High-velocity impact experiment of aluminum foam sample using powder gun

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Abstract

Porous materials such as aluminum foam have been investigated for possible use as impact shock absorbers in transportation aeronautic applications. However, the response of aluminum foam during impacts at high velocities of more than 100m/s is not yet fully understood. A high-velocity impact experiment was therefore carried out to clarify impact shock absorption properties of aluminum foam. A one-stage powder gun was used to accelerate an aluminum foam sample to impact a rigid wall. Velocity and deformation of the aluminum foam sample during impact was studied using a digital high-speed video camera, while the pressure wave in the aluminum foam sample was measured using a PVDF gauge. The experimental observations revealed uneven collapse of the aluminum foam sample structure during high speed impact with a general stress plateau effect, typical for cellular material structures when subjected to quasi-static loading.

Keyword: Porous materials, aluminum foam, high-velocity impact, powder gun, high-speed video camera, PVDF gauge

1. Introduction

Aluminum foam is an industrialized metal system foam material at an early stage of application. Open cell aluminum foam geometry consists of an aggregation of interconnected cells, and it excels in areas such as low weight, heat resistance, insulation, electromagnetic wave shielding, machinability, and design applications flexibility [1-3].

Recently, aluminum foam has been considered for use as impact energy absorption material for transportation equipment such as cars, trains and airplanes to take advantage of its lightweight and unique compression deformation characteristics [4]. A real-scale impact experiment of aluminum foam sample impacted by a 10 ton carriage at 1.94 m/s has been conducted, proving the effectiveness of its impact energy absorption ability [5]. However, the response of the aluminum foam to impacts at high velocities of more than 100m/s is not yet fully understood.

This paper reports on the results of a high-speed impact test of an aluminum foam sample accelerated to an impact speed of 400 m/s using powder gun conducted to study the sample's behavior and to determine its impact shock absorption efficiency. Measurements were conducted using a high-speed video camera and a PVDF gauge.

2. Experimental setup

2.1 Aluminum foam

The aluminum foam used in this research was industrially mass-produced by m-pore GmbH, Dresden, Germany. Hydrogenation titanium was used as a foaming agent. Fig. 1 shows appearance of the aluminum foam sample used. Basic properties and the size of the aluminum foam sample are given in Table 1.

2.2 One-stage powder gun

A one-stage powder gun is a simple device which can accelerate a projectile by the combustion gas of gun powder [5]. A schematic illustration of powder gun applied in this research is shown in Fig. 2. The device was composed of a breech with adequate strength, a barrel and a target chamber. The barrel inner surface was finished to high accuracy by a honing process, with an inner diameter 40mm. A window for optical observation, connector terminals for electrical measurements, and shock absorber for the projectile were set in the target chamber. The projectile sabot was made from ultra-high molecule weight polyethylene (UHMWPE); a metal plate (of copper, as is standard) was set to the front of the sabot as projectile driver. The aluminum foam sample was positioned on the metal plate driver, completing the entire projectile.

Because the target chamber was decompressed with the vacuum pump, the projectile was nearly unaffected by air resistance. Projectile acceleration of up to 1.5 km/s was possible by this one-stage powder gun.

2.3 Optical observation

Optical observation employing the shadowgraph method was conducted to evaluate aluminum foam sample deformation behavior during high speed impact. The shadowgraph system is shown in Fig. 3. The shadowgraph method is based on observation of a light shadow projection on a screen or the film of a camera, and is also known as direct projection technique.

A high-speed video camera (HPV-1, produced by SHIMADZU corporation, image capture number: 100, maximum resolution: 1μs) was used to observe the deformation behavior.

2.4 Pressure measurement

A PVDF gauge (Piezo film stress gauge, PVF2 11-, 125-EK, Dynasen) able to measure up to 10 GPa was used to measure the pressure of the aluminum foam during impact. This type of stress gauge is used for plane wave measurement. The arrival of a vertical pressure increment to the electrode induces a charge in the circuit, and voltage is generated in resistor or capacitor. This voltage can be connected with the derived function of pressure-time or the time of the stress impulse applied to the gauge. This gauge was connected to a digital oscilloscope (LT364L, LeCroy; bandwidth: 500 MHz, Simultaneous Maximum Sampling Rate/ch: 2 GSa/s) via charge integrator (CI-50-0.1 Dynasen). The charge integrator is simple non-inductive passive device that can be used with piezo film stress gauges and is capable of yielding direct and accurate wave forms of the interacting shock waves. The charge integrator is a general purpose converter capable of yielding direct wave profiles with time resolution of 2X10 -8 sec. using any size PVF 2 sensor over a 0-300 kilobar stress range. A direct output charge per unit area of the gauge can be obtained by multiplying its capacity (0.1 microfarad) by the measuring converter's output voltage and thus inferred into a state of stress using the piezo film gauge's calibration.

