Surface Passivation in LEO to Improve Lunar Dust Adhesion Mitigation

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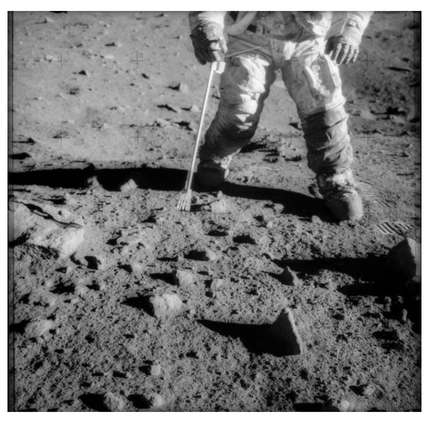
Artificial Intelligence (AI) Usage Disclosure
This document was created with assistance from Google Gemini for specified image generate. The content has been reviewed and edited by Chris Wohl. More information on the extent and nature of the AI usage is included in the Acknowledgements section of this presentation.

Introduction

Advanced materials will be critical for realizing NASA's Artemis goals, including establishing a sustained presence off Earth. Evaluating material performance can be challenging due to difficulty in replicating environmental conditions in laboratories. The tenacity of lunar dust to adhere to surfaces makes this a particularly challenging environmental factor.

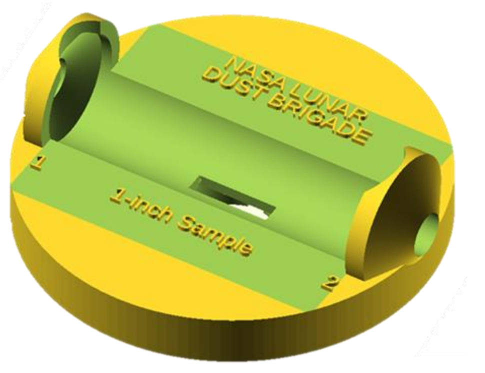


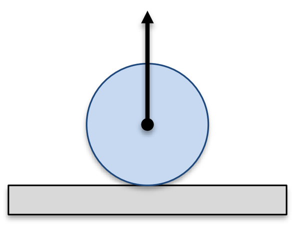
Astronaut Charles Conrad during extravehicular activity on lunar surface. NASA Image ID: AS12-48-7149

https://images.nasa.gov/details/AS12-48-7149

Centrifuge Adhesion Experiment

Centrifuge experiments enabled evaluation of passive lunar dust simulant adhesion performance. LHS-1D (Exolith Laboratories) was deposited on specimen surfaces via aerosolization. The samples were characterized at increasing rotational rates to determine the amount of simulant retention.



