The strength of rubble-pile bodies: Theory, observations, and predictions

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The strength and morphology of a rubble-pile body will control how fast it can rotate before shedding mass or deforming, influence the process by which multi-component asteroid systems are created, and could have significance for the mitigation of hazardous near-Earth asteroids (NEA) should this be necessary in the future [1,2,3]. The morphology of these bodies, including the size distribution of boulders and grains internal to the system, the macro-porosity of these bodies, and the shapes and spin states of these bodies, are important for understanding and interpreting spacecraft imaging of asteroids, for predicting the end-state evolution of these bodies, and for gaining insight into their formation circumstances. Despite these compelling issues and questions, real insight on the strength of rubble-pile bodies and their morphology remains elusive. We explore a theory recently developed by us [3] for the morphology and strength of a rubble-pile body based on the properties of cohesive powders and show that several observations of small asteroid properties are consistent with the predictions of this model.

That small asteroids can be rubble-pile bodies is clear based on several lines of evidence, including spacecraft imaging and sample analysis of Itokawa [4,5], the existence of the rotation spin rate barrier for bodies larger than a few hundred meters [6], and the recent observations of disrupting asteroids in the main belt [7,8]. A simple extrapolation from these observations are that bodies of at least a few hundred meters and larger are composed of a size distribution of components that range from decameter-sized boulders down to micron-sized grains. The relevant questions then become what the characteristics of these size distributions are and what physical implications for the strength of these bodies arise from this morphology.

Based on the theory of cohesive granular mechanics [9] combined with a thorough review of results from the Hayabusa mission [4,5], population statistics, and observations from the photometry of asteroids [10], recent observations of disrupting asteroids in the main belt [7,8], results from the Almahatta Sitta meteorite/asteroid 2008 TC_3 observations [11,12,13], and Apollo-era measurements of lunar regolith [14], we propose a theory for the strength and morphology of rubble-pile asteroids. Specifically, we find that rubble-pile bodies should have a weak, but non-zero, cohesive strength that arises from van der Waals attraction between the smallest grains in the rubble-pile size distribution that act as a weak cement [3].

There are a few key aspects of the small body population that are consistent with our model. First is the statistically significant lower-size cut-off in the binary asteroid population. Binaries are not found, or are significantly depleted, at sizes below a few hundred meters. This is consistent with a small, but non-zero, level of cohesive strength in rubble piles at the order of magnitude predicted by our model. Second are all aspects of observations related to the asteroid 2008 TC_3, which became the Almhatta Sitta meteorite fall [11,12,13]. Observations are consistent with a model of this asteroid as a size distribution of grains with minimum size on the order of 10 microns or less and the existence of cohesive strength in this distribution.

The model also makes a number of key predictions for the small-body population which will be presented.

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