3. Results of measurements and discussion

Fig. 4 shows the measurement system applied to this research. Used for acceleration of the aluminum foam sample-mounted projectile were 8g of smokeless gunpowder and 2g of black gunpowder for deflagration. The total mass of the projectile (aluminum foam sample, copper plate and sabot) was 114.65 g. The aluminum foam sample (D: 35 mm, H: 35 mm, W: 6.27 g) was bonded to the copper plate at the front of the sabot. Pins were used as an optical observation trigger. To evaluate pressure history and aluminum foam sample behavior over the duration of impact, the aluminum foam sample was collided with a PVDF gauge covered by a 1 mm-thick protective stainless steel plate. Pin contact measurement results measured the velocity of the aluminum foam sample as 413 m/s. Optical observation of aluminum foam sample behavior during impact was done using the high-speed video camera.

Framing photographs of aluminum foam sample behavior during impact are shown in Fig. 5. Rapid acceleration of the sample in the barrel of the powder gun led to observation of initial compression of the aluminum foam sample during free flight between barrel exit and impact, with the height of aluminum foam sample shrinking from 35 mm to 29 mm. Impact started at 20 μs. The aluminum foam sample was compressed during impact, and an impact flash was observed at 88 μs by high speed video camera. This impact flash may have been generated by ignition of the fully-densified aluminum foam sample. The relation between time and displacement, shown in Fig. 6, was derived by image analysis. The velocity of aluminum foam sample remained constant during impact at a measured 400.2 m/s. The sample deceleration by kinetic energy absorption through deformation was not confirmed, possibly due to excessively high kinematic energy of the sample in relation to its deformation resistance.

Fig. 7 shows the relationship between time and pressure (0 to 100 μs) derived from the PVDF gauge measurement results. Fig. 8 is a magnification of Fig. 7 up to 90 μs. The observed wave response from 20 to 80 μs is due to collapse of the irregularly shaped aluminum foam sample. The wave response is caused by the process of aluminum foam pore closing and the collisions of pore edges in small-sized regions. Of interest is observation of a general stress plateau effect in the foam sample response, typical of cellular material structures when subjected to a quasi-static loading. The rapid pressure rise starting from about 80 μm is due to gradual densification of the aluminum foam sample at the end of the impact process (Fig. 8) and corresponds to the results of optical observation. Fig. 9 is a magnification of Fig.7 after 85 μs, and shows two pressure areas which rise gradually and rapidly. P1 and P2 indicate 3.5 GPa and 6.2 GPa, respectively. It can be concluded that P1 was generated by impact between condensed aluminum foam sample and stainless steel plate. In case of impact between aluminum and stainless steel (copper and stainless steel) at speed of 400 m/s, 4.5 (7.7) GPa is generated according to impedance miss matching method [6]. The generated pressure at the collision depends on the velocity and the density of the materials. The copper plate at the base of the aluminum foam sample resulted in higher impact pressure at the final stages of impact [7]. There are errors of pressure value between PVDF measurement and impedance miss matching. If the collision velocity was 320m/s, generated pressure between aluminum and stainless steel, copper and stainless steel were 3.5 and 6.2 GPa by means of impedance miss matching method. Because a steel block where the gauge was set was not rigid material, the block could be accelerated to about several tens of m/s during a compression of aluminum foam.

4. Conclusion

A high speed impact experiment was conducted in which an aluminum foam sample was accelerated to 400 m/s using a one-stage powder gun. The velocity was measured by pin contact measurement and optical observation. The aluminum foam sample experienced limited buckling during rapid acceleration in the barrel of the powder gun, but planar impact between it and the stainless steel plate was accomplished. The sample velocity was observed to be constant during impact. The sample deceleration by kinetic energy absorption of aluminum foam sample through deformation was not confirmed, possibly due to excessive kinematic energy of the sample in relation to the aluminum foam deformation resistance. However, a general stress plateau effect in the foam sample response, typical for cellular material structures when subjected to quasi-static loading, was observed. Aluminum foam sample wave response caused by collapse of foam pore edges was measured using a PVDF gauge. This experiment has shown that kinetic energy absorption is negligible when using low-density aluminum foam in high speed impact. To confirm the effectiveness of aluminum foams used as impact shock absorbers, lower impact velocities or higher-density aluminum foams should be employed. Further experiments are being prepared in this regard. Also, the measured data will be used to build relevant numerical models for parametric computational simulations of aluminum foam behavior during various impact scenarios.

