EXPLORING THE PHYSICAL PROPERTIES OF HIGH FIDELITY MARTIAN AND PHOBOS REGOLITH SIMULANTS: SUPPORT FOR MISSION DEVELOPMENT AND HARDWARE DESIGN.
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Introduction: JAXA is developing a major mission with the goal of returning a sample from the Martian moon Phobos. The design of the Martian Moons eXploration (MMX) mission is challenging in part because of the unknowns about the mineralogy and origin of Phobos and Deimos. There are two leading theories for the formation of the Martian moons. (1) That the moons formed from a debris disk composed of ejecta from a major impact on Mars. In this scenario Phobos and Deimos would be composed of a mixture of impactor and target material. Because of the low albedo and relatively featureless reflectance spectra of the moons, the suggestion is that the impactor was a low-albedo primitive asteroid and this material is mixed with Mars crustal material to form the moons. (2) The other theory is that the moons formed from a debris disk of primitive asteroid material that broke up within the Martian Hill Sphere. In this case the moons would be largely composed of primitive asteroid material.

MMX will be interacting directly with the surface regolith of Phobos. For the design, testing and validation of the spacecraft hardware and mission operations concepts, high fidelity simulants for the possible range of Phobos mineralogies can be an important part of mission development. Our group has been developing high-fidelity, mineralogy based simulants using the latest mineralogical data from asteroids and Martian surface missions. The advantage of this mineralogy-based approach is that it captures the inherent physical properties and grain-grain interactions of the constituent minerals. The development efforts are reported in [1]. Here we describe our program of physical and mechanical properties measurements with the goals of supporting the MMX mission and characterizing the physical properties of the possible Phobos regolith mineralogies.

Physical Properties Testing: As described in [1] we are using two simulant mixtures to represent the different possible origins of Phobos: Phobos Captured Asteroid (PCA-1) based on CI chondrites [2], and Phobos Giant Impact (PGI-1) containing a mix of 57% CI carbonaceous chondrite simulant material and 43% Martian mantle material (primarily olivine and pyroxene). Our group is currently performing a range of physical properties measurements on these materials.

Compressive Strength: Previous experiments with volatile-rich simulants indicate that most strength comes from cementation of the hydrous clay particles. We will measure the compressive strength range of the Phobos simulants and test for a difference between the more clay-rich PCA-1 and the more clay-poor PGI-1.

Tensile and Shear Strength: There is very little published data on the tensile/shear strength of volatile-rich meteorites. Previous experiments with volatile-rich simulants indicate that as with compressive strength, tensile and shear strength are mostly due to cementation of the hydrous clays. We will characterize the tensile and shear strength range of the Phobos simulants.

Figure 1: Simulant test slab for tensile strength testing.

Electrostatic Properties: This depends critically on the environment, and for Phobos there will be an asteroid-like electrostatic sheath caused by photoemission on the illuminated side and solar wind interactions on the dark side [3]. Material electrostatic behavior will be constrained using simulants to measure the charge and boundary layer as well as Tribocharging.

Magnetic Properties: Magnetic properties will be a function of the constituent minerals. This will be directly measured from the simulants.

Grain Hardness (hardness indexes): The mineralogy of possible Phobos materials is well constrained and reflected in the recipes for the simulants. The hardness of the individual grains is well known. We will measure the hardness of our conglomerate mixtures.

Abrasivity: Abrasivity is a function of the hardness of the minerals and the shape of grains. We can characterize the range of possibilities in our simulant recipes and preparation methods by changing the angularity and size of the grains. The characteristics can then be measured directly from simulants using calibrated scratch tests.

Surface Friction, Angle of Repose, Internal Friction: These parameters depend on particle shapes and size distribution. We control for the morphology of the particle shapes in our simulant production along with the mineralogy and size distribution. This will allow us to directly test the sensitivity of these parameters to changes in morphology and mineralogy.

Powder Cohesion: Probably similar to (or lower than) dry lunar soils because of the depletion of the fines. A good figure of merit at this stage is 30-200 Pa. We can experiment with variations in simulant mineralogy, particle morphology, and particle size.

Adhesion: This will depend on tool material, but it will test the simulants on variety of potential tool materials to characterize adhesion.

Compressibility of Regolith: Microgravity and depletion of fines on Phobos will probably produce different results from the lunar case. It is reasonable to conclude that Phobos is less compressible in upper 20 cm because of the loss of fine fraction. Experiments have been developed for compressibility of lunar materials and we can apply similar experiments to Phobos simulants.

Compactibility of regolith: We will use the Proctor Compaction index test on the simulant materials. We can vary the proportion of fines and particle morphology to characterize the sensitivity of compactibility to these parameters.

Heat Capacity, Thermal Conductivity, Thermal Diffusivity, Thermal Expansion: Data for a number of volatile-rich meteorite types is available from our group's recent measurements. We will follow the same procedures for the Phobos simulants.

Figure 2: Simulant test "pucks" for thermal cycling tests.

Thermal Cracking Behavior and Thermal Cycling: We have been using volatile-rich simulants to characterize the changes in strength and surface hardness from thermal cycling [4]. Cracking and strength can be measured using the Vickers Hardness test from our Phobos simulants.

Future work: The measurements have begun and the first results will be reported at LPSC. The advantage of our mineralogy-based approach to simulants is that it realistically captures the physical properties of the grain-to-grain interactions of the materials that make up exploration targets. Data from these measurements can be used to constrain design and functional requirements for a range of future hardware and missions.

References: [1] Cannon et al., (2017) *this issue*. [2] Covey et al. (2016) *Proceedings of 2016 ASCE Earth and Space Conference.* [3] Colwell et al., (2005) *Icarus*. [4] Schultz et al., (2017) *this issue*.