Dynamic property of aluminum foam

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ABSTRACT

Aluminum in the foam of metallic foam is in the early stage of industrialization. It has various beneficial characteristics such as being lightweight, heat resistance, and an electromagnetic radiation shield. Therefore, the use of aluminum foam is expected to reduce the weight of equipment for transportation such as the car, trains, and aircraft. The use as energy absorption material is examined. Moreover aluminum foam can absorb the shock wave, and decrease the shock of the blast.

Many researchers have reported about aluminum foam, but only a little information is available for high strain rates (10^3 s^{-1} or more). Therefore, the aluminum foam at high strain rates hasn't been not characterized yet.

The purpose in this research is to evaluate the behavior of the aluminum form in the high-strain rate. In this paper, the collision test on high strain rate of the aluminum foam is investigated. After experiment, the numerical analysis model will be made.

In this experiment, a powder gun was used to generate the high strain rate in aluminum foam. In-situ PVDF gauges were used for measuring pressure and the length of effectiveness that acts on the aluminum foam. The aluminum foam was accelerated to about 400 m/s from deflagration of single component powder and the foam were made to collide with the PVDF gauge.

The high strain rate deformation of the aluminum form was measured at two collision speeds. As for the result, pressure was observed to go up rapidly when about 70% was compressed. From this result, it is understood that complete crush of the cell is caused when the relative volume is about 70%. In the next stage, this data will be compared with the numerical analysis.

1. INTRODUCTION

Aluminum foam has various beneficial characteristics such as being lightweight, heat resistance, and an electromagnetic radiation shield. Therefore, the use of aluminum foam is expected to reduce the weight of equipment for transportation such as the car, trains, and aircraft. Moreover the use as energy absorption material is examined. Aluminum foam can absorb the shock wave, and decrease the shock of the blast.

Many researchers have reported about aluminum foam, but only a little information is available for high strain rates (10^3 s^{-1} or more). Therefore, the aluminum foam at high strain rates hasn't been not characterized yet.

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2. EXPERIMENTAL PROCEDURE

2.1. HIGH PRESSURE SHOCK EXPERIMENT

There are two methods of generation of the shock wave used for the impact very high pressure experiment. One is a method of introducing the shock wave generated when explosion blasts directly into the sample. And, another one is a method of using the shock wave generated by the collision of the projectile that accelerates with explosion or the impact gun. The former is called the dynamite method and the latter is called the powder gun method from an experimental viewpoint. The explosion method can generate the shock wave in the large range. And the powder gun method can generate planar shock wave, and the control of pressure is easy.

In this research, to observe the deformation of the aluminum form at high strain rate, the experiment on the explosion method and the powder gun method was conducted.

2.2. EXPLOSION METHOD

2.2.1. Experimental method

The shadowgraph method and a high-speed video camera (HPV-1) were used to observe the transmitted shock wave. The velocity of a shock wave was obtained by taking a framing photograph using the shadowgraph method. A schematic illustration of the shadowgraph method is shown in Figure 1. And a schematic illustration of the experimental device is shown in Figure 2. Water is poured in the clear container made by PMMA (200 mm × 200 mm × 135 mm). A high explosive, called SEP (detonation velocity 7 km/s, density 1310 kg/m^3), is used. A pipe, (PVC, inner diameters: 30 mm, height: 50 mm) was loaded with 50 g of high explosive. The booster explosive is set on the top surface of PMMA, and it is initiated by No. 6 electric detonator. Aluminum foam(40 mm × 40 mm × 40 mm) is put 60 mm beneath .

2.2.2. Experimental result

Framing photographs were obtained by optical observation using the high-speed video camera. The framing photographs are shown in Figure 3.

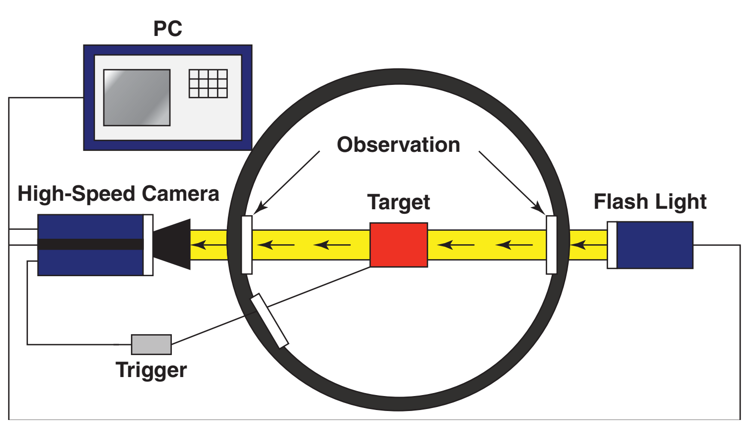

Figure 1 Schematic shadowgraph method for optical observation.

