Low Temperature Durable Siloxane/Epoxy Nanocomposite Coating for Drastic Reduction in Lunar Particulate Adhesion

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TDA Research Inc. | Wheat Ridge, CO 80033 | www.tda.com

About TDA Research, Inc.

- In Business since 1987
  - Privately held— 8 partners, 6 active in daily operations
  - ~109 employees, 30+ Ph.D.'s chemistry/engineering
  - About $17-20 million in annual revenue
- Facilities
  - Combined 75,000 ft^2 laboratory and office space near Denver, Colorado
  - Catalyst testing: Continuous PFR, CSTR, batch, large scale, high P&T systems
  - Sorbents: Sulfur removal from natural gas; post-combustion CO2 capture; heavy-metals removal
  - Materials processing and testing
  - Process development (e.g., gas sweetening)
- Business Model
  - Identify opportunities with industry
  - Perform R&D
  - Secure intellectual property
  - Commercialize technology via spin-offs licensing, joint ventures, internal business units

TDA’s business areas

Defense and Aerospace

- Protective Paints and Coatings
- Chemical and Biological Defense
- Aerospace Cleaners
- Corrosion Inhibitors
- Personal Protective Equipment

Chemical Technologies

- Conducting Polymers
- Specialty Carbons

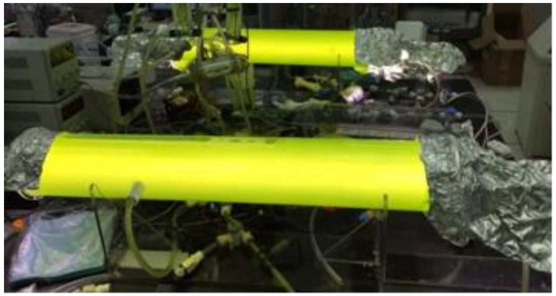
Energy Technologies

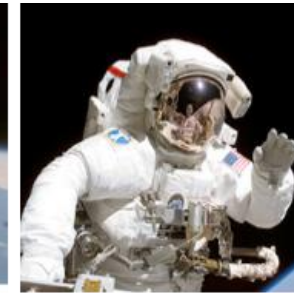
- Liquid Fuel & Syngas Cleanup
- Flue Gas Cleanup
- Carbon Capture

University of Colorado Boulder
Bioastronautics

Bioastronautics Focus Area

The study and support of life in space




Ann and HJ Smead Aerospace Engineering Sciences Department

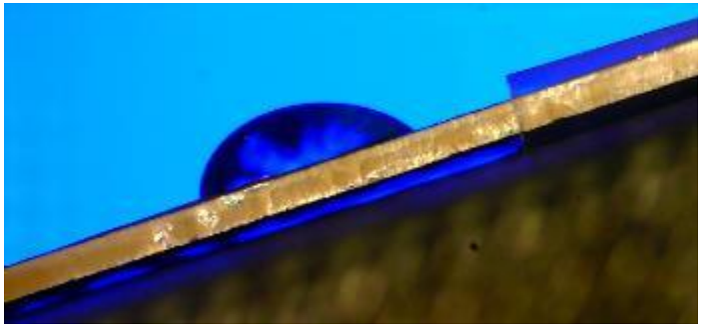
University of Colorado Boulder collaborators:
Professor James Nabity, Amrita Singh

Motivation and Background

- NASA Artemis program requires passive lunar dust mitigation technologies
- Goal: >90% dust mitigation efficacy
- Coating requirements:
  - Performance at cryogenic temperatures
  - Abrasion resistant
  - Good adhesion to metal, plastic, and fabric surfaces
  - Low surface energy
  - Match work function of lunar dust

Low surface energy coating research at TDA

- NAVAIR SBIR to develop hydrophobic/ oleophobic coating for V-22 Osprey heat exchangers (Contract # N68335-20-C-0089)
- Acrylic coating with siloxane additives
- Electrodeposition is used to coat complicated fin structure of HX
- Coating results in 50% reduction in initial soiling, with 72% cleaning efficiency
- Durable to abrasion, thermal shock, water immersion



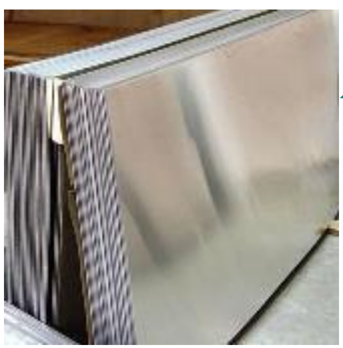
Initial Soiled Cleaned

Coating formulation

Polysiloxane additives: Reduce coating surface energy

Nanoparticle (NP) additives: Abrasion resistance

Commercial cryogenic epoxy resin: Performance over wide temperature range (-269°C → 125°C)



Aerospace aluminum (AA2024)

