Visualization of Underwater Sympathetic Detonation of High Explosives

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The experiment for the sympathetic detonation (Sudo et al., 1951) (Fukuyama et al., 1958) in water was conducted. Composition B (RDX: 64%, TNT: 36%, Detonation velocity: 7900m/s) was used for both donor (the thickness was 50mm, and the diameter was 31mm) and receptor charges. The distance between the donor and the receptor, and the thickness (5, 7.5, 10mm) of the receptor were varied in the experiments. In order to investigate the basic characteristics of the underwater sympathetic detonation of high explosive, the sympathetic detonation phenomena were visualized by a high-speed camera (HADLAND PHOTONICS, IMACON790) in forms of streak and framing photographs. The 200 ns/mm streak velocity was used when the streak photographs were taken. In the framing photographs, the interval time was 2μs. Manganin gauges (KYOWA Electronic INSTRUMENTS CO. SKF-21725) were used for the pressure measurements. The gauges were set under the receptor. The pressures during the complete and incomplete explosions were measured.

Key Words : Sympathetic Detonation, High-Speed Camera, Underwater Shock Wave, Manganine Gauge

1. Introduction

The shock wave and high-temperature gases are the active factors for sympathetic detonation. The basic characteristics of the underwater sympathetic detonation of high explosive were investigated. This study is important, since the data may result in a reference for designing a new device of high pressure generation. If underwater sympathetic detonation is initiated on a surface of a cylinder or spherical explosive, the detonation wave may converge at the center of the cylinder or spherical explosive charge. As a result, the device may generate high pressure, and can be used for material processing such as shock consolidation of metallic or ceramic powders.

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2. Photographic Study

In order to investigate the basic characteristics of the underwater sympathetic detonation of high explosive, the streak photographs and framing photographs were taken. The streak photograph can record a variation of a phenomenon on one axis. Therefore, it is often used to obtain the data such as the underwater shock wave or the detonation velocity. The framing photograph is

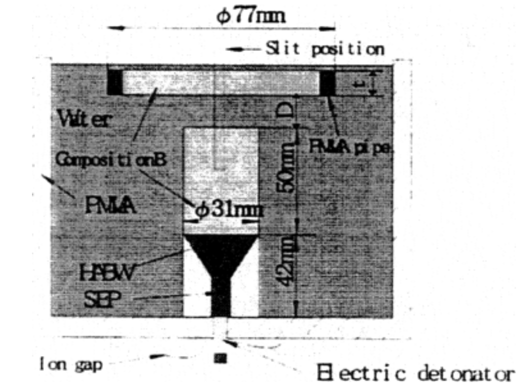


Fig. 1 Schematic diagram of optical observation device used in the experiment of underwater sympathetic detonation

taken with the selected interval time, and it is possible to judge the occurrence of the phenomenon such as the sympathetic detonation. The principle of shadowgraph method was used in these photographs. Shadowgraph method is a visualization technique which projects a shade of light generated by difference of the medium density on a screen or a film. Figure 1 shows the experimental set up. Composition B was used for donor and receptor charges. The thickness of the donor was 50 mm, and the diameter was 31mm. The diameter of the receptor was 77 mm, and the thickness were 5, 7.5 and 10 mm, respectively. As shown in Fig. 1, the receptor and donor charges were set in tank filled with water. The tank was made of PMMA plates. In order to obtain the flat detonation, an explosion lens (consists of SEP and HABW explosives) was set under the donor charge. **D** shows the distance between the receptor and the donor, and **t** shows the thickness of receptor in the figure. The dashed line shows the slit position, and the relation of the arrival distance of the underwater shock wave and time was recorded continuously on the film in the case of streak photographs (Itoh et al., 1995). The streak velocity was chosen to be 200ns/mm. Also, the configuration of the underwater shock wave from the receptor and detonation wave was observed in the framing photographs (Itoh et al., 1995). The interval time was 2μs. The camera is the image converter camera (HADLAND PHOTONICS, IMACON790, fastest framing speed 20 million fps, fastest streak writing speed of 1mm /ns). The illumination uses the Xenon flash light (HADLAND PHOTONICS, HL20/50 output 500J) of 50μs duration. In order to synchronize the detonating start time of the Composition B and the flash start time, a delay generator (HADLAND PHOTONICS, THREE CHANNEL DELAY GENERATOR and TYPE JH-3CDG) was used.