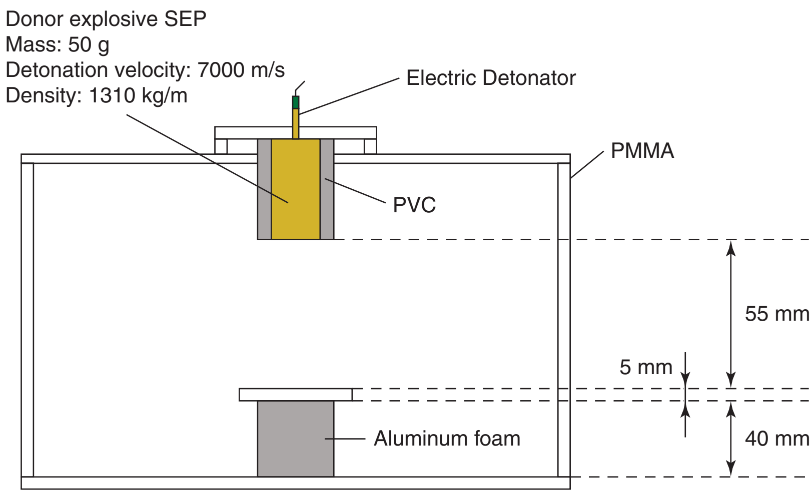

Figure 2 Schematic illustration of experimental set-up.

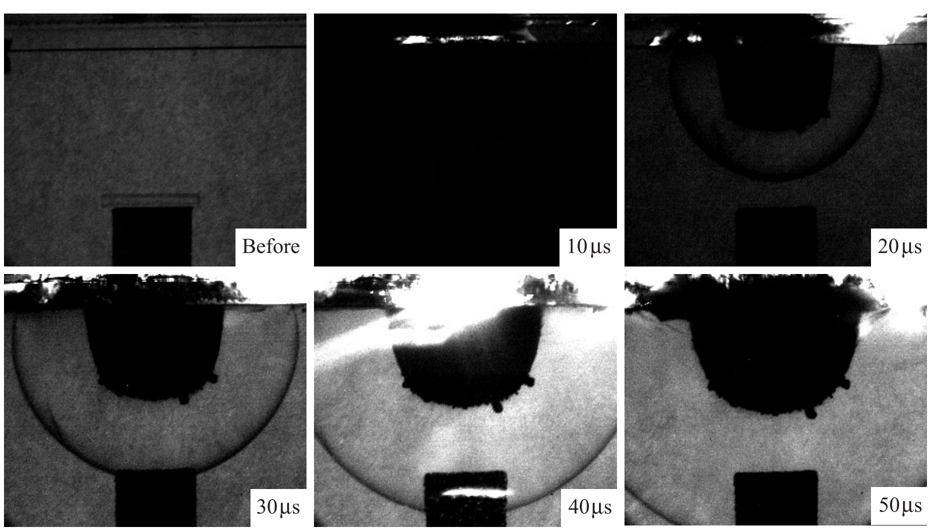

Figure 3 Framing photographs.

The motion of shock wave that acted on the sample was observed. But, Aluminum foam was not deformed by pressure of shock wave.

2.2.3. Numerical simulation

To confirm how much pressure had acted on aluminum foam surface, numerical analysis model was made by means of LS-DYNA3D. Numerical analysis is conducted by using LS-DYNA. The model is shown in Figure 4. It is 1/4 solid model, and initial velocity 1711 m/s is given to first detonation point. And numerical analysis condition is shown in Table 1.

In this numerical analysis, we applied Jones-Wilkins-Lee (JWL) equation of state [4] for the high explosive. This equation is well used for the structural analysis accompanied by a

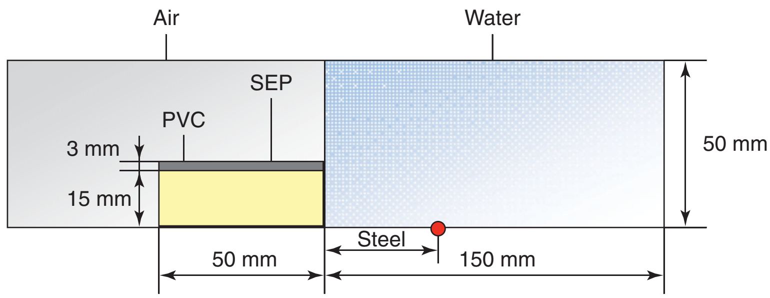

Figure 4 Numerical simulation model.

