Shape, Size, and Density of Clusters Formed in Granular Stream

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Introduction: It is known that granular flow forms discrete structures due to inelastic collision between particles. Mesh-like patterns in the ejecta curtain from craters of glass beads and silica sand targets have been found to be formed, and such patterns have also been reproduced by numerical simulations of inelastic particles. This process may be relevant for the origin of rays around fresh craters on the Moon or airless bodies (Kadono et al., 2015). The ejecta curtain produced by natural collision onto planetary bodies or an artificial impactor may show discrete structures such as mesh patterns, clusters, or the aggregates of ejecta particles and provide valuable information on physical properties of the particles.
The simplest granular flow is a free-falling stream of particles. Both laboratory experiments (Royer et al., 2009) and numerical simulations (Waitukaitis et al., 2011) have shown that clusters are formed in free-falling granular stream, and the numerical simulations have also shown that the clusters have an average coordination number of 4 and that particles consisting of the clusters have vanishing relative velocity.
In our experiments of free-falling granular stream using spherical and irregularly shaped particles of several tens of microns whose adhesion was measured by centrifugal method, it was shown that irregularly shaped particles are easier to form clusters than the spherical particles with the same degree of adhesion (Nagaashi et al., 2017; the fall meeting of the Japanese Society for Planetary Sciences). In this study, we measured the shape, size and density of clusters and discuss the influence of particle shape on the physical properties of clusters formed in free-falling granular stream.

Experimental method: A plastic funnel containing the sample particles was placed at a height of 1.6 m from the bottom of experimental chambers. The particles exited the bottom of the funnel through an aperture (diameter: 12 mm). Following the opening of an electromagnetically sealed shutter at the bottom of the funnel, particles fell freely from the aperture as a granular stream. In the chamber of ISAS, flash X-ray image was taken for clusters downward 110 cm from the bottom of the funnel to estimate the bulk density of the clusters. On the other hand, optical high-speed images of clusters at the same height were taken in the chamber of Kobe University to analyze the size and shape of the clusters. Experiments were carried out mainly under atmospheric pressure and some were under evacuated condition. In this study, spherical 50-μm glass beads and irregularly shaped 70-μm quartz sand were used.

Results: In this experiment, the funnel aperture was larger than those of the previous study (maximum 6 mm), and clusters were about twice as large as the maximum clusters of the previous study. The aspect ratio of the cluster is defined as the ratio of the length in the direction along the stream to the width in the perpendicular direction. The aspect ratio was in the range of approximately 1 to 3 for both particles, which is consistent with the results of previous laboratory experiments (Royer et al., 2009). However, clusters composed of irregularly shaped particles had larger variations in size and shape than those of spherical particles: the cluster width was 3.93 ±0.63 mm for 50-μm glass beads and 4.32 ±1.40 mm for 70-μm quartz sand, and the circularity of quartz-sand clusters was smaller than glass-beads clusters.
On the other hand, the porosity of the clusters of glass beads estimated from the X-ray transmission image was 0.58 ±0.02. The coordination number of the aggregates with porosity of 0.6 is between 3.7 and 6.5 (Wada et al., 2011). Therefore the porosity of the glass-beads clusters in this study does not contradict

the numerical simulation of spherical particles. In addition, the porosity of the clusters of quartz sand was 0.59 ±0.03, and the cluster porosity showed no difference depending on particle shape.

Keywords: Granular Stream, Cluster, Particle Shape