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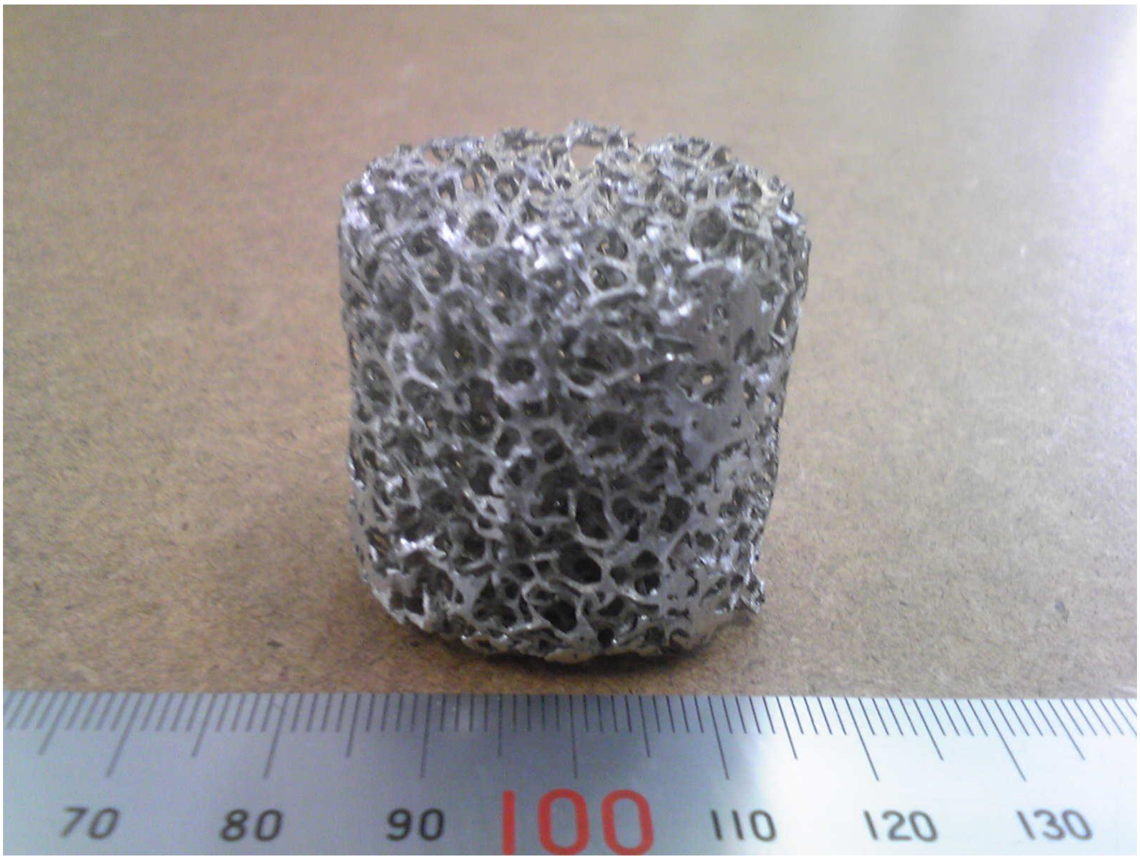