3. Measurement of Pressures

Figure 2 shows the set up for the measurement of pressure. As shown in the figure, the manganin gauge (Masimo et al., 1988 ; Nakamura et al., 1993) was set under the receptor charge, and the tank was filled with water. Utmost care was exercised to prevent the entry of water into the pressure measurment gauge.

The manganin gauge used in this study is a low-impedance gauge (0.3～0.6Ω) provided by the Kyowa Electric Instrument Co., Ltd. The gauge consists of a 6μm-thick manganin foil (83.5wt. % Cu, 11.5wt. %Mn, 4.4wt. %Ni) of 0.5～1.0mm in width, and 10μm-thick four-terminal copper foils which are placed on a 12.5μm thick polyimide film by the photoetching method. The manganin foil is connected on terminals by spot soldering and rolling. The length between the first and fourth terminal is 8.5mm. Section (A) shows the pressure measurement section in Fig. 3. The manganin foil between the second terminal and the third terminal is the pressure measurement section, and the pressure can be measured by varying the electric resistance in this manganin section.

Figure 4 illustrates the manganin pressure gauge. A PMMA plate of 2mm thickness was used as the stress medium in this study. A PMMA plate of 10mm thickness was used to protect and fix the gauge. Epoxy was used as the bond to fix the manganin gauge. The gauge was completed in the following way: PMMA-Epoxy-manganin gauge-Epoxy-PMMA. The total thickness of the manganin foil was reduced to about 30-35μm by decreasing the volume of solder and pressing the

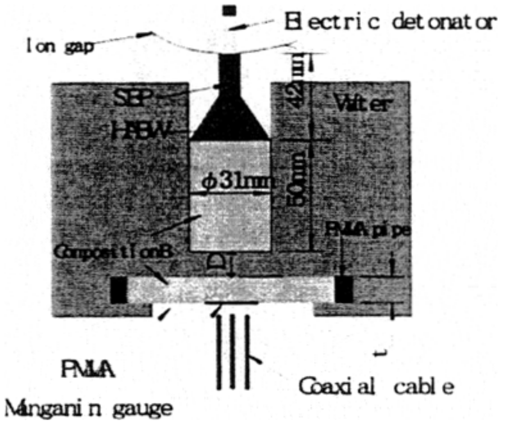


Fig. 2 Schematic diagram of pressure measurement by manganin gauge device

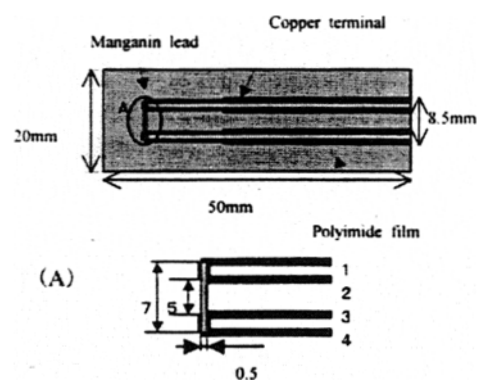


Fig. 3 Detail illustrations of manganin gauge(The manganin foil of between the second terminal and the third terminal is the pressure measurement section)

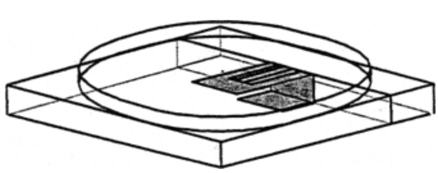


Fig. 4 Schematic illustration of the manganin pressure gauge(Upper plate was used as the stress medium, and lower plate was used to protect and fix the gauge)

junction part at the welded spot. In addition, the thickness was reduced to be less than about 10μm-thickness by pressing the gauge.

