

The Need for High Fidelity Lunar Regolith Simulants

Abstract:

The case is made for the need to have high fidelity lunar regolith simulants to verify the performance of structures and mechanisms to be used on the lunar surface. Minor constituents will in some cases have major consequences. Small amounts of sulfur in the regolith can poison catalysts, and metallic iron on the surface of nano-sized dust particles may cause a dramatic increase in its toxicity. So the definition of a high fidelity simulant is application dependent. For example, *in situ* resource utilization will require high fidelity in chemistry, meaning careful attention to the minor components and phases; but some other applications, such as the abrasive effects on suit fabrics, might be relatively insensitive to minor component chemistry. The lunar environment itself will change the surface chemistry of the simulant, so to have a high fidelity simulant at must be used in a high fidelity simulated environment to get a high fidelity simulation. Research must be conducted to determine how sensitive technologies will be to minor components and environmental factors before they can be dismissed as unimportant.

The Need for High Fidelity Lunar Regolith Simulants



James R. Gaier

NASA Glenn Research Center



Acknowledgements

- **Minor component additives**
 - Aloysius F. Hepp
 - Jeremiah S. McNatt
 - Ching-Cheh Hung
- **Activation**
 - Randall L. Vander Wal (NCER)
 - Kenneth W. Street
 - Scott R. Panko (ARCO)
- **Funding**
 - GRC Internal Research and Development (FY07)



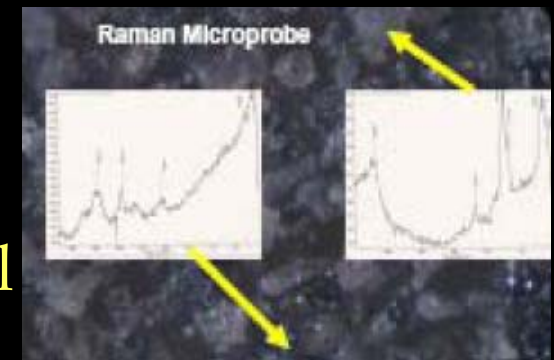
What Is High Fidelity?

- Answer dependent on application
 - ISRU oxygen production
 - Correct fraction of oxygen producing mineral
 - Correct fraction of interfering materials
 - Adhesion to spacecraft components
 - Correct size and shape distributions
 - Correct surface chemistry
 - Correct electrostatic properties
- Lunar environmental changes dust properties
 - No adsorbed water, carbon dioxide on surfaces
 - Lunar dust contains implanted solar wind
 - Lunar dust subjected to solar and galactic radiation
 - Lunar dust subjected to meteoroid bombardment
- *How high fidelity is high enough?*



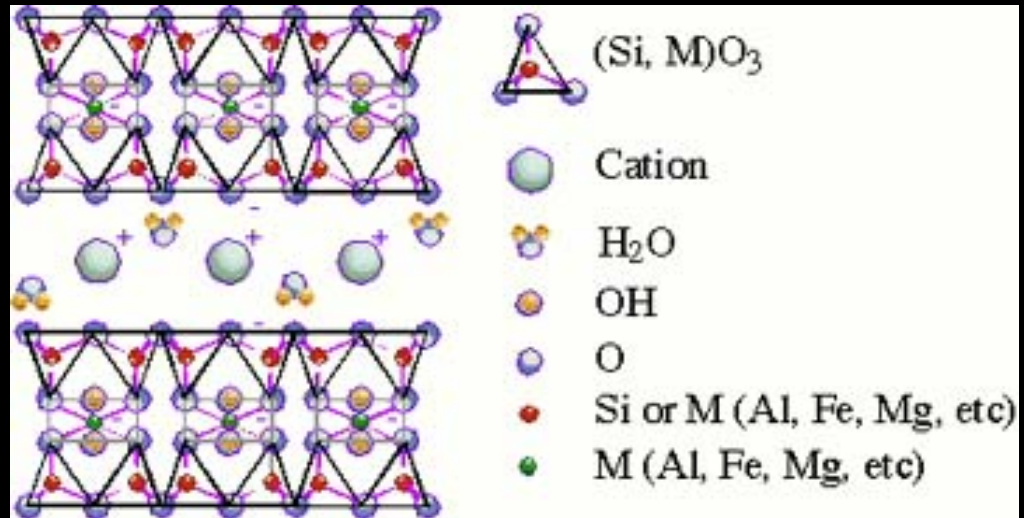
Lunar Minerals in High Fidelity Simulants

