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Considering heat transfer mechanism in powders by thermal conductivity measurements of different constituent particles

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Surface of atmosphere-free planets, asteroids, and satellites is covered with the fine regolith, whose thermal conductivity is extremely low compared with that of rocks. The thermal conductivity of the regolith layer is a fundamental physical quantity for estimation of crustal heat flow. Therefore, in order to understand thermal state and thermal evolution of the bodies, it is necessary to determine the thermal conductivity of the surface. However, although the thermal conductivity of powder media is considered to depend on many parameters, such as particle size and its distribution, porosity, applied stress, temperature, particle shape, constituent of particles, and optical property of the particle surface, these dependencies have not been clarified. We aimed at understanding the heat transfer mechanism in the low thermal conductive materials under vacuum conditions by means of the measurements of the thermal conductivity of powder media with well-controlled parameters. In this instance, we report the experimental result obtained by changing the two parameters; constituent of the particles and optical property of the particle surface.

Five samples were used for thermal conductivity measurements; solid glass beads, hollow glass beads, titanium powder, carbon coated glass beads, and oxidized titanium coated glass beads. The particle size of these samples is from 100 to 500 micrometers approximately. The ambient temperature was about 20 degC. The thermal conductivities ware measured at the depth of 1 cm for all samples. The thermal conductivity measurement was conducted by the line heat source method, in which a constant heat is supplied to a line heater in the sample and the thermal conductivity is estimated from the temperature increase rate of the heater line. Nichrome wire was used for the line heater, but because of the electric conductive property of titanium powder and carbon coated glass beads, a nichrome wire coated with electrical insulator was made for measuring the thermal conductivity of these two samples. The temperature increased by less than 5 degC during the measurement time of 1000 seconds. The effect of this temperature increase on the thermal conductivity is negligibly small. In this abstract, the experimental results for the solid glass beads and hollow glass beads are described as an example. The particle size, bulk density, and bulk porosity of these samples are shown in above table.

First, thermal conductivities were measured at atmospheric pressure. As the results, while the thermal conductivity was 0.211 W/mK for the solid glass beads, it was 0.048 W/mK for the hollow glass beads. That is, the hollow glass beads have lower thermal conductivity than the solid glass beads with the air remaining. On the other hand, under vacuum conditions ($<$ 0.01 Pa) at which the heat transfer by the gas is negligible, both solid and hollow glass beads had the thermal conductivity of 0.0022 W/mK. This result possibly indicates that the heat transfer under vacuum condition are almost contributed to the radiative heat transfer, and independent of the particle constituent and contact network between the particles. In addition, the oxidized titanium coated glass beads with the particle size of almost the same had the thermal conductivity of 0.0037 W/mK. The thermal conductivity difference between the oxidized titanium coated glass beads and the solid glass beads may caused by the difference of the radiative heat transfer due to the variations of optical properties of the particle surfaces.

	particle diameter (μm)	bulk density (kg/m^3)	bulk porosity
solid glass beads	90-106	1540	0.39
hollow glass beads	90-115	40	0.98