Figure 1 Appearance of aluminum foam sample

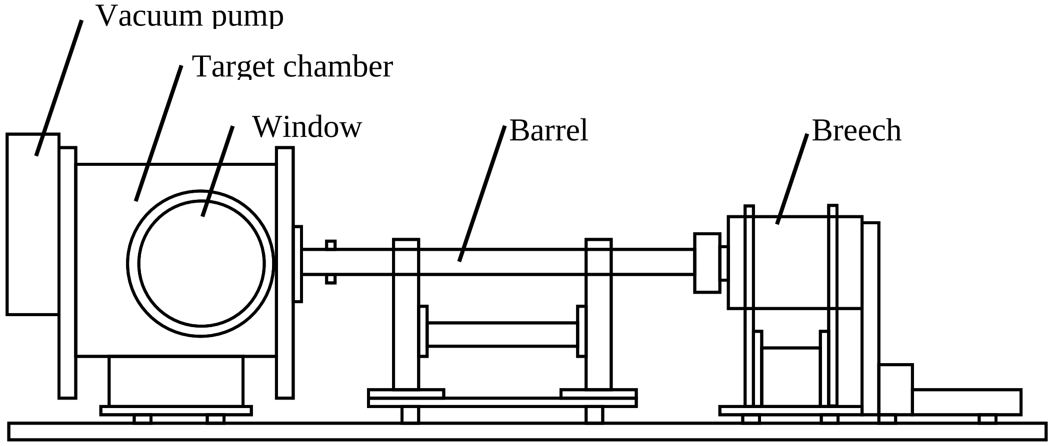

Figure 2 Schematic illustration of one stage powder gun

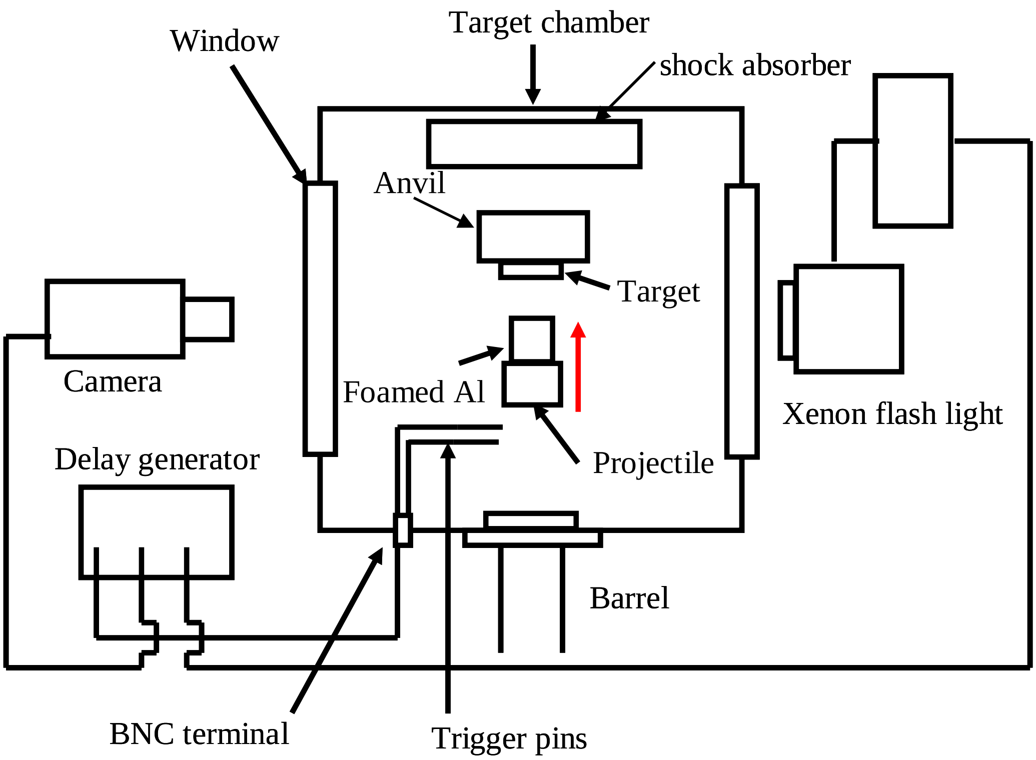

Figure 3 Shadowgraph system of optical observation for collision between aluminum foam sample and metal plate

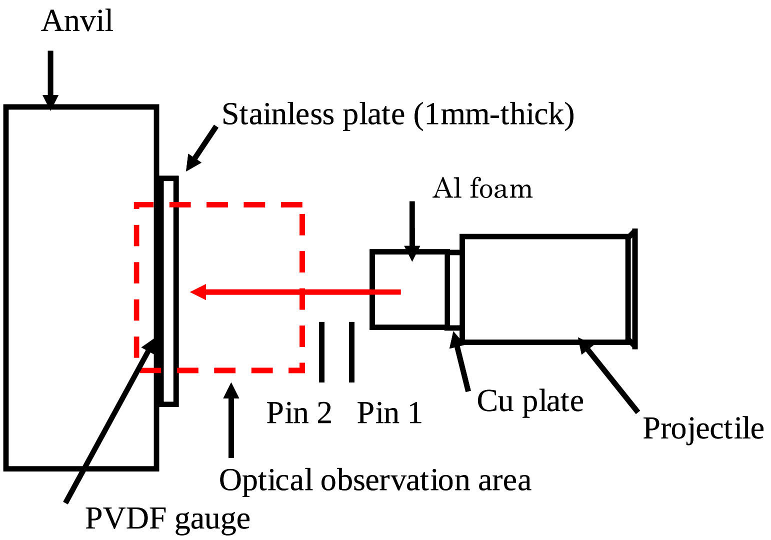

Figure 4 Measurement system for aluminum foam sample impact pressure and optical observation