A circuit of the plus power source used in this studyis shown in Fig. 5. The electric power source

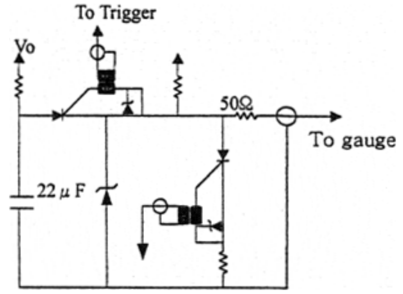


Fig. 5 Schematic diagram of the power source circuit for the manganin gauge method

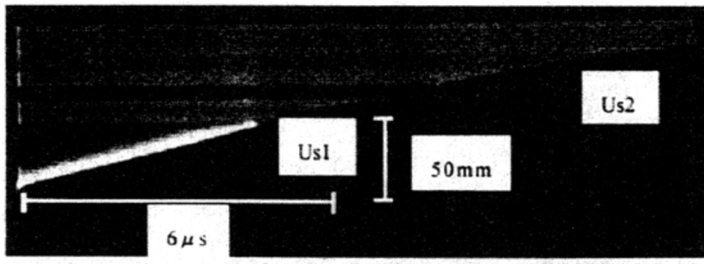
in the present study was made by Massimo. Its voltage is 500 Volts, and it can send a constant direct current (5~10A) within about 50μs. The state time for the current to become a constant is about 5μs after the trigger detected the input signal.

In this study, the digital oscilloscope produced by theLeCroy, Co., Ltd. Japan was used as the recorder of the output from the manganin gauge. The oscilloscope, the manganin gauge, and the source of pulse power were connected with a 50Ω coaxial cables (3D-2V) respectively. Sampling time of the oscilloscope is 2ns.

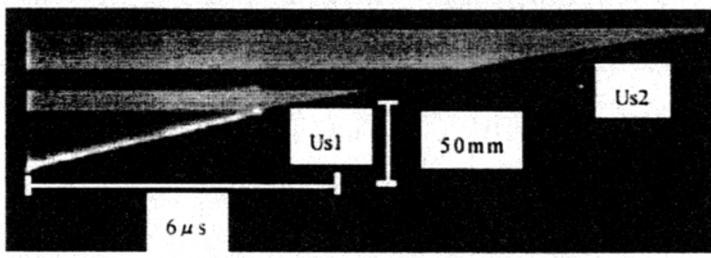
4. Results

4.1 Photograph

Figure 6 shows the streak photographs (Itoh et al, 1999) of a complete and an incomplete explosions. The experimental conditions are indicated in Fig. 6. A white line in the figure is an explosion wave that progresses in the donor charge. It was found that the underwater shock wave was generated from the upper surface of the donor and receptor charges. Both underwater shock waves (U_{s1} and U_{s2}) are shown in the figure. Since the receptor was covered by the PMMA pipe (which protects the receptor), it is difficult to judge whether the explosion has occurred or not, solely based on the streak photographs. Therefore, we make the judgement by measuring the difference between L_1 and L_2 for the optional time, where L_1 shows arrival distance of U_{s1} for the optional time, and L_2 show arrival distance of U_{s2} for the optional time.



a. Complete explosion (t=10mm, D=20mm)



b. Incomplete explosion (t=10mm, D=25mm)

Fig. 6 Streak photographs by Shadowgraph method (A white line is an explosion wave that progresses in the donor charge. Usl and Us2 shows the underwater shock wave)

