Article

A study on expansion process in the copper pipe by the detonation of PETN using metal wire explosion

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Abstract

The expansion process of copper pipes filled up with PETN has been investigated. A copper wire was exploded to initiate the PETN. In this investigation, the explosion power of copper wire and the expansion velocity of the copper pipes have been examined. The expansion of copper pipes was investigated in two sets. In one set of experiments, a metal wire was set at the central axis of a copper pipe (central initiation) and in the other set the wire was placed at 8 mm from the central axis of a copper pipe (eccentric initiation). In these results, the expansion velocity of the copper pipes using eccentric initiation was found to be higher than those of central initiation.

Keywords: Initial detonation, Metal wire explosion, Optical observation

1. Introduction

In recent years, the ability of high energy has been realized in many industries. Many manufacturing processes employing high pressure and the shock wave produced by the high energy are in practical use. There is a continued interest in understanding the response of metal structure when high energy is acted upon it.

The present study was undertaken to investigate the behavior of copper pipes when detonated by PETN. A copper wire exploded using wire explosion technique, was used to initiate the PETN filled in the copper pipes. The wire explosion technique generates plane shock waves produced by exploding parallel metal wire rows using a high voltage impulsive current[1)-3)]. The explosion power of the copper wire to detonate PETN, was initially evaluated. The evaluation was done by measuring the current value passed through the wire, the velocity and the pressure of underwater shock wave generated by the copper wire explosion. The expansion velocity of the copper pipe by the detonation of PETN was observed optically using high-speed camera.

2. Experimental method

2.1 Measurement of the explosion power of the copper wire

Firstly, we investigated the explosion power of the copper wire to detonate PETN powder (ASAHIKASEI CHEMICALS Co.). The copper wire used in this study has the diameter of 0.5 mm.The explosion power of the copper wire was evaluated from three experiments of the current measurement, the optical observation and the pressure measurement.

The experimental set up for the optical observation of underwater shock wave is shown in Fig. 1.The length of the explosion wire between the electrodes was 140 mm. A PMMA tank of 130 mm filled with water was kept in between the two terminals of the explosion wires. Both

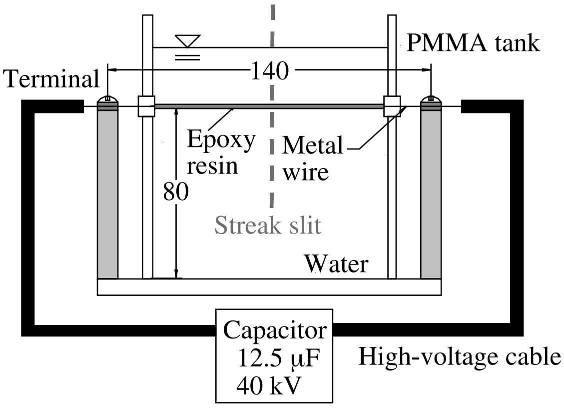

Fig. 1 Experimental setup for optical observation of underwater shock wave produced by metal wire explosion.

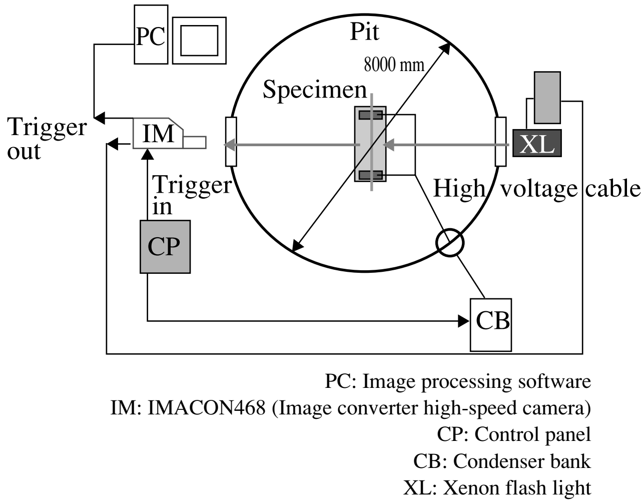

Fig. 2 Shadowgraph system for optical observation.

ends of the explosion wire were fixed to one end of a copper strip of 2 mm in thickness. The other end of the copper strip was connected to a high voltage cable. The strips rest on insulated bakelite plates of height 80 mm. The power was supplied to the high voltage cable from the condenser bank (NICHICON Co. maximum voltage 40 kV, electrical capacitance 12.5 μF, maximum energy 10 kJ).

