MEASUREMENTS OF SOUND SPEED IN GRANULAR MATERIALS SIMULATED REGOLITH. K. Teramoto[1, 2] and H. Yano[2], [1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Tokyo, Japan, [2]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency(JAXA), Kanagawa, Japan (teramoto@planeta.sci.isas.jaxa.jp).

Introduction: Up until now, many asteroids have been observed from ground but only a few have been explored by spacecraft. Gravity measurements by these spacecraft, observations of asteroid mutual perturbation events, and discoveries of asteroid satellites have revolutionized our understanding of asteroid bulk densities [1]. Most asteroids appear to have bulk densities that are well below the grain density of their likely meteorite analogs. This implies that many asteroids have significant porosity values [2]. All information of spacecraft measurements come from only surface of asteroids with the exception of mass and density data. Thus, although high porosity of asteroids is suggested, we have never investigated asteroid internal structure directly.

On the other hand, the existence of regolith on small asteroids has been proven by surface images from the *Galileo* and *NEAR* missions [1]. (25143) Itokawa, a sub-km asteroid as a target of HAYABUSA mission, is also suggested of that there is regolith layer on its surface [3].

Recently, radar sounder exploration for internal structure is applied to some planets and a comet; this method is better adapted to large spatial resolution (>1 km) than small objects. Thus, we need another way to investigate as small asteroids internal structure as Itokawa in fine spatial resolution. We attempt to apply elastic waves for small scale sub-surface structure of asteroids. If asteroids have regolith generally, it is necessary to understand physical property of granular materials and their motions first.

For the above reasons, one of the most basic physical value, sound speed (P-wave velocity) measurements are demonstrated in granular materials simulated regolith in this study.

Experiments: Figure 1 shows the experimental schematic. Spherical glass beads of average diameters of 220 µm, 160 µm, 80 µm and 40 µm, respectively, were contained each in a rigid cylindrical container whose diameter was 200 mm and depth was 148 mm. In order to simplify parameters of regolith on asteroid surfaces, we used these sizes and shapes while glass beads were free from compaction effect by impact. The beads were filled 100-mm deep in the container and a pair of AE (acoustic emission) sensors (NF Corporation, model number: AE-900S-WB) were embedded in the glass beads at 43-mm deep from top of the surface. Distances between sensors were changed for 36 mm, 67 mm and 97 mm. To compare with obtained results from this system, measurements of sound speed of solid aluminium blocks and air were conducted.

Then, we derived the sound speed of these granular medium by measuring the time delay between pulse generation and its arrival at the sensor. In order to simulate asteroid environment without propagating medium (i.e., air) and to eliminate effects of air moisture which may severely affect physical property of glass bead surface, the container was placed in a vacuum chamber under 5 torr. The frequency of the acoustic waves is fixed at 10 kHz because high frequencies (>30 kHz) showed poor S/N in these medium. The phenomenon was also reported by Liu and Nagel (1992).

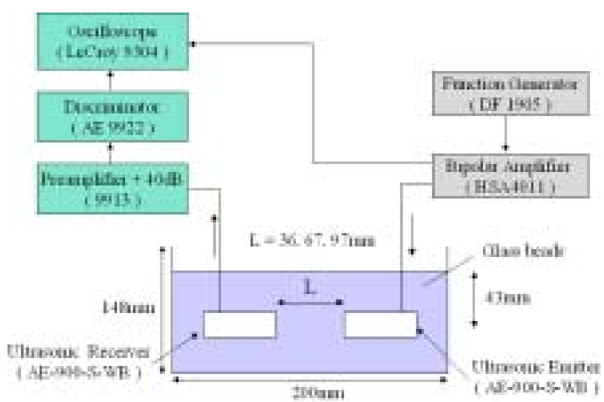

Figure 1: Experimental schematic for measuring sound speed in granular medium under the vacuum.

