Measurements of cohesive force of regolith- simulated particles using centrifugal method

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Introduction: On small bodies, interparticle forces, such as, van der Waals force and electrostatic force, are thought to be dominant compared to gravitational force for smaller particles. Laboratory studies showed that strength and porosity of regolith layer depend on interparticle forces (Omura & Nakamura, submitted) and that not only gravitational force but also particle-particle interaction has an effect on low-velocity impact onto regolith-covered surface of small bodies (Kiuchi et al., private communication). Furthermore, fast rotators spin in excess of what gravity alone could hold together were shown to be explained by cohesive force between constituent particles (Sánchez & Scheeres, 2016). For all of these reasons, measurement of cohesive force between regolith-simulated particles is important for understanding physical processes on small bodies.

Experimental method: Previously, cohesive force between micron-size spherical silica particles was measured using an atomic force microscope cantilever (Heim & Blum, 1999). On the other hand, in this study, centrifugal separation method (centrifugal method) (e.g., Krupp, 1967) was used in order to measure cohesive or adhesive force between a particle and a plate. This method can directly measure the cohesive or adhesive force of many particles at the same time, which enables us to statistically analyze the results. Additionally, we measured the force acting not only to spherical particles but also to irregularly shaped particles, and we discuss the effect of particle shape.

The measurements were conducted with either petri plates (coarse surface) or optical glass plates (polished surfaces) with surface roughness of 158.2 nm or 63.3 nm, and irregular alumina grain of diameter 59 and 77 μm, irregular silica sand grain of diameter 73 μm, and spherical glass bead of diameter 50 and 100 μm. We discretely increased the rotation speed of the centrifuge from 300 to 5000 rpm and took optical microscope images of the same location of the plate before and after applying centrifugal force at each rotation speed. We determined the range of rotation speed within which the particle separated from the plate based on the microscope images and estimated the cohesive or adhesive force between the particle and the plate. The mass of each particle was estimated using the size of the particle on the images and used it for the calculation of the centrifugal force.

Results: We compared the experimental results with the theoretical values expected from Johnson–Kendall–Roberts (JKR) theory and Derjaguin–Muller–Toporov (DMT) theory, both of which account for elastically deformable surface and the surface energy. The results of the experiments using the coarse surface are as follows. Similar to the predicted by both theories, for alumina grains, it seems that adhesive force increases with increasing particle size, whereas, for glass bead, cohesive force does not significantly increase with particle size. Because the scatter of the data is large, i.e., more than orders of magnitude, the material difference could not be evaluated in these measurements. The experimental results were smaller than the theoretical values for all particles except for 50 μm glass bead. Larger scatter in the measurement values was seen for the irregular particles, so the cohesive force is likely to be influenced by macroscopic shape. On the other hand, the data of macroscopically spherical 100 μm glass bead also have scatter, so cohesive force is also likely to be greatly influenced by microscopic surface roughness.

The scatter in the measurement values of 100 μm glass bead with the optical glass plates is smaller than for coarse surface as shown in the figure, suggesting that microscopic surface roughness has a significant effect on cohesive force.

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