The optical observation[4)] that uses the shadowgraph system was used to evaluate the underwater shock wave generated by the copper wire and the expansion process of the copper pipe. The shadowgraph system used in this study is shown in Fig. 2. This system uses a technique, also called as direct projective technique in which the shadow of the light was observed and projected by density change on a screen or the film of the camera. A high-speed camera, IMACON468 (HADLAND PHOTONICS, interframe times 10 ns to 1 ms in 10 ns steps independently variable, number of channels framing: 4 streak: 1) was used.

The Nonlinear Curve Fitting method[5)] was used for the approximation of the plot data on the streak photograph. This is a method of determining the coefficient of arbitrary function by the least squares method and can be applied for linear function or nonlinear function. We approximated the data measured from the photograph using the following equation on Nonlinear Curve Fitting method.

$$y = A_1 [1 - \exp(-B_1 t)] + A_2 [1 - \exp(-B_2 t)] + ct \qquad \text{(I)}$$

Where y is the perpendicular distance from the metal wire, t is the time, c is the sound velocity of water, and A_1, A_2, B_1 and B_2 are the fitting parameters determined by Nonlinear Curve Fitting method.

The Rogowski coil is used for current measurement. The Rogowski coil is a kind of current transformers. However, it does not have toroidal magnetic cores so that it is relatively easy to design for high frequency. Since there is no contact between the Rogowski coil and the conductor where the target current flows and the structure is simple, it is used widely. The diagnostic fundamental consists in the measurement of variation in magnetic flux produced by target current.

The pressure measurement of underwater shock wave was performed by the pressure transducer[6)] using the elastic bar and the semiconductor strain gauges. This transducer consists of an elastic bar, which receives the pressure of underwater shock wave, a protective cap (SKD 11, 18 mm in the outside diameter), and a protective stainless steel pipe (SUS 304, 18 mm in the outside diameter, and 3 mm in thickness). The elastic bar is a tungsten bar of 5 mm in diameter and 300 mm in length (0.2 % stress 1.4 GPa and dynamic Young's modulus 412.7 GPa and characteristic frequency 500 kHz). In this tungsten bar, two semiconductor strain gauges (Kyowa Electric Instrument Co., Ltd., 1 mm in the gage length, resistance 350 Ω, and maximum strain 3000×10^{-6} and gauge factors 151) are fixed at a distance of 30 mm from the pressure-receiving end. The elastic stress wave propagates through the bar when an underwater shock wave is received at the end of the bar and a potential difference is caused in the bridge circuit by the generated stress. The elastic stress in the tungsten bar is measured and the peak pressure of the underwater shock wave on the surface of the bar is obtained from the following expression by matching the acoustic impedance in water and tungsten bar.

$$P_w = \frac{1 + \dfrac{\rho_w \cdot C_w}{\rho_B \cdot C_B}}{2} \cdot P_B \cdot K_2 \qquad \text{(II)}$$

$$P_B = \frac{2E}{G \cdot V_C} \cdot K_1 \cdot V_{out} \qquad \text{(III)}$$

Where ρ_B is the density of tungsten (19088 kg m^{-3}), C_B is the sound velocity of tungsten bar (4650 m s^{-1}), E is Young's modulus, ρ_w is the density of water (1000 kg m^{-3}) and C_w is the sound velocity of water (1490 m s^{-1}). Also, the values of the constants K_1 and K_2 are 1.173 and 1.4

respectively. G is the gauge factor (144), V_C is the circuit voltage and V_{out} is the output voltage.

2.2 Experimental setup for the optical observation of the expansion of copper pipes

The process of expansion of copper pipes (D = 25.4 mm, L = 100 mm and t = 2 mm) filled up with PETN was investigated when PETN was detonated. The copper wire exploded by a high current was used to initiate PETN. The charge density of PETN used in this study was 800 kg m^{-3} and 900 kg m^{-3}. When the charge density of PETN is 800 kg m^{-3}, the C-J detonation velocity and the C-J detonation pressure are 4983.4 m s^{-1} and 5.65 GPa, respectively. When the charge density is 900 kg m^{-3}, the C-J velocity and pressure are 5367.3 m s^{-1} and 7.21 GPa, respectively. The experiments were conducted in two sets as shown in Fig. 3. A metal wire was set at the central axis of the copper pipes (central initiation) in one set, whereas in the other, the wire was set at 8 mm from the central axis of the copper pipe (eccentric initiation). The experiment was conducted in open air. The expansion velocity of the copper pipes was determined experimentally by optical observation using a high-speed camera.