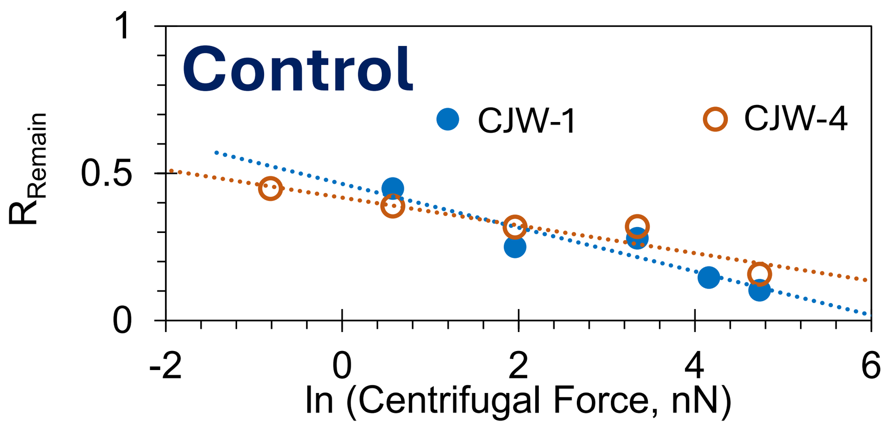


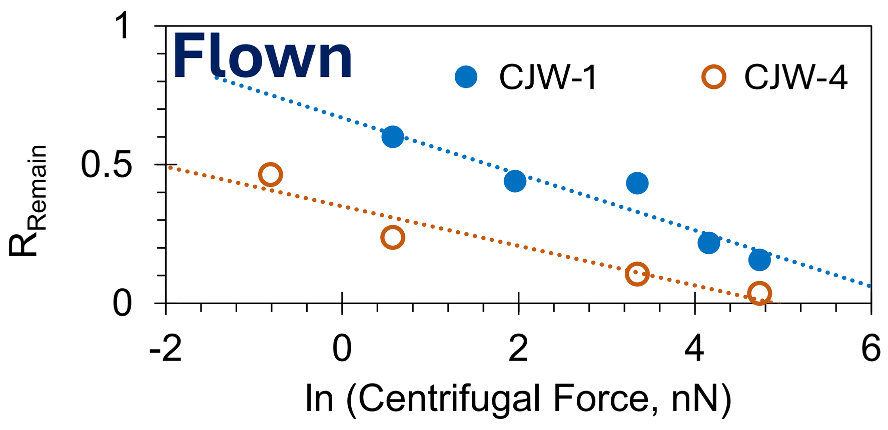
Pull-off Force (Tensile)

$$R_{Remain} = \frac{M_n}{M_o}$$

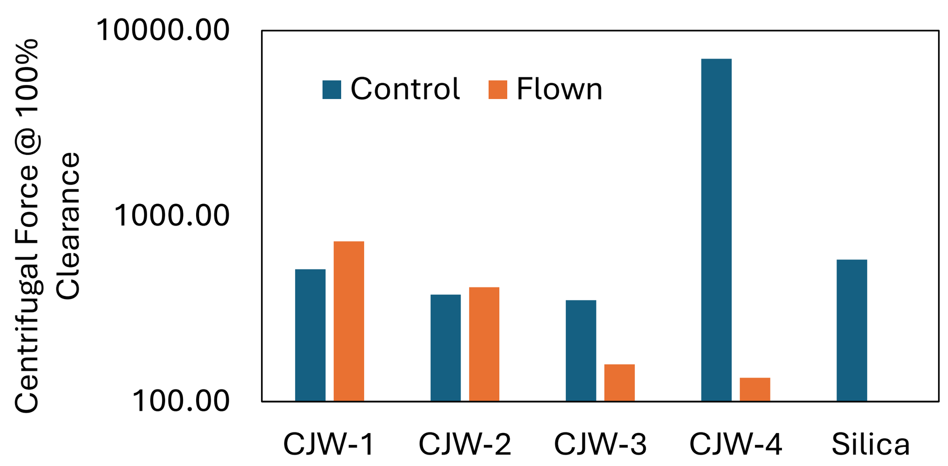
***R_{Remain}**: Remaining simulant mass ratio*
***M_n**: Simulant mass after n step*
***M_o**: Initial simulant mass*

Mass decreased as rotational rate increased. Fitting this data enabled determination of a required centrifugal force for 100% lunar simulant clearance. Experiments were performed on a silica disc for comparison.





Increasing slopes indicated greater lunar simulant removal rates. A lower X-axis intercept value indicated a lower 100% clearance force requirement, $C_{F,100\%}$.

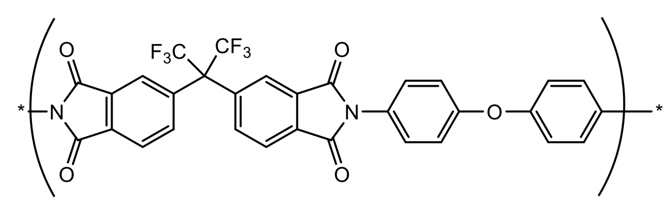


CJW-4 had the highest $C_{F,100\%}$ likely arising from surface softening. Both polysiloxane-containing materials exhibited a significant reduction in $C_{F,100\%}$.

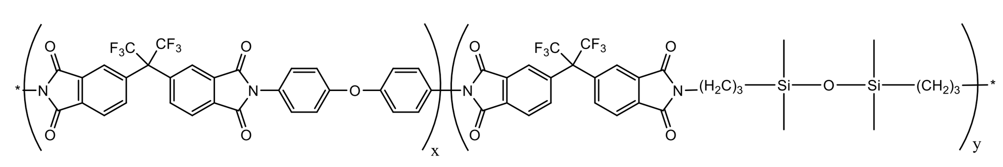
Copolyimide Siloxanes

Polyimide materials exhibit several properties advantageous for extreme environment applications: thermal stability, chemical resistance, strong mechanical properties, and good radiation properties. A series of copolyimide siloxanes were synthesized to evaluate the efficacy of low surface energy migration for passive lunar dust adhesion mitigation.

