet. In this study, we tried to estimate the behavior of the cavitation clouds at the impingement. Especially, the behavior of the cavitation clouds was observed using a high-speed video camera triggered by the cavitation impact, and analyzed with an image processing technique.

1. INTRODUCTION

It is known that a cavitation appears in a vortex ring at a jet boundary in water (e.g., Hoyt & Taylor 1981, Chahine & Genoux 1983). The cavitation forms high-impulsive cavitation clouds which show unsteady periodic behavior (Franc & Michel 2004, Saito & Sato 2003, Sato & Shimojo 2003). The cavitating-jet has been used for various engineering filed (for example; Cutting, peening or gettering). Recently, it is also widely used in the environment field. There are many studies for these cavitating-jet technologies (e.g., Kato 2003, Kumano & Soyama 2003). They show that erosion pits appeared to be a ring-shape distribution at material specimen, and that the weight loss of the specimen changes with the stand-off distance. And the distribution of impulsive pulses is also shown by many researchers (e.g., Yamaguchi & Shimizu 1987, Kobayashi et al. 1988, Yamauchi et al. 1995, Momma & Lichtarowicz 1995). There are, however, some instantaneous observations of cavitation clouds impinging on the wall, but there seems to be few examples of collapsing behavior directly related to its impact. So, we tried to quantitatively estimate the behavior of cavitation cloud synchronized with the impact.

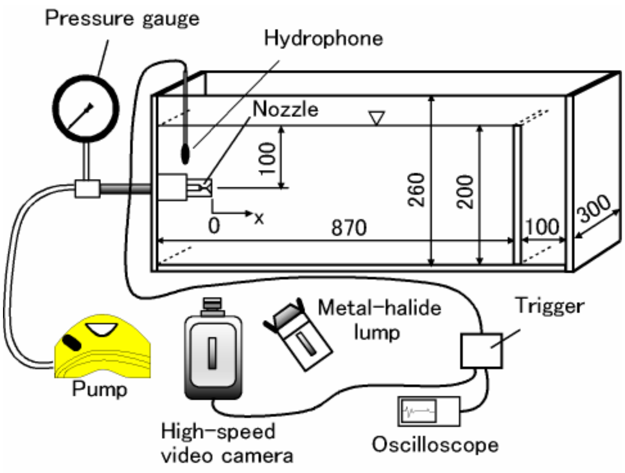


Fig.1 Test section

In this study, the cavitating-jet behavior impinging on the wall and its impact is measured simultaneously. Collapsing behavior of cavitation cloud, its impact and the erosion distribution are experimentally examined using an image processing technique.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 Observation of cavitation cloud

A water-jet vessel as shown in Fig. 1 was used for experiments. High-speed water from a nozzle was injected to the still water in the vessel by a pump. The test nozzle was a horn-type one which had a horn angle of 60 degree and 12 mm in length, a throat of 1 mm in diameter and 4 mm in length. Water was injected at a pressure of P_1=6 MPa into the vessel under atmosphere pressure P_2. In order to observe collapsing behavior of cavitation cloud on the wall surface, a transparent wall was placed in the normal to the axis of the jet. A mirror was placed behind the wall at the angle of 45 degree, so that the behavior of cavitation cloud could be observed from two directions. Erosion tests were performed during 15 minuets using an aluminum plate (A5052) placed at an arbitrary standoff distance x/d.

