

REGOLITH SINTERING: A SOLUTION TO LUNAR DUST MITIGATION? T. L. Wilson¹ and K. B. Wilson², ¹NASA, Johnson Space Center, Houston, Texas 77058 USA. ²Rice University, Houston, Texas 77251 USA.

Introduction: The prospect for a human outpost or permanent lunar base conducting exploration science on the Moon has been discussed in a number of different venues [1-4]. Of all the technological difficulties that confront observatory science on the Moon, dust mitigation remains a serious issue that is either discussed candidly or is oversimplified. In view of the fact that fundamental physics and astronomy research continues to be proposed for a lunar base, the problem of lunar dust must be confronted. In particular, the recent suggestion to place a 20-meter liquid mirror telescope (LMT) on the Moon because “the Moon and liquid mirrors were made for each other” [5-6] shows that the technical readiness level for any new vision of returning to the Moon with such grand-scale ideas is immature. Dust mitigation needs to be addressed, and we present a conceptual strategy for providing a clean area for observational science on a return-to-flight basis using existing technology rather than an evolutionary one that remains undeveloped. Under certain assumptions and caveats, we believe it addresses the problem.

Lunar Dust: The Moon is covered with dust that adheres electrostatically to everything coming in contact with it [7]. Unlike Earth-based dust that is formed by chemical alteration and is smoothed by weathering, lunar dust is created primarily by fragmentation and is highly abrasive. It can levitate in sunlight due to electrostatic potentials produced by UV photoelectron effects, it migrates in dusty plasmas [8], and it is believed to have been observed by Surveyor 5, 6, and 7 in the form of horizon glow as part of a tenuous exosphere. In short, it is ubiquitous on the Moon, and where there is activity dust will present a mitigation problem.

While the Apollo 12 astronauts discovered that Surveyor was covered in dust, clever new solar panel designs have attempted to preclude such effects [9]. In contrast to the Surveyor observation, however, the laser-ranging Apollo retroreflectors [10] have been functioning for 35 years and may continue indefinitely. One might surmise from Surveyor and Apollo that in areas of little activity, dust may not be a problem. However, a 20-meter LMT spinning at high rates is hardly a quiescent activity, particularly since it may be a nice electrodynamic generator that has an affinity for charging dust. Such a mirror involves a tedious high-maintenance, hands-on process for cleaning the liquid and removing dust, by human or robotic means. High activity equals dust, so dust will be everywhere unless

mitigation measures continue to be developed.

Dust Mitigation: From solar panels to launch and landing activities, it appears that human and robotic activity need to be isolated as much as possible from the scientific observatory area. Previous Apollo methods for coping with lunar dust consisted of brushing it off and using duct-tape to make dust-flaps for the rear wheels of the Lunar Rover. Contamination of science results was otherwise not an issue.

We propose an interim solution, consisting of constructing a thin *in situ* pavement similar to an airport tarmac in the contiguous area where large-scale observatories are maintained – thus preserving a necessary clean haven for science. The measure scales up in the sense that the same surface-blanket functions as the subfloor for subsequent tiling with thin-layered brick-ing-tiles produced by regolith sintering, although that may not be necessary. A critical step in the concept, depicted in Figure 1, is the use of epoxy and hydrogen.

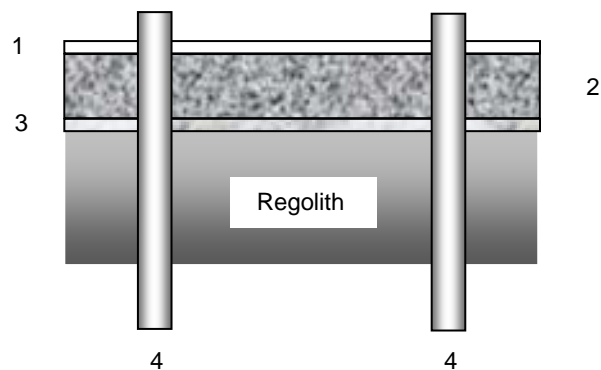


Figure 1. A plasma-sprayed layer of hydrogen (1) covers an epoxy-regolith mixture (2), with a subfloor (3) of pressed regolith. Piers (4) support heavy telescopes.

