

Growth and Collapse of a Single Bubble near a Plate by Spark Discharge in Water

I Akcam^{1,2} K Inaba¹ K Takahashi¹ K Kishimoto¹

¹ Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo 152-8550, JAPAN

E-mail: akcam.k.aa@m.titech.ac.jp

Abstract. Single bubble dynamics in the vicinity of a solid boundary submerged in water were studied experimentally. Single bubble inside a water tank was generated by a spark discharge of capacitor into a couple of copper wires closing a simple circuit. A circular polycarbonate plate was placed horizontally above the bubble creation site. Polycarbonate plates with two different thicknesses were tested by changing the distance between the plate and the creation site. The effects of distance to the wall and wall thickness on the bubble motion is observed by considering the fluid-structure interaction. It is shown that motion of the two boundaries during the bubble generation differ from each other. Jetting behavior of two cases is also different.

1. Introduction

Establishing the interaction between the bubbly liquid and solid boundary is important in order to estimate damage mechanisms and potential and there have been many investigations on the bubble behavior or bubble dynamics near solid boundaries ^[1-7]. Emission of shock waves from a collapsing bubble, which are high-pressure pulses originate from the compression of bubble contents due to pressure difference with the outer surface of the bubble, was firstly demonstrated by the famous work of Rayleigh ^[1]. It is recently predicted that profile of a shockwave passing through a bubbly liquid is not uniform but gradually changing ^[8]. In order to estimate such profile, bubble motion should be known. It is known that if the boundary is flexible, the pressure variation of the fluid near the boundary will be different than that of a rigid boundary case. In order to reveal the effect of a flexible boundary, firstly single bubble motion by considering the fluid-structure interaction should be addressed.

In the present study, effects of a thin solid wall on cavitation bubble dynamics were investigated by observation of a single bubble generated by spark-induction technique near the wall. The purpose of this research was to investigate the effect of the motion of a solid wall, placed near bubble-generation site, on bubble dynamics by the pressure reduction around the bubble due to the Joukowski pressure that was created by the motion of the plate.

2. Experiments

Polycarbonate plates with different thicknesses were used in the experiment. High speed video camera, KEYENCE VW-9000 is used to record bubble generation and collapse. Matlab® Image Processing Toolbox is used in order to find the maximum radius and oscillation period. Polycarbonate circular plates of thickness 1 mm and 2 mm are clamped by a single steel annular disc of 4 mm thickness which is bolted to the main frame. Downward face of the polycarbonate plates are in contact with the water

² Author to whom any correspondence should be addressed



and four strain gages, shown as g1, g2, g3 and g4 in Figure 1, of 10 mm in distance to each other are applied to the upward face in order to observe the plate motion. Theoretically the radial and tangential strains must be equal due to the equi-biaxial membrane stretching. It is assumed that the plates are thin and deform like a membrane by Rajendran and Narasimhan [9]. All the effects of bending are neglected. Boundary condition of the plate is assumed as fixed boundary. Bubble is created directly under the center of the plate, which corresponds to the location of gage number 1, indicated as g1.

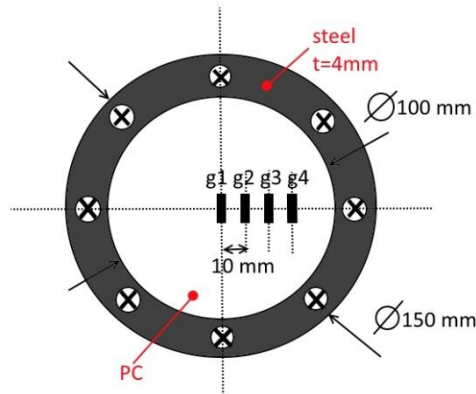


Figure 1. Schematic representation of strain-gage arrangement on clamped circular plate.

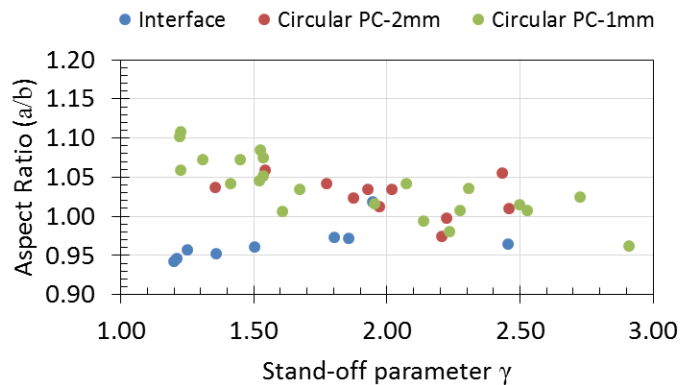


Figure 2. Aspect ratio vs. stand-off parameter of the bubbles near different boundary conditions.

Electrical discharge technique was employed in order to create a single bubble. Spark was generated by two electrode wires slightly in touch under water. Spark-generated bubbles are generally produced by high voltage, however, low-voltage can also be used provided that the electrodes in direct contact. This technique produces spherical bubbles of different sizes. The maximum bubble diameter depends on energy discharge from capacitor and diameter of generating wires.

