# Quantification and Maximization of Shockwave during Aluminum Wire Explosion

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***Abstract*— The purpose of this study is to quantitatively evaluate the shockwave generated during the rapid volume expansion of thin aluminum wire by applying pulsed power. Conventional building demolition work involves the use of dynamite and excavators, which are noisy and labor intensive. Another problem is the difficulty of moving heavy equipment in urban and residential areas. To solve these problems, we developed a new method that applies pulsed power to thin aluminum wires installed at demolition points in advance and utilizes the shockwaves generated when the aluminum wires are exploded. In order to obtain the highest shockwave pressure during aluminum wire explosion, we investigated the dependence of the applied voltage, wire diameter, current rise time, wire material, wire shape, and number of wires. The voltage and current waveforms were measured with an oscilloscope, and the shockwave generated by the wire explosion was observed using Schlieren method with a high-speed camera. As a result, what emerges from the wire explosion is a shockwave and an expansion wave of evaporated gas after the explosion. Shockwave was investigated in terms of average velocity and pressure. For the expansion wave, the arrival distance was investigated. It was found that the highest values for the shock force and expansion wave were obtained when the number of fine wires was increased, and their volume was large.**

***Keywords—shockwave, expansion wave, velocity, pressure***

## I. INTRODUCTION

The purpose of this study is to quantitatively evaluate the shockwave generated during the rapid volume expansion of thin aluminum wire by applying pulsed power.

Conventional building demolition work involves the use of dynamite and excavators, which are noisy and labor intensive. Another problem is the difficulty of moving heavy equipment in urban and residential areas. To solve these problems, we developed a new method that applies pulsed power to aluminum wire installed at demolition points in advance and utilizes the shockwaves generated when the aluminum wires are exploded. This is because the shockwave pressure is considered to exceed the compressive strength of the concrete, resulting in crushing.

We observed in water to visualize the shockwave. Although thin wires are crushed in solid such as buildings, this study quantitatively evaluates the velocity, pressure, and expansion force of thin wires by observing shockwave after it explodes in water. The principle of underwater shockwave generation is that water is heated by an electrical discharge in the liquid, and the shockwave is generated and propagated by the volume expansion of the water.

In order to obtain the highest shockwave pressure during aluminum wire explosion, we investigated the dependence of the applied voltage, wire diameter, current rise time, wire material, wire shape, and number of wires.

In this study, we focus on the velocity and pressure of the shockwave. For expansion waves, we focus on the reaching distance (degree of expansion). We also investigate what pulse power application conditions are optimal for these two waves.

## II. EXPERIMENTAL SETUP

### *A. Overrall Summary*

Fig. 1 and Fig. 2 show the thin wire arrangement and the experimental circuit, respectively [1]. Capacitor used in this study was 12.5μF, and distance between electrodes was 100 mm. Thin wire was adjusted to a length of 100 mm and connected straight between the rod electrodes. The electrodes with thin wire was placed in a 200 mm x 200 mm x 200 mm acrylic water tank, and the acrylic water tank was filled with tap water. After the voltage was applied, the temperature of the thin wire increases rapidly, and the wire explodes when it reaches the boiling point.

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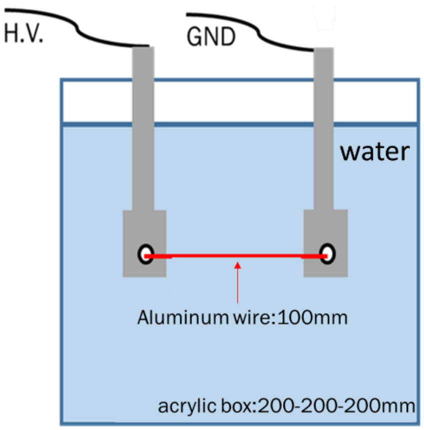

