Experiment study of ejecta composition in impact phenomenon

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Summary. Impact tests were held to clarify the relationship between the composition of ejecta and these of the projectile and the target plate under different impact kinetic energy and impact velocity. Two sets of impact experiments were held, one using high carbon chromium bearing steel (SUJ-2) projectile and Al2017-T4 plate (Fe/Al impact), and the other using Al2017-T4 projectile and SUJ-2 plate (Al/Fe impact). The spherical projectile is of 7.94 mm in diameter, made of Al2017-T4 or SUJ-2. The impact velocity considered is from 2.5 to 4.2km/s. By recovering and analyzing the injected SUJ-2 and the Al2017-T4 fragments separately, we can quantitatively measure the composition of the injected fragments, and clarify how it depends upon the material of the projectile and the target plane. We further investigate the effects of velocity and kinetic energy of the projectile on the ejecta composition.

1 Introduction

In the history of the earth, species mass extinction has repeatedly occurred. And, the impact of a huge meteorite on the earth is thought as one of the causes of these mass extinction events [1-4]. The diameter of the colliding meteorite reaches several kilometers, and its speed may reach dozens of kilometers per second. When this meteorite collides with surface of the earth at the hypervelocity ranges, the crater that reaches tens of times the diameter of the meteorite is formed in the collision point, and a large amount of crushed materials of the earth and the meteorite are ejected into the atmosphere. These ejected materials would significantly reduce the amount of sunlight that could reach the surface otherwise, and could remain in the atmosphere for months and years as tiny dusts and gases. The impact of such meteorite is therefore believed to able to change the global weather drastically. The physical and chemical effects of the ejected materials on the weather depend strongly on their compositions.

In this study, we are going to clarify how the ejecta composition is related to the original material of the meteorite and the earth surface by a laboratory experiment. As a part of geophysical application of shock wave research, a hypervelocity impact test was performed in a 15 mm diameter two-stage light gas gun at IFS, Tohoku University. In order to examine the effect of test materials on ejected fragments, spheres made of high carbon chromium bearing steel and AL2017-T4 aluminum alloy were individually projected against aluminum and steel targets. In keeping impact energy of steel and aluminum spheres identical, the impact speed of steel sphere is about 2.5 km/s and that of aluminum sphere is about 4.2 km/s. We examined not only the impact crater shape but also size and number distribution of ejected fragments.

2 Experimental setup

2.1 Two-stage light gus gun

We used a light gas gun to launch a 15 mm diameter projectile at 1 to 4 km/s into reduced pressure environments down to 50kPa in air. The gun can be operated under two-stage and one-stage modes for launching projectile at different velocity range. Figure 1 shows the gun system consisting of a 51 mm diameter and 3.4 m long pump tube, a high-pressure coupling, a 15 mm diameter and 3 m long launch tube, and a 1.66 m diameter and 12 m long recovery tank which has a test section equipped with two pairs of 600 mm diameter observation windows and three pairs of flash X-ray ports. The observation windows are made of 20 mm thick acryl, which enabled to observe free flight objects.

