New theoretical results on asteroid regolith specific heat, cohesion and heat transfer, and a revisit of comet 67P surface strength

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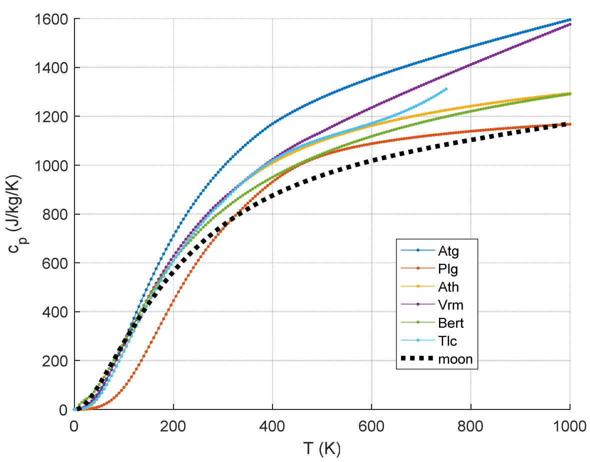
We report and discuss on some of our recent theoretical advances on asteroid regolith specific heat c_P, van der Waals-force between regolith particles, and heat transfer in the regolith. We also report on the strength of comet surface material, including a refined model of its size dependence and wide variability depending on the degree of "cementation" (sintering) and a re-appraisal of some particularly low and high strength values for comet 67P reported earlier in the literature. Thermal and mechanical properties are correlated.

Specific heat

Surface temperature models could be impacted by the drastic decrease in $c_P(T)$ values toward low temperatures; thermal models generally assume lunar basalt calorimetric properties, which are not well known outside the data range 90 K to 350 K. Indeed, 'knowledge of specific heat variability as a function of temperature and bulk material composition remains largely under-constrained for the need of planetary thermal modelers'[1]. In particular, the specific heat capacity of geological materials relevant to solar system body surfaces below room temperature is not particularly well constrained and the thermal modeling community only has a limited set of adequate ready-to-use $c_P(T)$ trends for planetary surface temperature modeling. - We provide the means to calculate synthetic $c_P(T)$ from a known bulk composition, for almost any solar system material from 10 K to 1000 K, and additionally a method to predict the specific heat curve beyond the temperature range measured, even if the composition is not (well) known. [2]



Van-der-Waals force

[3] have calculated the pull-of force due to van der Waals interaction, and due to capillary bridges, between particles with self-affine fractal (random) roughness, which is realistic. They have shown that surface roughness, if big enough, results in an interaction (VdW) force which is independent of the size of the particles, in contrast to the linear size dependency expected for particles with smooth surfaces (simple JKR, DMT). For fractured rock particles a realistic surface roughness reduces the pull-of force between micrometer sized particles by a factor of ~ 100, and even more for larger particles, it is of the order of 0.1 – 1 nN. This means that the dependence of cohesive strength (or tensile strength, in N/m²) of the granular medium on particle size is due to the increase in the number of particle-particle contacts (per unit area) alone. A decrease in particle size only increases the number of contacts without changing the strength of the particle-particle adhesive bond. The small-particle glue idea, figure 1, of [4] is a good one! This results also affects the predicted (high) porosity of granular media in micro-gravity, since the granular Bond number is very different now.

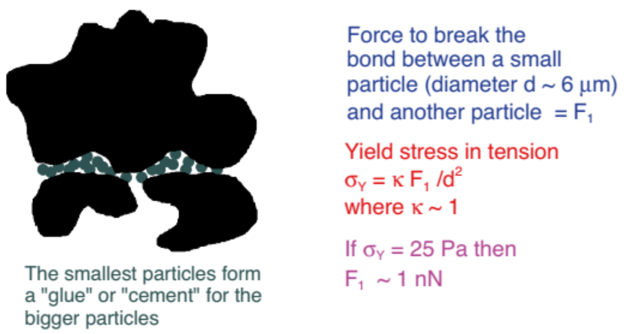


Figure 1. The big particles (fragments) in an asteroid could be kept together by a matrix of smaller particles. Effective yield stress of rubble pile asteroids of order (or less than) $\sigma_Y \approx 25$ Pa.

Heat transfer

Thermal conductivity k of granular media and porous rocks seemed well explained by classical theories (Maxwell equations, Stefan-Boltzmann radiative transfer, contact mechanics like Hertz or JKR theory). All those classical thermal conductivity theories operate with models from the 19th century (Maxwell, Fourier, Stefan-Boltzmann law, Hertz) and completely neglect phonons and quantum mechanics! We are revising the underlying assumptions, and find that most are doubtful.

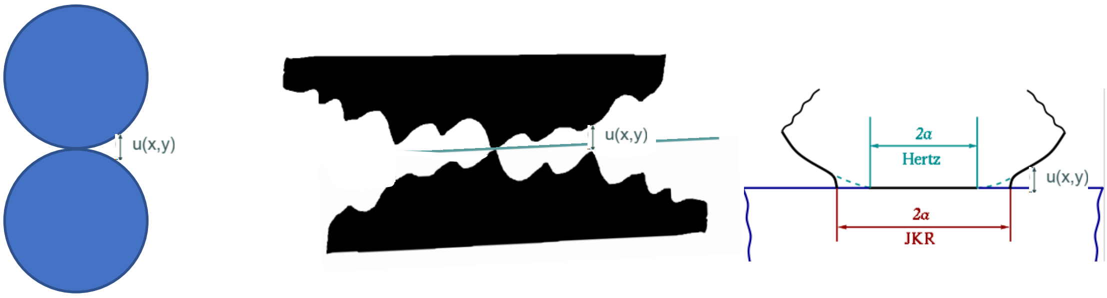


Figure 2 Cartoons depicting idealized (left and right) and realistic contact (middle)

Rough irregular rock (silicate) particles do not form strong contacts when granular, not much phonon conduction across point contacts, JKR not applicable at all, heat transfer by near-field evanescent EM waves at least equally important, (NFRHT) $\sim 1/R^{0.8}$-dependence. Radiative conduction is not $\propto T^3$ either, if grains are not well conducting (non-isothermality); different regime if void scale <= thermal wavelength $\lambda_T \approx 3000/T$ µm K (radiative transfer, dense media scattering and transmission, Planck not valid if particle size $< \lambda_T$); Most assumptions on porosity dependence, in particular of k_{rad}, were wrong [5, 6]. Porous rock effective conductivity (meteorites) as function of porosity in not Maxwell „swiss cheese“, much lower values at medium porosities ➔ rather weakly cemented/sintered ex granular matter. Cracks, percolating and close pores, .. no theory is available! We are working both theoretically and experimentally to understand this better [7, 8].

Revisit of Comet Surface Strength

For comet 67P, we have re-analyzed the data for the apparently exceptional 67P Abydos site, where originally a *lower* limit of several MPa for compressive strength was suggested. We use a correlation going back to Digby [9, 10] between strength, Young’s module and thermal conductivity for weakly sintered porous media; our revised value for compressive strength is 28–690 kPa on the 5–30 cm scale, still representing the probably most competent material on the comet, potentially with a reduced porosity compared to the average 70–80%. The size effect law [11] for quasi-brittle failures bridging the small-size asymptotic strength (compressive or tensile) and the power law $\sim 1/d^{1/2}$ of LEFM seems to apply for cometary and meteoritic material: the strength of very small lab samples cannot be simply extrapolated to larger sizes!

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