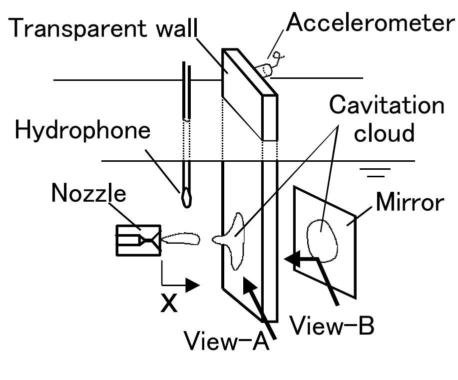


Fig. 2 Test section for observation from two direction

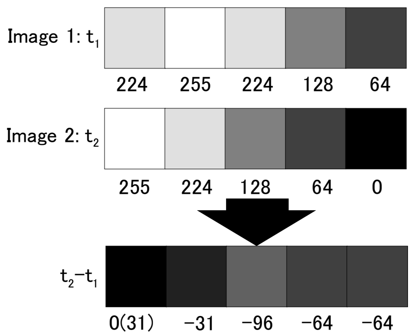
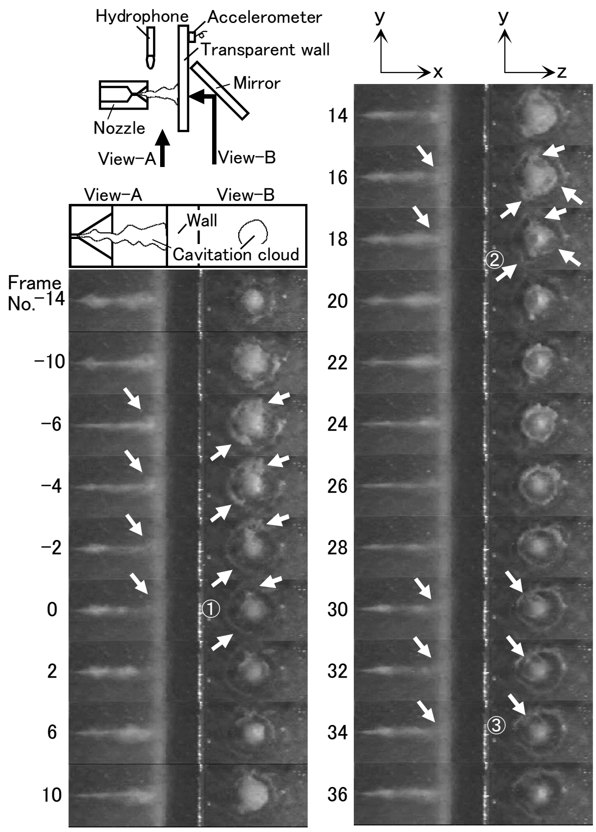
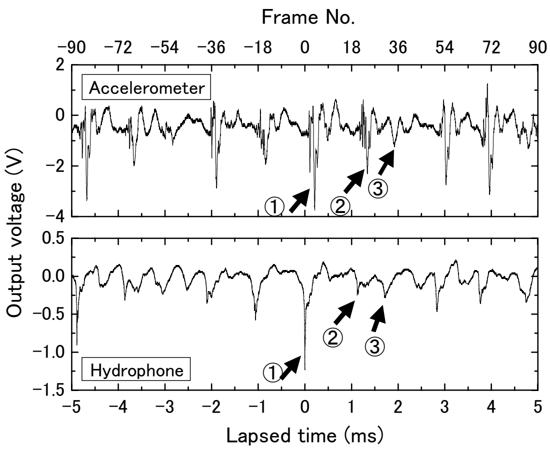


Fig. 3 Image processing method



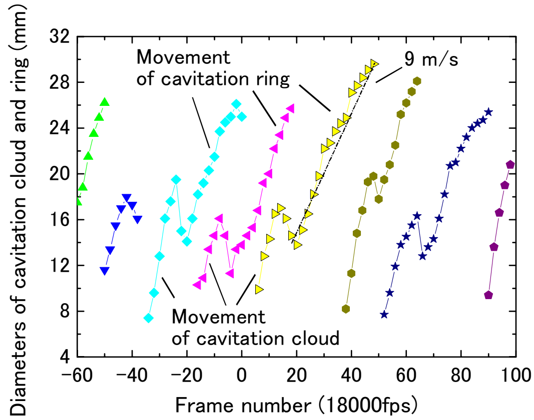
(a) Behavior of cavitation cloud



(b) Fluctuation of pressure and acceleration

P_1=6MPa, P_2=0.1MPa, β=8.0mg/ℓ, Tw=286K, Fs=18000fps

Fig. 4 Collapse of cavitation cloud with high impact



P_1=6MPa, P_2=0.1MPa, β=8.0mg/ℓ, Tw=286K, Fs=18000fps

Fig. 5 Spreading behavior of cavitation cloud on solid wall

Behaviors of cavitation cloud downstream of the nozzle were observed by a high-speed video-camera (Kodak, HS4540) triggered by a hydrophone (B&K, 8103) or an accelerometer (Teac, 703FB). Dissolved oxygen β was measured by dissolved oxygen meter (HORIBA, OM-51).

