Experimental investigation on effect of particle size distribution and irregular shape on thermal conductivity of powdered materials

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Thermal conductivity of regolith on planetary bodies including the Moon and asteroids is one of the most important physical properties for calculating their surface temperature and thermal evolution. We have experimentally investigated the parameter dependences of the thermal conductivity of powdered materials under vacuum conditions mainly using glass beads as a model material. Together with these experimental results, we developed an integrative model for the thermal conductivity, which enable us to estimate the thermal conductivity of powdered materials from the parameter values. However, this model does not explicitly include the effects of particle size distribution and particle shape. Evaluation of their effects on the thermal conductivity is a critical issue to apply our thermal conductivity model to natural regolith on the planetary bodies.
In this study, we measured thermal conductivity of a lunar regolith simulant, JSC-1A, and samples with narrow particle size distributions prepared from JSC-1A by sieve. From these experimental results and our previous experiment data about the glass beads, we evaluated the effects of the wide particle size distribution and irregular particle shape on the thermal conductivity.
Particle sizes of JSC-1A is less than 1 mm, and volumetric median diameter and volumetric arithmetic mean diameter are about 100 μm and 40 μm, respectively. By sieving JSC-1A, we prepared four samples with particle sizes of 53-63 μm, 90-106 μm, 355-500 μm, and 710-1000 μm. We call the sample that is not sieved “JSC-O (Original)” and the samples that are sieved “JSC-S (Sieved)”. Their thermal conductivity was measured by the line heat source method. Degree of vacuum during the measurements was about 0.01 Pa, and ambient temperature was controlled from -25 to 60 ℃. Temperature dependence of the thermal conductivity for each sample was utilized to determine solid conductivity (contribution of the thermal conduction through contact points between the particles) and radiative conductivity (contribution of radiative heat transfer through void spaces between the particle surfaces). The particle size, density, and porosity of the measured samples are summarized in Table 1.
Figure 1 shows experimental results. Because the porosity values of the JSC-S were lower than that of JSC-O (42%) and were scattered from 47% to 66%, we corrected the conductivity to that at the porosity of 42% with using our thermal conductivity model, and these corrected data are also plotted. Moreover, the results for glass beads (porosity of 42%) are also shown.
(1) Effect of particle size distribution: Comparison of JSC-O and JSC-S.
We found that the solid conductivity of JSC-O is comparable with that of JSC-S of 90-106 μm. This particle size is comparable with the volumetric median size of JSC-O. That is to say, it implies that the solid conductivity of a powdered media with a given particle size distribution can be represented as that of a powdered sample with single particle size of the volumetric median. The radaitive conductivity of JSC-O was also comparable with JSC-S 90-106 μm. From these results, we can suggest that the particle size representative of the thermal property is the volumetric median particle diameter.
(2) Effect of particle shape: Comparison of JSC-S and glass beads
The solid conductivity values of JSC-S were comparable with or lower than those of glass beads with the same particle size of each JSC-S. These differences would reflect the difference of the particle shapes, and it is implied that irregular particles have lower solid conductivity than the

spherical particles. On the other hand, we found that the radiative conductivity values of JSC-S and glass beads were comparable. Therefore, we can conclude that the effect of the particle shape on the radiative heat transfer is small, and the radiative conductivity can be modeled with approximation by spherical particles.

Keywords: Regolith, Thermal conductivity

Table 1: Sample list

Sample	Particle size	Density	Porosity
JSC-O	< 1000 µm median 100 µm	1690 kg/m³	42%
JSC-S	710-1000 µm	980 kg/m³	66%
	355-500 µm	1110 kg/m³	62%
	90-106 µm	1460 kg/m³	50%
	53-63 µm	1540 kg/m³	47%

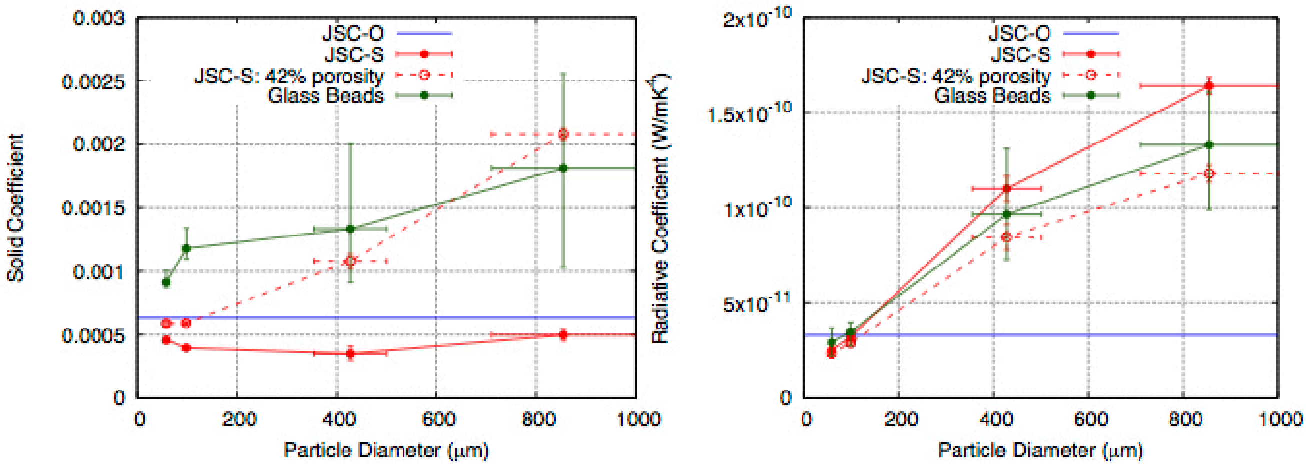

Figure 1: Solid (left) and radiative (right) coefficient of JSC-O (blue), JSC-S (red), and glass beads (green). Dashed red points represent each coefficient that is corrected to porosity of 42%.