Table 1 Numerical analysis condition

software	LS-DYNA
Equation of states	
SEP	JWL
PMMA	Grüneisen
Water	Grüneisen
Air	Linear Polynomial
Mesh size	1.0 × 1.0 × 1.0 mm

Table 2 JWL parameter of SEP

A[GPa]	B[GPa]	R_1	R_2	ω
364	2.31	4.3	1	0.28

detonation phenomenon. JWL coefficients are given in Table 2. Expression of JWL equation of state is described as follows:

$$P = A\left[1 - \frac{\omega}{VR_1}\right]\exp(-R_1V) + B\left[1 - \frac{\omega}{VR_2}\right]\exp(-R_2V) + \frac{\omega E}{V} \quad (1)$$

$V = \rho_o$(Initial density of explosive)/ρ (Density of detonation products)

P is Pressure, E is Specific internal energy

A, B, R_1, R_2, ω are JWL parameters

And we have applied Mie-Gruneisen equation of state for the PMMA and water. Mie-Gruneisen equation of state is given as follows the parameters of PMMA and water are shown in Table 3.

Table 3 Mie-Gruneisen parameter of PMMA and Water

	ρ_0 (kg/m^3)	C_0 (m/s)	s	Γ_0
PMMA	1180	2260	1.82	0.75
Water	1000	1490	1.79	0.65

Table 4 Linear polynomial parameters

	ρ_0 (kg/m^3)	γ	C_4	C_5
Air	1.252	1.4	0.4	0.4

$$P = \frac{\rho_0 c_0^2 \eta}{(1 - s\eta)^2}\left[1 - \frac{\Gamma_0 \eta}{2}\right] + \Gamma_0 \rho_0 e \tag{2}$$

$h = 1 - \rho_o$(Initial density of the medium)/ρ (Density of detonation medium)

P is Pressure, e is Specific internal energy

C_0, s are Constant of material, Γ_0 is Gruneisen coefficient

Accordingly, we have applied Linear Polynomial equation of state for the air. Linear Polynomial equation of state is given as follows the parameters of air are shown in Table 4.

$$\begin{aligned} &P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E \\ &C_0 = C_1 = C_2 = C_3 = C_6 = 0 \qquad C_4 = C_5 = \gamma - 1 \end{aligned} \tag{3}$$

C: Polynomial equation coefficient

g: Ratio specific heats

$m = r/r_0$: Ratio of current density to reference density

E: Initial internal energy

2.2.4. Numerical analysis results

Pressure history that obtained by numerical analysis is shown in Figure 5. From this result, over 200 MPa acted on aluminum foam surface. So aluminum foam received sufficient pressure. However, because the pressure acting time was too momentary, the deformation was not able to be observed.

Therefore, it is difficult to observe the deformation of Aluminum foam under water condition.

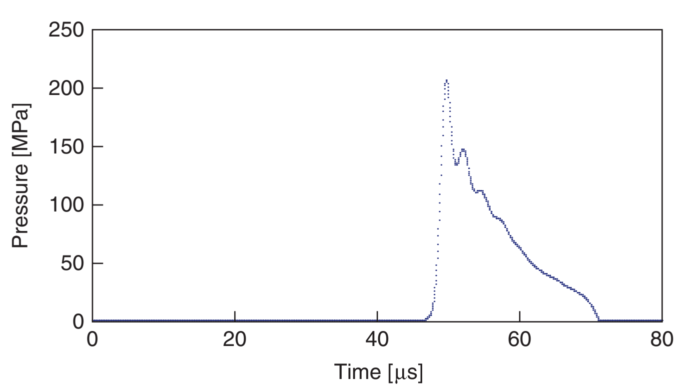

Figure 5 Pressure histories on the top point of Aluminum foam.