- **Silicate minerals/glass** make up to **90%** regolith volume
 - Pyroxene - $(\text{CaFeMg})_2\text{Si}_{12}\text{O}_6$
 - Plagioclase feldspar - $(\text{CaNa})(\text{AlSi})_4\text{O}_8$
 - Olivine - $(\text{MgFe})_2\text{SiO}_4$
- **Oxide minerals** make up to **20%** volume
 - Ilmenite - $(\text{MgFe})\text{TiO}_3$
 - Spinel - FeCr_2O_4 , Fe_2TiO_4 , FeAl_2O_4 , MgTiO_4
 - Armalcolite - $(\text{MgFe})\text{Ti}_2\text{O}_5$
- **Low abundance of native metals**
 - Fe, Ni, Co
- **Most sulfur contained in single mineral**
 - Troilite - FeS
- **Traces of many other minerals (~100)**



Minerals Absent from High Fidelity Simulants

- Rare on moon (though common on earth)
 - Potassium feldspar - KAlSi_3O_8
 - Silica - SiO_2
- Absent on moon (because they contain water)
 - Clays
 - Micaceous
 - Amphiboles

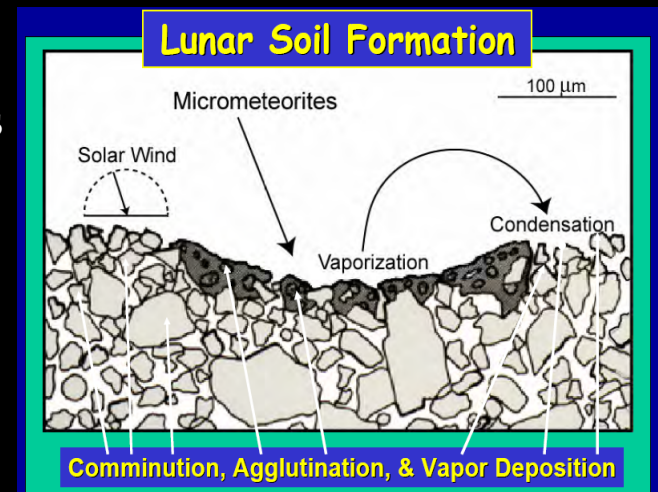


Clay structure from NASA SSC on www7430.nrlssc

Lunar Agglutinate Formation

- Meteoroid strikes on the surface
 - Hottest zone underneath impact melts rock together
 - Adsorbed H, He from solar wind escape
 - Oxygen from rock vaporizes and escapes
 - Iron is reduced, vaporizes and re-deposits
 - Mineral grains structure shocked
 - Minerals melted into glass
 - Glass flows down into regolith and glues grains together
 - Forms frothy agglutinates
 - Zone beneath hot zone feels pressure
 - Fractures rock into small, sharp particles
- More agglutinates in “mature” soils

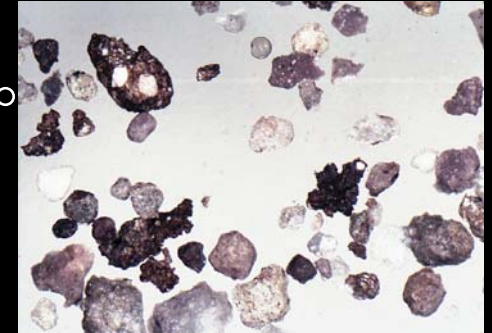
Figure from L. Taylor presentation at Lunar Simulant Materials Workshop, Jan 2005.