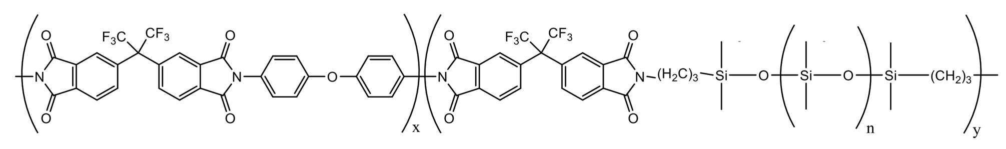
Sample CJW-1:



Sample CJW-2 (10 wt% Disiloxane):



Sample CJW-3 and CJW-4 (1 wt% and 10 wt% polysiloxane, respectively):



Chemical Reaction in Low Earth Orbit (LEO)

Siloxanes enables a new pathway resulting in generation of a passivation layer in the extreme LEO environment

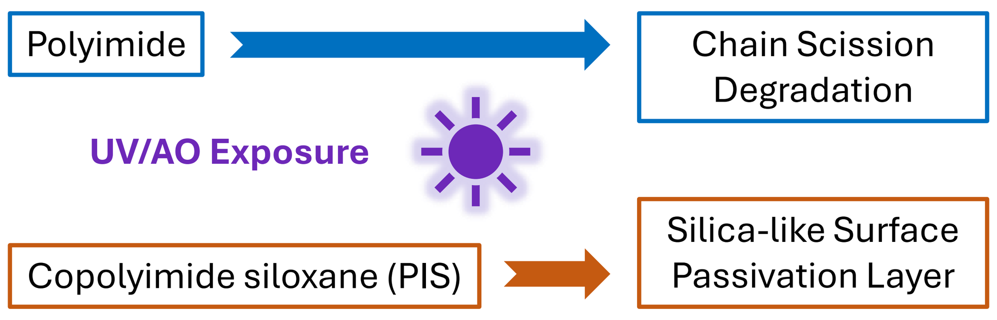
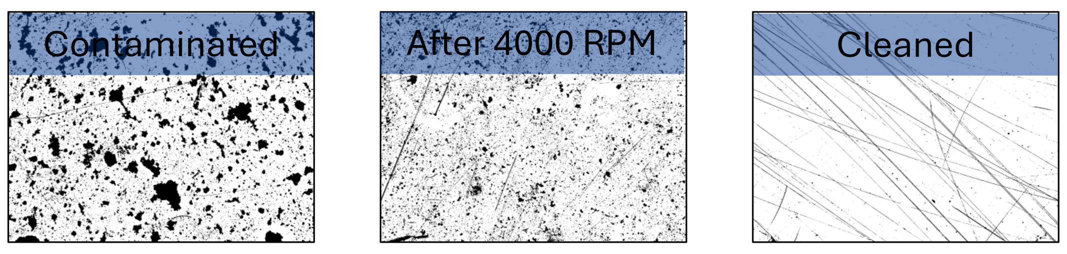
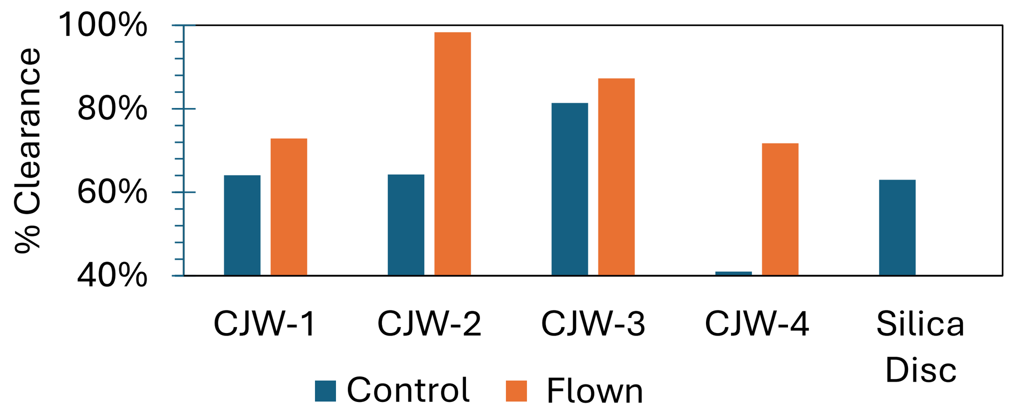


Image Analysis

Optical images of test samples were collected after deposition, at the completion of the adhesion experiment, and once cleaned to determine areal coverage of lunar dust simulant.

