# Passive Dust Mitigating Materials Evaluation Supporting NASA's Patch Plate Materials Project


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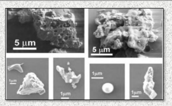
The NASA Artemis mission plans to send humans back to the Moon which has initiated widespread efforts to identify materials and mechanisms to effectively mitigate lunar dust surface contamination and infiltration. Lunar dust is hazardous to humans and tends to adhere strongly to all exposed surfaces causing equipment degradation and premature failure. Lunar dust can adversely influence mission success and scope across a range of exploration vehicles, habitats, and activities. Lunar dust adhesion can arise from several phenomena: mechanical interlocking, chemical reaction, electrostatic, magnetic, etc. [1]. It is crucial to study lunar dust interactions and develop strategies to mitigate lunar dust adhesion and contamination [2]. An important approach is passive dust mitigation, in which the material surface itself can reduce dust adhesion. Passive dust mitigation may be an intrinsic property of the material or might be imparted by surface modification such as a coating, topographical modification, or both. These materials must also be able to endure the harsh lunar environment. The Lunar Surface Patch Plate Materials Compatibility Assessment experiment will deliver an array of materials to the lunar surface to ascertain our technology readiness to mitigate this hazard. A brief overview of the initial dust adhesion test results and other characterization conducted for selecting the optimum candidates from different classes of materials for passive dust mitigation in ground-based tests simulating the lunar environment is discussed.



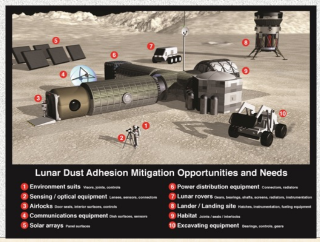
**[1]** Stubbs, T. et al. (2007) Impact of Dust on Lunar Exploration. Dust in Planetary Systems. 239-243. **[2]** Afshar-Mohajer, N. et al. (2015) Adv. Space Res., 56, 1222-1241.


## Opportunities and Needs

**Lunar dust characteristics:**
- Abrasive, jagged edges
- Chemically reactive
- Electrostatically charged
- Sometimes magnetic
- Strongly adheres to surfaces



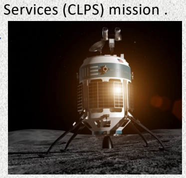
SEM images of Apollo 17 lunar dust




## Patch Plate Experiment

The Patch Plate Materials Compatibility Assessment Project under the Space Technology Mission Directorate's Dust Mitigation Program aims to develop passive dust mitigating materials technologies, demonstrate their performance in ground-based tests simulating the lunar environment, and finally fly them to the lunar surface for actual evaluation.

The experiment will be flown to the lunar surface for evaluation in the operational environment on a Commercial Lunar Payload Services (CLPS) mission .


Example CLPS Lander


Patch Plate Experiment

## Materials Evaluation Steps, Phase I

The first step is the repeatable application of a uniform contamination layer to the surface of a material sample. The lunar highland dust simulant, LHS-1D, with particle size < 25 µm was obtained from Exolith Lab. A controlled airborne dusting technique using short bursts of air through a Hirsch funnel containing a measured quantity of the simulant delivered optimal results for reliably depositing the simulant, Fig 1.

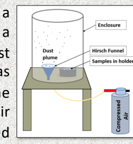


Fig 1.

The contaminated surfaces are attached to the tip of an ultrasonic wand and made to vibrate at varying amplitudes and time according to a set recipe, Fig 2. Dust particles are detached from the surface when the accelerating force exceeds the force of adhesion and are collected by the optical particle counter. Optical microscopy images of the surfaces are taken at each step.

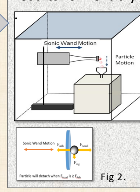


Fig 2.

## Materials Selection, Phase II

Material candidates selected at the NASA Langley Research Center will be sent for further evaluation in the NASA Glenn Research Center Lunar Dust Adhesion Bell Jar followed by other environmental exposure testing.

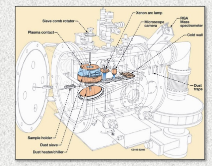


Image credit: NASA TM 2007-214704

## Polymeric Materials and Composites

The polymeric materials chosen were commercially available materials with extensive space heritage, and with promising chemical, mechanical and thermal properties [3,4]. Several classes of polymers: polyimides, polyesters, fluoropolymers and polycarbonate were evaluated to encompass a broader application space. Previous studies have indicated that topographical modification via laser ablation patterning can improve the dust adhesion mitigation properties of material surfaces, and surfaces of some polymers were modified by laser ablation patterning. The laser patterned Dupont™ Kapton® HN polyimide showed significant dust simulant adhesion mitigation.

| No. | Material | Surface characteristics | Images, 20x Dusted & final |
|---|---|---|---|
| 1) | Polyimide Kapton HN | As-received | |
| 2) | Polyimide Kapton HN | As-received | |
| 3) | Polyimide Kapton HN | Laser patterned #1 | |
| 4) | Polyimide Kapton HN | Laser patterned #2 | |
| 5) | Polyimide clear | As-received | |
| 6) | Teflon FEP | As-received | |

A carbon fiber reinforced low creep low relaxation bismaleimide (BMI) composite was fabricated in house and evaluated for dust adhesion mitigation [5]. It was found that the laser patterned surface exhibited promising dust mitigating properties.

