Investigating the Adhesion Force of Lunar Regolith Particulates on Air Plasma Sprayed Alumina Coatings

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Presentation Overview

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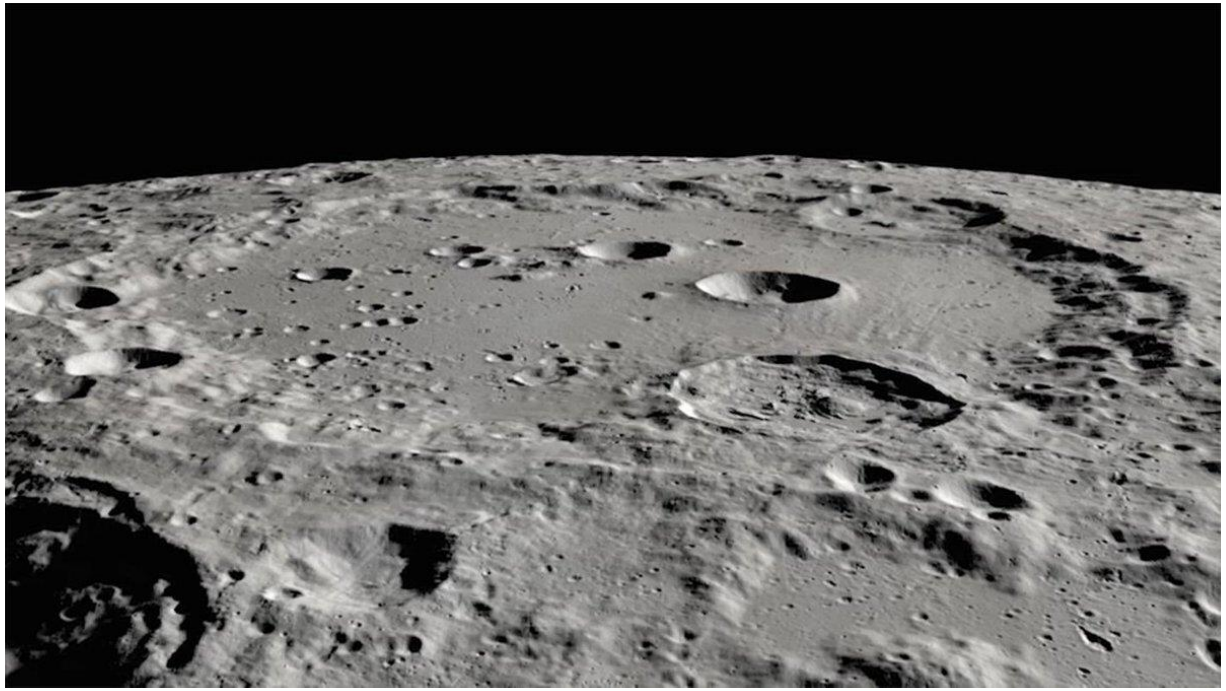
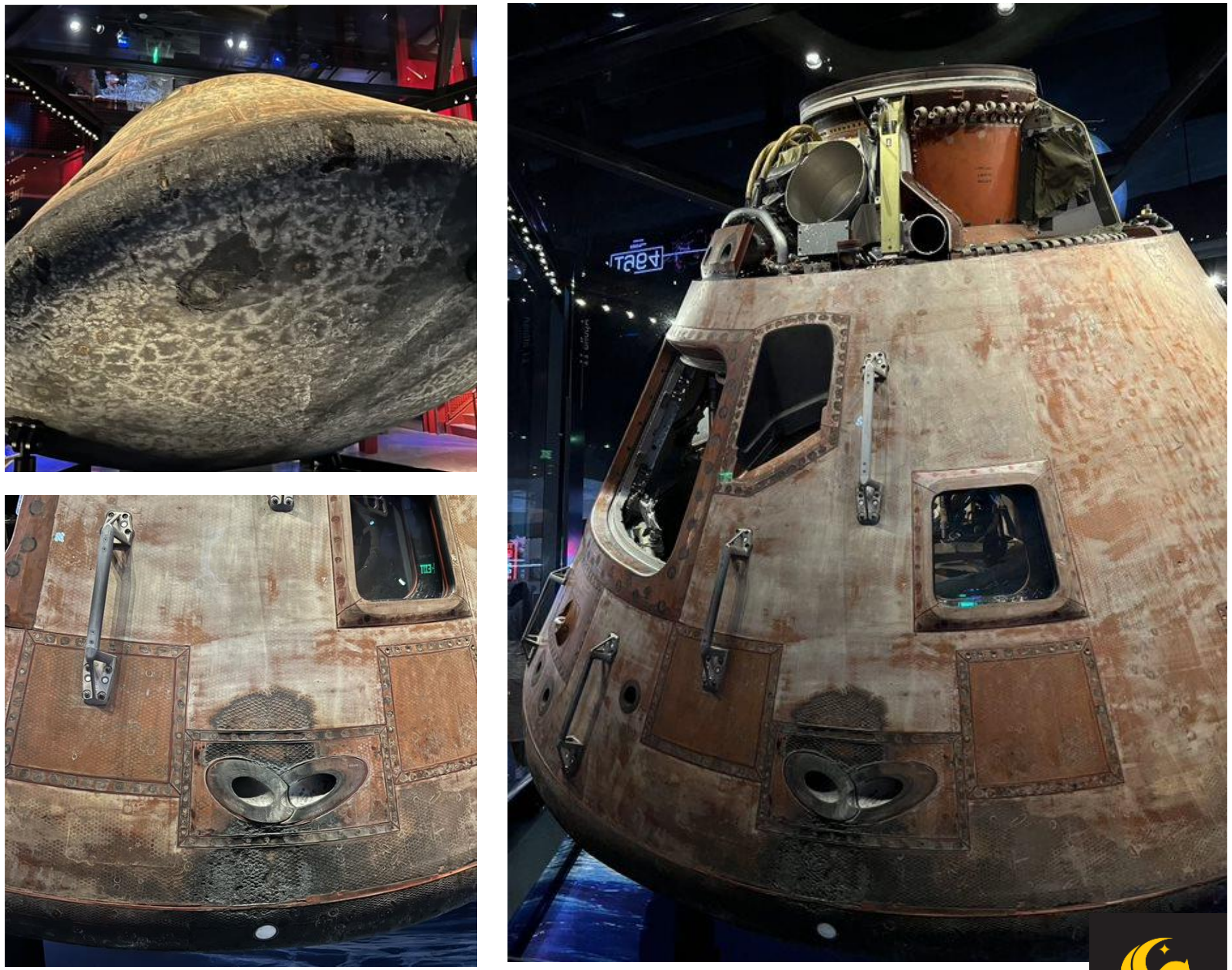


