2P4-4

Single underwater spark discharge induced shock wave propagated within the waveguide
導波路形状内を伝搬する単一水中火花放電誘起衝撃波

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1. Introduction

High pressure pulsed waves such as shock waves in liquids are used for applications such as calculi destruction in human body[1)] and algicidal treatment[2)]. On the other hand, Ohl et al. have reported that foreign substances are taken into cells by a single shock wave generated by an extracorporeal shock wave lithotriptor[3)]. Until now, we irradiated without converging the single underwater shock wave to the human cells seeded on the bottom of the culture vessel in application to the foreign substance introduction[4)]. In this experience, shock waves induced by underwater spark discharge directly under the culture vessel propagate in a spherical wave shape. The shock wave power at the outside of culture vessel bottom becomes weak rather than that at the center, therefore, the pressure applied to the culture vessel bottom becomes nonuniform. In order to uniformly apply the pressure necessary for introducing foreign substances to adherent cells on the bottom of the culture vessel, it is necessary to convert the spherical wave to a plane wave with a short propagation distance beacause of keeping the enough high pressure.

Asaoka et al have been shown using three-dimensional sound field simulation that focuseed ultrasonic waves are converted to plane wave, and then those pressure can be averaged through a cylindrical acoustic waveguide[5)]. In this study, we experimentally investigated the effect of cylindrical waveguide propagation on single shock wave generated by underwater spark discharge.

2. Experimental procedure

2-1. Waveguide

In analytical model reported by Asaoka et al., water and air are used inside the waveguide and for the cylindrical part, respectively. In this structure, the acoustic energy is confined in the waveguide, however, cavitation occurs near the water/air interface in the case of high intensity ultrasonic waves. In order to avoid this problem, we propose the use of a waveguide wall whose acoustic velocity is faster than that of water. **Figure 1(a)** and 2(b) show the relationship between the cylindrical waveguide and the point acoustic source and the top view of a cylindrical waveguide, respectively. A polycarbonate (PC) plate is used as waveguide wall because of faster sound speed than water at the same temperature, excellent electrical insulation and shock resisitance. The shock wave from a point acoustic source propagates through the water filled column (waveguide). The position of the sound source is located on the central axis of the cylindrical waveguide. The waveguide diameter D was changed at the range from 0 (without waveguide) to 5 mm. The PC plate thickness h, which corresponds to the waveguide length, was fixed at 5 mm.

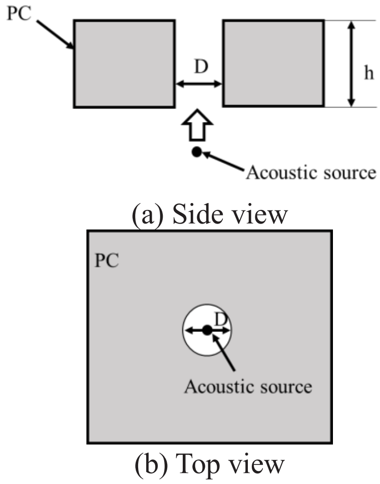

Fig. 1 Illusrations of the relationship between cylindrical waveguide and acoustic source in (a) side view, and in (b) top view.

2-2. Shock wave generation and measurement method

In this experiment, a high voltage is applied between two needle electrodes installed in water using an impulse voltage generator to induce a spark discharge and generate an underwater shock wave. This generator includes a charging circuit and a gap switch (GS). When a GS turns on, the charged voltage in the capacitor is applied to the needle electrode attached to the shock wave irradiation device[4]. In this experiment, the GS interval and needle tip distance were fixed at 3 mm and 2 mm, respectively. The applied voltage and the discharge current were measured using a high-voltage probe (Nisshin Pulse Electronics, EP-50K) and a current transformer (Peason Electronics, 110). These waveforms were measured using a digital oscilloscope (Iwatsu, DS-5414).

The PC plate with the cylindrical waveguide was fixed to the shock wave irradiation device by an acrylic plate. We assume that a shock wave source is located in the middle between the needle tips, therefore its position is placed on the central axis of the cylindrical waveguide. The shock wave irradiation device fixed at a PC plate with a cylindrical waveguide was immersed in an acrylic tank (100 x 200 x 100 mm) containing pure water. The tip of a hydrophone sensor (Muller Platte Needle Probe, rise time 50 ns, sensitive diam. <0.5 mm) was installed at the position of 1 mm away from the end of the cylindrical waveguide. In this experiment, the distance from the needle electrode to the tip of the hydrophone sensor was fixed at 8 mm.

3. Experimental results and discussions

3-1. Pressure waveforms

Figure 2 shows a typical pressure waveform, in which the red and black lines indicate the waveform through cylindrical waveguide (a diameter *D* of 4 mm) and without PC plate (without propagating through the waveguide), respectively. The time at the first rise position of the pressure waveform was set to 0 seconds. In Fig. 2, the applied voltage, peak discharge current, peak discharge power, and discharge energy were about 10.5 kV, 326 A, 1.78 MW, and 0.45 J, respectively. The both pressure waveforms showed steep pressure rise with a large positive pressure component. The pressure value of the shock wave propagated through the cylindrical waveguide became about twice large (31.5 MPa), as compared with that (15.9 MPa) of the shock wave without propagating through the waveguide. In the case of propagating through the cylindrical waveguide, the negative pressure was observed after the positive pressure component.

3-2. Pressure distribution

In order to investigate the pressure distribution at the end of the cylindrical waveguide, the pressure

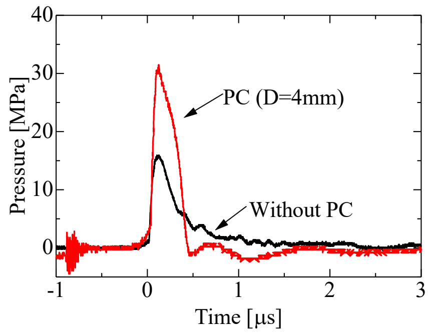

Fig. 2 Typical pressure waveform. The red and black lines indicate the waveform through cylindrical waveguide (a diameter *D* of 4 mm) and without a PC plate, respectively.

distribution was measured by moving the hydrophone sensor every 0.5 mm along the horizontal direction from the central axis. The maximum pressure values showed between 15 to 30 MPa within the range from the center to 1.5 mm, whereas, decreased sharply at the position of 2 mm and more from the center. The variation of the measured pressure value within a waveguide was similar to that of the underwater spark discharge induced shock wave[6].

4. Conclusion

It is found that maximum pressure of the single underwater shock wave generated by the spark discharge is enhanced by propagating through water cylindrical waveguide with PC as wall material. It is also seemed that the pressure within the waveguide is made uniform in plane.

Acknowledgment

This work was partly supported by JSPS KAKENHI Grant Number 18K04271.

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