Properties of Agglutinates

- **Properties**

- Part mineral, part glass, nanophase Fe⁰
- Very high surface area, low density
- Mechanically fragile
- Irregular surfaces



Lunar agglutinate image
from Union College on
www.Union.edu

- **Implications**

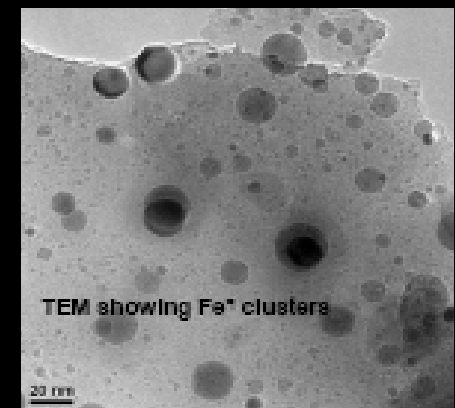
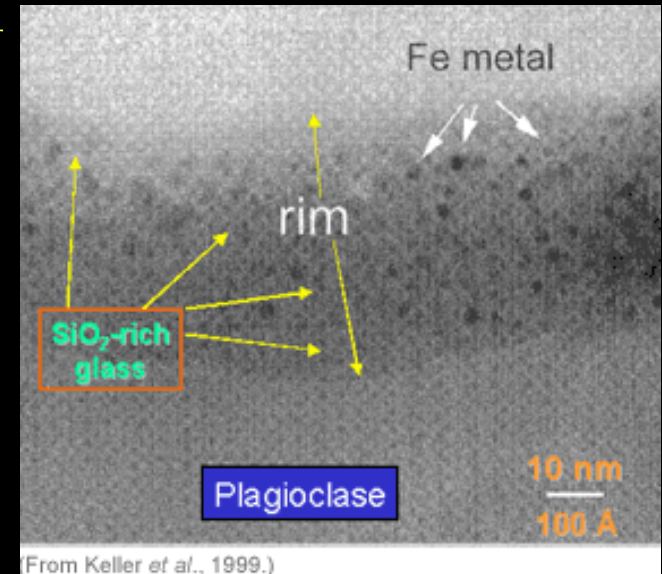
- Will break up when mechanically worked
 - May need to be replaced regularly in mechanical testing
- Shape will effect adhesion
 - Few points of contact will lower van der Waals adhesion
 - Jagged edges may hook into fabrics

- **Synthetic agglutinates being made**

- USGS, Orbitec, PPI

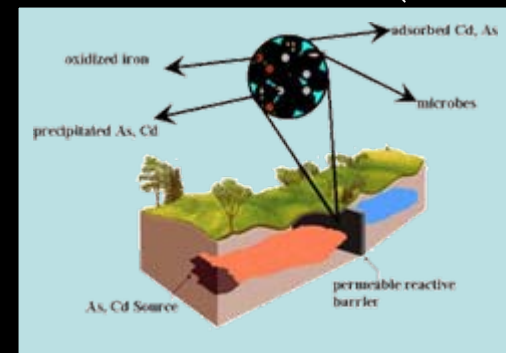
Properties of Nanophase Iron

- Fe° deposited during agglutination
 - Much in glassy rinds covering surface
 - Some deposited as metal on surfaces
- Implications
 - Fe° affects magnetic properties
 - Nanophase superparamagnetic
 - Larger particles ferromagnetic
 - Good microwave absorber
 - Surface Fe° on nanoparticles toxic?
 - Enter bloodstream through lungs
- Synthetic nanophase Fe° being fabricated
 - GRC, Orbitec, USGS



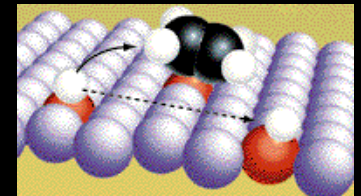
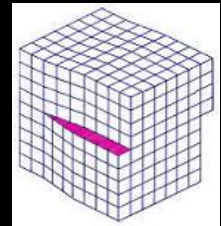
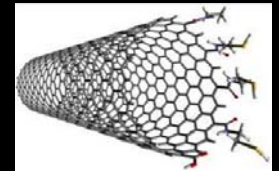
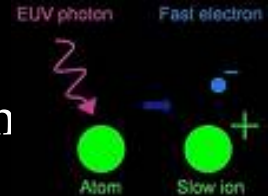
Properties of Lunar Sulfur

- Troilite (FeS) reactive mineral ~ 1% all lunar regolith
 - FeS rare in terrestrial surface rock
 - Must be added to simulants
- FeS can react with ISRU processes
 - H₂S and SO₂ production likely
 - Must be removed from breathable O₂
- FeS can poison catalytic surfaces
 - Fisher-Tropsch catalysts for reforming CH₄
 - Sulfur compounds may poison fuel cell catalysts
 - Nobel metals poisoned
- FeS may be a resource
 - Hayes (UM) has proposed nanophase FeS to filter toxic metals (As, Cd) from water
 - NiS or other metal sulfides in regolith?