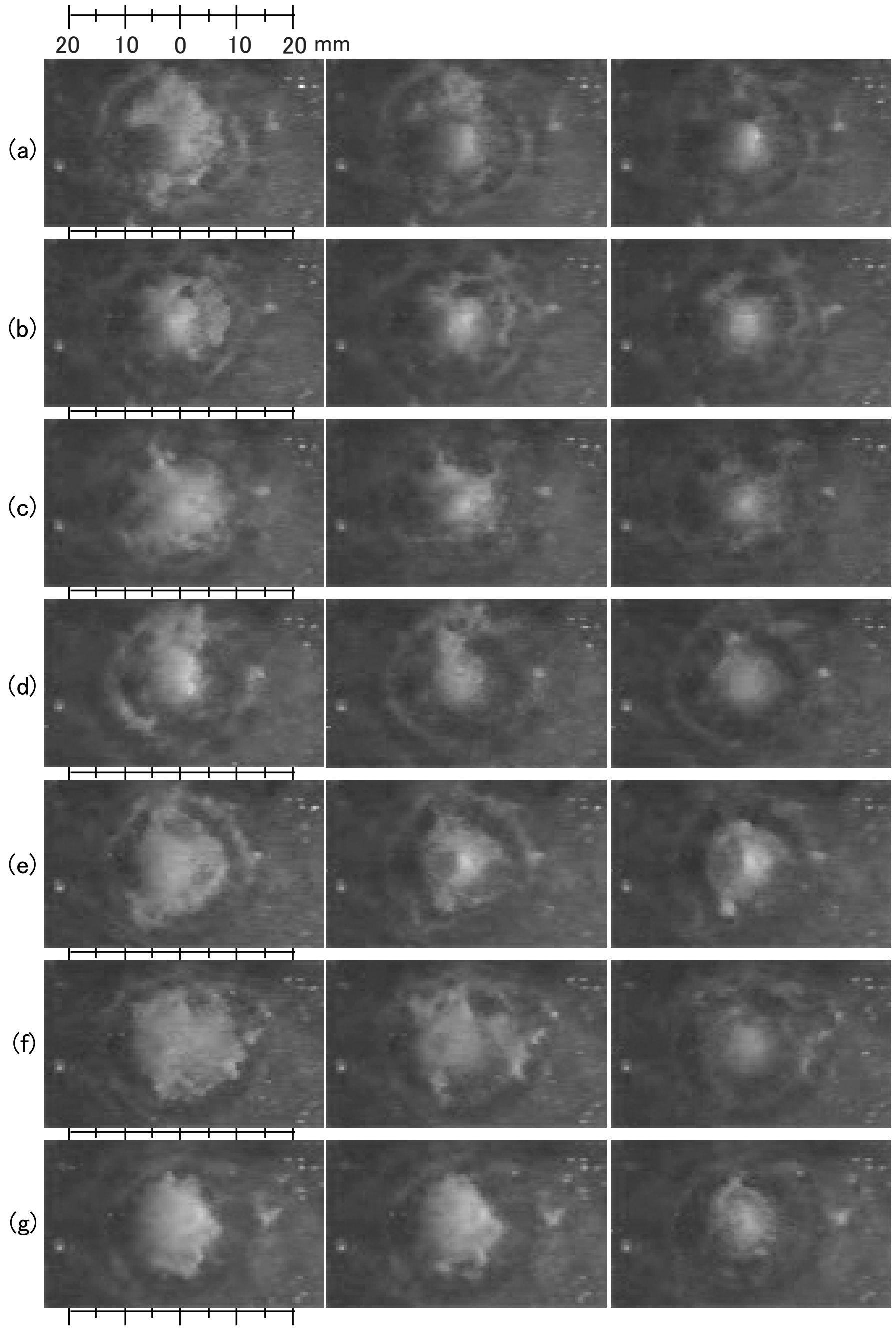
2.2 Image processing method

When the cloud collapses, the image intensity of cavitating region changes because small bubbles collapse with a chain-reaction manner. In this study, we tried to estimate quantitatively the behaviors of cavitation cloud using an image processing (Pham et al. 1999). The 256-tones picture was used for the image analysis. In the case of 2 images of different time t_1 and t_2 (t_1:Image1, t_2:Image2), the gray level of each cell was taken out and was estimated about the intensity change region with the difference in the every frame. Here, the sign of difference in two frames of Fig. 3 was finally inverted so that the change from white to black was made to be a positive value and negative value was 0. This technique was applied to a measured image in each time (each frame of the high-speed video camera), and a series of temporal change of the tone was illustrated. In the image of this object, the bubble region was whitely displayed. Here, the change from white to black was mainly analyzed in order to estimate the bubble collapse behavior. And, only the thin region near the center of the analysis was analyzed in order to estimate the cavitation behavior to the radial direction.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Behavior of cavitation cloud on the wall

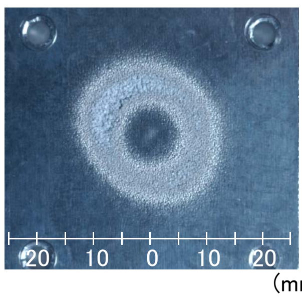
The result of observing the cavitating jet which impinges on the wall made of transparent acrylic resin is shown from two directions in Fig. 4(a). Here, the wall surface is installed for the position of x/d=25. They are results of observation from View-A observed from the transverse direction and from View-B observed from behind the impingement wall. And, Fig. 4(b) shows the output-voltage waveform of the hydrophone and the accelerometer measured simultaneously with the



