Laboratory Experiments of Compaction and Fragmentation of Porous Bodies at Low Velocity Collisions

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Introduction: We performed low velocity collision experiments of gypsum spheres in order to study the collisional process of porous bodies at low velocities [1]. Such process plays important roles in planetesimal growth, dynamical and collisional evolution of particles in the rings of giant planets, and reaccumulation of ejecta from impact cratering, impact disruption or rotational burst onto small bodies. We prepared spheres of dihydrate gypsum of five different diameters, 25, 30, 40, 50, and 70 mm and studied if any size dependence exists in the process as was found for low velocity collision of non-porous ice spheres [2]. The bulk density and porosity of the spheres were 1.22 ± 0.12g/cm^3 and 51 ± 6%, respectively. As a result, gypsum spheres broke differently from the ice spheres. No excavation cratering was occurred. Instead, compaction near the impact point was observed. No clear size dependencies were found in the degree of compaction and in the restitution coefficient. The restitution coefficient decreased rapidly to a small value (less than 0.4) when the impact velocity exceeded 1 m/s probably due to the energy consumption due to compaction. In this study in order to focus on the porosity-dependence, we performed low velocity collision experiments of gypsum spheres with a fixed diameter, but with different porosities.

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Experiments: We newly prepared 50 mm-diameter spheres of three different porosities, 31 ± 1, 51 ± 5 and 62 ± 4%. The uniaxial compressive strength of the samples were measured for cylinders of 13mm in diameter and 17mm in height at a loading rate of 6mm/min and summarized in Table 1. The compressive strength increased with the decrease of porosity. The spheres were impacted against an iron plate of $40\times400\times300$mm^3. The impact velocity was from 0.2 to 22m/s.The spheres were accelerated by free fall. The velocities of the spheres before and after the impact were measured on the images taken by a high-speed video camera at 500 or 1000 frames/s. We also measured the crush curves of cylindrical samples of 10mm mm in diameter and 12mm in height. The samples were put into a stain-less steel cylinder and compressed by a stainless cylinder with diameter of 10 mm at a loading rate of 6mm/min.

Results: In the previous study, we could classify the outcome into 3 types from their appearance. They are intact, compaction, fragmentation. Figure 1 shows the diameter of the flattened part of the spheres when they were compacted. The diameter increased with impact velocity. Figure 1 shows that no clear porosity dependence is found in the degree of compaction. The restitution coefficient was defined as the ratio of the rebound velocity in the vertical direction to the impact velocity of the gypsum spheres. Figure 2 shows that the value of restitution coefficient gradually decreases with increase of the impact velocity. The slope of the curve is similar to the -1/4 relationship expected from Hertz theory of elastic contact [3] Figure 3 shows the results of the crush curve measurements. As for the targets with 62%, the specific volume decreases with increasing pressure. On the other hand, in 31%, the specific volume is nearly-constant with varying pressure. In 51%, it behaves intermediate them.

Discussion: No clear porosity dependence is found in the degree of compaction as shown in Fig. 1. On the other hand, clear porosity dependence is found in the crush curves. Interestingly, the spheres of 31% porosity were obviously compacted when they were impacted, whereas the cylindrical samples of 31% porosity were not compacted drastically as shown in Fig.3. This discrepancy may be explained by the difference of the loading rate or maybe to some extent due to the difference in the shape (sphere and cylinder). The former is about 10^3 mm/s, the latter is about 6 mm/min. Further investigation is needed to clarify the effect of the loading (or strain) rate on compaction.

Summary: We performed low-velocity collision experiments of gypsum spheres. The porosity of the spheres was about 31, 51 and 62%. 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 porosity dependencies were found in the degree of compaction and in the restitution coefficient that gradually decreases with impact velocity. On the other hand, clear porosity dependence was found in the crush curves. This may be because strain rate dependence exists when the compaction occurred. Future work shall focus on the possible strain rate dependence.

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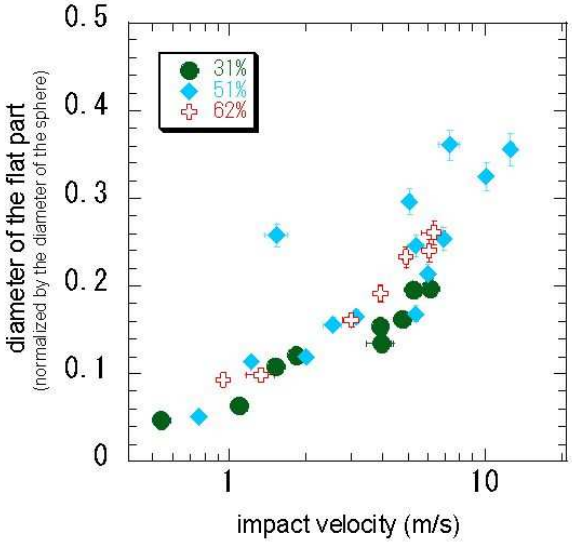

Figure 1: Diameter of the flattened surface of the spheres

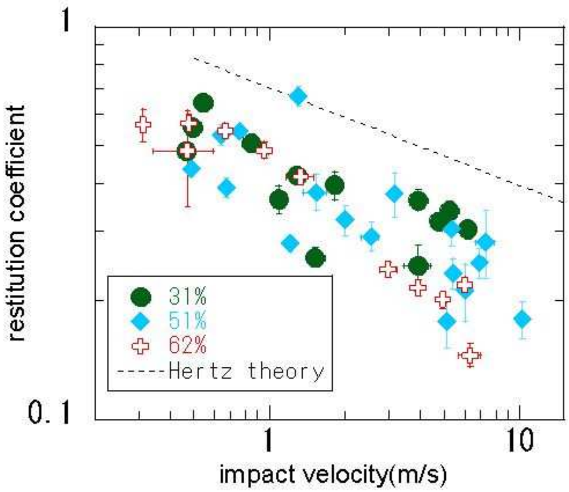

Figure 2: Relationship between the restitution coefficient and the impact velocity. The dashed line represents the estimated value based on Hertz theory.

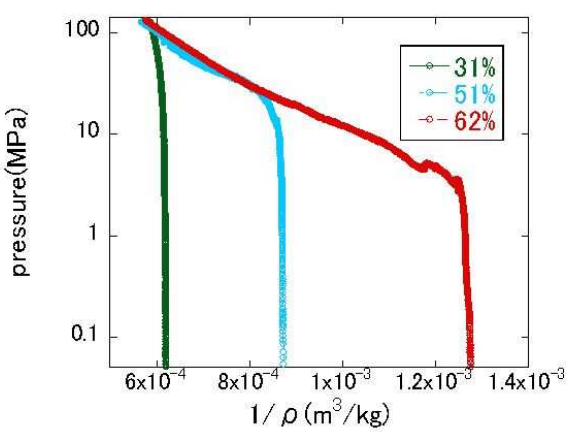

Figure 3: Comparison of the crush curves of the samples with different porosity.

Table 1: Sample properties

Porosity (%)	Uniaxial compressive strength(MPa)
31±1	18.66±3.69
51±5	15.57±1.34
62±4	7.61±0.61