Next, we measured sound speed mixtured grains ranging from 220 µm and 80 µm, or 40 µm. Results of these measurements showed large scattering of the data. In order to treat them statistically, we measured about twenty times for each distance (about sixty times in total). Average porosity of these glass bead medium was divided to two classes; we named them as "fluffy" and "compacted". "Fluffy" was high porosity and "compacted" was lower than the other. The "compacted" state was made by tapping the container with a wooden hammer. The grain size and porosities are shown in Table 1.

Table 1: Glass bead grain size and bulk porosity.

grain size	"fluffy"	"compacted"
40 µm	47%	40%
80 µm	43%	38%
160 µm	41%	37%
220 µm	40%	37%

Results: The results of non-mixed grains are shown in Table 2. Since no significant difference was found between these two porosity classes ("fluffy" and "compacted"), sound speed of glass beads in this size range seems independent from their porosities. On the contrary, these figures seem to show that the sound speed of these medium depend on the size of glass beads: the faster it is, the larger grains they are. These findings seem contradicting with initial prediction that sound speed depends on porosity of the solid medium. We also found sound speed in granular materials much slower than that of the some materials in solid and even in liquids.

Mixtures results are shown in figures 2 and 3. These values are close to the non-mixed values.

Table 2: Average sound speed of glass beads.

grain size	"fluffy" [m/s]	"compacted" [m/s]
40 µm	92±7	93±13
80 µm	141±10	134±11
160µm	141±15	144±16
220µm	171±17	171±18
bulk glass	4.64km/s	

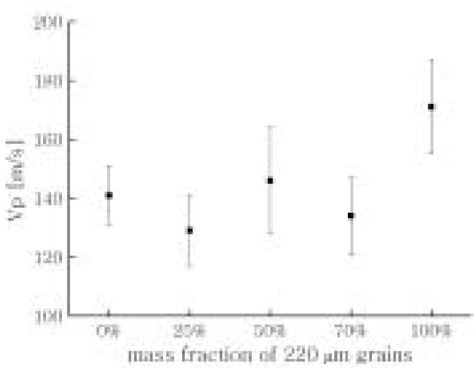

Figure 2: Average sound speed of mixed glass beads consisted of 220 µm and 80µm in size.

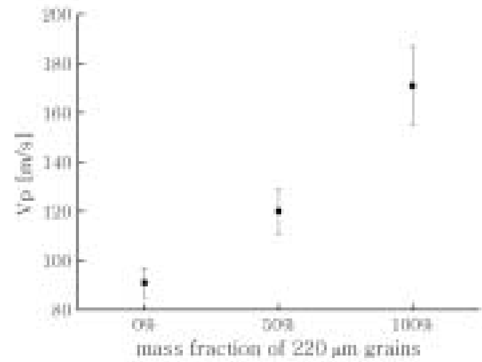

Figure 3: Average sound speed of mixed glass beads consisted of 220 µm and 40µm in size.

Discussions: Glass beads we used are in four size ranges, all spherical, and their propagating distances are far longer than each grain size. Therefore, acoustic wave passages should be independent from the grain sizes. The reason why sound speed apparently does not depend on the medium porosity, may be that there is no difference between two porosity classes of "fluffy" and "compacted" at the depth near the sensors. The porosity values we measured are for an overall container, but did not measure them along the depth. Thus, these results, are unable to distinguish between the grain sizes and the medium porosity as a governing parameter of the sound speed in the granular materials.

In order to investigate why glass beads have very slow sound speed values, we measured these values of large spherical glass modeled the mechanism of the speed decrease whose results will be presented at the conference.

Conclusion: We have measured sound speeds in regolith simulants in the 40–220 µm range. These results suggest the possibility of using velocity measurement of elastic waves in order to investigate major regolith size near asteroidal surfaces.

References: [1] R. J. Sullivan. et al .(2001) *AsteroidsIII*,pp.331-350. [2] D. T. Britt. et al. (2001) *AsteroidsIII*, pp.485-500. [3]M. Ishiguro. et al. (2003) Publ. Astron. Soc. Japan 55, 691-699. [4] C.-H. Liu and S. R. Nagel. (1992) Phys. Rev. Lett. 68, 2301