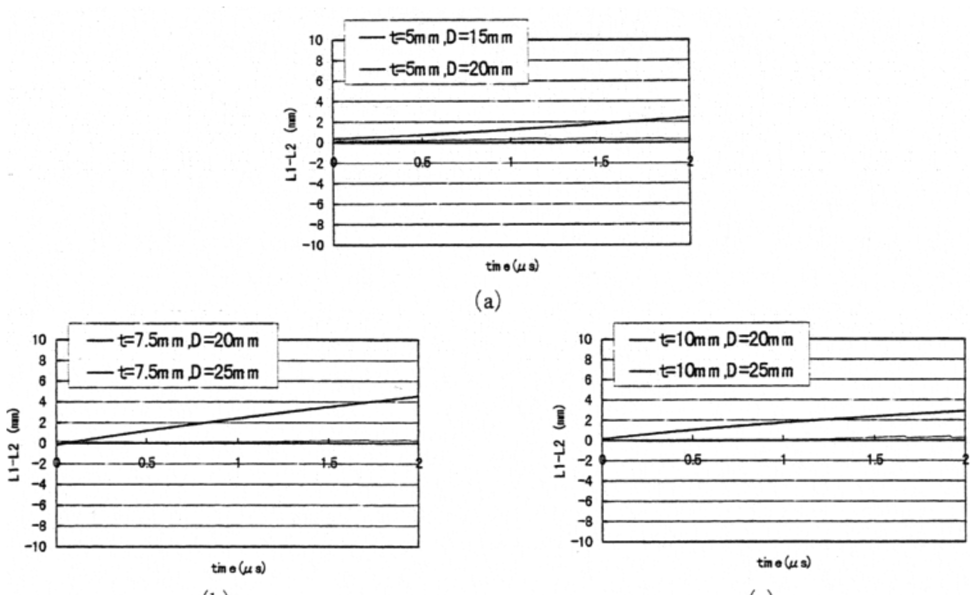


Fig. 7 Distance between L_1 and L_2 obtained form streak photographs (L_1 shows arrival distance of U_{s1} for the optional time, and L_2 show arrival distance of U_{s2} for the optional time)

The difference between L_1 and L_2 for the optional time is shown in Fig. 7. The vertical axis shows the difference between L_1 and L_2, and the horizontal axis shows the time. As shown in Fig. 7(a), where the receptor thickness was 5mm, the difference between L_1 and L_2 is practically nothing when D is 15mm. But the difference between L_1 and L_2 becomes large with the time when D is

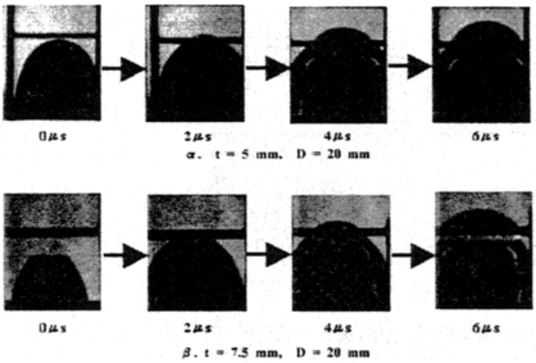


Fig. 8 Framing photograph by Shadowgraph method (The detonation wave was generating from the receptor charge in the case of β. But it could be seen in the case of α)

20mm. Therefore, it was found that when D was 15mm, the receptor was at the complete explosion, however, when D was 20mm, the incomplete explosion happened. Similar to Fig. 7(a), it could be judged that the complete or incomplete explosion in Fig. 7(b) and (c). As a result, it is observed that the thickness of the receptor changes the distance of the complete explosion.

The incomplete and complete explosion could be verified from framing photographs as well. Figure 8 shows the framing photographs of the propagating process of the underwater shock wave. The photographs have 2μs inter-frame time. Similar to those in the streak photographs, t shows the thickness of the receptor, and D shows the distance between the donor and the receptor. From the photographs we see that the underwater shock wave already hit the receptor, the detonation wave of the receptor in the α can not be seen. In the case of β, since both upper and lower of the receptor become white, it could be recognized that the complete explosion occurred in the receptor. Figure 8 gives the same result as Fig. 7. The accurancy of the photographic study could, thus, be ascertained.

From the results in Figs. 7 and 8, we found that a factor of the explosion delay. In this paper, the explosion delay means the time range in which the underwater shock wave hits the receptor till the beginning of the steady detonation.

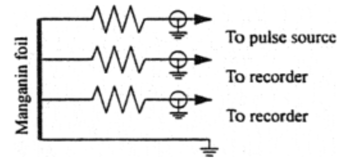


Fig. 9 Differential amplificationcircuit used to record the resistance of manganin gauge

4.2 The measurement of pressure

The circuit of the gauge is shown in Fig. 9. In this circuit, the first terminal was connected to the plus source, the second terminal and the third terminal were connected to the oscilloscope respectively. The forth terminal was connected to the ground.

