Abrasion experiments of quartz particles simulating the regolith abrasion on airless bodies: change in their 3D shapes

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Some of Itokawa and lunar regolith particles have rounded edges and mechanical abrasion was proposed for these particles [1,2]. Particles should rub against each other on a body without fluids by particle motion. On Itokawa, seismic wave induced by micro-meteoroid impacts [1], YORP effect and tidal motion [3] were proposed for the abrasion process. In this study, we made abrasion experiments in order to understand how the shapes of particles and their edges change in 3D.
The experiments were made using quartz particles with a mill (Multi-beads-shocker: YASUIKIKAI Co.). We chose quartz because the strength is similar to olivine and pyroxene although it is almost absent in meteorites and moon samples and also because a large amount of the sample is available. Single crystals of colorless quartz were crushed in a tungsten carbide mortar, and particles 1-2 mm in size were selected with sieve. These particles (~6.5g) were put into an agate vessel (10 mL) with ~50% fraction without any crushing tool. Then the vessel was rotated together with the vertically-vibrational motion.
Two types of experiments were performed. In the first type of experiments (Exp-1), the samples were rotated at a rate of 1500 or 2500 rpm for durations of 5, 30, 120 and 180 min. In each run, powder (<250 μm) produced by abrasion was collected with sieve, and the mass of the powder was calculated from the difference between the particle mass before and after the run. More than 150 particles randomly sampled were imaged by X-ray CT at Tohoku University (X-ray tube voltage140 kV, pixel size: 14.5 μm) to obtain their 3D shapes. In second type of experiments (Exp-2), three kinds of colored quartz crystals (amethyst, citrine and morion) were crushed and two particles (1-2 mm) of each (totally six particles) were mixed with colorless quartz particles. The samples were abraded at a rate of 1500 or 2500 rpm for accumulated durations of 1, 5, 10, 30, 60, 120 and 180 min. After each abrasion cycle, the colored particles were picked up and their 3D shapes were imaged using X-ray CT system at BL20B2 of SPring-8 (25keV, pixel size: 2.75 μm). After the imaging, the particles were cleaned and returned to the agate vessel, and the abrasion cycles were repeated.
The volume, *V*, surface area, *S*, and 3-axial lengths of each particle were obtained from the CT images. Then, we calculated the 3-axial ratio, angularity (*V* of approximated ovoid/*V*) and sphericity (*S*/*S* corresponding to approximated ovoid). In Exp-2, 3D models of colored particles after each abrasion cycle were made for examining change in their 3D shapes.
The powder mass produced by abrasion and sphericity increased while *V*, *S* and angularity decreased with time in Exp-1 and -2. Changing rates of these parameters were larger at 2500 rpm than 1500 rpm except for sphericity, and the changing rates largely decreased in the initial 30 min. In Exp-1, the average 3-axial ratio was almost unchanged with time at 1500 rpm while it increased at 2500 rpm (the particle shape became equant). In Exp-2, the 3-axial ratios of the colored particles differently changed grain by grain suggesting that the behavior of the 3D-axial ratio observed in Exp-1 should occur as a total behavior of individual particles.
Changes in the colored particle shapes showed that abrasion advanced by chipping particle edges at 2500 rpm while by gradual wearing almost without chipping at 1500 rpm. The present results on the difference by the rotation rates can be explained by these two abrasion modes. Comparison with Itokawa and lunar regolith particle shapes may suggest that Itokawa particles only experienced light abrasion

without chipping while lunar particles experienced heavy abrasion with chipping as discuss in more detail in [4].

[1] Tsuchiyama et al. (2011) *Science*, 333: 1121. [2] Tsuchiyama et al. (2016) 4th *Symp. Solar System Materials*, abstr. [3] Connolly et al. (2015) *EPS*, 67: 12. [4] Tsuchiyama et al. (2017) *JpGU*, abstr.

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