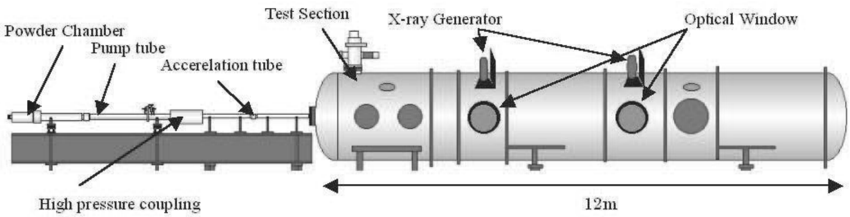


Fig. 1. Schematic of two-stage light gas gun at IFS, Tohoku University

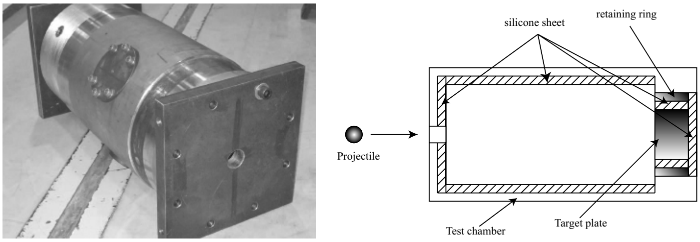
To launch projectiles up to 1.5 km/s, we operated the gun using the single stage mode, in which a cartridge (Winchester 300) filled with high-speed smokeless powder (HS-7 Hodgdon Powder Co.) of 3 g in weight was inserted at the end of the launch tube and ignited with a detonator (GM210M Federal Gold Medal Match). For projectile speed over 1.5 km/s, the two-stage light gas gun operational mode was used instead. A cased charge filled with medium-speed smokeless powder, as propellant charge (H50-BMG Hodgdon Powder Co.) of up to 400 g was inserted in the combustion chamber. To ignite propellant powder in a uniform and controlled fashion, an igniter was inserted in the center of the cased charge.

The igniter contained, in its perforated cylinder, black powder of 13 g in weight and ignited by the Winchester 300 igniter. A 1.5 m long and 15 mm cylindrical tube was connected to the launch tube for attenuating the strong blast wave released from it. This blast remover was basically a perforated tube consisting of four guide rails and a thick wall stainless steel supporting tube. Along the space between two guide rails, 10 mm diameter venting holes were uniformly distributed, through which the precursory blast wave was released into the recovery tank.

A test chamber was placed on a carrier on rails in the recovery tank, so that its position inside of a collimated light beam path passing through the first observation window can be adjusted for the visualization of impact phenomena in the chamber.

2.2 Test chamber for HVI experiments

The test chamber for the present HVI experiments is shown in Fig. 2. It has a single wall structure consisting of stainless steel tube of 200 mm in inner diameter, wall thickness of 25 mm, and 500 mm in length. Target materials and retaining ring are installed in this chamber. The inner wall of this chamber is protected by the silicone rubber sheet of 10mm in thickness. The projectiles are introduced into the chamber through a small diameter entrance hole on the frontal plate as seen in Fig. 2. A sketch of the chamber is depicted in Fig. 2b.



(a) (b)

Fig. 2. Test chamber for HVI experiments

2.3 Experimental conditions

Two sets of impact experiments are held, one using high carbon chromium bearing steel (SUJ-2) projectile and Al2017-T4 plate (Fe/Al impact), and the other using Al2017-T4 projectile and SUJ-2 plate (Al/Fe impact). The spherical projectile is of 7.94 mm in diameter, made of Al2017-T4 or SUJ-2. The impact velocity considered is from 2.5 to 4.2km/s. The Experimental setup for the experiments is shown in Fig. 3.

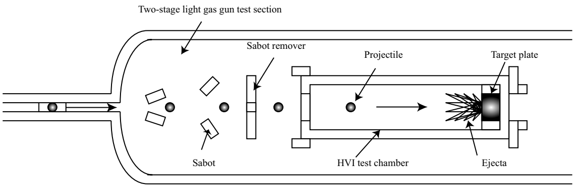


Fig. 3. Experimental setup for HVI tests

We used a 7.94 mm (5/16 inch) diameter spheres to represent a meteorite, and accommodated it in the sabot that consists of four poly-carbonate segments produced by plastic extrusion. The four segments formed a 15 mm diameter and 18 mm long and 3 g weigh cylindrical shape. Upon the release of the sabot and the sphere from the muzzle of the blast remover, the sabot was separated gradually to four segments. The sabot separation was realized by receiving a large aerodynamic force on their blunt frontal surface of the sabot segments.

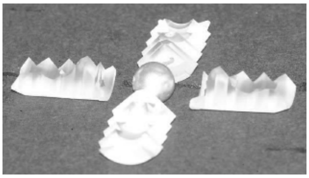


Fig. 4. Spherical projectile and sabot

To promote the sabot separation, we installed a sabot remover before the segments reach the test section, which consisted of a thick steel plate with a hole in the middle. The spherical specimen can pass through the hole but the pieces of sabot segments crashed on the frontal surface and were stopped.

We evacuated the recovery tank by using a rotary pump combined with a mechanical booster pump. The pressure was set to 50 kPa, which can produce aerodynamic forces high enough for spontaneously splitting a sabot from a sphere model.

Three conditions were tested for projectile speeds ranging from 2.5 km/s to 4.2 km/s. The projectile materials, impact velocity, projectile mass, kinetic energy, and target materials of the tests are tabulated in Table 1.