Frame No.−2 Frame No. 0 Frame No. 2

P_1=6MPa, P_2=0.1MPa, β=8.0mg/ℓ, Tw=286K, Fs=18000fps

(b) Collapsing behavior of cavitation cloud



P_1=6MPa, P_2=0.1MPa, β=6.3−8.1mg/ℓ, Tw=288−293K
x/d=25, t=15min

(a) Erosion pit distribution

Fig. 6 Collapsing behavior of cavitation cloud and erosion pit distribution cavitation behavior shown in Fig. 4(a). The cavitation cloud periodically impinges on the wall. The cavitation cloud shows a ring-shape and spreads radially on the wall surface.

Figure 5 shows a change in the diameters of cavitation cloud and ring with lapse in time. Where the diameters were approximately measured by the width of cloud region in the z-axis (e.g. as shown in Fig. 4(a)). This behavior can be divided into two patterns. One is the pattern in which the cavitation cloud spreads toward the circumference of jet on the plate after the impingement. The other one is that of a ring-shape cavitation cloud which is formed around the collapse of the former-type clouds and moves outward on the plate. The cavitating jet impinges on the wall and collapses with spreading to a radial direction (around Frame No.0, 18, 34). Then, the cavitation cloud spreads to a radial direction. The movement velocity is estimated to be on the order of 5 to 10 m/s. By synchronizing with these collapses, the peak is detected for an output from the accelerometer and the hydrophone. With the periodic collapse of the cavitation cloud, the impact periodically attacks the wall surface.

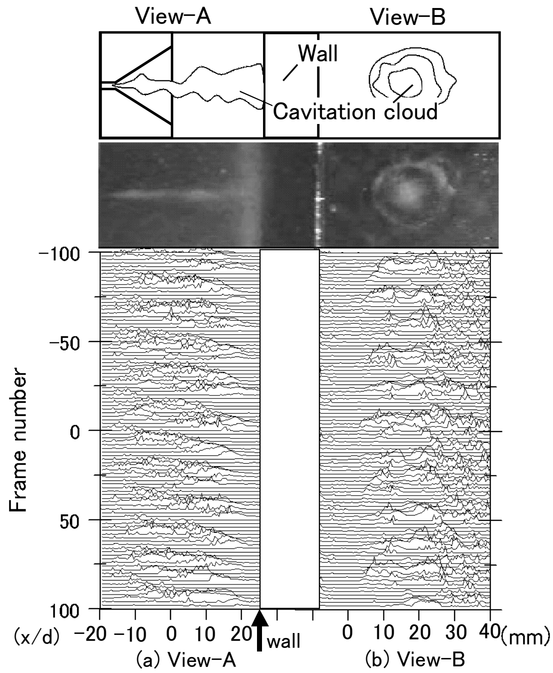
3.2 Collapse behavior at the impact generation of cavitation cloud