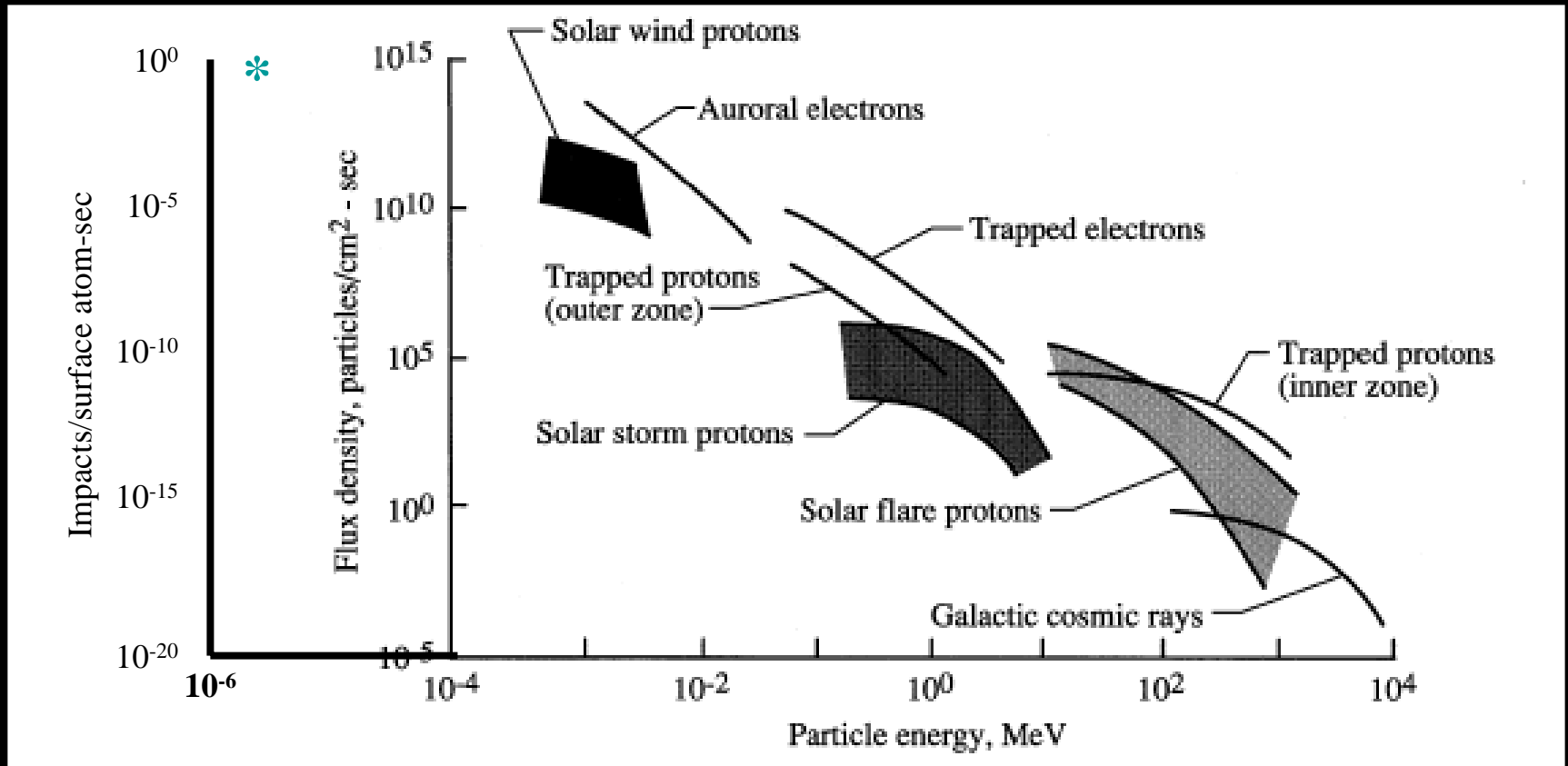
Activation Definitions

- **Activated Surfaces defined:**
 - A relatively large number of highly reactive surface atoms
- **Types of reactive surface sites**
 - Free radicals – atoms with unpaired electrons
 - Dangling bonds – unsatisfied valence shell bonding
 - Crystal defects – create highly unstable, strained bonds
- **Activation energy**
 - Energy difference between ground state and excited state
 - Energy to remove electrons
 - Energy to displace atoms from equilibrium lattice positions
- **Passivation**
 - The relaxation of excited states into ground states
 - Includes reactions with foreign bodies