3. Results and consideration

3.1 Copper wire explosion

The streak photograph of underwater shock wave generated by copper wire explosion is shown in Fig. 4. It is evident from this figure that the shock wave propagates in a self – similar manner. The streak photograph represents the time in the horizontal axis and the distance in the vertical axis.

The time and the current value taken for the initiation of the copper wire after the electric current was passed through the copper wire, along with the velocity of the underwater shock wave at 15 mm from the copper wire is presented in Table 1.

The pressure of underwater shock wave generated by the explosion of 0.5 mm diameter copper wire was measured at each 5 mm distance starting from 10 mm to 40 mm away from the copper wire. The variation of pressure with the distance is shown in Fig. 5.

3.2 Expansion process of the copper pipe

Figure 6 shows the framing photographs when PETN of charge density 800 kg m^{-3} was detonated at the central axis. A uniform radial expansion of the pipe can be observed as shown in the figure. A streak photograph taken for the same condition is shown in Fig. 7. The copper pipe started to expand after a time of 17.58 μs. This is due to the fact that the copper wire of diameter of 0.5 mm requires 13.24 μs to initiate PETN surrounding the wire,

Table 1 Experimental results.

Current (kA)	Initiation time (μs)	Velocity of shock wave (m s^{-1})
31.27	13.24	1838

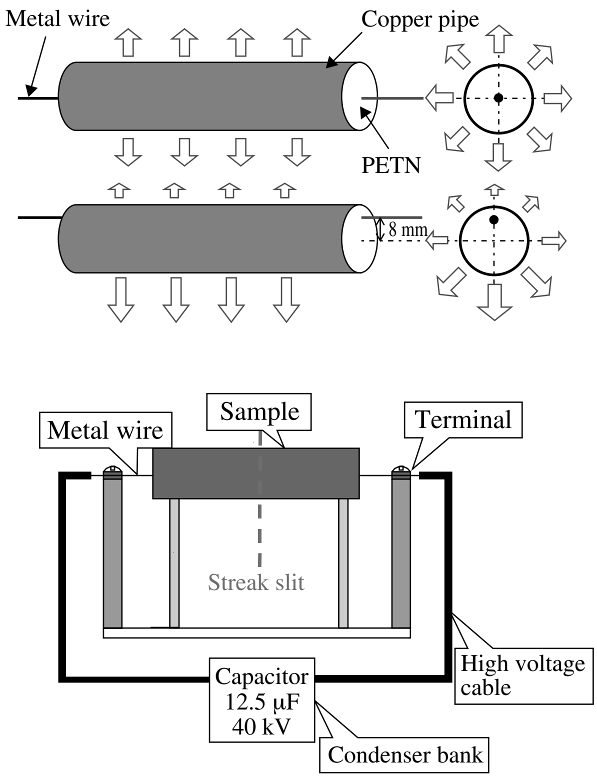

Fig. 3 Experiment setup used for expansion of copper pipe.

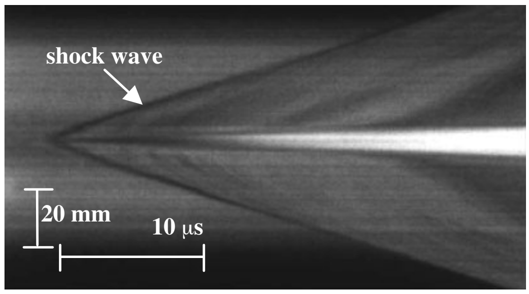

Fig. 4 Streak photograph of underwater shock wave generated by copper wire explosion.

