IMPACT CRATERING EXPERIMENTS IN MICROGRAVITY ENVIRONMENT.

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Introduction: The MUSES-C/Hayabusa mission found that Asteroid (25143) Itokawa is a rubble pile and some parts of the surface are covered by regolith or mm to cm size gravel layer [1, 2]. Although the number is limited, some craters were found on the regolith or gravel plain of Itokawa by Hayabusa [3]. These results reconfirmed that the understanding of impact cratering phenomena is important for studies of surface processes on small bodies. However, impact cratering experiments in microgravity environments were rare due to technical difficulties. Recently Colwell [4] performed some impact experiments into a dust-covered surface in a space shuttle payload. However, the impact velocities were very low (< 100 cm/sec). Only data available to the scaling law are data in Fig. 1 of Gault and Wedekind [5]. Impact cratering experiments in the microgravity environment are desired to elucidate process on small bodies and to make the best use of the wealth by asteroid explorations.

The microgravity environment can be achieved in parabolic flight aircraft or free-fall capsules. Although the duration time of microgravity in parabolic flight aircraft is longer than that in a free-fall capsule of drop tower, the quality of microgravity is not good generally. We performed impact cratering experiments in microgravity environments using a drop tower. The same facility and experimental devices were used in the performance tests of MUSES-C/Hayabusa sampling devices [2].

Experimental Procedures: Impact experiments in microgravity environment were performed using the Microgravity Drop Experiment Facility of MGLAB, Toki, Japan. Since the length of the free-fall section of the vertical vacuum drop tube is 100 meter, the duration of microgravity environment is 4.5 sec. The gravity level in a falling capsule is estimated to be less 10^{-5} G. However, the exact value of gravity is not known, because the dynamic range of the onboard accelerometer is not large enough. After the free fall, the capsule is stopped by friction dampers in the braking section. The length of braking section is 50 m. The maximum braking acceleration is 10 G. Total 50 drop experiments were performed.

A vacuum chamber with inner diameter of 550 mm and height of 700 mm was set in the payload space of freefall capsules. The ambient air pressure in the chamber was maintained at less than 100 Pa until powder gun ignitions.

A set of gun-target assembly was mounted in the chamber. Two kinds of gun-target setups were used. The Setup-A composed by two single-stage powder guns and two target pans were used for 30 drops. Two shots were performed during one drop. For 20 drops, the Setup-B (one gun and one larger target pan) were used.

Nylon, aluminum, and steel spherical projectiles were launched at velocities between 45 and 360 m/sec. The projectiles were 2 to 7 mm in diameter and 5 to 510 mg in mass. The incident angle was fixed at 73 (Setup-A) or 90 (Setup-B) degrees. Sabot and sabot stopping mechanism were employed to prevent the propellant gases from perturbing ejecta. The launch velocity was measured by the wire-cutting method.

Soda-lime glass beads with mean diameter of 80 to 900 μm were used as the main target material. Ottawa quartz sand F-75 (US Silica) was also used as a target material. Target materials were set in 150 mm depth cylindrical pans. The diameter was 180 mm (Setup-A) or 300 mm (Setup-B). The side walls of the cylindrical pans of soda-lime glass beads were tapped carefully by wooden hammers in order to ensure the consistent degree of glass particle compaction. The Ottawa quartz sand target was not compacted.

Since the capsule deceleration up to 10 G destroys

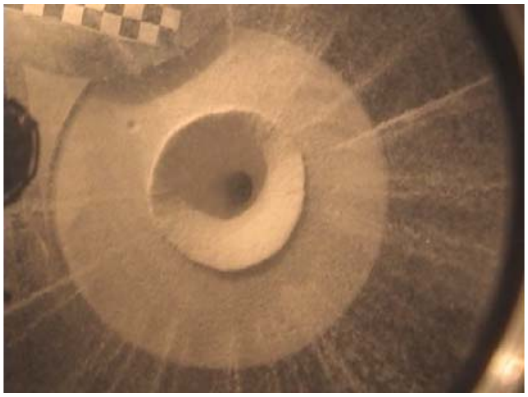

Fig. 1. An example of video images; Impact of 5 mm steel sphere (509 mg) to Ottawa quartz sand F-75 at 250±17 m/sec. The crater diameter is 83 mm.

