# A study of particle ejection by high-speed impacts

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**Summary.** The fragmentation of solid plates impacted by a high-speed projectile has been studied intensively in the past. However, the ejection and shattering process of fragmented particles have not been well resolved yet. To simulate the earlier stage of particle ejection, we performed an analogue experiment of the ejection of aluminum spheres attached on a thin aluminum plate in a row and impinged at tis reverse side by a high-spee plastic cylinder of 51 mm in diameter. The ejection of spheres was observed by using a high-speed digital camera and also holographic interefrometry. These image analysis revealed the motion of ejected spheres. .

## 1 Introduction

Projectile impingements at high speed on a metal plate creates a shock wave propagating in it, which is then reflected from its reverse surface and instantaneously bulges it. Pressures generated behind the shock wave exceed well over the value of yielding stress and then crack propagation behind the shock wave takes place, which results in the fragmentation of the reverse surface of the target plate. This is a brief explanation of debris cloud formation during hypervelocity impacts. In order to collect design data of space debris bumper shields, they performed an analogue experiment [1, 2]. The free flight of micro-particles occurs even in laser ablation assisted drug delivery systems [3]. To instantaneously eject small spherical particles from the plate surface, we impacted with a plastic cylinder, an aluminum plate on the reverse side of which the spheres were attached in a row. The ejection particle was visualized by shadowgraph and the images were recorded sequentially by a high-speed digital video camera and quantitatively by double exposure holographic interferometry. Then we clarified experimentally the process of shattering of aluminum spheres.

## 2 Experiment

### 2.1 Facility

We used a gas gun in the Interdisciplinary Shock Wave Laboratory of the Institute of Fluid Science, Tohoku University. Ultra high-density polyethylene cylinders of 51 mm diameter and 55 mm long were projected at a transonic flow range. Figure 1 shows a 5 mm thick aluminum target plate AL5052 of 200 mm by 200 mm and aluminum spheres of 3.2 mm, 4.0 mm, and 4.8 mm, respectively. The spheres were weakly attached in 48 mm length in a row, where the x-axis is defined as the axial direction and y-axis as the vertical direction along the arrayed aluminum spheres. Sphere diameters, numbers, materials, and their weights are tabulated in Table.1. The target plate was cramped at its four corners as shown in Fig. 1(a).

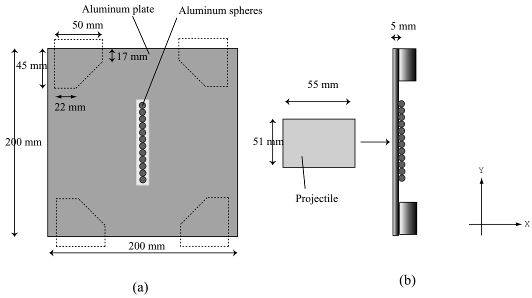


**Fig. 1.** The target plate and installation of aluminum spheres: (a) frontal view of target plate; (b) side view and impact of the plastic cylinder

**Table 1.** material information of spheres

| Diameter | Number of spheres | Material | Weight per one sphere [g] |
|---|---|---|---|
| 3.2 mm | 15 | Al5052 | $4.53 \times 10^{-2}$ |
| 4.0 mm | 12 | Al2017 | $9.17 \times 10^{-2}$ |
| 4.8 mm | 10 | Al1050 | $1.58 \times 10^{-1}$ |

### 2.2 Experimental condition

The gas gun was operated with a diaphragm-less operation system, in which a 51 mm diameter cylinder inserted at the entrance of an acceleration tube, separating test air at 0.1 MPa and room temperature from 1.55MPa helium was held in its initial position with a piston backed up with 1.4MPa helium from behind and then a sudden decrease in the back-up pressure instantaneously released the piston to move backward. Hence the high pressure helium gradually accelerated the cylinder motion. The piston motion was mechanical controlled so that this system warranted a higher degree of reproducibility than conventional diaphragm rupture systems. We achieved a repeatable cylinder impingement onto the target plate. Three experiments were repeated for each sphere size. The optical flow visualization was performed with a commercial flash lump as light source by using shadowgraph and its sequential images were recorded by a high-speed digital video camera of inter-frame time of 16 $\mu$s and exposure time of 8 $\mu$s. (Hyper Vision HPV-1, Shimadzu Co. Ltd.) Flow fields were quantitatively visualized by using a double exposure holographic interfrometry.