3. Results & Discussion

Dynamical behavior of collapsing bubble near a boundary strongly depends on the non-dimensional stand-off parameter γ [2-3]. It is observed that as stand-off decreases, bubble takes a nearly ellipsoid shape due to interaction with the wall. In this study, bubble shape is assumed as an oblate ellipsoid and an equivalent radius of same volume of perfectly spherical case is approximated for the sake of simplicity. Non-dimensional stand-off parameter was defined as initial distance of boundary wall to bubble generation site divided by the maximum radius of the equivalent spherical bubble ($\gamma = L_i/R_{max}$). In order to indicate amount of deformation in the bubble symmetry, which is related to proximity of the bubble generation site to the solid wall, the aspect ratio (a/b) of the elliptically approximated cavitation bubble versus stand-off parameter is plotted for each boundary condition. Aspect ratio is defined as the ratio of major radius to minor radius, major radius being the smaller angle to horizontal, when bubble reaches its maximum equivalent radius R_{max} . It is seen that aspect ratio is larger and smaller than 1.0 up to $\gamma = 1.5$ for PC boundary plates and water-air interface respectively. After $\gamma = 1.5$, bubble converges to a spherical shape. Since 1 mm and 2 mm plates indicate similar behavior, plate thickness may not be dominant for the first expansion of the bubble.

3.1 Effect of Boundary Motion

Experimental results display the strain on the four points on the polycarbonate plates. Strain histories of the two plates are given in Figure 3. Figure 4 shows the strain signals with respect to specific times when

each gage reach its first peak value. According to Figure 3 and Figure 4, thinner 1 mm plate deforms slower than 2 mm plate and larger strains were observed with 1 mm plate.

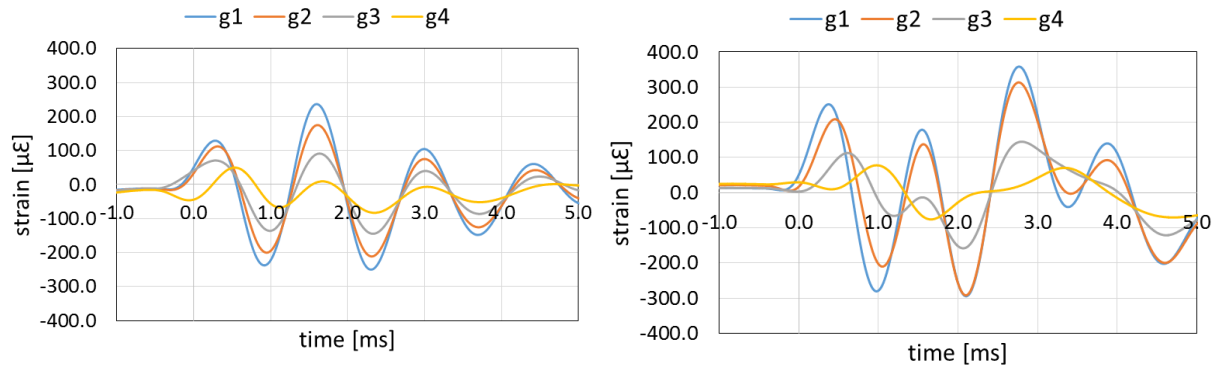


Figure 3. Strain signals from two plates (left) 2 mm (right) 1mm, $L_i=6.0$ mm, $\gamma=1.5$

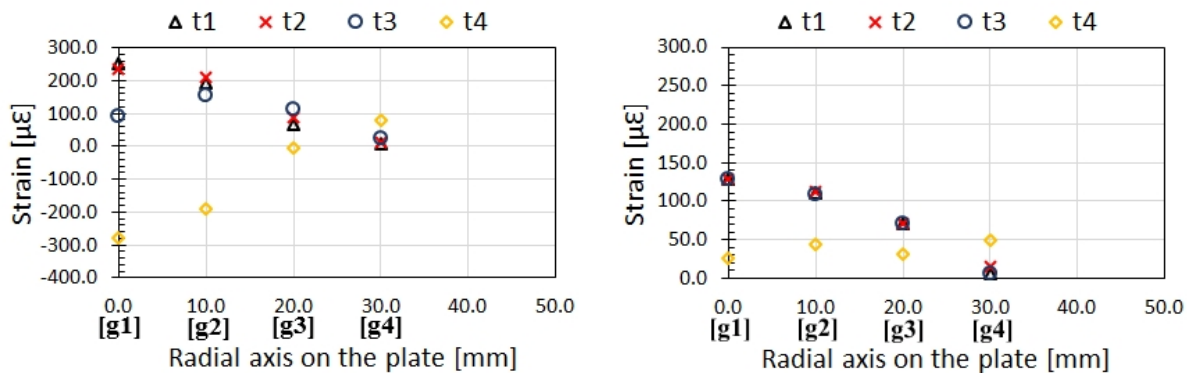


Figure 4. Strain signals from the gages along the radial axis for two plates (left) 2mm (right) 1 mm. t_1, t_2, t_3 and t_4 indicates the time gages g_1, g_2, g_3 and g_4 reaches maximum value, respectively.