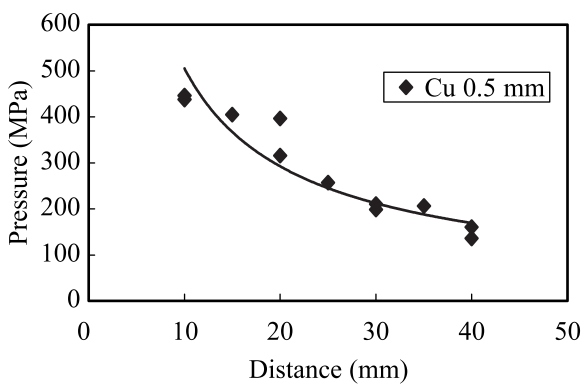

Fig. 5 Variation of pressure with distance for underwater shock wave.

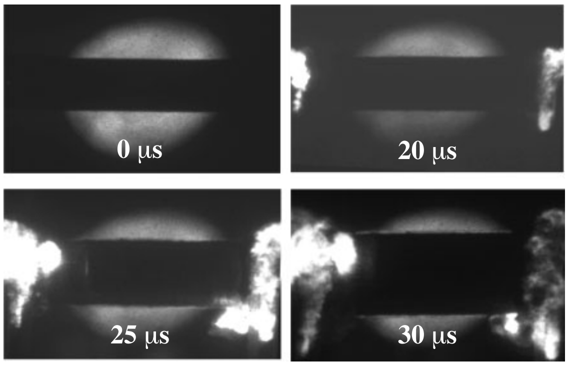

Fig. 6 Framing photographs of expansion of the copper pipes for central axis initiation.

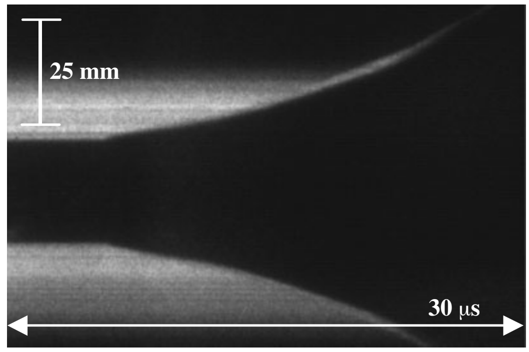

Fig. 7 Streak photograph of expansion of the copper pipes for central axis initiation.

after the electric current is passed through the copper wire. The time required by the detonation of the PETN to expand the copper pipe is 4.34 µs.

Figure 8 presents the relation between time and the radial distance of expansion of the copper pipe obtained from the streak photograph. In this case a charge density of 800 kg m^{-3} was used. The radial expansion distance reaches its maximum in value for the eccentric initiation towards the bottom side1 of the copper pipe. This could be attributed to the thickness of PETN along the bottom side in an eccentric initiation.

Figure 9 displays the expansion velocity history of the copper pipe as a function of time for central and eccentric initiation of PETN with a charge density of 800 kg m^{-3}. As indicated in Fig. 9, the expansion velocity varies according to the initiation and the amount of PETN used for the expansion. A considerable difference could be observed in the expansion velocity history obtained from the eccentric initiation towards the topside and bottom side. This is because that the velocity is not simply controlled by the thickness of PETN, and in this case the reflection waves can also play an important role. The thickness of PETN from the eccentric axis towards the topside was 2.7 mm and 18.7 mm towards the bottom side. This variation, in turn, significantly alters the duration of the reflection waves in eccentric initiation in contrast to that of central initiation. The velocity of expansion was found to increase drastically for eccentric initiation towards the bottom side and converged at a velocity of 1060 m s^{-1}. Conversely, the expansion velocity of the eccentric initiation at the topside was found to increase gradually. This could be attributed to the duration in the travel of the reflected shock waves. The distance was shorter towards the top, but after reflection at the top the distance towards the bottom was longer, which caused the attenuation of the waves. In the case of the expansion at the topside, the expansion velocity in the topside was not converged easily, because the travel distance of the detonation wave was shorter but thickness of the explosive was sufficient to produce energy in the bottom side.

