COMPACTION AND FRAGMENTATION OF POROUS TARGETS AT LOW VELOCITY COLLISIONS

Y. Fujii and A. M. Nakamura[1], [1]Graduate School of Science and Technology, Kobe University, 1-1 Rokkodai-cho, Nada-ku, 657-8501, fujiko@harbor.scitec.kobe-u.ac.jp

Introduction: Physical processes of planetary formation from dusts to planetesimals are not well understood. Collision, in particular, low velocity collision, is one of the most important processes in the planetary formation. Collisional outcome varies with critical velocity that is defined as the velocity at which a body begins to break-up. A previous laboratory study of ice spheres [1] showed that the critical velocity is size-dependent at low impact velocity condition. Non-porous ice spheres were used in their experiments. However, dust aggregates have high porosity at least at the very beginning of the planetesimal formation. In order to investigate the collisional process of porous bodies, we performed low velocity collision experiments of gypsum spheres.

Experiments: We prepared spheres of dihydrate gypsum. The diameter of the spheres was 25, 30, 40, 50, and 70 mm. The bulk density and porosity were 1.22 ± 0.12g/cm^3 and 51 ± 6%, respectively.

The spheres were impacted against an iron plate of $40\times400\times300$mm^3. The impact velocity was from 0.4 to 22m/s. The velocities of the gypsum spheres were measured on the images taken by a high-speed video camera at 500 frames/s.

Results: (1) Outcome: We could classify the outcome into 3 types from their appearance. They are intact, fragmentation, and the intermediate state between them. The intermediate outcome is characterized by a flattened surface occurred at the impact point. Such flattening has not been reported as the outcome of non-porous bodies. Figure 1 shows the diameter of the flattened part of the spheres. The diameter increased with impact velocity. At the same impact velocity, it was proportional to the diameter of the spheres. In order to examine whether or not the flattening occurred by compaction or chipping-off of the part of the surface, we compared the mass loss derived by the pre-and post- impact weights of the spheres with the calculated mass loss from the bulk density and the volume loss. We found that the calculated mass loss exceeded the measured mass loss when the impact velocity was more than 10m/s. Accordingly, we concluded that compaction occurred in the above mentioned velocity range in between the velocity ranges for intact and fragmentation. Furthermore, we could identify the compacted zones at the near-impact point on scanning electron microscope (SEM) images as shown in Fig. 2.

(2) Degree of fragmentation: We define the degree of fragmentation as the largest fragment mass over the total mass of the original sphere. The value of unity means that the target is intact. Figure 3 shows that the degree of fragmentation didn't have the value between 0.7 and 1. Absence of the data points here indicates that usual excavation cratering process did not occur in the collision of gypsum spheres.

(3) Critical velocity: There are two critical velocities. One is the boundary velocity between fragmentation and compaction. The other is those between compaction and intact. No clear size dependence was found in these boundary velocities, however, the size of the spheres we used didn't vary over one order of magnitude. Therefore, if the size dependence is very small, we could not detect it.

(4) Restitution coefficient: The restitution coefficient was defined as the ratio of the rebound velocity to the impact velocity of the gypsum spheres. Figure 4 shows that the values became low at the impact velocities larger than 1 m/s. The restitution coefficient gradually decreased with increasing impact velocity with a power-law index of -0.33 ± 0.07. This is different from the -1/4 relationship found for steel balls (Johnson et al. 1985 [2]) and a power-law index of -1/5 found for ice spheres [3]. The steeper slope of the gypsum spheres than those of the steel and the ice spheres probably is due to extra energy consumption by compaction, however, it may be due to difference in experimental conditions, such as target materials.

Summary: We performed low-velocity collision experiments of gypsum spheres. The porosity of the spheres was about 51 %. Gypsum spheres broke differently from the ice spheres previously investigated. No excavation cratering was occurred. Instead, compaction near the impact point was observed. No clear size dependencies were found in the critical velocities for compaction and for fragmentation. The restitution coefficient decreases rapidly to a small value (less than 0.4) when the impact velocity exceeds 1 m/s probably due to the compaction. This value decreased with increasing impact velocity with the power-law index of -0.33 ± 0.07. Future work will focus on the study of the restitution coefficient of the spheres of wider diameter range.