(Image credit: NASA.gov)

Effects of Lunar Regolith in Previous Lunar Missions

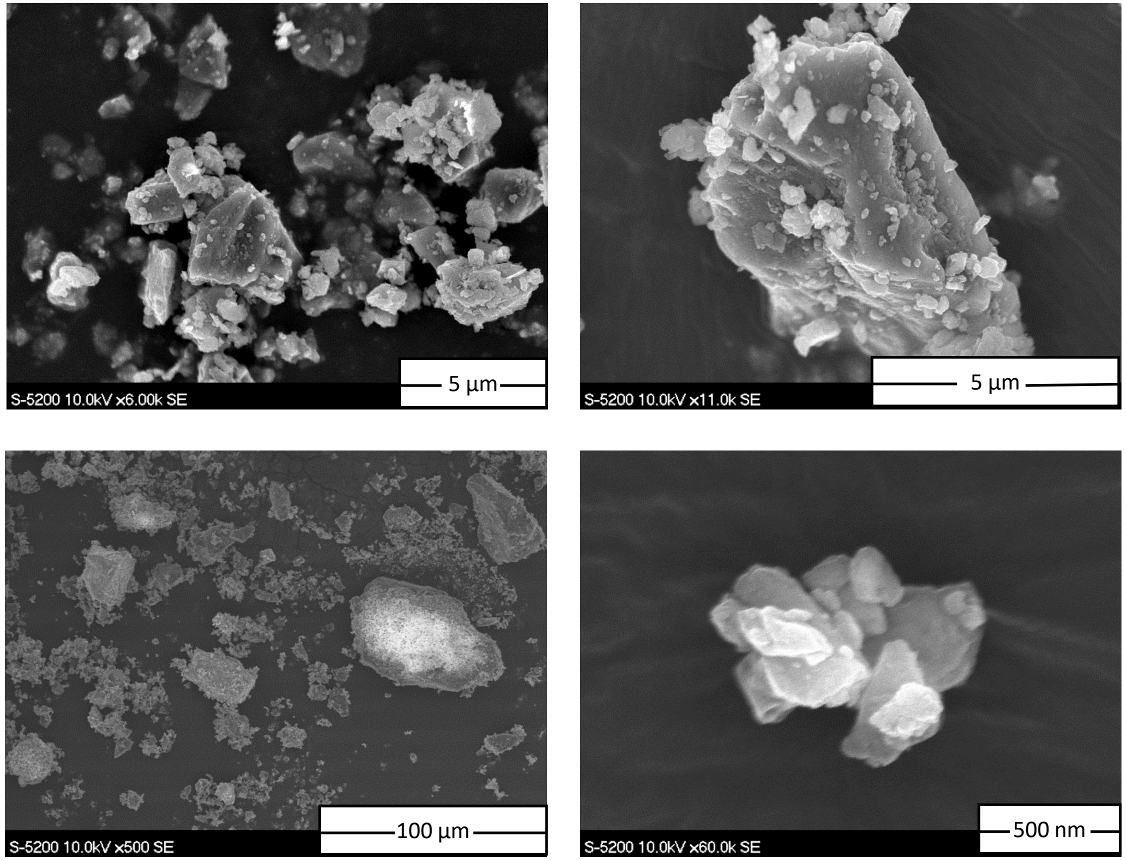
- The Apollo missions demonstrated that the lunar regolith could cause health concerns and affect the mechanical and electrical components of the systems used for lunar exploration.
- The lunar regolith affected the lunar module, clogged mechanisms, interfered with instruments, caused radiators to overheat, and abraded spacesuits.
- Results from Apollo 11 and Apollo 12 led to separation of lunar regolith types into four groups based on texture: porous and unshocked, shock-compressed but still porous, glass-welded, and thermally metamorphosed.