Figure 10 presents the expansion velocity history of the copper pipe as a function of time for different charge densities initiated at the central axis. As suggested from higher velocity values for a specific time, one can see that the velocity produced from higher charge densities tend to be higher than those of low charge densities. It should be noted here that although the initial velocities rise at the earlier

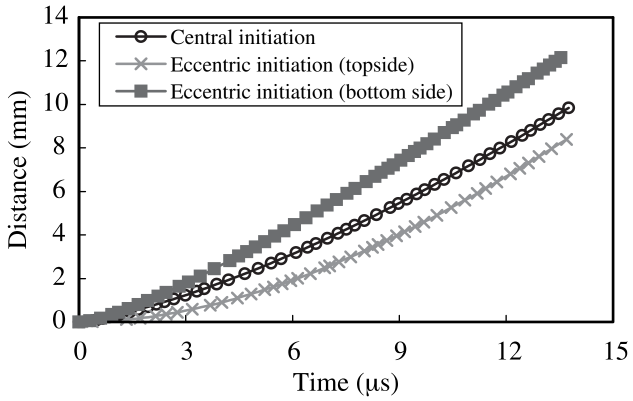

Fig. 8 Relation between the distance and time of the expansion of copper pipes.

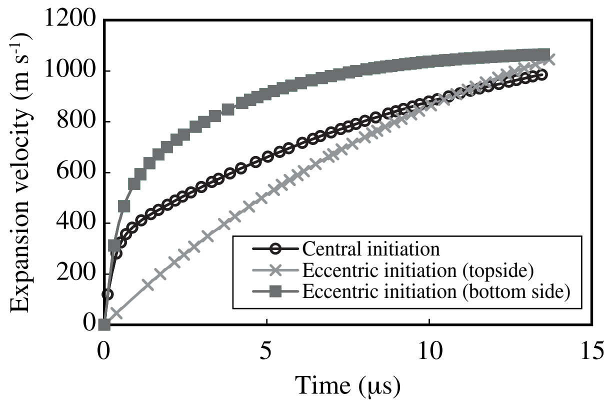

Fig. 9 Relation between velocity and time of the expansion of copper pipes.

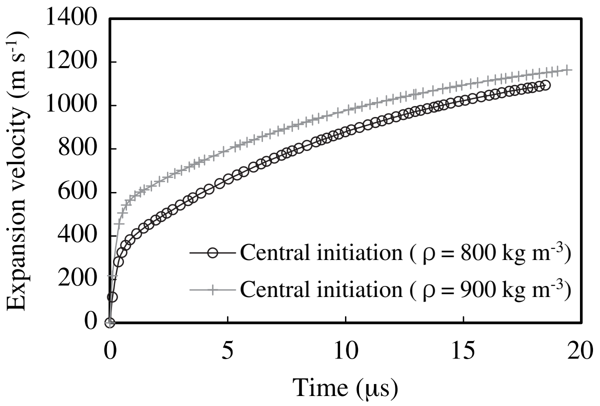

Fig. 10 Expansion velocity history of the copper pipes for different charge densities.

stage for higher charge densities, it tends to saturate at higher velocities and converges with the low charge density.

4. Conclusion

In this study, the explosion power of copper wire and the expansion velocity of the copper pipes were investigated. The explosion power of copper wire was measured by the current measurement, the optical observation and the pressure measurement. The velocity of underwater shock wave generated by copper wire explosion was determined as 1838 m s^{-1}. The expansion velocity of copper pipes varied according to the initiation and the amount of PETN used for the expansion. The expansion velocity of the copper pipes using eccentric initiation was found to be higher than those of central initiation. Research is underway to estimate the expansion velocity and the detonation pressure by the numerical analysis to compare with the experimental results.

Acknowledgement

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金属線爆発を用いたPETNの爆ごうが銅パイプの膨張速度へ及ぼす影響について

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爆薬が発生する高圧力，高エネルギーは様々な利用例があることが知られている。近年，爆薬の有効利用についての研究が盛んにおこなわれており，この利用の一つに金属線によって爆薬を瞬時起爆させることがあげられる。

本研究において，金属線爆発によって瞬時起爆された爆薬が対象物へ及ぼす影響および対象物の指向性について研究をおこなった。筆者らはPETN粉体爆薬が充填された銅パイプの中心軸上もしくは中心軸からある程度偏心させた軸上に金属細線を配置し，金属細線を衝撃大電流により起爆させ銅パイプの膨張を光学的に観察した。

光学的写真観察実験によって銅パイプの膨張速度を調査した結果，パイプの膨張速度はPETN粉体爆薬の薬厚，充填密度の違いにより異なることが明らかになった。

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