Fig. 1. Aluminum wire array arrangement in this study

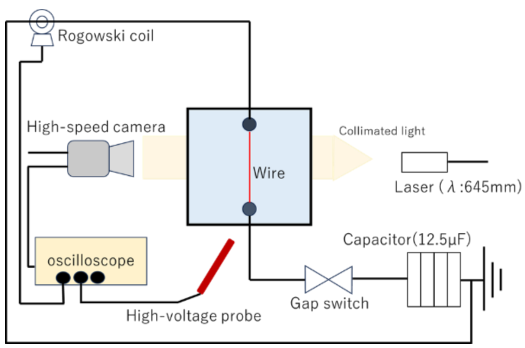

Fig. 2. Experimental Circuit

The voltage and current waveforms were observed with an oscilloscope, 256 images and movies were taken with a high-speed video camera (HPV-X2, Shimadzu Corporation, Kyoto, Japan). The camera frame rate was 200 ns, and the trigger signal for the high-speed camera was utilized by the voltage waveform measured from a digital oscilloscope (DPO7254C, Tektronix, Inc., Beaverton, OR, USA).

## *B. Experimental Conditions*

In this study, we varied the parameters of aluminum wire diameter, current rise time, wire material, wire shape (with fixed volume), and number of aluminum wires. A typical experimental condition is an aluminum wire (AL-011387, The Nilaco Corporation, Tokyo, Japan) with a diameter of 0.5 mm and length of 100 mm with applied voltage of 30 kV. The applied voltage was measured using a high-voltage probe (EP-50K, Nissin Pulse Electronics Co., Ltd., Tokyo, Japan) connected to the anode, and the current was measured using a current transformer (current monitor 101, Pearson Electronics, Inc., San Jose, CA, USA) placed on the cathode side. The voltage and current waveforms obtained under the typical conditions of this experiment are shown in Fig. 3. The applied voltage was negative polarity. In this study, the applied voltage of 30 kV and the length of the thin wire of 100 mm were fixed, and other conditions were caried in various conditions. Firstly, the wire diameter of the aluminum thin wire was changed between 0.101 mmφ to 0.2 mmφ. Next, coils of 5 μH, 10 μH, 15 μH, and 20 μH were added in series with the load to vary the rise time of the current.

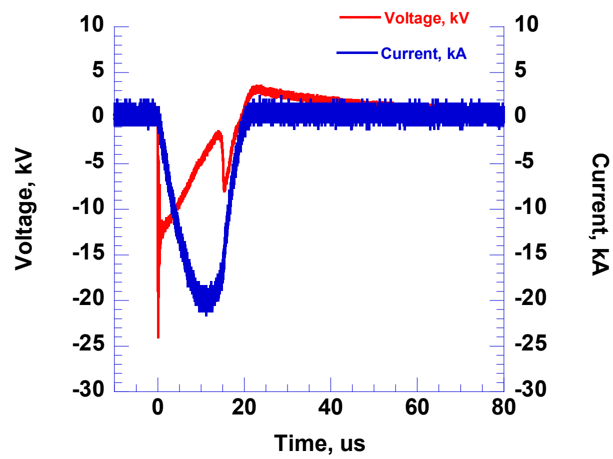

Fig. 3. Current and voltage waveform (1 aluminum wire, 0.5 mmφ, V = 30 kV)