Apollo capsule from the Smithsonian (Image credit: Perla Latorre)

J. Gaier, (2005)

Adhesion of Lunar Regolith Dust

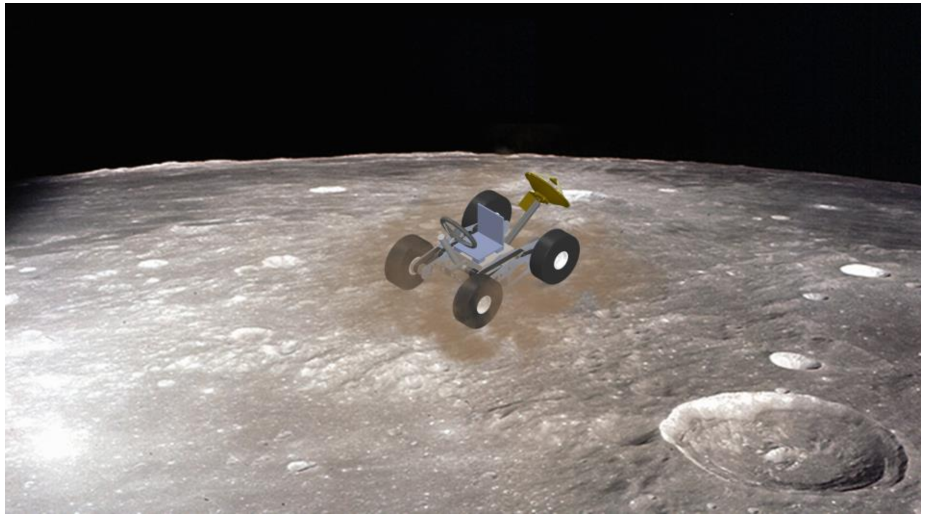


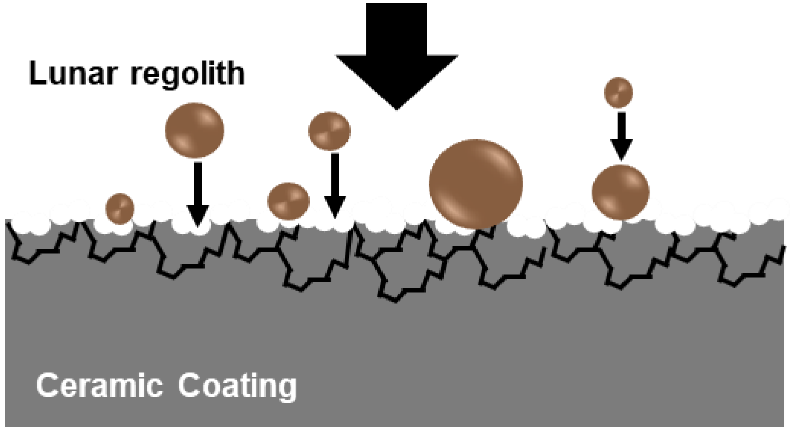
SEM images show the surface physical properties, particle size, and shapes of the lunar simulants from the Mare region. (Image credit: Perla Latorre)

- The dust is electrically charged, which enhances its adhesive properties [1].
- Mechanical adhesion was demonstrated to be due to the barbed shapes of the dust grains [1].
- The low electrical conductivity of the regolith allows individual dust grains to retain electrostatic charge.
- During the lunar day, dust is positively charged by photoelectric effects, while at night, it is negatively charged due to the interaction with solar wind electrons.
- Forces related to adhesion:
  - Gravitational
  - Van der Waals
  - Capillary
  - Chemical
  - Mechanical
  - Electrostatic

[1] Stubbs, T. J, & Farrell, W. M. (2005).