| Material | Source | Surface characteristics | Images, 20x Dusted & final |
|---|---|---|---|
| LCLRA | Developed @LaRC | Laser patterned #1 | |
| LCLRA | Developed @LaRC | Laser patterned #2 | |
| LCLRB | Developed @LaRC | Laser patterned #1 | |
| LCLRB | Developed @LaRC | Laser patterned #2 | |
| LCLR1 | Developed @LaRC (MISSE-16) | As-is | |
| LCLR1 | Developed @LaRC (MISSE-16) | Laser patterned #2 | |

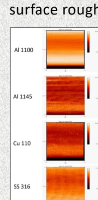

[3] Wohl, C. et al. (2007) Langmuir 26(13), 11469.
[4] Wohl, C. et al. (2015) J. Appl. Polymer Sci. 132(9), 41538.
[5] Peterson, R. et al. (2021) NASA/TM–2021-0021369


## Metals and Alloys

Several metals were tested, aluminum, stainless steel, Ti-6Al-4V alloy, and copper. Some of these surfaces were polished to impart different surface roughness and laser patterned to create different topographies. It was found that the laser patterned Ti-Al-6V surface showed promising adhesion mitigating properties.

| No. | Material | Surface characteristics | Images,20x Dusted & final |
|---|---|---|---|
| 1) | Ti-6Al-4V | Laser patterned | |
| 2) | SS-316 | As-received | |
| 3) | Al 1100 | Shim as-received | |
| 4) | Cu110 | Shim as-received | |
| 5) | Al1145-H19 | Shim as-received | |

Optical profilometry measurements were conducted to characterize $R_a$ and $R_q$ , the average and root mean square surface roughness, respectively.




| Substrate | $R_a$, mm | $R_q$, mm |
|---|---|---|
| Al 1100 | 1.227 | 1.580 |
| Al 1145 | 0.656 | 0.841 |
| Cu 110 | 0.338 | 0.447 |
| SS 316 | 0.386 | 0.499 |

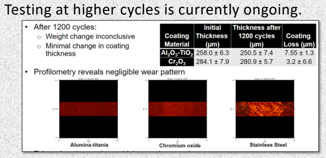
The results indicate that the surface roughness of Al 1100 and Al 1145 are the highest, and they also exhibited minimum dust adhesion. Further work is being done to investigate the effects of surface roughness and conductivity on lunar dust simulant adhesion behavior on these metals and others.

## Wear Resistant Ceramics

Compared to traditional polymeric and metal-based materials, many ceramic materials provide enhanced durability and superior wear properties and have applications such as lunar lander leg coatings. Commercial off the shelf (COTS) ceramic coatings were evaluated for dust adhesion. Some of the coatings showed promising dust mitigating properties.

| No. | Material | Surface characteristics | Images, 20x Dusted & final |
|---|---|---|---|
| 1) | PTI-25-1/Chrome oxide, plasma sprayed | As-received | |
| 2) | PTI-54-1/Alumina Titania, plasma sprayed | As-received | |
| 3) | PTI-101-1/Triboloy T-800/ HVOF coated | As-received | |
| 4) | PTI-262-2/CrC-NiCr/ HVOF coated | As-received | |

Preliminary Taber abrasion tests (ASTM D4060) were conducted on the samples and optical profilometry was used to evaluate wear pattern as shown below. The results indicate negligible wear pattern. Testing at higher cycles is currently ongoing.




| Coating Material | Initial Thickness (µm) | Thickness after 1200 cycles (µm) | Coating Loss (µm) |
|---|---|---|---|
| $Al_2O_3$-$TiO_2$ | 258.0 ± 6.3 | 250.5 ± 7.4 | 7.55 ± 1.3 |
| $Cr_2O_3$ | 284.1 ± 7.9 | 280.9 ± 5.7 | 3.2 ± 6.6 |

Some ceramic oxide materials that have superhydrophobic properties are currently being synthesized in-house.

Compact ceramic powder into disc using cold press → Densify powder compact via sintering → Characterize densified ceramic disc

## Miscellaneous Materials and Surfaces

Other samples evaluated include different glassy materials that have applications in optical equipment, such as windows and solar panels.

| No. | Material | Surface characteristics | Images, 20x Dusted & final |
|---|---|---|---|
| 1) | Glass | As-received | |
| 2) | Gorilla glass window uncoated | As-received | |
| 3) | CAF2 window TS uncoated | As-received | |
| 4) | BAF2 window TS uncoated | As-received | |

Biological surface structures that have low surface energy, such as the lotus leaf, often exhibit anti-contamination properties. A part of this research is investigating bio-inspired surface structures for lunar dust mitigation.

| Material | Images, 20x Dusted and final |
|---|---|
| Rose petal replica | |

Fig: Rose petal positive replica developed at LaRC for lunar dust simulant adhesion testing.

Fig: Anti-Contamination/self-cleaning properties assessment of untreated and treated Lotus coated radiator samples. Image credit: [6]


[6] Margiotta, D. et al (2010) SPIE Conference Series, vol. 7794


## Summary

The materials described here are a subset of the material types being considered for the Lunar Surface Patch Plate Experiment. Other material types include bulk metallic glass, seal materials, optically transparent coatings, textiles, etc. All these materials are being evaluated and the optimum performing candidates will be down selected for application in extended lunar surface missions.

**All images credit: NASA**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