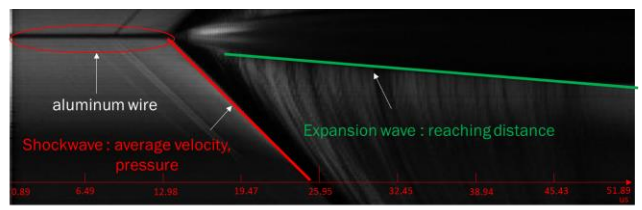

Fig. 4. Streak image of shockwave and expansion wave

Next, Fe (FE-221387, The Nilaco Corporation, Tokyo, Japan), W (W-461387, The Nilaco Corporation, Tokyo, Japan), and NiCr (691387, The Nilaco Corporation, Tokyo, Japan) other than Al were used as wire materials. Also, in order to investigate the effect of wire volume, the total wire diameter was adjusted to 0.5 mm by changing the number of wires for 0.101 mmφ, 0.1 mmφ (AL-011167, The Nilaco Corporation, Tokyo, Japan), and 0.2mmφ (AL-011267, The Nilaco Corporation, Tokyo, Japan) to 24, 25, and 6, respectively. Finally, in order to investigate the effect of increase of wire number, the number of 0.5 mmφ aluminum wires was varied to 2 and 3.

## *C. Shockwave and expansion wave*

Fig. 4 shows a typical streak image of the shockwave at an applied voltage of 30 kV for a 0.5 mm diameter aluminum wire. It has be mentioned that Fig. 4 was made by extracting and connecting specific regions from 256 Schlieren images during the shockwave propagation, which was taken from 0.89 μs to 51.89 μs. The horizontal axis is time, and the vertical axis is the reaching distance of the shockwave and expansion wave. From Fig. 4, voltage and current waveforms, and movie taken with camera, the red line and green line indicates shockwave and expansion wave, respectively. Shockwave is generated from the moment when the wire reaches the boiling point and explodes due to the rapid temperature rise and volume expansion of the wire after the pulse power is applied. Expansion wave is the wave propagated by the evaporating gas after the explosion of the wire. As can be seen from Fig. 4, the expansion wave propagates slowly and the effects of velocity and pressure are considered to be very small, so the expansion wave is investigated in terms of its reaching distance. On the other hand, the shockwave has velocity and pressure effects. Therefore, we investigated the velocity and pressure of the shockwave and the reaching distance of the expansion wave, and investigated which wave may have significant contribution for building demolition.

*D. Instantaneous velocity, average velocity, pressure of shockwave, and reaching distance of expansion wave*

Firstly, two important properties of shockwave were calculated: instantaneous velocity and average velocity. The instantaneous velocity is used to calculate the shockwave pressure. It is the velocity of the distance between 1 μs of the shockwave. Average velocity is calculated by reaching distance and reaching time of the shockwave as shown in (1). Shockwave pressure is calculated from (2) and (3). Using the calculated instantaneous velocity of the shock wave, the pressure can be calculated from (3) by calculating the particle velocity from (2). Next, the reaching distance of the expansion wave was tracked by an image analysis software, and reaching distance was quantified. From above, shockwave was investigated by average velocity and pressure, and expansion wave investigated by reaching distance (degree of expansion).

$$\boldsymbol{average\ velocity} = \int_0^T \boldsymbol{dzdt/T} \qquad (1)$$

$$\boldsymbol{U_s = 1.45 + 1.99U_p} \qquad (2)^{[2]}$$

$$\boldsymbol{pressure = U_s \times U_p} \qquad (3)^{[2]}$$

## III. Result And Discussion

*A. Average velocity, and pressure of the shockwave*

Fig. 5 shows the average velocity of the shockwave for all conditions in this study. The average velocity shows the velocity of the wave from the time when the thin wire exploded, and the shockwave is generated to a certain time. It is also observed from Fig. 5 that when a coil is added to delay the current rise time, the onset time of wire explosion is also delayed, however, the average velocity of shockwave remains unchanged. From Fig. 5, there is little difference in average velocity for any of the conditions except 0.5 mm*3: three wires with 0.5 mmφ. When the number of wires increases to 3 aluminum wires with a diameter of 0.5 mmφ, the explosion of the wires is delayed compared to the case when one wire is used, but the velocity increases and reached around 37 μs. Similarly, the pressure of the shockwave shown in Fig. 6 suggests stronger pressure in case of 3 aluminum wires with diameter of 0.5 mmφ. Fig. 7 and Fig. 8 show Schlieren images of partial and entire explosion of wires, respectively. The blue line is the tracking line on the software program that tracks the wave front. Since the volume of wire in Fig. 7 and Fig. 8 was the largest among all conditions, the explosion does not start with the entire wire but rather begins with a partial explosion (Fig. 7), followed by the explosion of the entire wire (Fig. 8). Therefore, it is considered that the velocity and pressure increase instantaneously. The shock wave pressures in Fig. 6 are much higher than the JIS (Japanese Industrial Standards) approved compressive strength values for concrete of 18-45 MPa. Therefore, the wire explosion conditions