Motivation and Objective





Schematic of the lunar regolith particles at the ceramic coating. (Image credit: Perla Latorre)

Motivation

- Lunar dust mitigation in structural components is currently a limiting factor to return to the lunar surface.

There is a need for wear-resistant ceramic coatings that can significantly contribute to protecting mechanisms from damage caused by the lunar regolith.

Objective

- Analyze the surface energy, surface tension, and roughness of the surface of the ceramic coating to test the adhesion forces between the lunar regolith particles and the ceramic coating through centrifugal experiments.

Sample Manufacturing Overview

Air Plasma Sprayed Alumina Coating

- APS Al_2O_3 has demonstrated the potential to protect the surface to which they are applied due to its high strength and wear resistance.

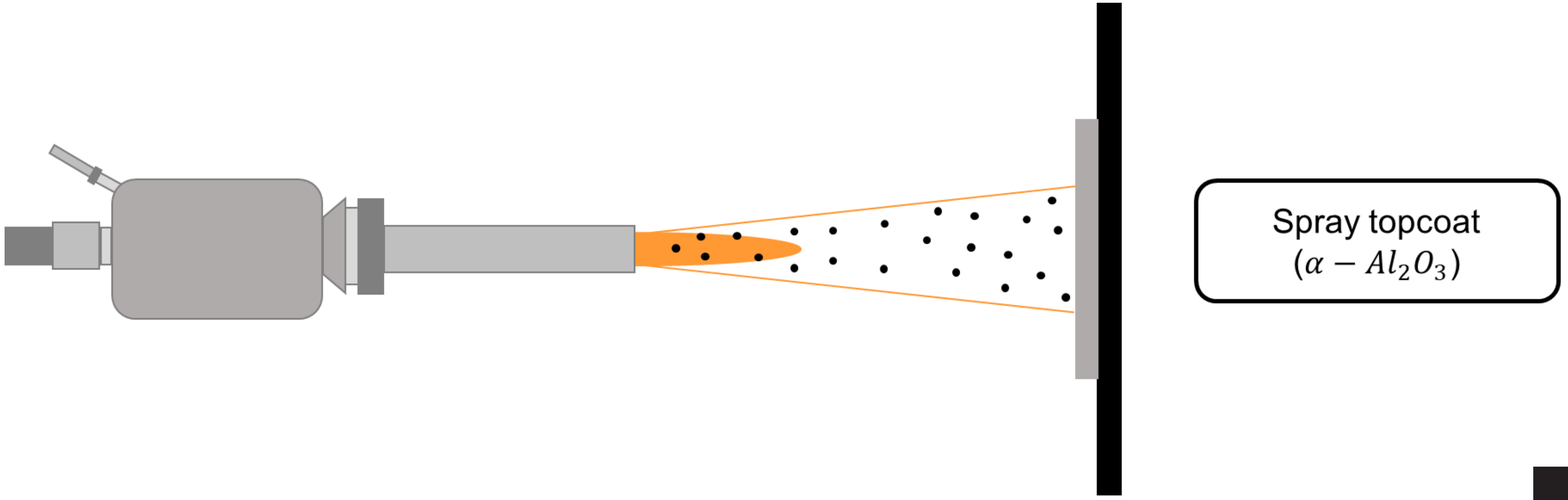
Spraying Parameters

- Parameters such as the spraying distance, substrate temperature, coating thickness and substrate roughness affected the hardness, porosity and roughness of the aluminum oxide coatings [1].
  - Increasing the coating thickness lowered the hardness and increased the porosity and roughness.

Parameter	**Value**
Spray distance (cm)	10
Current (A)	900
Voltage (V)	43.9
Argon (SLM)	54
Helium (SLM)	44