Space Radiation at the Lunar Surface

- About 5.8 eV will eject an e^- from a mineral surface
- Mineral bonds are broken by the input of 3-9 eV
- Minerals have about 10^{15} surface atoms/cm² (*)



John H. Glenn Research Center Figure derived from J.W. Wilson, et al., NASA Ref Pub 1257 (1991).

Environment Activates Lunar Regolith

- Energetic solar particles and galactic cosmic rays
 - Hard UV, x-rays, and γ -rays
 - Implantation of H^+ , He^{2+} , ...
 - Sputtering of atoms off of surface
- Micrometeoroid strike surface
 - Fractures regolith, shocking structures
- Large thermal cycles
 - Equatorial regions range 100 – 400 K (-280 to 260 °F)
 - Polar range 210 – 230 K (permanently shadowed craters 40 K?)
- Ultra-high vacuum (10^{-12} – 10^{-14} Torr)
 - Each surface atom hit once a day by a gaseous atom
 - On earth each surface atom hit 10^8 times per second
 - Passivation of dangling bonds and defects is *very slow*

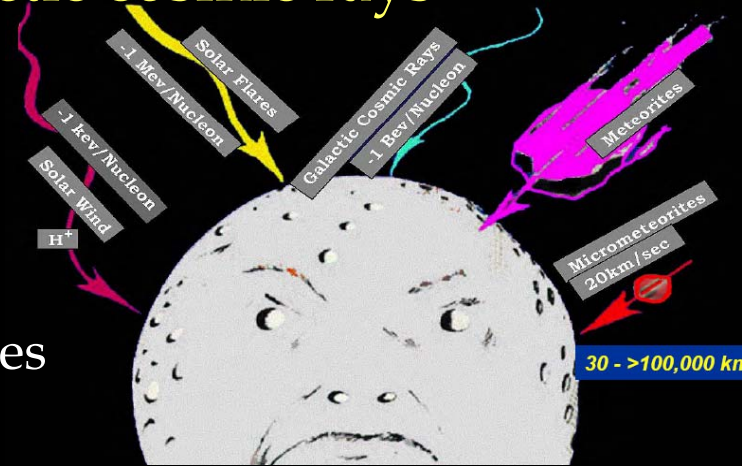


Figure from L. Taylor presentation at Lunar Simulant Materials Workshop, Jan 2005.

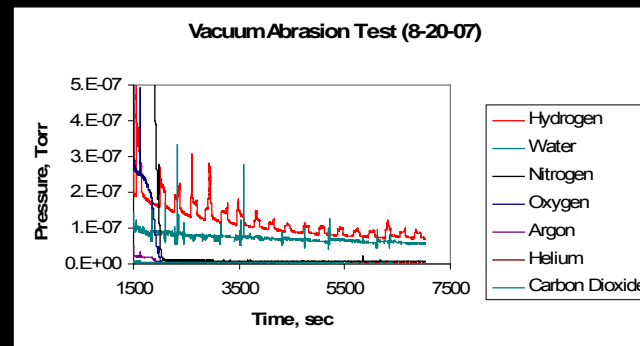
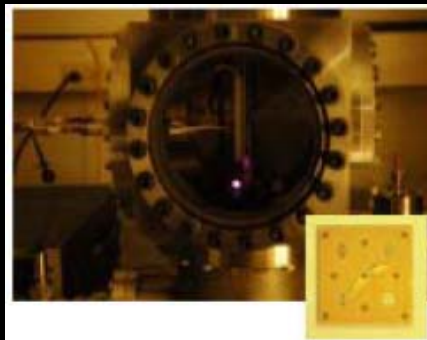
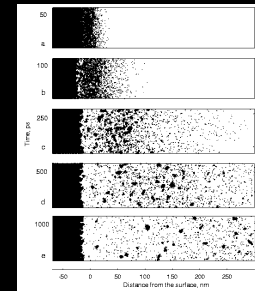
Evidence for Activated Dust

