THERMAL INERTIA OF SURFACE MATERIALS OF SOLAR SYSTEM SMALL BODIES AND ITS DEPENDENCE ON POROSITY. T. Okada[1-3], [1]Department of Solar System Sciences, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), 3-1-1 Yoshinodai, Chuo-Ku, Sagamihara 252-5210, Japan, [2]Astromaterials Science Research Group, ISAS/JAXA, Sagamihara, Japan, [3]Department of Chemistry, University of Tokyo, Japan. Email: okada@planeta.sci.isas.jaxa.jp.

Introduction: Thermal inertia is a thermo-physical property which is often used to determine the physical conditions of planetary surfaces from planetary orbiters and from observatories on or around the Earth. It is expressed as a square root of the products of thermal conductivity k, bulk density ρ, and specific heat C of surface materials as $(k \cdot \rho \cdot C)^{0.5}$ in TIU (J m^{-1} K^{-1} $s^{-0.5}$). It is dependent on the typical particle size and porosity of the materials, as well as the surface gravity. Under a micro-gravity condition, thermal conductivity, and also thermal inertia as well, tends to be smaller than the 1-G condition due to weaker contact between grains in the surface materials [1, 2]. Therefore, it is considered that the thermal inertia is typically small for surface regolith layer of small bodies. Although dependency of grain size on thermal conductivity has been studied even for small gravity conditions [e.g., 1, 2], its dependency of porosity has not been well investigated under vacuum conditions. We are planning to conduct a laboratory experimental study for this purpose, but in this paper, the data which was conducted in the past experimental study in vacuum [3] is used to estimate dependency of porosity on thermal inertia of rocky materials.

Thermal Conductivity of Porous Materials under Vacuum Conditions: Thermal conductivity is affected by heat transfer by conduction in solids, radiation in pores, and convection in fluids. On the surface of small bodies, there are a lot of pores in the materials where it is not filled with fluids but in vacuum. It was not often the case that experiments were conducted for materials with pores under enough high vacuum conditions, where any convection is negligible for the total heat transfer. In the previous studies by Robertson (1988) [3], the experiments were conducted for lunar rocks and soils as well as some terrestrial rocks and soils under vacuum conditions. Only those data conducted under the vacuum of < 10^{-2} Pa were extracted from the database to investigate the dependency of the porosity (or solidity = 1 - porosity) on thermal conductivity. The result is shown in Figure 1. The plots in Figure 1 shows quite a good fit as the exponential equation between thermal conductivity and porosity from dense rocks to fine soils. The best fit of approximate curve indicates an absorption of heat transfer by porous materials. The porosity of about 0.08 corresponds to a skin depth by the vacancy to prevent from the conduction of heat.

Thermal Inertia of Small Bodies: Thermal inertia is related to thermal conductivity for rocky materials, and in most of cases the heat capacity $\rho \cdot C$ is almost the same within a factor for planetary surfaces. There is a relation of asteroid diameters to thermal inertia and also to thermal conductivity [4]. In general, a larger asteroid has a smaller thermal inertia because such a surface is covered with the fine regolith which is the sedimentation of impact ejecta, while a smaller one has a larger thermal inertia because fine regolith ejected by impact events is not sedimented but lost away due to low gravity on the surface, and the basement rocks or the large boulders are exposed.

Physical conditions of the surfaces of small bodies could be investigated with the relation to the previous experimental results under vacuum conditions. When the bulk density and specific heat of surface materials are assumed, their thermal inertia is estimated as shown in Figure 2. For the past data [3], porosity and rock species are studied so that the heat capacity can be calculated. Therefore thermal inertia is derived for each of lunar rocks and soils, along with terrestrial materials. Dependency of porosity on thermal inertia is expressed using an exponential function. This relation shows the thermal inertia of < 30 TIU for very fine materials probably on the regolith of Ceres or other larger bodies, 40~60 TIU for the fine sand like lunar regolith (typically < 0.1 mm), ~100 TIU for sand of 10^0 mm, ~200 TIU for pebbles of 10^1 mm, 300~400 TIU for rocks or breccia of 10^2 mm, ~1000 TIU for porous rocks, and > 2000 TIU for dense rocks.