Thermal Plasma Spraying Technology: The subject of lunar dust mitigation is actually a matter for investigations in new emerging fields of materials science. One area of importance is the development over the past 40 years of thermal spraying technology [11], used to minimize fatigue in turbofans for high-performance turbines and aircraft engines. It is this technology that we apply to lunar thin-surface paving or blanketing for mitigating dust contamination.

Hydrogen-Thermalized Epoxy Paving: In Figure 1, epoxy is mixed with regolith to create a blanket-layer (2) over (3); or alternatively, layer (2) is sprayed

as pure epoxy on (3) if epoxy-regolith mixing presents difficulties. The thickness of layer (2) is a function of compressive load and volume fraction of regolith. Standard epoxies (matweb.com, for specific gravity γ from 0.5 to 2.0) provide deflection and processing temperatures safely outside the temperature extremes on the Moon [7], easily withstanding pressures of 60 MPa, although this number diminishes to 2 MPa at the deflection temperature. The compressive load requirements are further reduced by use of piers (4) to support the heavy weight of large objects. Since the volume fraction of mixture requires a trade study, dimensions are not illustrated but an estimate of mixed-layer thickness is on the order of one centimeter for (2). The estimate for a sprayed pure-epoxy layer is one millimeter for (2). The regolith must be prepared by leveling and compressing the surface area, resulting in subfloor (3). This can be accomplished using a thin-shelled cylindrical roller filled with lunar material to increase its weight.

The two epoxy components can be mixed with the regolith in a simple cart that rolls along the subfloor (3). The same roller that prepared (3) is used to prepare (2). In the spraying option for (2), the same cart can be utilized. Finally, the cart applies the plasma spray (1). Inactive areas are prepared only as (3).

Regolith Sintering: Sintering is the bonding of particles below the melting temperature, causing particles to cross grain boundaries by means of temperature and pressure. Sintering of the lunar regolith has been discussed at some length [12] as a method for producing construction materials from *in situ* resources at a lunar base. As actual regolith sintering technology matures on the Moon, alternatives for layer (2) may evolve, including something similar to silica-based epoxy. Also *in situ* production of hydrogen will occur.

Proof of Concept: Using a small sample of JSC lunar simulant, a thin layer of (2) was produced. The mixing of epoxy and simulant was found to create bubbles. This will occur even *in vacuo*. Also, the simulant sank to the bottom of (2), contiguous with layer (3) – begging the issue of simple epoxy-spraying of (3) with (2) instead. A 360-lb astronaut with shoes of 60 in² on a 1/6-gravity surface produces 1 psi (0.007 MPa), hardly challenging a 2-60 Mpa figure of merit for pure epoxy in (2). A 1 m²-area that is 1 mm thick with numerical density ρ_s (in g c⁻³) means a clean-haven requires ρ_s kg per m²-area of pure epoxy – a figure that needs to be charged to the LMT proposal [5-6].

Issues and Caveats: A number of questions and issues pose themselves. These include surface erosion, wear resistance, maintenance, and damage repair in Figure 1. Cosmic-rays (CRs) and micrometeoroids impact the lunar environment constantly. The solar

wind and insolation bathe the Moon throughout most of its orbit. Such weathering effects will alter the plasma hydrogen layer (1) in Figure 1 whose function is to preclude erosion and corrosion of (2) by space weather (CRs, solar wind, and surface chemistry).

Trade and proof-of-concept studies are required. Chemical erosion of the epoxy-regolith layer (2) at its interface with the lunar regolith (3) is possible and needs to be addressed. The *in vacuo* lifetime for lunar surface conditions of thermalized hydrogen on an epoxy-regolith or epoxy substrate must be investigated, and alternatives to plasma considered. In addition, operational constraints including power for employing a plasma spray on the Moon must be worked out.

Finally, the ultimate issue is science and program requirements versus cost and schedule. The question of transporting epoxy material for blanketing regolith versus *in situ* resource utilization or ISRU (e.g., regolith sintering) is a trade study driven by science as well as other program constraints. The thickness of layer (2) in Figure 1 is determined by the compressive load bearing requirement (1-psi astronaut walkways or vehicle pathways). This in turn drives the volume of epoxy material, at least until a lunar base matures to the point that an ISRU substitute can be used for layer (2) and hydrogen is readily available *in situ*.

Conclusion: We have presented a concept for hydrogen-layering a thin epoxy surface to provide a clean-area that can support observatory-class science on the Moon. With that summary statement and given the caveats, this strategy can support even a first flight to the Moon. We consider the strategy worthy of further investigation.

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