Direct Measurement of Interparticle Adhesion of Titan Aerosol Analogs ('Tholin') Using Atomic Force Microscopy
Xinting Yu[1], Sarah M. Hörst[1], Chao He[1], Patricia McGuiggan[2] and Nathan T. Bridges[3], [1]Department of Earth and Planetary Sciences, Johns Hopkins University (xyu33@jhu.edu), Baltimore, Maryland 21218, [2]Department of Materials Science and Engineering, Johns Hopkins University, Baltimore, Maryland 21218, [3]Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland 20723.

Introduction: Initiation of saltation on Titan has been investigated by measuring threshold wind speed using the Titan Wind Tunnel (TWT) [1]. Complementary to such investigations, threshold wind speed can be predicted by deriving the force balance of stationary stacking particles. These forces include: the wind drag and lift forces, gravity, and the interparticle forces [2]. The wind drag and lift forces can be manipulated by changing the wind speed and flow regimes in the wind tunnel. The gravity on Titan can be simulated by using lower density material in the wind tunnel on Earth. However, the interparticle forces are highly dependent on instrinsic material properties. The low density materials in use in the TWT may have different interparticle forces compared to the real transporting materials on Titan (presumably a mixture of 'tholin' and water ice [3]). Thus measurements of interparticle forces of both tholins and the low density materials used in the TWT are necessary, so we can correctly translate TWT results to real Titan conditions. The interparticle forces consist of van der Waals forces, adhesion forces, and electrostatic forces. In humid environments, adhesion forces are much greater than van der Waals forces and electrostatic forces. Here in this study, we measured the adhesion forces between particles.

Methods:

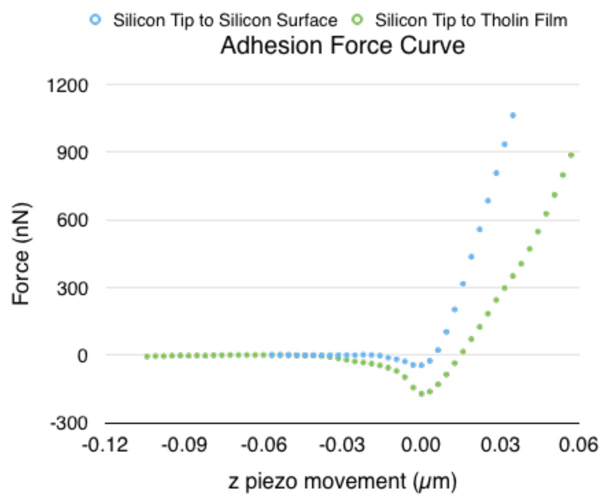
Samples and preparation. Tholins were produced by exposing 5% CH_4/N_2 gas mixture to a glow plasma discharge (pressure: 3 torr, temperature: 100 K), with 10 sccm flow rate [4, 5]. Tholins were deposited both on a quartz film and on the wall of the chamber. Tholin particles deposited on the chamber wall were collected in a N_2 glove box. The low density materials (walnut shells 125-150 µm) are original batches from the TWT [1].

AFM and cantilevers. The AFM we used is Bruker Dimension 3100 atomic force microscope. Cantilevers of spring constant approximately 40 N/m were calibrated by thermal tuning.

Force Curve Measurement. 1) To study tip-flat adhesion, we conducted force distance curve measurements with a bare silicon AFM tip to both flat tholin film and the quartz surface. 2) To study particle-particle cohesion, a tholin particle (~20 µm) and a walnut shell particle (~100 µm) (a common wind tunnel material [1]) were glued to cantilevers with epoxy resin. Force curve measurements were conducted for 1) tholin particle to flat tholin film; 2) tholin particle to other tholin particles (20-100 µm), and 3) walnut shell particle to other walnut shell particles (50-100 µm).

Results:

Tip to flat adhesion forces. Shown in Figure 1 is the tip to flat adhesion force curves (only retract force curve is shown). The 'dip' of the force curve represents the adhesion force. Here the adhesion force between silicon tip and silicon flat surface is about 45 nN, while the adhesion force between silicon tip and tholin film is 3 times larger, about 172 nN.



Particle to particle adhesion forces. The force curve between particles is more complex since macro-spherical particles are usually very rough. In Table 1 we show the results for particle-particle adhesion forces for walnut shells and tholins. The walnut shell particle (~100 µm) is much bigger than the tholin particles (~20 µm). According to JKR and DMT contact mechanics [6, 7], the adhesion forces scale linearly to the particle size. Thus the adhesion forces should be much larger between tholin particles compared to walnut shell particles, if the particles are of the same size.

This study shows the first direct measurements of adhesion forces between tholin particles. It indicates that the threshold wind speed on Titan could be larger than reported in [1], since the interparticle forces between tholins are much larger than walnut shells used in the TWT.

The gravity for a 100 µm walnut shell particle is only ~7 nN (density value of walnut shell adopted from [8]), for a 20 µm tholin particle is only ~0.06 nN (density value of tholin particle adopted from [4]). At friction wind speed of 2 m/s, the drag force for a 100 µm walnut shell particle is ~202 nN, for a 20 µm tholin particle is ~21 nN. The lift forces for both particles are several magnitudes smaller than drag forces (~0.005 nN). Comparing these forces to the adhesion force we measured by AFM, we find that adhesion force is much greater than gravity and lift forces for both walnut shell and tholin particles, but it is of similar magnitude to the drag forces at 2 m/s friction wind speed.

Walnut Shell Particle to Walnut Shell	Average Adhesion Force (nN)	Tholin Particle to Tholin Particle	Average Adhesion Force (nN)
100 µm to 100 µm	272 nN	20 µm to 80 µm	177 nN
Particle A to 120 µm	231 nN	20 µm to 50 µm	424 nN
		20 µm to 60 µm	1408 nN

References: [1] D. M. Burr, et al. *Nature*, 517:60-63, 2015. [2] Y. Shao and H. Lu, *J. Geophys. Res*., 105, 22437, 2000. [3] J. W. Barnes, et al. *Icarus*, 195, 400, 2008. [4] C. He and S. Hörst, *DPS* 2016. [5] C. He, et al. *Manuscript in Preparation*. [6] K. L. Johnson, K. Kendall, and A. D. Roberts, *Proc. R. Soc. Lond.*, A 324, 301, 1971. [7] B. V. Dejaguin, V. Muller, and V. P. Toporov, J. Colloid Interface Sci, 53.2: 314-326, 1975. [8] X. Yu et al., DPS 2016.