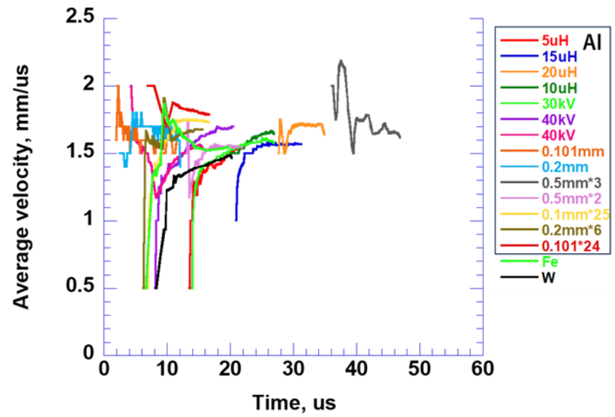


Fig. 5. Average velocity of shockwave (All conditions)

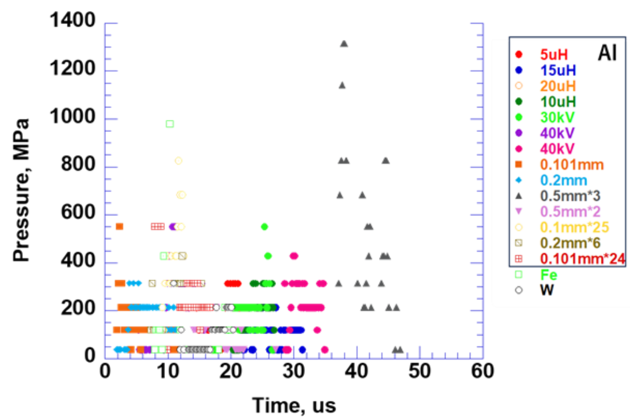


Fig. 6. Pressure of shockwave (All conditions)

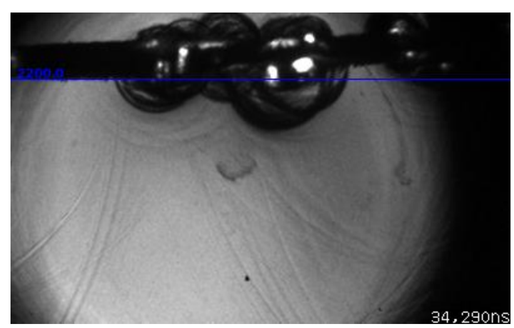


Fig. 7. Schlieren image of partial explosion taken at 34.29 μs (3 aluminum wires, 0.5 mmφ, V = 30 kV)

in this study are considered to have the potential to destroy concrete.

*B. Reaching distance of the expansion wave*

Fig. 9 shows the results of the reaching distance of the expansion wave for all conditions in this study. From Fig. 9, the reaching distance of the expansion wave is small when the wire diameter is 0.1 mmφ and 0.2 mmφ. Therefore, it can be considered that the reaching distance of the expansion wave will be larger in the case of larger wire volume, which is 3 aluminum wires with 0.5 mmφ in Fig. 9. Fig. 10 shows the expansion wave of evaporated gas observed.

