Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-16 Room:304 Time:May 20 15:00-15:15

Effect of compressional stress on thermal conductivity of powdered materials under vacuum

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Lunar and asteroid surface is covered with powdered materials and planetesimals in the early solar system are considered to have consisted of powdered materials. Thermal conductivity of powdered materials is one of the essential parameters in order to examine thermal state or thermal evolution of these bodies. Especially under vacuum conditions, the thermal conductivity of powdered materials is known to be extremely low (order of 0.001 W/mK). Therefore, existence of such powders significantly affects the above problems. For example, to measure crustal heat flow on the moon, it is necessary to insert a heat flow probe. However, compaction of the regolith due to the inserting can change the thermal conductivity of the regolith from original one, which enlarges the error of the estimated heat flow (Grot et al., 2010). It is important to expect the degree of the compaction and correct the thermal conductivity values. In addition, Ogawa (2013) calculated thermal evolution of planetesimals composed of powdered materials. She showed that planetesimals as small as 10 km possibly experience melting or differentiation.

However, it is difficult to estimate the thermal conductivity value of the powder materials, because under vacuum it depends on various parameters such as particle size, density, and compressional stress. We have investigated the parameter dependence of the thermal conductivity of powder samples. In this presentation, we report the effect of compressional stress. It is one of the essential parameters in order to correct the heat flow values and to estimate the difference of the conductivity by planetesimals size (gravity) and the variation in the direction of the depth.

For the measurements of the stress dependence, we designed and fabricated a new experimental apparatus. The stress range we require is up to relatively low stress about a few tens kPa. To achieve this, we adopted a technique, in which six weights with known mass superimpose the powder sample by turns for controlling the compressional stress. Each weight suspended with strings at interval of 2 cm and they were moved up and down by an ultrasonic motor. Total mass of the weights was 7.5 kg, which corresponds to the maximum stress of about 18 kPa. Under such system, there was a sample container having two stress transducers with relatively low capacitance and a thermal conductivity measurement system by the line-heat source method. The sample was spherical glass beads of 0.1 mm diameter. Above apparatus was evacuated in the vacuum chamber and the thermal conductivity was measured without and with the weights.

As a result, the thermal conductivity was ranged from 0.003 to 0.008 W/mK and definitive trend that the conductivity increases with the compressional stress. This trend is considered to be due to increasing thermal conductance through elastically deformed and enlarged contact area between the particles.

The effective thermal conductivity under vacuum condition is defined as a sum of contributions of thermal conduction through the solid particles (so-called solid conductivity) and thermal radiation between particle surfaces (radiative conductivity). Because the observed trend is due to the variation of the solid conductivity, we subtracted the radiative conductivity for the same sample, which was determined by another experiment (Sakatani et al., 2013), from the measured conductivity and deduced the solid conductivity as a function of the stress. By fitting of these data by an appropriate function, we found that the solid conductivity depends on the stress with an exponent of 0.32 to 0.40. This value is compared with Hertzian theory that states the contact radius between spherical particles is proportional to the confined pressure with 1/3 exponent. This consistency strongly supports that the observed stress dependence is caused by the elastic deformation of the particles and that the solid conductivity is proportional to the contact radius.

Keywords: thermal conductivity, powdered materials, compressional stress, vacuum