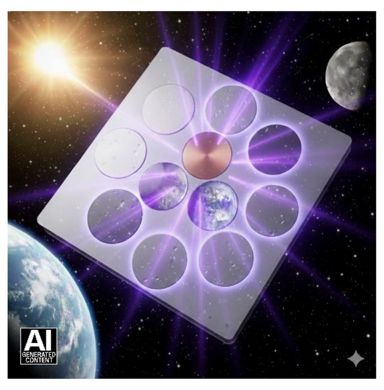


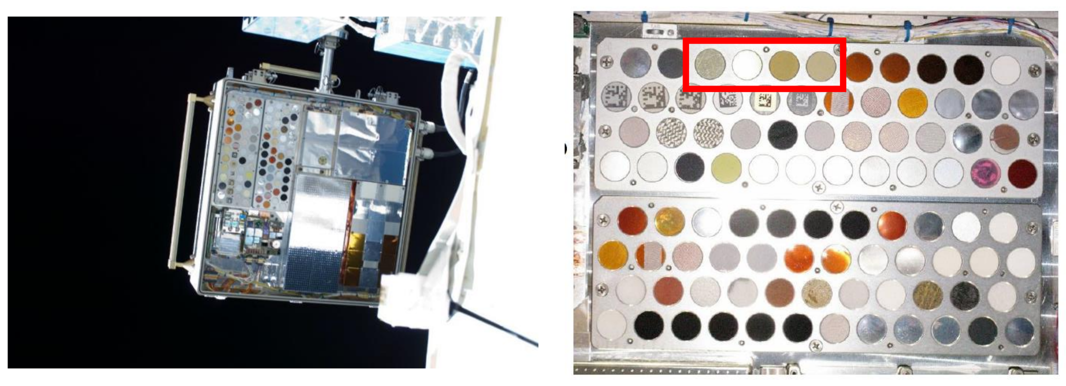
CJW-4 Control sample binary images



Materials International Space Station Experiment (MISSE)

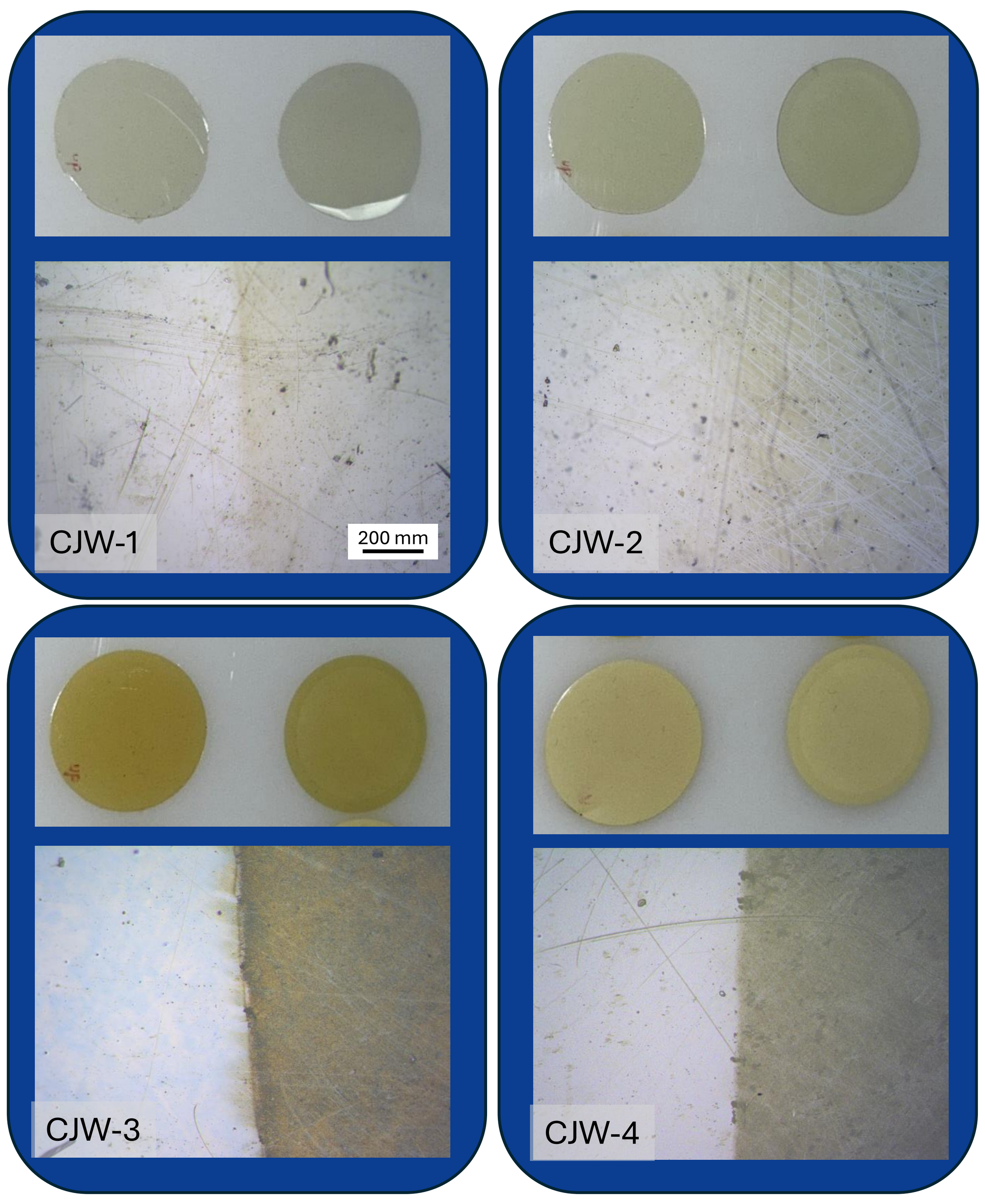
MISSE experiments enable evaluation of materials in Low Earth Orbit where extreme UV exposure and atomic oxygen are both present. Orientation on the International Space Station will influence relative exposure levels. Four samples were flown on MISSE-8, launching aboard space shuttle Endeavor on May 16, 2011 (STS-134) and returning aboard the SpaceX-3 Dragon capsule on July 9, 2013.