Coating Deposition Parameters

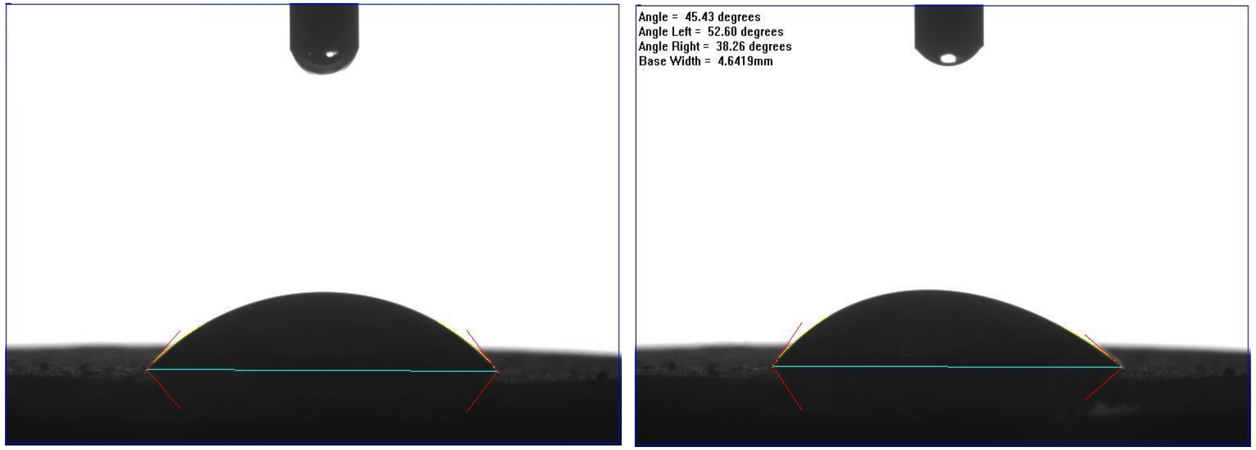
cm: centimeter
SLM: standard liter per minute



Schematic of coating deposition using air plasma spray. (Image credit: Perla Latorre)

[1] Sarikaya, O. (2005)

Contact Angle Goniometry



Layer thickness 128 µm

Contact angle goniometry of APS alumina (Image credit: Perla)

Layer Thickness (µm)	Advancing Contact Angle
122	71.36
128	52.6
150	59.44

Surface energy equation:

$$\gamma_s = \frac{0.5\gamma_L(1 + cos\theta)^2}{\gamma_L}$$

γ_S : Surface energy of the surface of the coating
γ_L : Surface energy of the liquid
θ : Advancing contact angle

Background

- Contact angle goniometry allows determination of surface wettability of a surface and calculation of the surface energy.

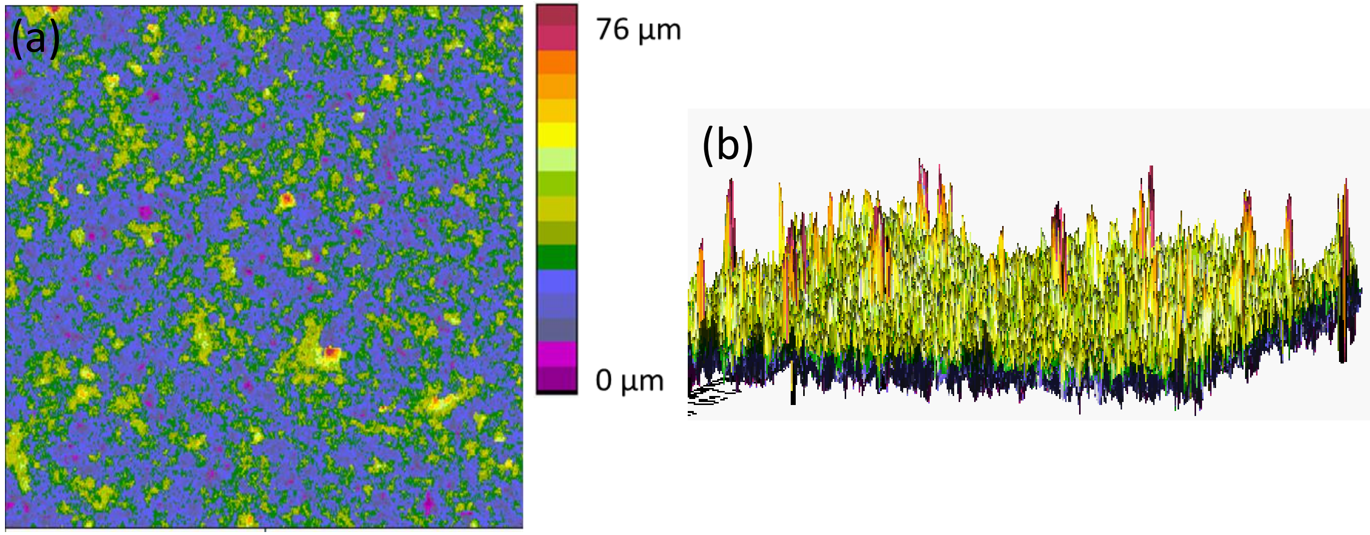
Surface Tension

- The APS Al_2O_3 samples were determined to be hydrophilic since the contact angles were smaller than 90º.

Surface Energy

- The surface energy of the Al_2O_3 coatings was calculated to be 32.6 mN/m.
  - Typical surface energy range: 20 – 2000 mN/m
- Factors such as roughness and porosity might have contributed to the surface energy of the APS alumina.