## 3 Results and Discussion

### 3.1 High-speed video images

Shadowgraph images are sequentially displayed at time interval of 80 $\mu$s. The plastic cylinder impacted on the target plate: at 345 $\mu$s in Fig.2; at 342 $\mu$s in Fig.3; and at 340 $\mu$s in Fig.4. As seen on the second frames in Figs.2-4, the impact flash was observed and the target plate started to deform. The arrayed spheres started to be ejected to move. The plate deformation drove a spherical shock wave, which was precursory to the sphere shattering motion. The shock wave, as later confirmed on the interferograms, was initially strong enough to accompany its particle velocity, which would accelerate spheres. This is a general trend observed in dusty gas shock tube flows, in which individual dust particles are accelerated behind the incident shock waves, resulting in the non-equilibrium region behind the incident shock.

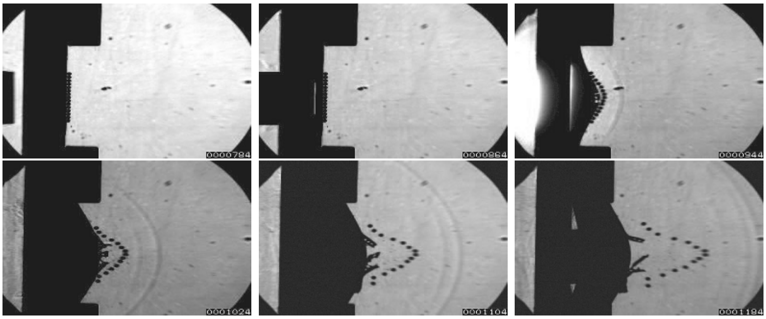

**Fig. 2.** Spherical diameter of 3.2 mm.

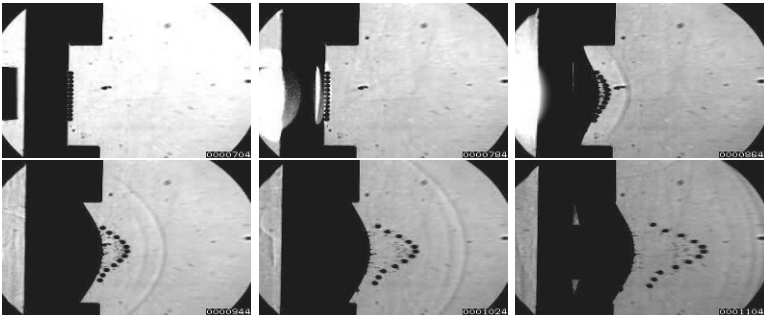

**Fig. 3.** Spherical diameter of 4.0 mm.

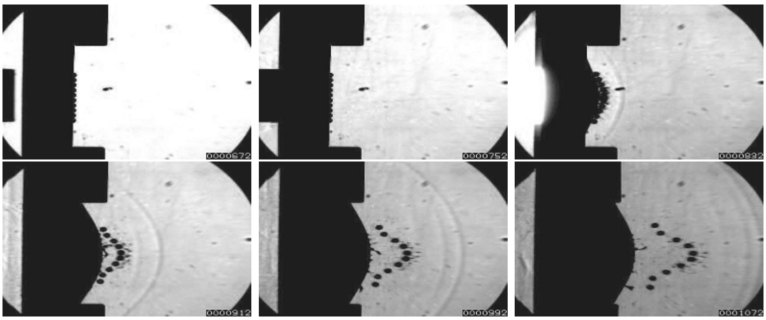

**Fig. 4.** Spherical diameter of 4.8 mm.

The spheres are departed from the target plates on the fourth frame of Figs. 2-4. The target plate was not ruptured, but the tape attaching to the plate was removed from the plate surface in Fig.2.