Applications to Small Body Missions: Surface physical conditions are one of basic characteristics to be explored and studied by space missions. Those thermo-physical properties are most easily derived from investigating thermal inertia. To obtain the surface thermal inertia and its regional distribution, infrared imaging spectroscopy or consecutive thermal imaging are needed. The former method needs a large data of image cube with high spectral and spatial resolutions. The latter method needs tens of images as rotation of the small body, but relatively smaller data is needed. For the surfaces with higher thermal inertia, the change of temperature peak to peak becomes smaller and the timing to reach the peak is delayed. Thermal inertia can be determined with such time profiles of temperature.

For the Hayabsua2 mission [5], the second sample-return mission from a near-Earth asteroid 162173 Ryugu, the surface thermal inertia will be investigated with thermal infrared imager TIR [6]. The surface will be characterized with the optical and thermal images by ONC-T and TIR, as well as the surface experiments with the radiometer MARA on the small lander MASCOT [7]. The detailed features such as micro-porosity inside the materials will be investigated by analysis of the returned samples. Then the surface conditions of the small body will be investigated by such cross scale studies from remote sensing, *in situ* observations, and to analysis of returned samples.

Concluding Remarks: From the data obtained in the past experimental study for the thermal conductivity under vacuum conditions, the thermal conductivity, and also the thermal inertia, is highly dependent on the porosity. And its relation is expressed as an exponential function from dense solid rocks to fine powdery regolith. These relation is applicable to remote sensing for determining the surface thermo-physical properties and surface physical conditions. In Hayabusa2, thermal infrared imager TIR will determine the surface conditions of asteroid 162173 Ryugu.

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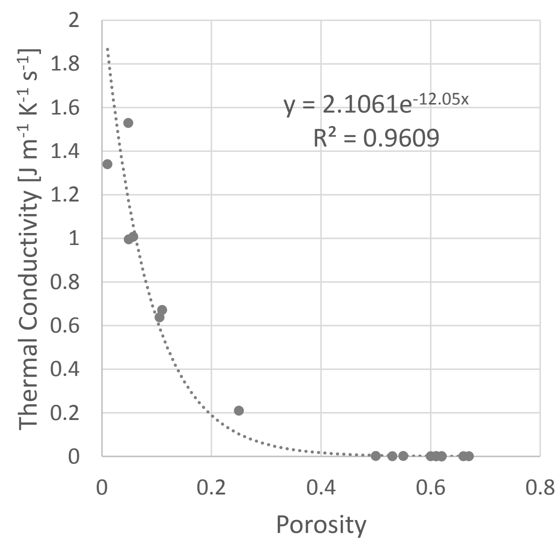

Figure 1. Dependency of porosity on thermal conductivity for lunar and terrestrial rocks and soils (data from [3]).

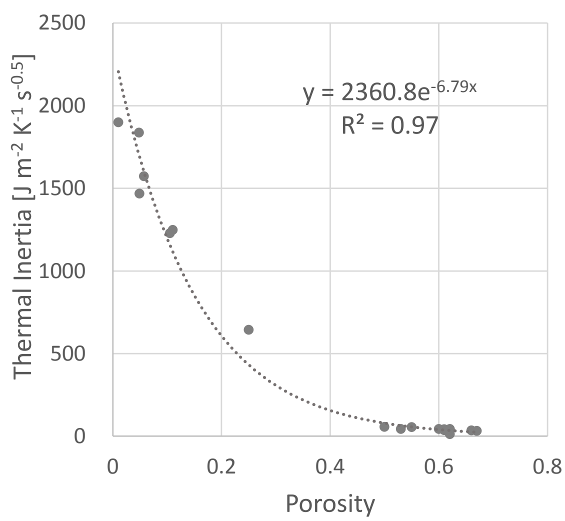

Figure 2. Dependency of porosity on thermal inertia for lunar and terrestrial rocks and soils (data from [3]).