Profilometry



128 µm thickness APS alumina surface roughness results of the APS alumina using the profilometer (a) top view (b) side view (Image credit: Perla Latorre)

Layer Thickness (µm)	Surface Roughness (µm)
122	4.171
128	3.714
150	4.304

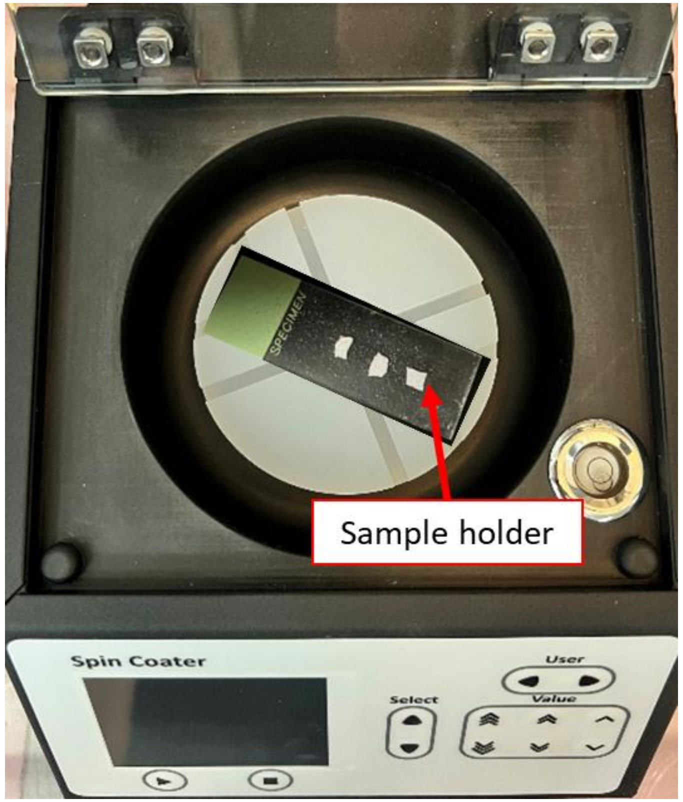
Background

- Profilometry is a technique to extract topographical and surface morphology data from a material's surface.

Roughness

- The peak height difference may increase the number of lunar particles entrapped at the surface of the coating.
- The high roughness values decrease the contact angle and affect the surface energy and surface tension of the coating.
- The high roughness values may also affect the wear and abrasive behavior of the coating.

Centrifugal Experiment

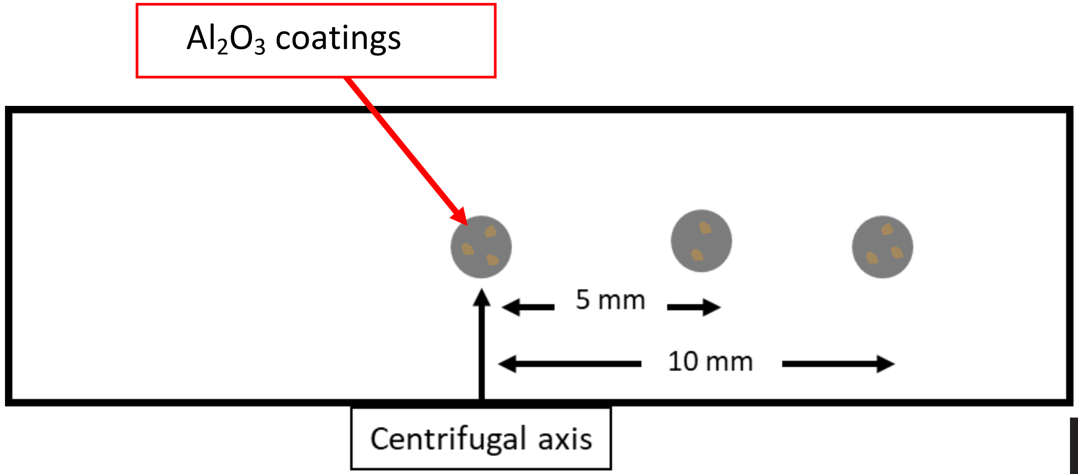


Centrifuge instrument and tested specimens (Image credit: Perla Latorre)

- The centrifugal experiment establishes the adhesion force between particles with different shapes on smooth or rough surfaces [1].
- A single measurement is sufficient to determine the adhesion force based on the distribution of the adhesion force with a large number of particles [1].
- The APS coating was tested at three different locations from the centrifugal axis, with a speed range of 500 – 3000 rotations per minute (rpm).