### 3.2 Distribution of spheres

Although the sphere distribution looks initially spherical on the third frame of Figs. 2-4 but transits with the elapsed of time to more or less the Gaussian distribution on the fourth to sixth frames of Figs.2-4. This trend is presumably attributable to the process of target plate deformations. The deformation of target plates is governed by its supporting conditions at its edge. As explained in Fig.1, in this experiment the target plates were cramped at its four corner. Then the process of its deformation can not be axially symmetry. It is also confirmed in this series of experiments, the spheres are moving at constant speed. We recorded images at every 64 $\mu$s from the moment of the impact and calculated the center of each sphere from each pixel constituting one sphere. Then sequential distributions of each sphere at given time instance are drawn for individual sphere sizes in Figs.5(a)-(c). We compared the measured spatial distribution of the spheres to the Gaussian distribution and found a good agreement. However, the difference between experiment and the Gaussian one departs with the elapse of time. It is concluded that the Gaussian distribution is a good approximate to describe the sphere distribution.

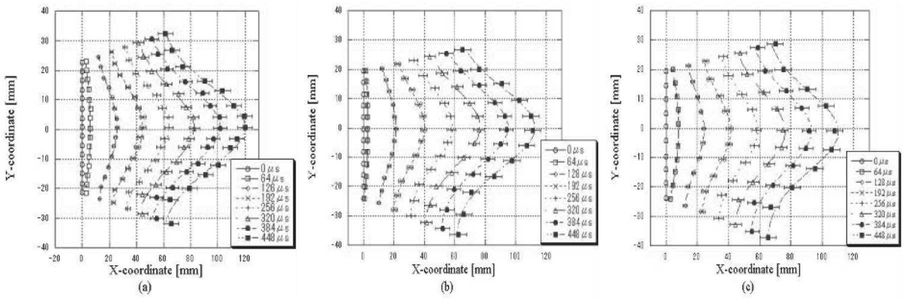


**Fig. 5.** Sequential distribution of spheres and comparison with Gaussian distribution: (a) 3.2 mm; (b) 4.0 mm; and (c) 4.8 mm

### 3.3 Velocity and acceleration

We estimated the sphere velocity and the acceleration out of Figs.5(a)-(c) and the results are shown in Figs.6-8 for individual sphere diameters. The x-t diagram and y-t diagram are shown in Figs.6-8(a) and Figs.6-8(b), respectvely. The individual time instants correspond to those in Figs.5(a)-(c). Assuming complete symmetry, we measured only the spheres upper part of the axis.

$V_x$ becomes larger closer to as the central axis. By contraries, $V_y$ becomes smaller closer to the central axis. We confirmed the spheres maintain a constant speed within the frame of the present observation. It may be oversimplification to say that the sphere shattering is analogous to dusty gas flows behind the spherical shock waves. However,