Table 1. Test condition for HVI experiments

	Projectile material	Impact velocity (km/s)	Projectile mass (g)	Kinetic energy (kJ)	Target material
Case 1	Al2017-T4	4.17	0.73	6.35	SUJ-2
Case 2	SUJ-2	2.50	2.04	6.38	Al2017-T4
Case 3	SUJ-2	3.00	2.04	9.18	Al2017-T4

3 Results and discussion

Figure 5 shows two photos of the crater on the target material formed in case 1. The crater is roughly hemispherical, and the local radius on the bottom of the crater is seen to be smaller than that on the top. The surface of this crater is covered with a ruler, and the lip structure is seen on the edge of the crater.

Figure 6 shows the crater on the target material formed in case 2. In this case, the cross-section of the crater looks more like a circular cylindr as shown in Figure 6b. The crater is much deeper compared with case 1.

Therefore, when the projectile has same kinetic energy and the projectile with large density collides with the target plate with small density, it can be confirmed that the depth of the crater tends to grow compared with the case where the projectile with small density collides with the target plate with large density.

A lot of cracks can be confirmed on the surface of the crater, and they have grown in the direction of the projectile impact.

Figure 7 shows the crater on the target material generated as a result of case 3. In this case, it is seen that the crater configuration is similar to the case 2, and the diameter and the depth of the crater are larger than case 2. The number of cracks appeared in the crater section and the lip structure are also larger than the case 2. In case 3, the crack appears almost everywhere on the surface except the vicinity of the crater section.

(a) (b)

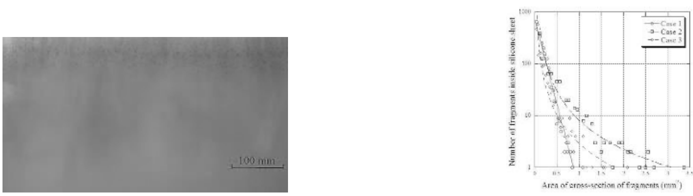
Fig. 5. Target plate after impact (Al/Fe impact (Case 1)): impact velocity = 4.17 km/s; (a) frontal view, and (b) side view of crass section

(a) (b)

Fig. 6. Target plate after impact (Fe/Al impact (Case 2)): impact velocity = 2.5 km/s; (a) frontal view, and (b) side view of crass section

(a) (b)

Fig. 7. Target plate after impact (Fe/Al impact (Case 3)): impact velocity = 3.0 km/s; (a) frontal view, and (b) side view of crass section



(a) (b)

Fig. 8. Captured ejecta fragments inside silicone sheet; (a) sample silicone sheet after HVI experiments (Case 1), and (b) relationship between the size and number of ejecta fragments

Figure 8a shows a photograph of the silicone rubber sheet after the experiment. A large amount of impact fragments are captured by the silicon sheet in all cases. However, there is different in the distribution of the impact fragments in case 1 and case 2. In case 2, the amount of impact fragments was less than that captured in case 1, and has concentrated farther from the collision point. It is clear that even for the same kinetic energy, the distribution of impact fragments are greatly influenced by the combination of materials of the projectile and target material. The relationship between the size and number of ejecta fragments inside silicone sheet is shown in fig. 8b. A number and the size of ejecta fragments which captured in the silicon sheet are different according to the impact velocity, the material of the projectile and the target plate.

The total mass of non-penetrated fragments collected in the HVI test chamber is shown in Table 2. The percentage in parentheses of table 2 shows what percentage collected among the mass of the projectile. The mass of the fragments of projectile at case 1 was 52 percent of initial projectile mass, and the remainder was penetrated in the silicon sheet. On the other hand, it was 74 percent of initial projectile mass that was collected at case 2. Though a further verification with a high-speed video camera etc. is necessary in the future experiments, in the case of Fe/Al impact, it was shown that total mass of fragments that originated in the projectile is fewer than the case of Al/Fe impact.

Table 2. Total mass of non-penetrated fragments collected in the HVI test chamber

	Al2017-T4	SUJ-2
Case 1	0.38 g (52.1 %)	1.05 g
Case 2	0.22 g	1.51 g (74.0 %)
Case 3	0.60 g	1.73 g (84.8 %)

4 Conclusions

Impact tests were held to clarify the relationship between the composition of ejecta and these of the projectile and the target plate under different impact kinetic energy and impact velocity. As a result, it is clarified that the distribution of impact fragments are greatly influenced by the combination of materials of the projectile and target material.

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