

Low-velocity impact compaction experiments of dust layers

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Planetesimals, which are dust aggregates, are thought to be porous, and many asteroids, which are thought to have evolved from planetesimals, are also porous. Parts of the asteroids have been coming to the earth as meteorites, and the porosity of these meteorites has been measured. However, it is difficult for dust aggregates to be compacted to the porosity of CI chondrites and CM chondrites by self-gravity alone during planetesimal accumulation [1], and factors other than self-gravity, such as thermal evolution and external forces are considered necessary for sufficient compaction. Dust grains form fractal aggregates by hit-and-stick collisions, and as their mass and collisional velocity increase, they transform into denser structures with compaction and fragmentation upon impact. Therefore, we focused on collision as a compaction process other than self-gravity. In this study, low-velocity impact compaction experiments of the dust layer by a free-fall projectile under earth gravity were conducted, and the moment of compaction was observed and analyzed by X-ray transmission images.

As experimental samples, irregularly shaped silica grains (median diameter $1.5\ \mu\text{m}$, grain density $2.2\ \text{g/cm}^3$) were filled into acrylic containers (inner diameter 7.4 cm, height 20 cm), and the top surface was scraped off with a spatula. Steel spheres of 3 cm diameter, steel cylinders (short) (3 cm high) and steel cylinders (long) (5 cm high) were used as projectiles, which were aimed at the sample and free-fall through the acrylic tube from a height of 1 m. The passage of the projectile was detected by a laser and optical sensor, which triggered a flash X-ray irradiation system, and the grains were photographed on an imaging plate while they were being compacted. Experiments were conducted at atmospheric pressures of 105 Pa and 3 Pa.

The relationship between time elapsed from projectile impact and depth of penetration best fits the experimental results when we assume Newtonian resistive force acts and frictional force does not act. The average porosity in the area just below the projectile decreased from 0.83 before compaction to 0.70 ± 0.04 after compaction for the steel cylinder (short) and from 0.84 before compaction to 0.71 ± 0.04 after compaction for the steel cylinder (long). The range of porosity estimated using the relationship between pressure and porosity in the compaction experiment of silica grains at a compaction rate of $10\ \mu\text{m/s}$ [1] were derived and compared with the experimental results. They were $0.70 \sim 0.74$ and $0.68 \sim 0.71$ for steel cylinders (short) and steel cylinders (long), respectively, and were within the average porosity and standard deviation after compaction in the experiment. This suggests that compaction of silica grains is similar for compaction rates of $10\ \mu\text{m/s}$ and several m/s.

We discuss why the average porosity after compaction in the experiment is consistent with the estimated porosity assuming that frictional force does not act. The initial porosity of the silica grains in this experiment (0.83) is significantly higher than the initial porosity (0.410 ± 0.004) of the sample used in a previous study where a penetration law into powder was presented [2]. Therefore, it is considered that the grains in the compacted area move to fill the voids of the surrounding grains, resulting in compaction, and the grains themselves do not move significantly enough to be affected by friction (i.e., they do not produce flow). In the range of compression speeds from $10\ \mu\text{m/s}$ to several m/s, the pressure change per unit of time is different, but since the pressure does not reach a level that would fragment the grains, the voids are considered to be filled only by the movement of grains due to compaction, showing a similar degree of compaction.

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[1] Omura, T. and Nakamura, A.M., 2021, The Planetary Science Journal 2, 41.[2] Katsuragi, H. and Durian, D.J., 2013, Physical Review E 87, 052208.

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