The high-speed video camera was synchronized with an output from the accelerometer installed in the wall surface where the cavitation cloud impinged as shown in Fig. 2, and the collapse of the cloud was observed in detail. Fig. 6(a) shows the photograph of the aluminum specimen after the erosion testing. Figure 6(b) shows the behavior of cavitation cloud around the time when the impulsive pulse is detected (Frame No.-2, 0, 2; here, Frame No.0 is the frame of cavity collapse). Here, both pictures of cavitation cloud and erosion distribution are shown on the same scale. The erosion test is preformed at a position of the standoff distance x/d=25, and the testing time is for 15 minutes. As a result of the erosion test, as shown in Fig. 6(a), there is the ring-shape cavitation damage, and this result corresponds with the previous study (e.g., Yamaguchi & Shimizu 1987, Kobayashi et al. 1988).

Collapsing behaviors of cavitation clouds are observed in Fig. 6(b). Collapsing cavitation cloud is located on or within the previously-shown ring-like cloud. That is, the whole of cavitation cloud collapses when it impinges to the wall and spreads to a radial direction. The position where the collapse of cavitation cloud is clearly observed agrees approximately with the position of cavitation damage distribution shown in Fig. 6(a). Afterwards, it seems that the cavitation cloud forms the ring shape, and spread to the radial direction. It is necessary to examine further the relation between this ring-like cloud and the vortex ring (Chahine & Genoux 1983) around the jet.

3.3 Analysis on behavior of cavitation cloud using image processing method

Figure 7 shows a result of image analysis for Fig. 4(a). The left-hand side of the figure (Fig. 7(a)) is the result of View-A and the right one (Fig. 7(b)) is of View-B. The change of the image from white to black, corresponding to the collapse (disappearance) of bubbles, has been chosen to be a positive value. Only the thin region near the center of the image is analyzed in order to pick up the cavitation behavior to the radial direction. The collapsing behavior of the cavity has the periodicity from the image of View-A for the jet behavior as shown in Fig. 7(a). However, the collapse behavior of cavitation cloud near wall surface appears to be not very clear, since the bubbly flow to the front (or back) direction interferes in observing. In the radial behavior of the cavity as shown in Fig. 7(b), some peaks accompany with the change from the white image to the black one, that is, the disappearance region of cavitation clouds radially spreads with lapse in time. And, there are some rather high peaks in the region of 8～15 and 22～30mm in the horizontal axis of Fig. 7(b). These peaks indicate the rapid collapse of cavitation clouds. The ring-like cavitation damage shown in Fig. 6(a) is evaluated to be about 10~25mm in diameter, and coincides with the collapsing region of the cavitation cloud in this analysis.



P_1=6MPa, P_2=0.1MPa, β=8.0mg/ℓ, Tw=286K, Fs=18000fps

Fig. 7 Image processing of cavitation cloud

4. CONCLUSION

The appearance of cavitating jet impinging on the solid wall was simultaneously measured with its impact. Quantitative estimation of the collapsing behavior of cavitation cloud was tried using the image analysis. And the collapsing behavior, impact and damage of cavitation cloud were related with each other.

(1) Collapsing behavior of cavitation cloud and its impact were measured simultaneously.

(2) Cavitation cloud impinges on the wall and spreads in a radial direction with the collapsing motion of clouds.

(3) Then the cavity forms a ring-like cavitation cloud accompanying with rebound motion and spreads in a

radial direction.
(4) Cavitation damage can be formed on the wall by the collapse of cavitation clouds impinging and spreading on the solid wall.
(5) The bubble collapse position was evaluated using the image analysis and related to the cavitation damage.

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