the formed craters, all impacts were recorded by two digital video camcorders. Framing rates were 30 per seconds. Crater diameters were measured from the digital video images. Figure 1 shows an example of images. Since each event was recorded by a single camcorder in the Setup-A, no crater depth data could be obtained. In the Setup-B, one impact event was recorded by two camcorders.

Ground-based experiments in 1 G environment were also performed at JAXA Sagamihara campus for comparison with MGLAB experiments. The same vacuum chamber, powder guns, projectiles, target materials, and target pans were used. Impact events were also recorded by camcorders.

Crater Formation Time: The weakest point of drop tower experiments is the short duration time of microgravity condition. We checked the crater formation time first. All the video images of microgravity experiments using glass beads smaller than 220 μm and quartz sand clearly show that the crater formation ends within 0.1 sec. Any difference between the crater formation time in 1 G and microgravity environment is not observed. This result certified that the microgravity duration time of the facility, 4.5 sec, is enough long for impact cratering experiments in this case.

Data analyses of experiments using glass beads larger than 300 μm are progressing, since the images are unclear due to the large amount of ejecta.

Crater Final Diameter: Figure 2 shows an example of the dependences of crater diameter on the late-stage effective energy [6]. Solid symbols represent results in microgravity environment. Open symbols represent results in 1 G environment. The least-square fit shown by the solid line is calculated from both microgravity and 1 G data. The result clearly shows that the diameters of craters formed in the 10^{-5} environment coincide with those formed in the 1 G environment within the data scatter. These results indicate the crater formation in the present experiments is not controlled by the gravity.

On the other hand, the exponent shown in Fig. 2 is 1/3.48. Exponents for other combinations of target-projectiles are 1/3.5 – 1/4.0. These values are close to the value of gravity scaling, 1/4, rather than the value of strength scaling, 1/3. The exponents suggest that the diameter does not depend on the strength scaling either. It is possible that the phenomena are controlled by a new scaling term related to the kinetic friction between particles.

The present results both on the crater formation time and crater final diameter are different from those by Gault and Wedekind [5]. The reason is not clear, but may be the difference of amount of kinetic friction. Since the grain sizes of Ottawa quartz sands they used were much larger than those of the present experiment, the kinetic friction for each unit volume may be small.

Conclusion: We performed systematic impact cratering experiments in microgravity and vacuum environment with impact velocities larger than 100 m/sec and obtained data on diameter of crater formed in the environment. The experiments showed that the drop tower is an appropriate tool for studies of surface processes on small bodies. The result shows that the formation time and final diameter of crater formed in the glass beads or quartz sand layer are not controlled by the gravity.

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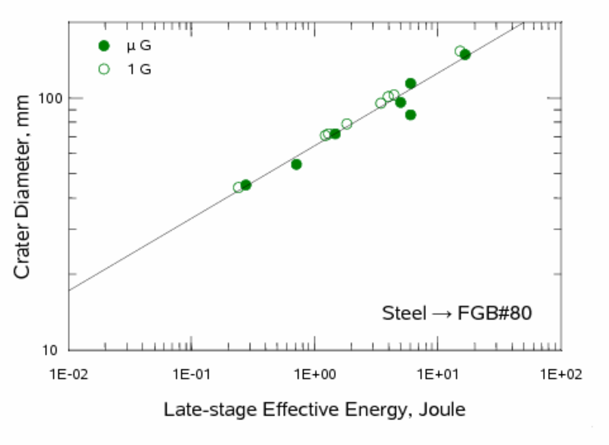

Fig. 2. The crater diameter on the late-stage effective energy [6] of experiments with steel projectiles and the glass beads of 220 μm diameter.