EPSC Abstracts
Vol. 8, EPSC2013-572, 2013
European Planetary Science Congress 2013

Thermal conductivity measurements of glass beads and regolith simulant under vacuum conditions

N. Sakatani (1,2), K. Ogawa (1,3), Y. Iijima (1), S. Tsuda (1,3), R. Honda (4), and S. Tanaka (1)
(1) Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan, (2) The Graduate University for Advanced Studies, Japan, (3) University of Tokyo, Japan, (4) Kochi University, Japan

Abstract

Past studies of in-situ and laboratory measurements of lunar regolith thermal conductivity imply that the conductivity would vary with depth due to change of density and self-weighted stress. In this study, we experimentally investigated the effect of the compressional stress on the thermal conductivity of the glass beads and regolith simulant using a new stress controlling system under vacuum conditions. We experimentally confirmed that the thermal conductivity increases with the compressional stress, which indicates that the regolith layer on the airless terrestrial bodies has various thermal conductivities according to the depth and their gravity.

1. Introduction

Most terrestrial bodies such as the moon and asteroids are covered with fine-grained regolith. Its thermal properties are essential parameters for understanding the thermal state and evolution of the bodies. On the moon, thermal conductivity of the surface regolith layer was measured in Apollo Heat Flow Experiments (HFEs). At a few meters depth, it was about 0.01 W/mK [1]. Keihm and Langseth [2] suggested that the most top surface of the regolith has lower thermal conductivity about 0.0015 W/mK. The difference between these values indicates that the thermal conductivity varies with the depth, which would due to the change of density [3] and/or self-weighted compressional stress [4, 5].

Returned lunar regolith samples were also measured in laboratories as a function of the bulk density up to 1950 kg/m^3 [6]. All data of the measured thermal conductivity were lower than 0.01 W/mK obtained form HFEs. Horai [4] measured thermal conductivity of lunar regolith simulant, whose thermal conductivity was near 0.01 W/mK. As he stated, in order to increase the thermal conductivity up to about 0.01 W/mK, the regolith samples must be compressed by the self-weight or artificial stress. Not only the bulk density but also the compressional stress must be essential parameters for determination of the thermal conductivity distribution in depth direction of the terrestrial regolith layer.

In this study, we aimed at investigating the effect of the compressional stress on the thermal conductivity of regolith-like powdered materials. We developed a system for controlling the compressional stress on the powder beds and measuring the thermal conductivity.

2. Experiments

We used two kinds of glass beads (grain diameter 90-106 μm and 710-1000 μm) and lunar regolith simulant as powder samples. Composition and grain size distribution of the regolith simulant are the same to that described by Horai [4]. Two glass beads have density of 1500 kg/m^3 and the regolith simulant has 1700 kg/m^3, which correspond to the porosity of 40% and 49%, respectively.

Figure 1 shows the experimental apparatus for controlling the compressional stress on the powdered samples and measuring the thermal conductivity. Six weights (7.5 kg total) were suspended by strings above a sample container and can superimpose the

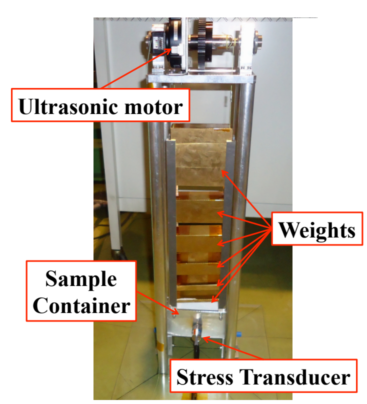

Figure 1: Experimental apparatus.

samples individually using an ultrasonic motor in vacuum chamber. In the sample container, two stress transducers were attached at the bottom and lateral side. This container also mounted a line heat source equipment for thermal conductivity measurements. A detailed description of the line heat source method can be found in our previous paper [5].

The apparatus was whole evacuated in the vacuum chamber down to 10^{-4} Pa. The lightest weight of the six weights was loaded on the sample, and we determined the effective stress using the stress transducers and the thermal conductivity of the sample by the line heat source equipment. Then, next weight was loaded and the same procedure was repeated.

