COHESIVE FORCE MEASUREMENTS OF METEORITE POWDERS. Y. Nagaashi[1], T. Aoki[1], and A. M. Nakamura[1], [1]Graduate School of Science, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, Hyogo, 657-8501, Japan (y.nagaashi@stu.kobe-u.ac.jp)

Introduction: The cohesive forces between the particles constituting of small bodies significantly affect their physical properties. Cohesive forces allow their fast rotation [1], and affect their deformation and failure [2]. The cohesive force of micron sized silica spheres measured using atomic force microscope cantilevers at an ambient pressure of 10^2–10^5 Pa and a relative humidity of 10–40% increases with particle size [3], which is consistent with the Johnson-Kendall-Roberts (JKR) theory [4]. However, an extrapolation of these measurements predicts several orders of magnitude larger cohesive forces than the measured for 50 μm spherical glass spheres in open air [5]. This may be due to microscopic surface roughness of the particles [1,5]. On the other hand, adsorbed water vapor on a particle surface, which is difficult to remove only by evacuating without heating, can reduce the measured cohesive force [6].

Here, we measured the macroscopic and microscopic shape of meteorite particles with several tens of microns in size, and measured their cohesive force. In addition, we measured the amount of water vapor adsorption on the particles, and discussed the cohesive strength of asteroids.

Experiments: We used the meteorite particles with median diameters of 48–65 μm obtained by crushing the pieces of the Murchison (CM2), Allende (CV3), Northwest Africa 539 (LL3.5), Northwest Africa 1794 (LL5), Northwest Africa 542 (LL6), and Millbillillie (eucrite) and by sieving them. We used polydisperse spherical glass beads, irregularly shaped glass powder and silica sand particles with similar size to the meteorite particles.

The macroscopic shape, circularity, of the particles were obtained using optical microscope while the microscopic shape, which is represented by the arithmetic mean roughness R_a, of the particles was obtained using a confocal laser scanning microscope. The cohesive force between the particles and a glass slide was measured in open air at a relative humidity of 30–40% using a centrifugal method [5,7], whose schematic diagram is shown in Figure 1a. We took optical microscope images of the slide to which the particles were attached, and applied a centrifugal force to it in the direction of pulling the particles vertically away from the slide in a centrifuge. We took optical microscope images of the same location as before the centrifugal force was applied, and then applied a larger centrifugal force than before. We repeated this process as shown in Figure 1b, and obtained the centrifugal forces resulting in the removal of the particles from the slide, which correspond to the cohesive forces.

We estimated the amount of water vapor adsorbed on the particle surface under the measurement condition of the cohesive force using a high-precision gas and vapor physisorption instrument.

Results: The circularity of the meteorite particles is 0.74–0.78 in median, larger than those of Itokawa rocks and impact fragments (~0.7), at the number of pixels constituting the particles of ~3000 pixels which affects the circularity [8]. The R_a of the glass slide, the meteorite particles, and the non-meteorite particles obtained from the surface topography were ~4 nm, ~300 nm, and ~30 nm, respectively.

Figure 2 shows the measured distributions of the cohesive force. The distribution extends over 2–3 orders of magnitude. A distribution predicted by the JKR theory for perfect spheres with size distributions consisting of all the Murchison and Allende particles we used is also shown in Fig. 2. The typical cohesive forces of the spherical glass beads, the non-spherical and non-meteorite particles, and the meteorite particles are ~0.6 μN, ~0.1 μN, and ~0.05–0.1 μN, respectively, 1–2 orders of magnitude smaller than expected by the JKR theory.

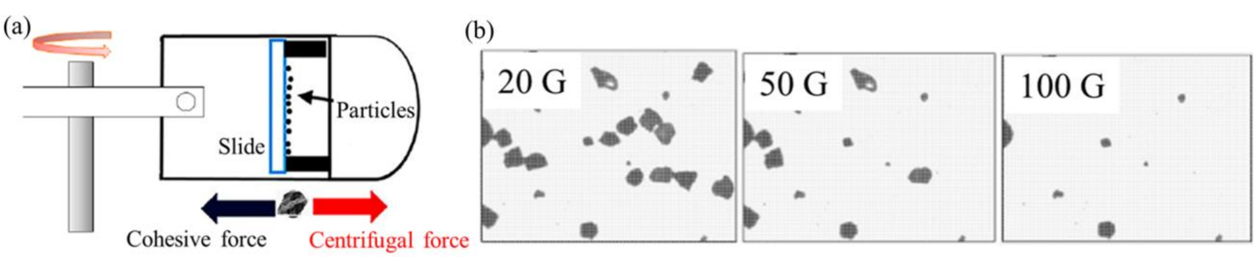

Figure 1. (a) Schematic diagram of the experimental configuration of the cohesive force measurements. (b) Optical microscope images of Murchison particles attached to a glass slide after applying the centrifugal accelerations of 20, 50, and 100 G. Here G is the Earth's gravitational acceleration.