3.2 Overview of Bubble-Boundary Interaction

Figure 5 illustrates the consecutive evaluation of bubble at a frame rate of 23,000 fps near two circular polycarbonate plates. It is observed that directions of the jets created during the collapse phase directed to opposite directions.

Jetting behavior of the bubbles are observed using different stand-off parameters for polycarbonate plates and no boundary case, i.e. water-air. During the experiments, it is seen that direction of the jet is always away from the boundary for the water-air interface. For PC plate boundaries, jet changes its direction towards to the boundary as the stand-off parameter decreases. The value of stand-off parameter to change jet direction is around $\gamma=1.80$ and $\gamma=1.20$ for 2 mm and 1 mm circular plate, respectively. Considering this behavior together with the different motion of the plates during the bubble generation, it can be said that fluid-structure interaction and plate flexibility plays an important role on collapse motion of the bubble.

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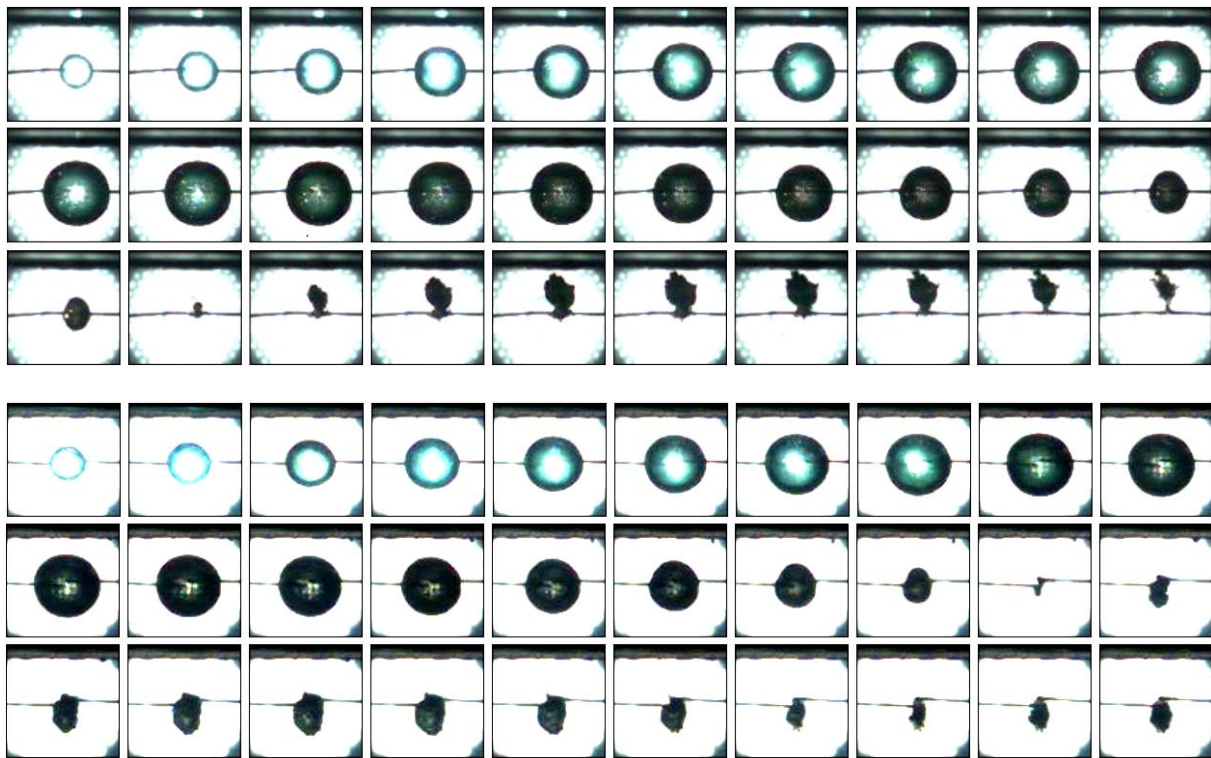


Figure 5. Bubble growth and collapse near polycarbonate plate of thickness (up) 2mm (down) 1 mm, $R_{max}=4.0$ mm, $\gamma=1.5$.

4. Summary

In this work, a single bubble created by spark-discharge near a polycarbonate plate. Bubble behavior for two different plate thickness and several initial stand-offs are observed. Plate motion is evaluated using strain gages. It is seen that for two different circular plates, plate motion is considerably different from each other. Direction of the jet is away from the boundary for both plates when the stand-off parameter is higher. Jet of the bubble changes its direction as the stand-off parameter gets smaller. Future work includes evaluation pressure reduction near the plate due to the different motions and its direct relation with the bubble behavior.

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