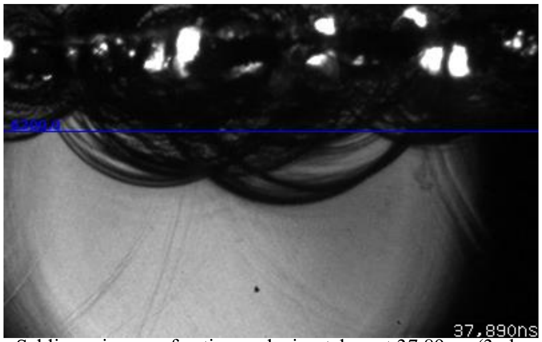


Fig. 8. Schlieren image of entire explosion taken at 37.89 μs (3 aluminum wires, 0.5 mmφ, V = 30 kV)

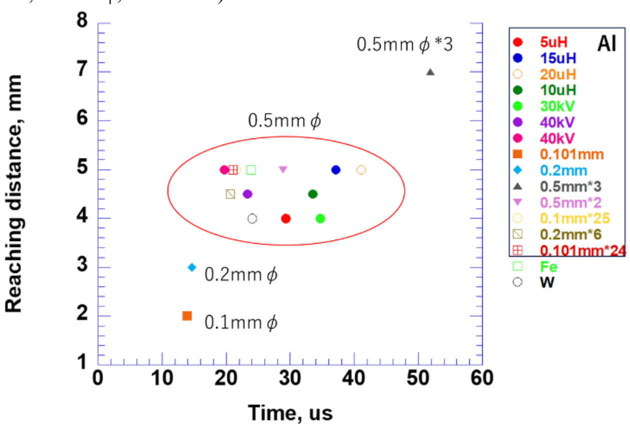


Fig. 9. Reaching distance of expansion wave (All conditions)

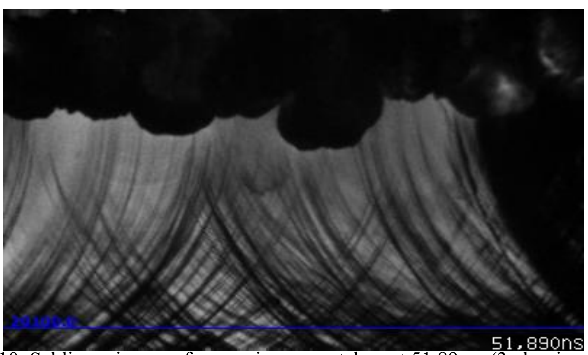


Fig. 10. Schlieren image of expansion wave taken at 51.89 μs (3 aluminum wires, 0.5 mmφ, V = 30 kV)

## IV. Conclution

We suggested thin wire explosion methods as a new method for building demolition. In this study, shockwave measurements in water were conducted to investigate the physical characteristics of shockwave generated by thin aluminum wire explosion. Influence of the experimental conditions including aluminum wire diameter, current rise time, wire material, wire shape (at the same volume), and the number of aluminum wires were investigated. We focused on shockwave and expansion wave generated after the wire explosion, and the average velocity and pressure of the shockwave and reaching distance (degree of expansion) of the expansion wave were quantitatively evaluated. The average velocity and pressure of the shockwave in the case 3 aluminum wires with a diameter of 0.5 mm were the highest. Shockwave pressure values were higher than the compressive strength values of concrete. It is considered that the larger volume of the aluminum wires results in higher impact force. Reaching distance of the expansion wave was lower when the wire diameter was smaller and increased when the volume of the thin wire increased. Neither the velocity nor the pressure of the shockwave makes much difference with respect to the aluminum wire diameter, current rise time, thin wire material, or thin wire shape, and only the number of thin wires has an effect. Although it is not clear whether shockwave or expansion wave is most effective in demolition buildings, this study shows that increasing the number of thin wires and increasing the volume of the thin wires are effective.

Since increasing the number of thin wires is effective in increasing the shockwave, we will maximize the number of thin wires that can be exploded with a certain energy. In addition, in order to proceed from water to shockwave fracture in solids, we will observe shockwaves and expansion waves in acrylic blocks.


## Acknowledgment

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