Table 5 Basic properties of aluminum foam

base material of the foam	mass of a specimen	relative density	pore size
Al 99%	6.27 g	6.1 %	20 ppi

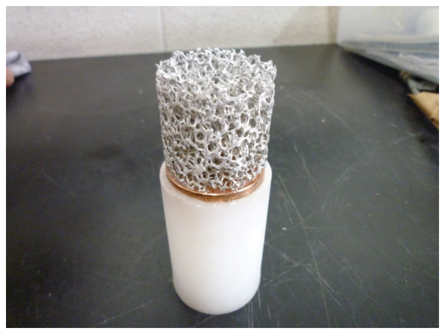

Figure 6 Projectile.

2.3. POWDER GUN METHOD

2.3.1. Experimental method

A powder gun is a device by which a projectile is launched using gun powder. It has a simple structure, mainly composed of a vacuum pump, target chamber, barrel and breech. It can achieve comparatively high velocity 1.5 km/s. And it is possible to impact a flat plate with minimal tilt and to conduct optical observation nearby.

Single Component Powder as propulsive powder (energy on combustion 700 cal/g), and Black Powder as ignition powder were used. The Black Powder was initiated by an Electric Match.

A high-speed image converter camera (HPV-1) was used to observe the deformation of Aluminum foam. The xenon flash (HL20/50 type flash unit, made by the Hadland Photonics (DRS) Ltd) was used as a source of light. At the same time, pressure was measured by PVDF gauge (made by the Dynasen Inc).

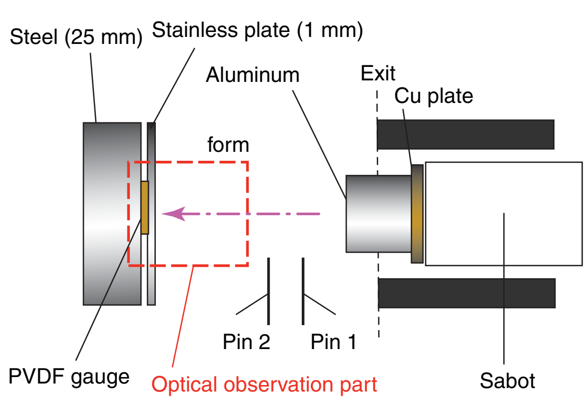

Figure 7 Experimental set-up.

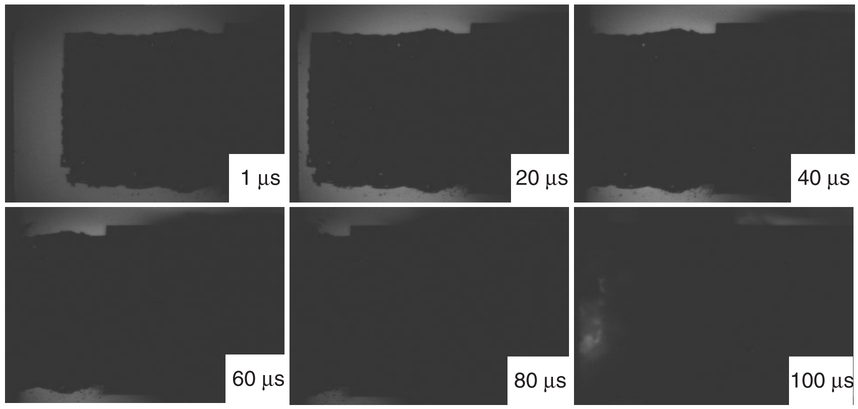

Figure 8 Framing photographs.

The basic characteristic of the foam which is used in this research is shown in Table 5. Projectile is composed of Aluminum foam and 5 mm thickness cupper plate and the sabot. Aluminum foam was cut in the column whose diameter was 35 mm and height is 35 mm (Figure 6). The sabot had a flared in the rear in order to prevent combustion gas leakage. Projectile was accelerated to about 400 m/s.

A schematic illustration of the experimental device is shown in Figure 7.

2.2.2. Experimental result

Framing photographs were obtained by optical observation using the high-speed video camera. The framing photographs are shown in Figure 8.

3. RESULTS

In powder gun method, deformation of Aluminum foam was observed. Relation between time and strain is shown in Figure 9. And from Eqn. (4), the strain rate was calculated. And the pressure measurement succeeded. The result is shown in Figure 10. Reached around 100 seconds, the aluminum foam was fully-densified, and the foam was complete crush.

From these two figures, stress-strain diagram was calculated. The result is shown in Figure 11.