Speed (rpm)	Time (s)
0	20
500	20
1000	20
2000	20
2500	20
3000	20

Centrifuge parameters

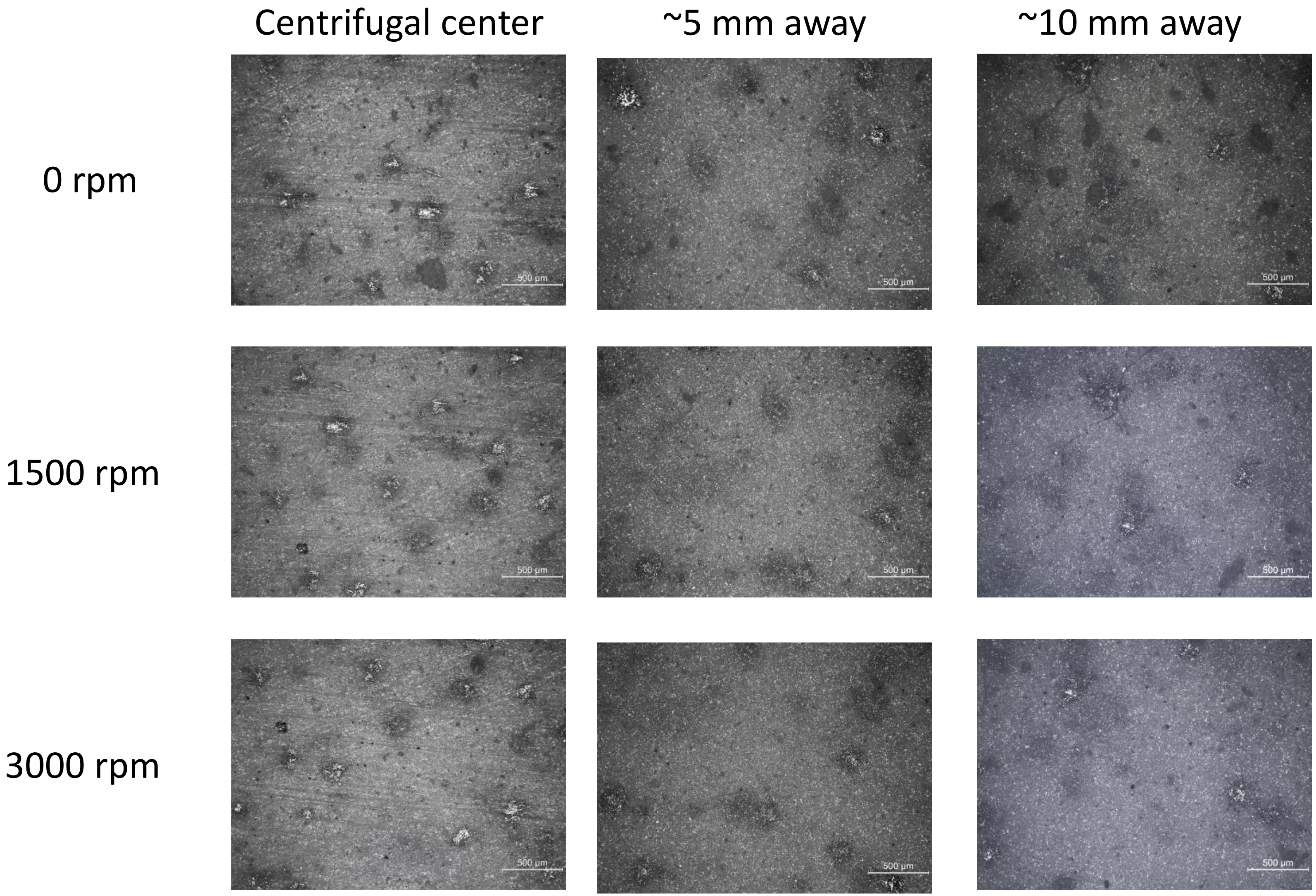


Glass slide with alumina coating and lunar dust particles

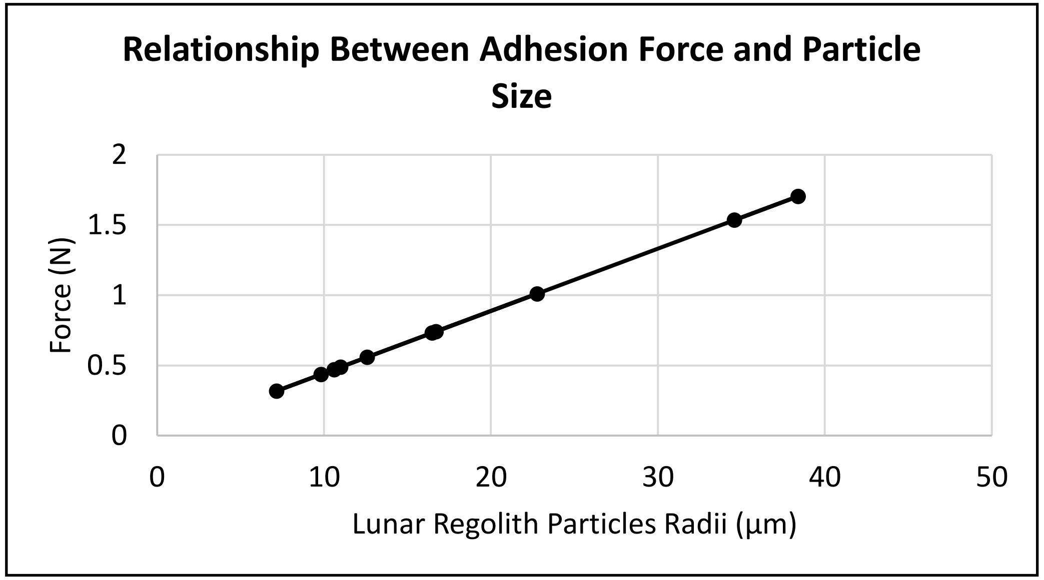
[1] Felicetti, M. A. & Aguiar, M. L. (2008).

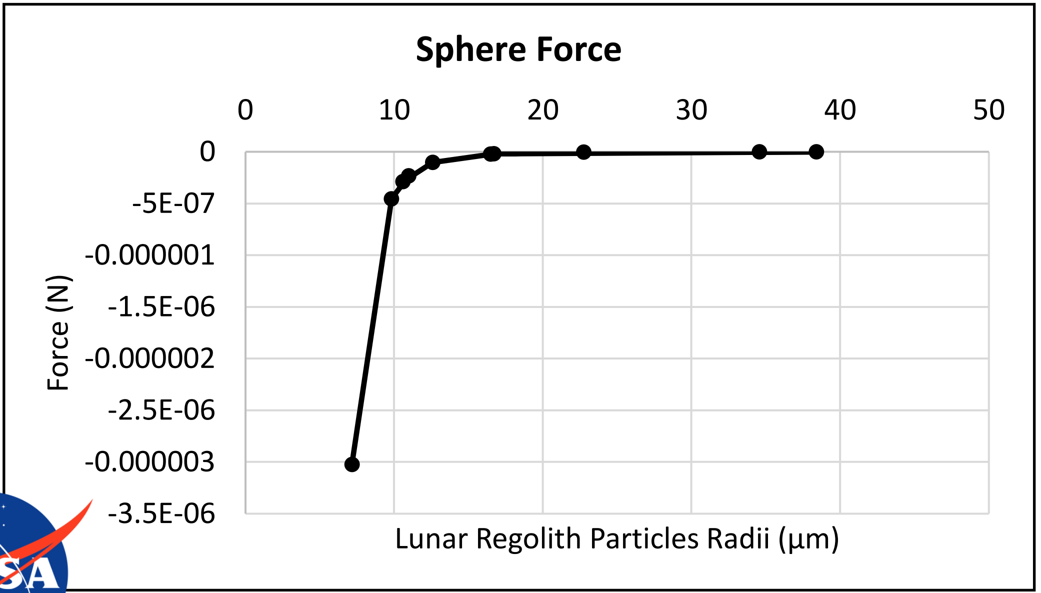
APS Alumina Coating and Lunar Regolith Monolayer

- To achieve a monolayer coating of the regolith particles, they were applied using aerosolization technique.
- The monolayer coating was applied to ensure that the lunar particles are were dispersed across the surface of the coating.



Adhesion and Sphere Forces Related to Regolith Particle Size





- Using centrifugal force equation:
  - $F_c = mR\omega^2$

  m: particle mass, R: centrifugation radius, ω: angular velocity

- The adhesion force between the lunar regolith particles and the coating surface increased with increasing particle size.

- Using the particle force equation:
  - $F_s = -4\pi R\gamma_{plane}$

  R: particle radius, γ_{plane}: surface energy.

- Accounting for the surface energy of the coating, the force of the lunar particles increased with increasing particle size.

Note: particle size is an average value neglecting its shape

Conclusion and Future Work

Conclusion

- The APS Al_2O_3 coating had a low contact angle and high surface energy, indicating it is hydrophilic and has high adhesion forces with lunar regolith particles.
- The adhesion force between the lunar regolith particles and the coating surface increased with increasing particle size.
- Accounting for the surface energy of the coating, the force of the lunar particles increased with increasing particle size.

Future Work

- Further analysis of coatings properties will be performed to identify factors that may decrease the adhesion forces between the regolith particles and the coatings.
- Additional studies are required to assess coating mechanical properties and surface characteristics in a more relevant simulated lunar environment.

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Thank you for your attention