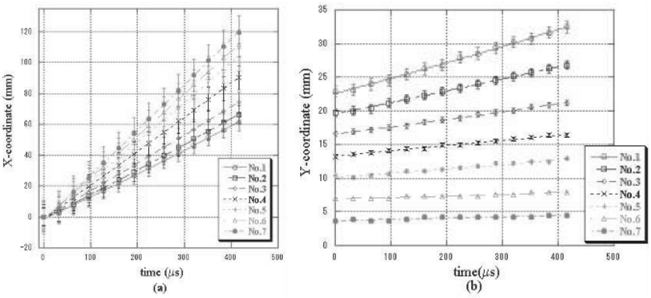


**Fig. 6.** 3.2 mm: (a)x-t plane; (b)y-t plane

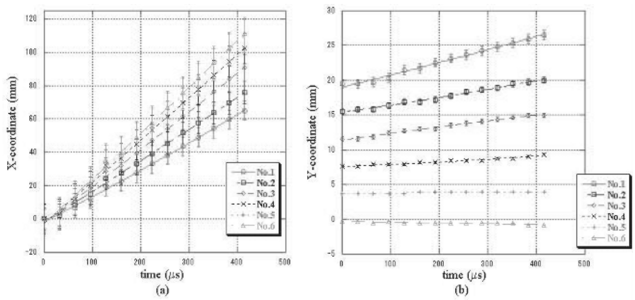


**Fig. 7.** 4.0 mm: (a)x-t plane; (b)y-t plane

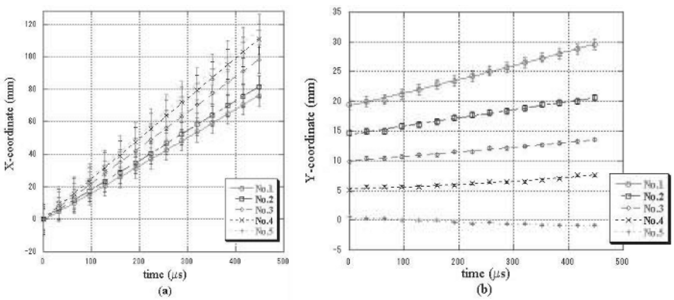


**Fig. 8.** 4.8 mm: (a)x-t plane; (b)y-t plane

the general trend agrees with such an analogy until we will numerically simulate sphere motion ejected from a high speed impact plate.

### 3.4 Holographic interferometry

To confirm the presence of the shock wave we performed double exposure holographic interferometric observation. Dark dots show spheres. Fringe distributions are slightly distorted from the axial symmetry but not very significant. Although a preliminary result, a result is shown in Fig.9 for 4.8 mm spheres. Although unobservable on shadow images, the flow field behind the diverging shock wave never be uniform but waves propagating

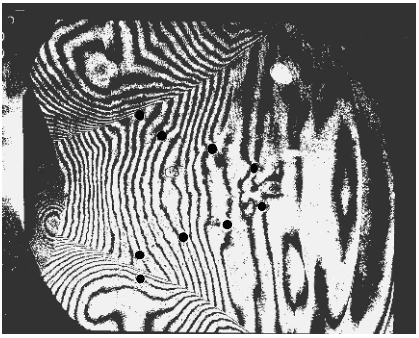

**Fig. 9.** Holographic interfermetry of shattering 4.8 mm spheres.

vertical direction exist, which may contributed to depart the particle motion from the Gaussian distribution. In the near future these holographic observation systems together with a digital streak recording would conclude flow information and to validate numerical results.

## 4 Conclusion

The impact generated sphere motion are observed sequentially by shadowgraph, recorded by high-speed digital video camara, and quantitatively by double exposure holographic interferometry. These spheres were ejected by the deformation of target plates and accelerated by the flows behind the impact generated incident shock waves. The region of the constant velocity was so extended, however, we failed to confirm the onset of deceleration. Holographic interferometric observation revealed that the present target plates were supported at their corner, which disturbed the axial symmetry of the flow field from complete symmetry. At the early stage the sphere distribution can be approximated by the Gaussian one. The departure from Gaussian one was attributable to the supporting condition. In the future work, we are planning, to rigorously simulate debris cloud formation, to impact packed spheres. Presumably an approach from a granular flow analyses would provide a good way.

## References


1. Piekutowski AJ: *Debris clouds generated by hypervelocity impact of cylindrical projectiles with thin aluminum plates*, Int.J.Impact Engng, vol.5, 1987,pp.509-518.
2. Piekutowski AJ:*Characteristics of debris clouds produced by hypervelocity impact of aluminum spheres with thin aluminum plates*, Int.J.Impact Engng, vol.14, 1993, pp.573-586.
3. Menezes V, Takayama K and S.H.R Hosseini:*Development of a biolistic apparatus for medical applications*, Symposium on shock waves, YOkohama, Japan,2006, 18-B-1-5.