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Material properties of Titan Aerosol Analogs "Tholin"

Xinting Yu (1,2), Sarah Hörst (2), Chao He (2), Patricia McGuiggan (3), and Xi Zhang (1)
(1) Department of Earth and Planetary Sciences, University of California, Santa Cruz, California, USA, (2) Department of Earth and Planetary Sciences, Johns Hopkins University, Maryland, USA, (3) Department of Materials Science and Engineering, Johns Hopkins University, Maryland, USA.

Abstract

Photochemically produced organics are important for Titan. They form the haze particles in Titan's atmosphere, and are believed to make up the dunes on the surface of Titan. To better understand the physical processes involving these organics, characterization of their material properties is needed. We used novel techniques such as atomic force microscopy (AFM) and nanoindentation to measure some important material properties of Titan aerosol analogs, 'tholin'. Relevant material properties include surface energy, mechanical properties (hardness, elastic modulus, and fracture toughness), and interparticle cohesion and electrostatic forces. With a surface energy of $\sim$70 mN/m, tholin is a relatively cohesive material, and most liquids on Titan would completely wet it (contact angle $< 20°$). Tholin's mechanical weakness (low hardness and high brittleness) compared to Earth sands suggests that Titan sand may not be able to be transported for long distances. Tholin also has higher cohesion relative to quartz sand, but is hard to be electrified through contact and frictional charging.

1. Introduction

Titan is an organic world. Energetic particles from Saturn's magnetosphere and UV photons from the Sun dissociate methane and nitrogen in Titan's upper atmosphere and induce complex chemical reactions, leading to formation of complex organic particles (see e.g., [1]). These organic particles form the haze in Titan's atmosphere, and also fall through the atmosphere, interact with clouds, and eventually reach to the surface, where they could interact with the surface liquids and the bedrock (e.g., [2]), and could also form the surface dune materials ([3]). Many efforts have been made to study the chemical structure and spectroscopic properties of the Titan haze analogs. However, material properties including mechanical and cohesive properties are less investigated, while these properties could provide crucial information on how the organic particles interact with each other and other materials, and how they evolve through time.

2. Methods

We produced the Titan aerosol analogs, 'tholin', using the Planetary HAZE Research (PHAZER) experimental system at Johns Hopkins University, with a 5% CH_4/N_2 cold gas mixture in a glow plasma discharge chamber. Tholin was deposited on smooth quartz discs and acid-washed glass spheres.

The surface energy of tholin film was measured using contact angle analysis using a polar (water) and a non-polar liquid (diiodomethane). A Ramé-Hart goniometer was used to image the droplet shape [4].

The mechanical properties of tholin were measured by nanoindentation. We used an iNano Nanoindenter and measured the elastic modulus, nanoindentation hardness, and fracture toughness of tholin and some common Earth sands [5].

We also measured the cohesion and electrostatic forces between single tholin particles using a Bruker Dimension 3100 atomic force microscope. We adhered a tholin-coated glass sphere to the end of an AFM cantilever and measured force-distance curves between the coated sphere and a tholin-coated surface.

3. Results and Discussion

3.1 Surface Energy and Contact Angles

The contact angle between water and the tholin film is measured to be $22 \pm 5°$, and it is $50 \pm 5°$ between diiodomethane and the tholin film. We then calculated the surface energy of tholin (γ_s) using the Owens-Wendt-Rabel-Kaelble (OWRK) method [6], which yields $70.9^{+4.6}_{-4.8}$ mN/m (Figure 1). The dispersion component (γ_s^d) is $34.3^{+2.7}_{-2.9}$ mN/m and the polar component (γ_s^p) is $36.6^{+3.7}_{-3.8}$ mN/m [4].

With the measured surface energy of tholin, we can estimate the contact angle between tholin and relevant liquids on Titan. For liquid methane, which has a surface tension (γ_l) of 16.7 mN/m under Titan's surface temperature, it would completely wet the tholin surface (contact angle θ=0°). For liquid ethane (γ_l = 32.9 mN/m at 94 K), its contact angle with tholin is <17° given the uncertainty of the surface energy of tholin. The low contact angle between liquids on Titan and tholin could support the possibility of a film of organics floating on Titan's lakes as proposed by [2].

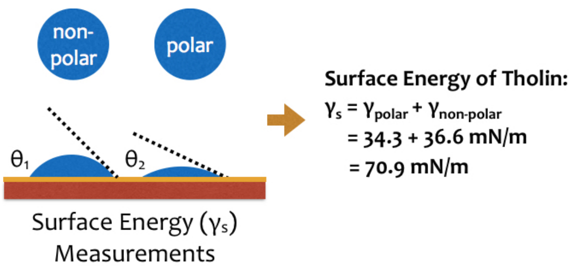

Figure 1: Schematic of the contact angle method on measuring the surface energy of a flat tholin film deposited on a quartz surface.

3.2. Mechanical Properties

The measured hardnesses of tholin and common Earth sands are shown in Figure 2. Compared to common amorphous polymers, which have hardness ∼0.6-5 GPa, tholin is on the hard end. However, the hardness of tholin is an order of magnitude lower than silicate sand such as basalt and beach sand. It is softer than even the carbonate and white gypsum sands, which are unable to be transported for long distances because of their mechanical weakness.

The fracture toughnesses for tholin and other materials are plotted in Figure 3. Tholin is more brittle than amorphous polymers and common Earth sands.

Because of tholin's lower hardness and higher brittleness compared to common Earth sands, tholin may be mechanically too weak to be transported for long distances on Titan, which indicates that the Titan sand could be derived close to where it is located currently in the equatorial regions of Titan.

3.3. Cohesion and Electrostatic Forces

By measuring cohesion forces between single tholin particles, we found that the cohesion between tholin particles is higher than silicate sand [4]. However, we are unable to generate any detectable electrostatic forces between tholin particles [7]. While for silicate sand, electrification was found to greatly affect sediment entrainment and trajectories. Our results indicate that cohesion could dominate over electrostatic forces for Titan sand, and the higher cohesion of tholin implies that it might be easier for small Titan aerosols to aggregate into larger sand particles on Titan's surface.

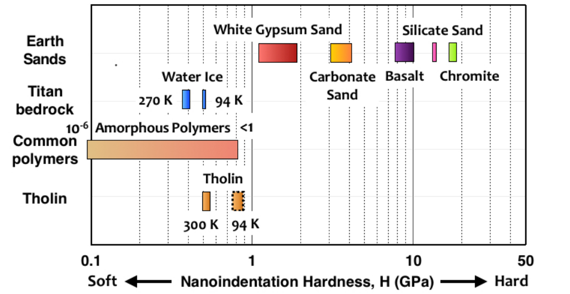

Figure 2: Measured nanoindentation hardness for common Earth sands and tholin and data for other materials for comparison (adapted from [5]).

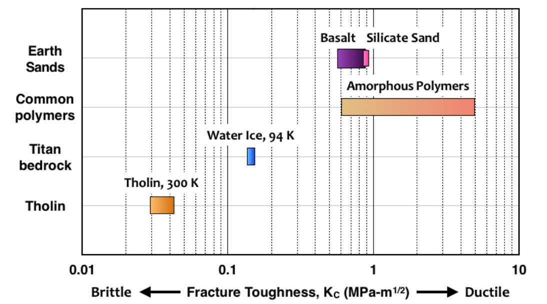

Figure 3: Measured fracture toughness for common Earth sands and tholin and data for other materials for comparison (adapted from [5]).

Acknowledgements

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