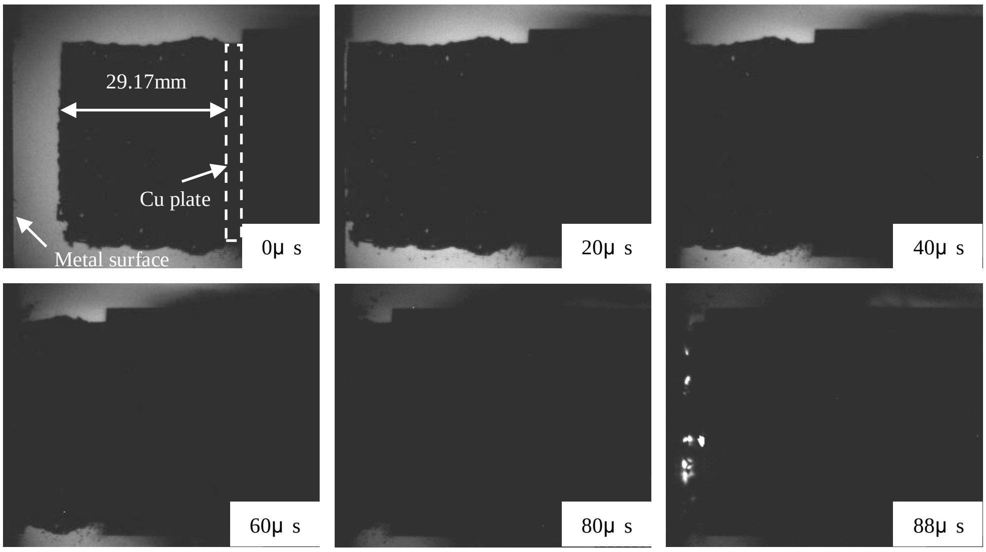

Figure 5 Deformation behavior of aluminum foam sample during impact

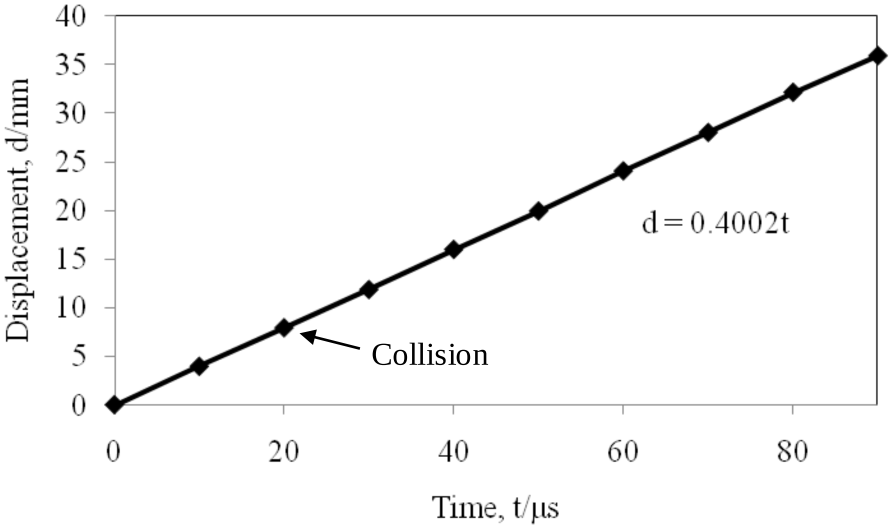

Figure 6 Relation between time and displacement obtained from optical observation