(Left) MISSE-8 samples mounted outside the International Space Station. (Right) MISSE-8 material samples with the materials described here in the red box.

Control specimens, retained on Earth, were characterized and compared to the results from the flown specimens to determine the influence that exposure in LEO had on materials properties.



Optical images of control (left) and flown (right) samples and microscopy images at the interface of exposed and protected flown sample surfaces.

Other Properties

Water contact angle and roughness values were measured to evaluate changes in surface chemistry and topography, respectively.

	Sample Exposure	Water Contact Angle Advancing/ Receding (°)	Roughness R_a / R_q (µm)
CJW-1	Control	87±2 / 76±1	0.417 / 0.825
	Flown	97±4 / 88±2	0.313 / 0.428
CJW-2	Control	93±4 / 80±1	0.093 / 0.156
	Flown	81±5 / 70±2	0.227 / 0.597
CJW-3	Control	101±3 / 90±2	0.052 / 0.068
	Flown	83±5 / 70±2	0.061 / 0.082
CJW-4	Control	104±3 / 91±2	0.076 / 0.099
	Flown	93±4 / 78±5	0.064 / 0.084

Conclusions

These results indicate that copolyimide siloxane properties may improve in LEO regarding passive lunar dust adhesion, likely due to the formation of a silica-like layer. Further characterization is underway to confirm this mechanism. Ideally, experiments conducted on the lunar surface would provide definitive insights.

[1] Heiken, G. H. et al. (1991) Lunar Source-book: A User's Guide to the Moon, Cambridge University Press, New York, NY. [2] Wohl, C. J. et al. (2024) Lunar Dust Considerations for Vertical Solar Arrays Volume 1: Lunar Environment and Dust Interactions, NASA TM-2024-3496. [3] Banks, B. A. et al. (2008) Lessons Learned from Atomic Oxygen Interactions with Spacecraft Materials in Low Earth Orbit, NASA TM-2008-215264. [4] Thibeault, S. A. et al. (2011) MISSE-X: An ISS External Platform for Space Environmental Studies in the Post-Shuttle Era, 2011 Aerospace Conference. [5] Wohl, C. J. et al. (2012) High Performance Polym., 24(1), 40-49. [6] Wiesner, V. L. et al. (2026) Dust Mitigation and Environmental Material Solutions (DMEMS): Application-Driven Materials Testing and Evaluation, 2026 LSIC Spring Meeting. [7] Wohl, C. J. et al. (2011) Evaluation of Particle Adhesion Properties of Materials Using a Sonication Device: Identifying Materials for Lunar Dust Adhesion Mitigation, NASA TM-2011-217048.