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Laboratory Investigation of Asteroid Regolith Properties

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Abstract

We are beginning a three-year effort to study regolith properties and processes on low-gravity, small asteroids by conducting analog experiments with cohesive powders in a 1-g laboratory environment. Our goal is to develop an improved understanding of the role of cohesion in affecting regolith processes and surface morphology of small Solar System bodies, some the targets of ongoing and proposed missions, and to quantify the range of expected mechanical properties of such regoliths.

1. Introduction

Over the last decade, the NASA *NEAR-Shoemaker* and JAXA *Hayabusa* missions to asteroids 433 Eros and 25143 Itokawa, and spacecraft-reconnaissance-quality radar observations of near-Earth and small main-belt asteroids (NEAs and MBAs), have caused a profound shift in our understanding of these bodies. Despite the clear evidence that small asteroids undergo drastic physical evolution, the geophysics and mechanics of the processes driving that evolution remain a mystery due to a lack of scientific data on the geophysics of these small bodies and on the mechanical properties of regoliths in the unique micro-gravity regime they inhabit. Although we might be tempted to extrapolate our knowledge of the properties of lunar regolith to the comminuted surfaces of small asteroids, the orders-of-magnitude lower surface gravitational accelerations on NEAs can lead to some at times counter-intuitive geological phenomena. Figure 1 illustrates just a sampling of interesting (and in some cases, wholly unexpected) regolith features on Eros and Itokawa that suggest interactions dominated by granular structures.

Scheeres et al. [1] performed a survey of the known relevant forces that act on grains and particles on asteroid surfaces (including gravitational and rotational accelerations, Coulomb friction, self gravitation, electrostatics, solar radiation pressure forces, and surface contact cohesive forces), developed their analytical form and relevant constants for the space environment, and considered how these forces scale relative to each other. Among key findings of that study is the result that van der Waals cohesive forces should be a significant effect for the mechanics and evolution of asteroid surfaces and interiors and that asteroid regolith may be better described by cohesive powders (for a familiar analogy, consider the mechanical properties of bread flour) than by traditional analyses assuming cohesionless grains.

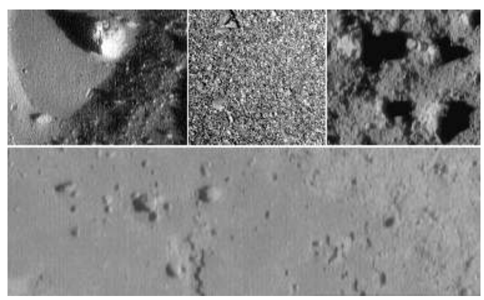

Figure 1: Evidence of processes at work on granular aggregates in the regoliths of Eros and Itokawa – ‘ponds’ (interpreted as accumulations of ~10-micron-scale grains that have migrated to topographic lows), centimeter-scale grains, evidence of clumping or cohesion of granules, and ‘rivulets’ in the finer material (suggesting cohesion of the granular material).

This observation implies that regoliths composed of impact debris of the sizes observed on small asteroids should behave on their microgravity surfaces like flour or other cohesive powders do in the 1-g environment here on Earth.

This is a paradigm-shifting perspective that would fundamentally alter our interpretation of the properties of and processes at work on NEA surfaces, and offers a novel experimental approach for regolith analog studies: rather than working with regolith simulants composed of mm- to cm-scale granules directly in reduced gravity conditions, we propose instead to work with cohesive powders in a 1-g, terrestrial laboratory environment.

2. Experimental Approach and Apparatus

Many previous experimental results with cohesive powders [e.g., 2–5] have been obtained under ambient atmospheric conditions and we will reproduce some of those measurements for the sake of comparison, before moving on to experiments in vacuum.

Free standing columns are created by manually pressing a mound of the powder between two 2”x3” glass rectangles on a metal tray. The resultant free standing structure is about ½” thick. The tray is then tipped up until full collapse of the column occurs as shown in Figure 2. A “rubble pile” forms at the base of the metal tray as shown.

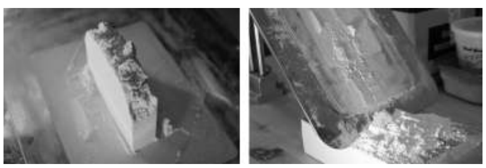

Figure 2: Left: Free standing column with view onto the top. Sides are straight, top is uneven; Right: flour pile (“rubble pile”) after column collapse

2. Results

2.1 Characterization of Powders

SEM images shown in Figure 3 demonstrate the wide variation in morphology available for this study. We expect the behaviour of these powders to vary depending on their size and morphology, and mix of sizes (fine powders mixed with “boulders”).

When the free standing column is tilted, the disintegration proceeds by small pieces detaching, followed by complete column collapse, resulting in what looks reminiscent of a rubble pile at the bottom of the slide. Figure 4 shows a comparison of a collapsed column of virgin white flour with one that was a mix of white flour and simulated asteroid “boulders”.

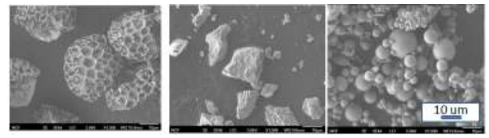

Figure 3: SEM images (left to right): pollen, JSC-1AF lunar simulant, glass microspheres.

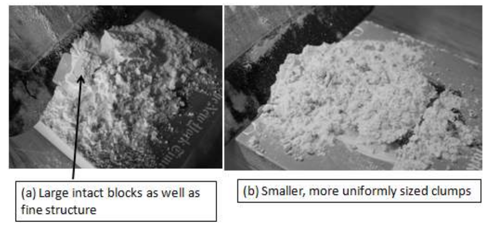

Figure 4: Comparison of “rubble pile” after collapse of virgin white flour column (a) and mixed white flour and simulated asteroid rocks (b). Rubble pile for (b) is more uniformly sized.

The virgin flour columns collapse at 50 degrees, and optimal flour/boulder mix columns collapse at 60 degrees suggesting an inhibition of fracture movement.

Acknowledgements

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