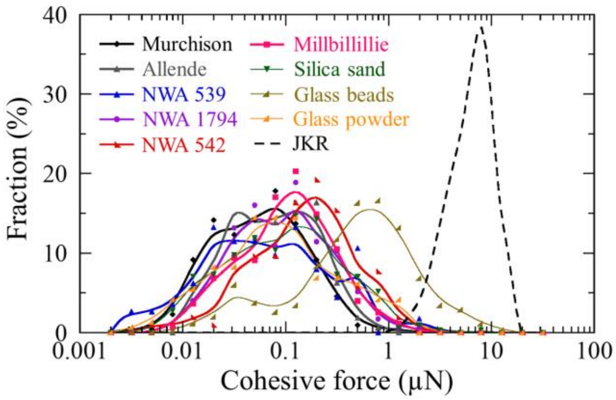

Figure 2. The results of the cohesive force measurements. Dashed curve is a model distributions predicted by the JKR theory in the case of spheres with a size distribution of carbonaceous chondrite particles used in this study. The cohesive force predicted by the JKR theory is $F_{\text{theo}} = 3\pi\gamma R$ where R and γ are the reduced radius and the surface energy, assuming 0.025 J/m^2 for silica in open air [9], of the particle, respectively.

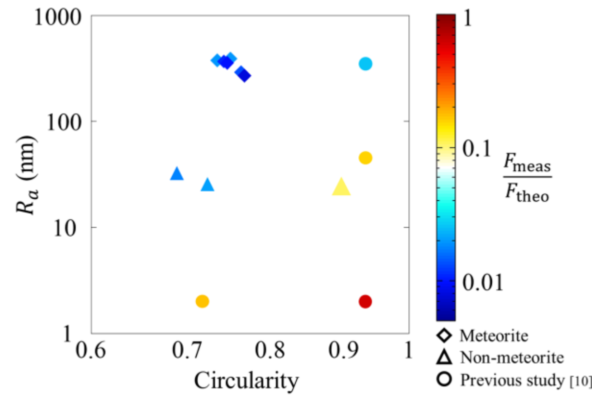

Figure 3. The effects of the circularity and the surface roughness R_a on the cohesive force. The colors of the plots show the $F_{\text{meas}}/F_{\text{theo}}$, which is given by the color-bar on the right. The diamonds, triangles, circles show the meteorite particles and the non-meteorite particles in this study, and the glass particles in the previous study [10], respectively.

We estimated approximately two adsorption layers of water vapor on the surfaces are formed on the Allende and NWA 1794 particle surfaces during the measurements of the cohesive forces of the particles.

Discussions: Figure 3 shows the effects of the circularity and the surface roughness R_a on the cohesive force. Here we normalized the measured typical cohesive force, F_{meas}, by the prediction of the JKR theory, F_{theo}. The particles with rougher surfaces and smaller circularities tend to have smaller cohesive forces. The cohesive forces of ~40 μm spherical and irregularly shaped glass particles to glass substrates with different surface roughness, measured by an impact separation method [10], are also shown in Fig. 3, where we used the R_a of the substrates.

We can estimate that if 2–4 layers of water vapor molecules are sandwiched between the contacting surfaces during the cohesive force measurements, the cohesive force in open air is ~5–13 times smaller than in airless environment [6]. This is consistent with previous suggestions that the surface energy of silica particles may be 10 times larger in vacuum than in open air [11].

Assuming that the surface energy in airless environment is 10 times greater than in open air and considering the difference in circularity between the meteorite samples and Itokawa rocks and impact fragments, the cohesive force between regolith particles is estimated to be sub-micronewtons in general. Using one of the relationships of the tensile strength of the particle layer with the particle size [12], we expect that the typical particle size of several tens of microns, similar to those used in this study, may be required for the fast-rotating asteroids with the estimated cohesive strength of several hundreds of pascals [13].

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