Mechanical properties of dust layer influenced by hierarchical grain structure: Results from laboratory experiments

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The particle structure of dust layers in planetesimals significantly influences their physical properties, which play a crucial role in their evolution. Observations suggest that planetesimals are formed by self-gravitational instability in protoplanetary disks. In this case, planetesimals should have a hierarchical structure, i.e., an ensemble of agglomerates (pebbles) of individual grains. Initially, this hierarchical aggregate behaves as an assembly of pebbles. However, after considerable compaction due to mechanisms such as self-gravity, the aggregate should behave as a homogeneous assembly of grains, because the pebbles undergo deformation, fracturing, and merging. In this study, we focus on this transition process and investigate the compaction behavior and structural changes of pebble layers. In this presentation, we compare the results of compaction experiments on pebble and homogeneous particle layers to discuss the influence of pebble properties on compaction behavior. We also present observations of internal structural changes during compaction.

We used glass beads with a diameter of 4.2 μm (Potters-Ballotini, EMB-10) as the sample powder. There are two types of samples: a grain sample, in which the sample powder was sieved into a cylinder, and a pebble sample, which has a hierarchical particle structure consisting of agglomerates (pebbles) of the sample powder. The pebbles are naturally formed agglomerates (dry pebbles) that developed during storage in the laboratory, or agglomerates formed by adding water to the powder (wet pebbles). We sieved these agglomerates and used agglomerates with a diameter of 1–2 mm in the experiments. The strength of the pebbles varies depending on the formation process. Therefore, we measured the crushing strength of the pebbles for each sample. Compaction experiments were conducted using a universal testing machine (Shimadzu, AG-X). The samples were compacted until the pressure reached 6×10^6 Pa. For some samples, we adjusted the maximum pressure in the range of 1×10^4 to 6×10^6 Pa. The internal structure of these samples was observed using a CT scanner (NAOMi-CT 3D-M) after the experiments.

The pebble and grain samples showed similar compaction curves as compaction progressed significantly. However, at earlier stages of compaction, a higher pressure was required to achieve the same packing fraction in the pebble samples than in the grain samples. The required pressure increased as the strength of the pebbles increased. Moreover, during the early stages of compaction, the compaction curves normalized by pebble strength collapsed into a single line for samples composed of the same type of pebbles (wet or dry). This suggests that, in this stage, compaction proceeds through the fragmentation of pebbles. CT scan observations also confirmed that, as compaction progressed, the outlines of the pebbles inside the samples became unclear and eventually disappeared. These results confirmed that the deformation of the particle layer leads to the fragmentation and fusion of the pebbles, and eventually, the presence of pebbles in the initial structure no longer affects the compaction behavior of the particle layer.