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Thermal conductivity measurements of sintered glass beads and application to planetesimal thermal evolution

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In the planetary formation process, dusts in the early solar nebula would have formed into planetesimals. Planets and asteroids have been formed by collisions of planetesimals. To constrain planetesimal ' s formation process and internal structure is an important issue. Especially, thermal evolution of planetesimal is key phenomenon for this purpose, and thermal conductivity of the planetesimal constituents is an essential parameter for understanding the thermal evolution.

As planetesimals are treated as dust aggregates, they would experience sintering when their temperature increases as a result of thermal evolution. The sintering makes neighbor particles bonded. The thermal conductivity of powered materials before sintering has been researched recently. However, thermal conductivity of sintered dust has not been measured under vacuum. Once dusts undergo the sintering, contact faces, so-called neck, are formed between dusts. The sintering causes growth of the neck and decrease of the porosity. It is thought that these changes make thermal conductivity higher than not-sintered dusts.

Based on our previous measurements of the thermal conductivity of glass beads, a positive correlation between thermal conductivity and compressional stress (thus, the inter-particle contact area) was observed with sample porosity remaining constant. Therefore, the thermal conductivity should be expressed as a function of not only porosity but also contact area between the particles.

This study aims at investigating thermal conductivity of the sintered materials under vacuum condition, in order to estimate effect of the sintering on thermal evolution of planetesimals. Especially, we focus on the dependence of neck size on the thermal conductivity.

We used three sizes of glass beads (250, 500, and 1000 μm) as analogous samples of dusts. For respective glass beads, we made three sintered samples with different degrees of sintering, or different neck size, in order to investigate the neck size dependence of the thermal conductivity. To measure the neck size, the sintered particles were separated and the neck crack size was observed using optical microscope. The thermal conductivity was measured by line heat source method under vacuum.

As a result of these experiments, we confirmed that the neck sizes of the nine samples had different ratio of neck size to beads radius, whose average values were ranged from 0.075 to 0.30. The thermal conductivity was ranged from 0.036 to 0.25 W/mK. These values were more than 10 times higher than that of not-sintered glass beads. Combining the results of neck size and thermal conductivity measurements, it was found that the thermal conductivity is proportionally related to the neck size ratio independent of the particle size. In these experiments, the porosity was constant about 40%. Therefore, when we calculate thermal evolution of planetesimals under sintering, the thermal conductivity should be estimated from the neck size at least until the neck size ratio grows up to 0.3 (initial stage of sintering).

Finally, we calculated the thermal evolution of the planetesimal using the relation of the thermal conductivity and the neck ratio we found in this experiment. Hypothesized planetesimals have radius between 100 m and 1000 m, formation age between 1 Myr and 3 Myr after CAI formation, and dust diameter of 1 and 1000 μm. As a result of the calculation, it was found that the sintering and resulting increase of the thermal conductivity make internal peak temperature more than 1000 K lower than the case when the sintering effect is not included in the calculation. In addition, internal temperature structure and neck size (or material strength) distribution in the planetesimals vary widely depending on the size and formation age of the planetesimals and particle size of dust.