Acknowledgements: We are grateful to N. Ogura for considerable support during the SEM observations. This work was supported by the "21st Century COE Program of Origin and Evolution of Planetary Science" of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

References: [1] Higa, M. et al. (1998) *Icarus 133,310-320* [2] Jonson, K.L. (1985) Contact Mechanics [3] Supulver, K. D. et al. (1995) *Icarus 113,188-199*

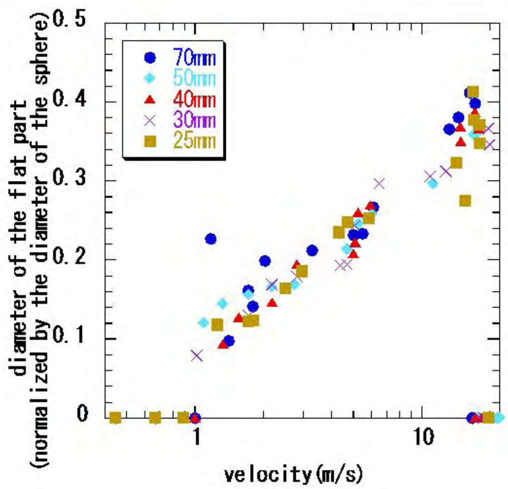

Figure 1: Diameter of the flattened surface of the spheres.

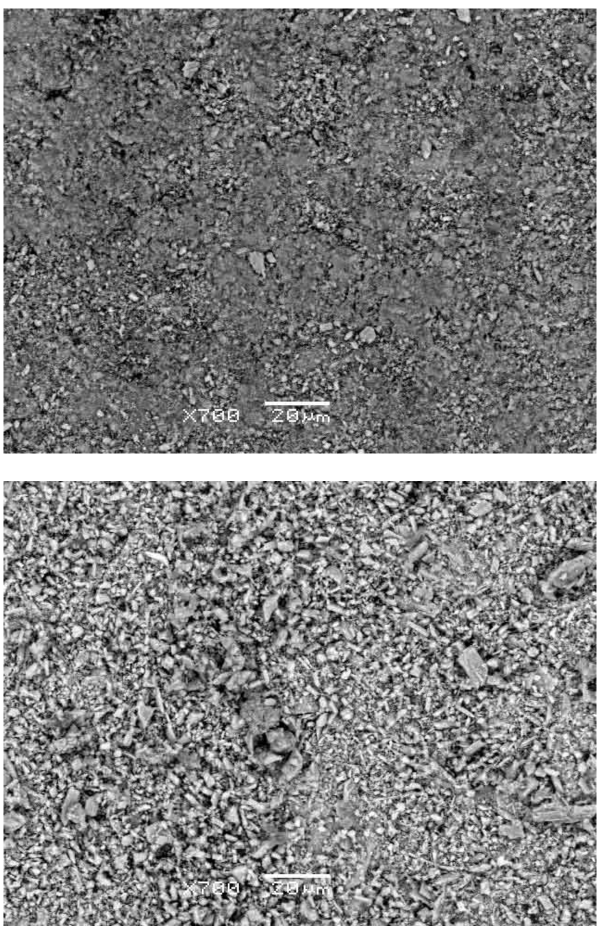

Figure 2: SEM images of a post-impact gypsum sphere. The upper image shows the area near the impact point and the lower image shows the central part of the sphere. The diameter of the sphere was 30mm and the impact velocity was 0.89m/s. The range of scale bars is 20 μ m.

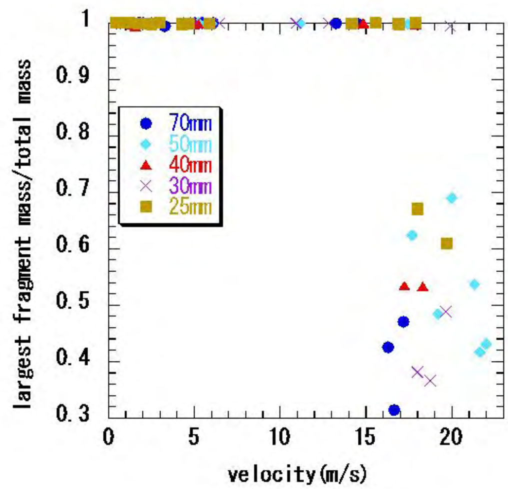

Figure 3: Relationship between the largest fragment mass over the total mass and the impact velocity.

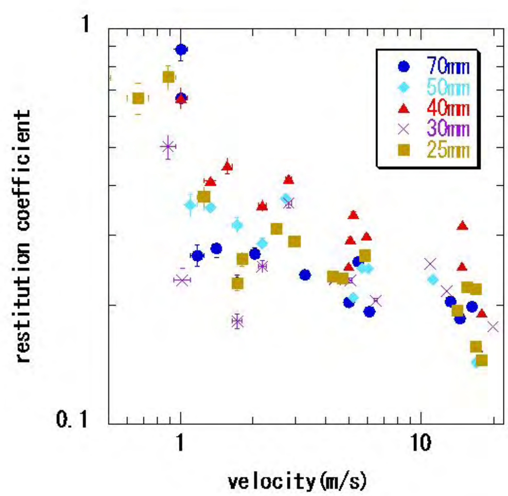

Figure 4: Relationship between the restitution coefficient and the impact velocity. The values became low from about 1m/s.