3. Results and Discussion

Figure 2 shows the thermal conductivity of the glass beads as a function of the mean stress, calculated from horizontal and vertical stress. We found that the thermal conductivity increases with the stress, which would be due to improving the thermal conductance at the inter-particle contacts. Measurement results of the regolith simulant are also plotted in Figure 2. The thermal conductivity of the simulant also increased when the higher stress was applied. The increasing rates were comparable among the three samples.
The result shows that the glass beads of 710-1000 μm had higher thermal conductivity than that of 90-106 μm beads. Theoretically, it is understood as increased radiative conductivity with inter-particle pore size. Causes of the difference between the thermal conductivity of the glass beads and the regolith simulant

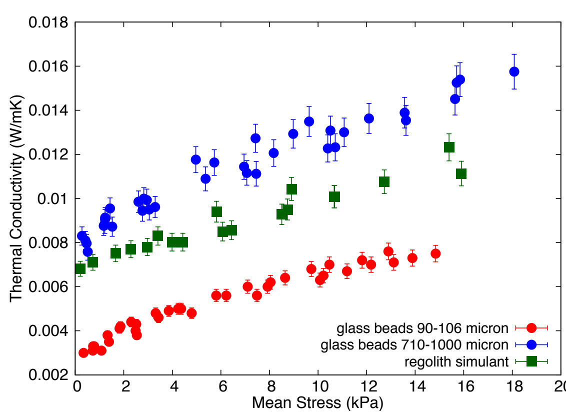

Figure 2: Thermal conductivity of glass beads and regolith simulant as a function of the compressional stress.

could be the effects of grain size distribution, their shape, and porosity.

The results of the regolith simulant shows that, in order to raise the thermal conductivity up to 0.01 W/mK obtained in Apollo HFEs, compressional stress of approximately 9 kPa must be applied on the regolith layer. This stress is compared with hydrostatic pressure at 3 m depth on the moon. Long-term bombardments of meteorites would compress the regolith and the stress became higher than the hydrostatic pressure, and the conductivity possibly got up to 0.01 W/mK even at shallower depth.

Our experiments showed that the thermal conductivity of the regolith depends on the self-weighted compressional stress, or the depth below the surface. Moreover, the regolith layer under microgravity environments, such as on asteroids, will have much lower thermal conductivity. In such cases, the thermal conduction through the inter-particle contacts would be negligible and the radiation between particles becomes dominant heat transfer mode.

References

[1] Langseth, M. G., Keihm, S. J., and Peters, K.: Revised lunar heat flow values, Proc. Lunar Sci. Conf., Vol. 7, pp. 3143-3171, 1976.

[2] Keihm, S. J., Langseth, M. G.: Surface brightness temperatures at Apollo 17 heat flow site: Thermal conductivity of the upper 15 cm of regolith, Proc. 4th Lunar Sci. Conf., Vol. 3, pp. 2503-2513, 1973.

[3] Fountain, J. A., West, E. A.: Thermal conductivity of particulate basalt as a function of density in simulated lunar and martian environments, J. Geophys. Res., Vol. 75, pp. 4063–4069, 1970.

[4] Horai, K.: The effect of interstitial gaseous pressure on the thermal conductivity of a simulated Apollo 12 lunar soil sample. Phys. Earth Planet. Inter. Vol. 27, pp. 60–71, 1981.

[5] Sakatani, N., Ogawa, K., Iijima, Y., Honda, R., and Tanaka, S.: Experimental study for thermal conductivity structure of lunar surface regolith: Effect of compressional stress, Icarus, Vol. 221, pp. 1180-1182, 2012.

[6] Cremers, C. J., Birkebak, R. C., and Dawson, J. P.: Thermal conductivity of fines from Apollo 11, Proc. Apollo 11 Lunar Sci. Conf., Vol. 3, pp. 2045–2050, 1970.