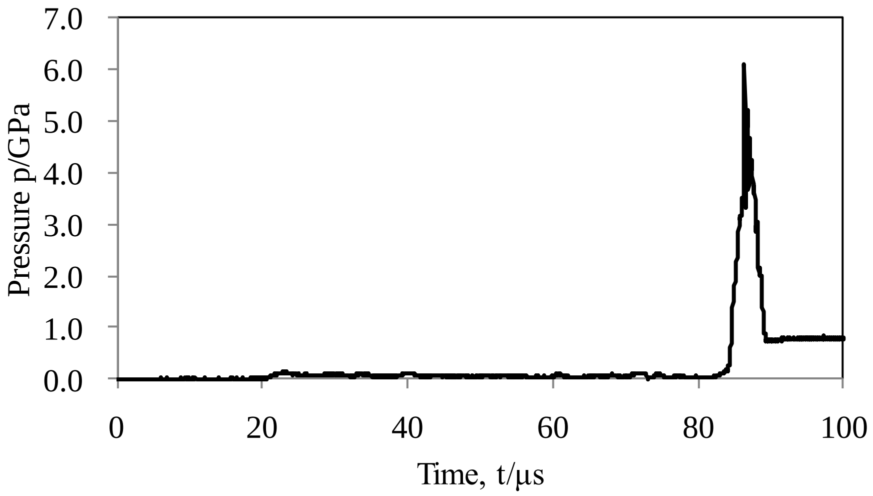

Figure 7 Relation between time and impact pressure of aluminum foam sample during impact

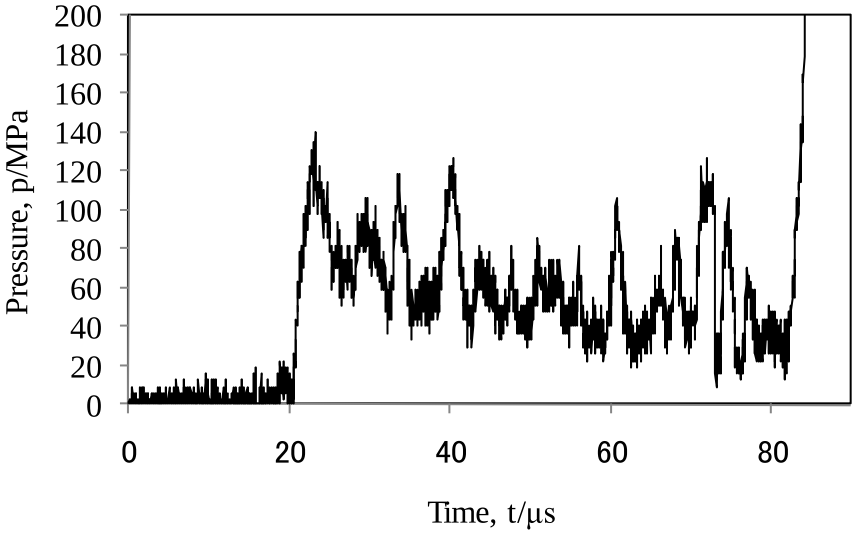

Figure 8 Relation between time and pressure focused on up to 90 μs

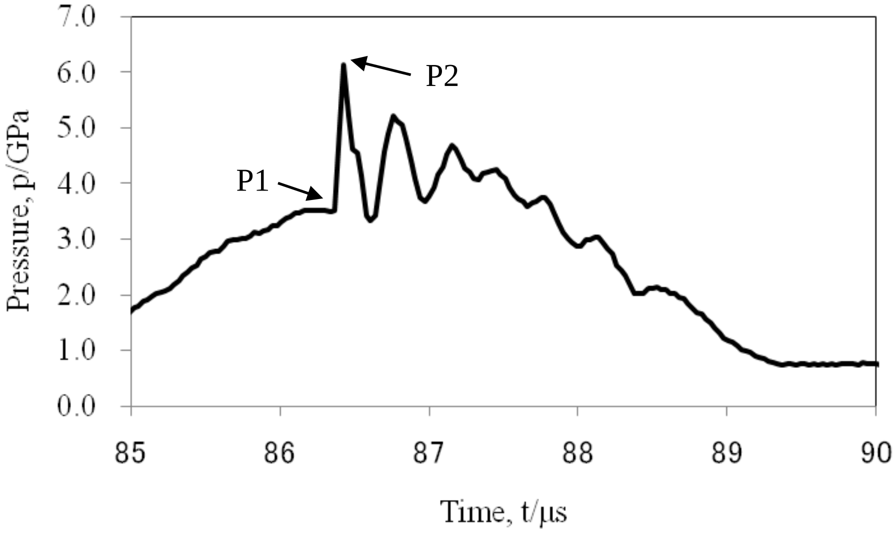

Figure 9 Relation between time and pressure focused on after 85 μs

Table 1 Basic properties, size and mass of aluminum foam

Basic properties			Size and Mass		
Foam base material	Pore size (ppi)	Relative density	Diameter (mm)	Height (mm)	Mass (g)
Al 99 %	10	0.061	35	35	6.27

ppi (pores per inch)