The typical output of the manganin gauge measurement is shown in Fig. 10. After the trigger detected the input signal, the current was channeled by the power source into the manganin foil, The constant direct current was supplied at the point (A) in Fig. 10. The current and voltage loaded on the manganin foil were constant. Outputs of the second and the third terminals when the voltage was loaded shows two waveforms in Fig. 10. This potential difference was considered the voltage loading on the manganin foil itself. As the shock wave propagated into PMMA, the pressure measured by the recorder was the shock stress generated in PMMA. The shock front reached the manganin foil at the point (B). Soon after the shock front reached the manganin foil, the manganin foil was compressed and its resistance increased. So the voltage that loaded on the manganin foil (Potential difference) increased. The resistance change (ΔR) can be calculated by using this voltage change, the pressure is estimated from the relationship between the resistance change and shock stress. The relationship between the resistance change ($\Delta R/Ro$) and shock stress was given by Nakamura et al., 1993. The liner relationship was shown as follow.

$$\Delta R/Ro = -0.0329 + 0.0276\sigma x \qquad (1)$$

where Ro is zero pressure resistance, ΔR indicates resistance change, and σx is a peak of the shock stress. After the stress reached the peak stress

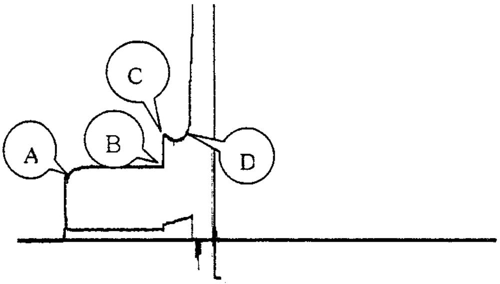


Fig. 10 Sample Output of manganin gauge method

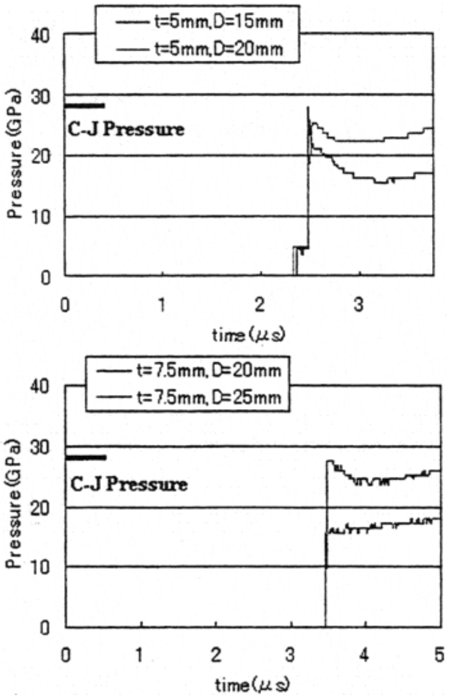


Fig. 11 The pressure history of output data obtainedby manganin gauge method in the underwater sympathetic detonation

shown in the point (C), it was decreasing at a short time, but a sudden ascending voltage was visible after the point (D). This correspondsto the destruction process of the manganin foil. Therefore, the significant data area is considereduntil the point (D).

Figure 11 shows the pressure history by manganin gauge. The experimental conditions are also shown in Fig. 11. In the case of t=5mm and D=15mm, maximum pressure value was 27GPa. This value agrees with the C-J pressure (Chapman-Jouget pressure) of the Composition B. As a result, it could be recognized that the complete explosion occurred in the receptor, when D was 15mm and t was 5mm.

But when D was 20 mm, the maximum pressure value is smaller than the C-J pressure. Hence, it could be concluded that incomplete explosion occurred. When t was 7.5mm, the maximum pressure value shows the C-J pressure even though D was 20mm. And when D was 25mm, the maximum pressure value was smaller than the C-J pressure. By comparison between the framing photograph and the pressure measurement, the occurrence of complete or incomplete explosion can be clearly judged.

5. Conclusion

The simple test of the underwater sympathetic detonation of Composition B were carried out by using high-speed camera and manganin gauge. The underwater shock waves from the top of the receptor and donor charge were taken by streak and framing photography. In the case of streak photography, complete or incomplete explosive was judged by measuring deference L_1 and L_2. In the case of framing photography, it was judged by observing detonation wave and underwater shock wave from receptor charge. The results of the optical measurement are as follows. When D was 20mm, 7.5mm thick receptor has a complete explosion, and 5mm thick receptor has an incomplete explosion. It is considered that a factor is due to the explosion delay for the thickness of receptor. Thus, difference of reaction for the thickness of receptor was also shown by pressure measurement. When D was 20mm and t was 5mm, maximum pressure was smaller than C-J pressure because the incomplete chemical decomposition (incomplete explosion) occurred in the receptor charge. However, in the case of 7.5mm thick receptor, maximum pressure value was C-J pressure because the complete chemical decomposition (complete explosion) occurred.

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