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} = \frac{1}{dt}\left(\frac{dl}{l}\right) = \frac{1}{l} \cdot \frac{dl}{dt} = \frac{v}{l} \tag{4}$$

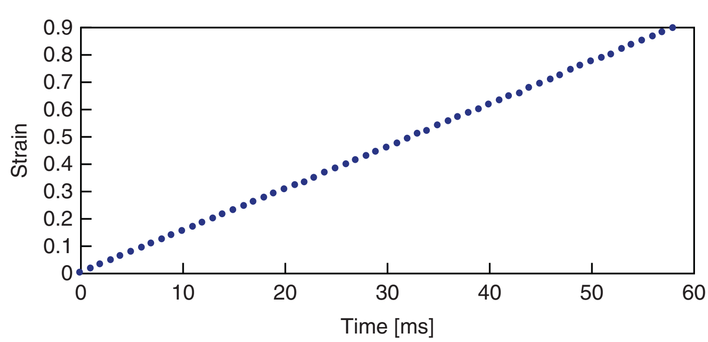

Figure 9 Relation between time and strain.

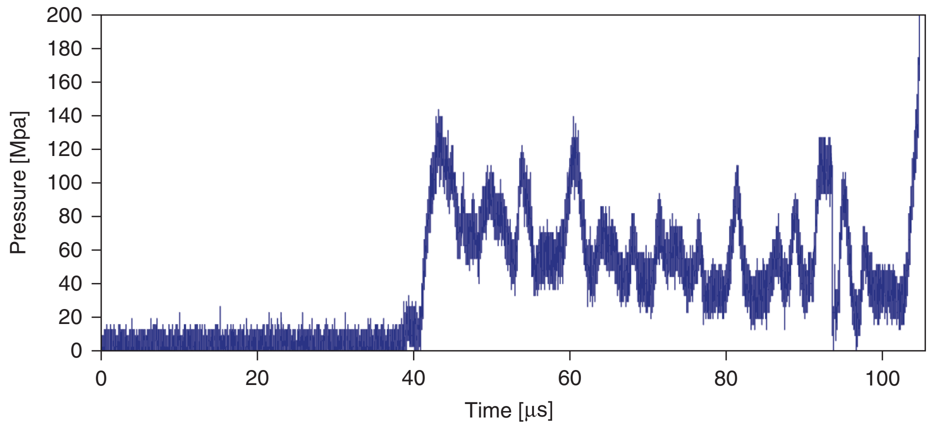

Figure 10 Relation between time and pressure.

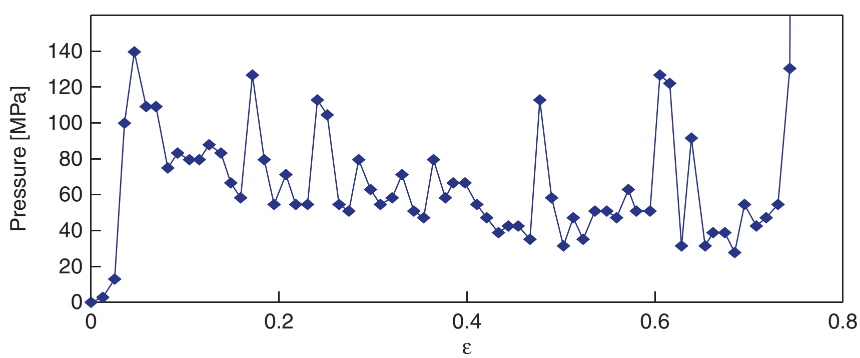

Figure 11 Stress-strain diagram.

$\dot{\varepsilon}$: strain rate, ε: strain

t: time, l: speecimen initial length

$$\dot{\varepsilon} = 1.1 \times 10^4 \text{ [1/s]} \quad (5)$$

From optical observation and PVDF data, stress-strain diagram was obtained though the wave was seen in the pressure because used aluminum was foam. And in this experiment strain rate was 1.1 × 104 [l/s]. The cell became dense where strain exceeded 0.7, and the pressure increased.

4. CONCLUSIONS

1. From the optical observation experiment, the deformation of the aluminum form at 1.1×10^4 [1/s] was clarified by the flaming photograph.
2. From the pressure measurement by the PVDF gauge, the stress wave form of the aluminum foam at collision speed 400 [m/s] was obtained.
3. From optical observation and PVDF data, stress-strain diagram in high strain rate 1.1×10^4 [1/s] was obtained.
4. It becomes apparent that the cell became dense where strain exceeded 0.7, and the foam was complete crush.

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