- Grossman (1970) measured cohesion in sample 10065-33
 - Porous and friable micro-breccia
 - Fractured in 7×10^{-10} Torr vacuum
 - Initial cohesion **800 dynes**
 - 4 min → **200 dynes**
 - 15 min → **~ 0**
- Pungent odor given off of lunar dust consistent with reactions with odorant receptors in nose
 - From David Scott in the Apollo 15 Technical Debriefing
 - *“When you took the helmet off, you could smell the lunar dirt. It smelled like – the nearest analogy I can think of is gunpowder.”*
- Odor dissipated in a short time, consistent with passivation of by oxygen or water vapor
 - Carlton Allen, Biological Effects of Lunar Dust Workshop (2005)
 - *“The gunpowder smell went away in a few hours.”*



Investigations into Simulant Activation

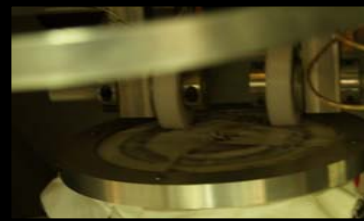
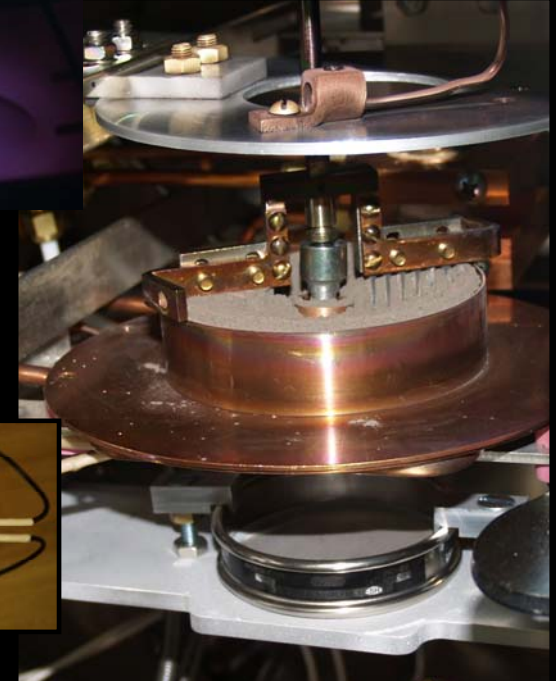
- Subject lunar simulants to surface activation processes:
 - Fracture using high impact milling
 - High energy RF plasma
 - High energy ablation
- Multiple characterization techniques:
 - SEM, TEM, HRTEM, SAED for physical structure
 - Fluorescence and Raman (*in situ*) for chemical structure
 - Quartz crystal microbalance, resistivity for *in situ* reactivity determination
 - RGA analysis of implanted solar wind volatiles



- Physical and Chemical Reactivity Testing
 - Adhesion studies upon materials and coatings
 - Abrasion characterization upon simple cleaning

Lunar Dust Adhesion Belljar Capabilities

- High vacuum (10^{-8} Torr)
 - Quantify residual gases
- *In situ* activation of dust
 - Stirring/heating to drive off terrestrial volatiles
 - Activation in oxidizing/reducing RF plasmas
 - Sieving dust onto samples
 - UV-Vis-IR irradiation
- Characterization of samples
 - Absorptance
 - Emittance to cold wall as low as 25 K
 - Steady state temperatures vs/applied power
 - Particle sizes/concentrations/mass on surface
 - Adhesion to surfaces
 - Abrasion testing (Taber test)



Conclusions

- No high fidelity simulants widely available
 - Not JSC-1, MLS-1, FJS-1...
- “High fidelity” definition application dependent
 - ISRU requirements may differ from dust mitigation
- Minor constituents may have major effects
 - Catalyst poisoning by traces of sulfur?
 - Enhanced toxicity by surface iron?
- Lunar environment changes properties
 - Activated surfaces affect adhesion, cohesion...
 - Must test properties in the right environment