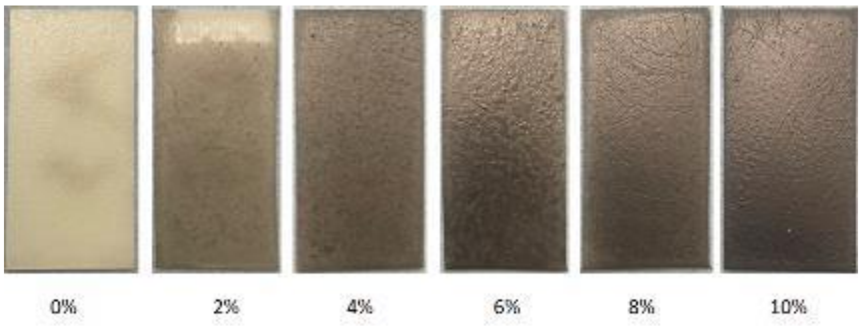
Nylon

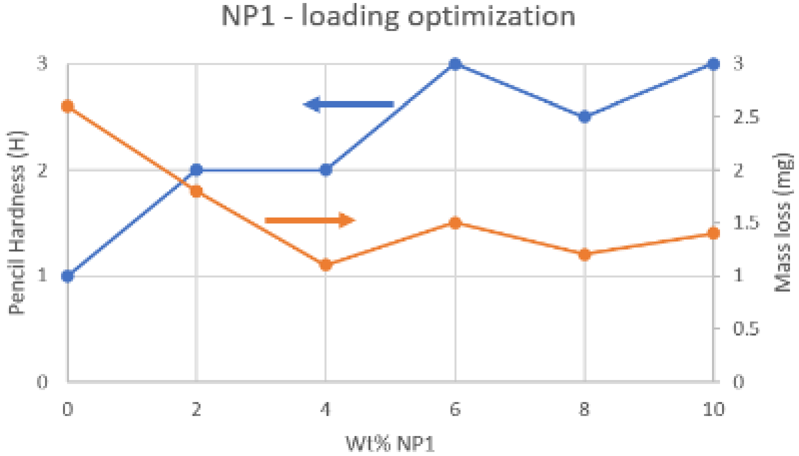
Kapton

Teflon

Coating chemistry optimization

- Several optimization experiments to determine exact coating formulation
- Iterative process with coating property measurements and dust mitigation performance





NP type	H_2O contact angle	Coating mass loss	Solar absorption change	Dust removal efficacy
NP1	61°	4.3%	+5%	87%
NP2	86°	2.9%	+2%	78%
NP3	75°	4.1%	-36%	92%
NP4	71°	1.6%	-8%	87%
NP3-NP4	73°	1.6%	-9%	90%

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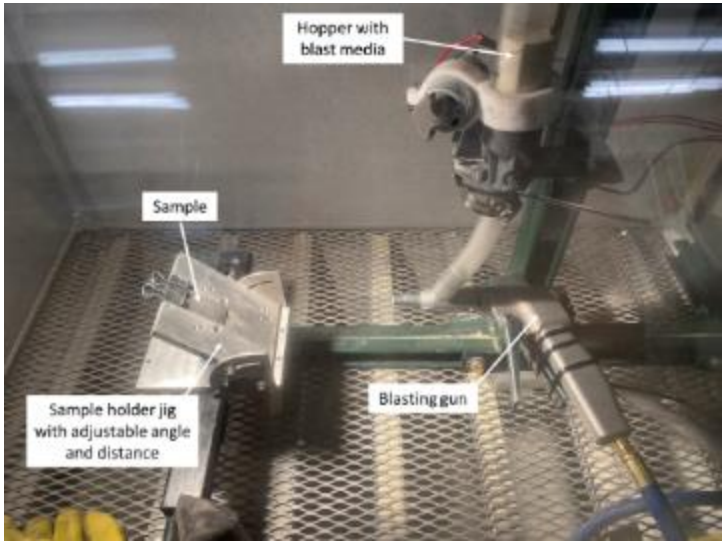
Coating physical properties

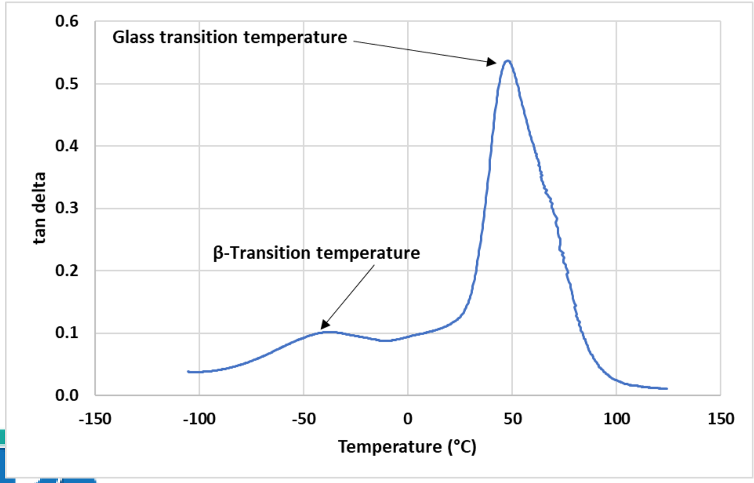
Substrate	Adhesion	Solar abs. change	Emissivity	H_2O contact angle
Nylon	5A	-9%	0.908	68°
AA2024	5A	-6%	0.874	68°
Teflon	5A	-16%	0.913	73°
Kapton	5A	-1%	0.908	67°

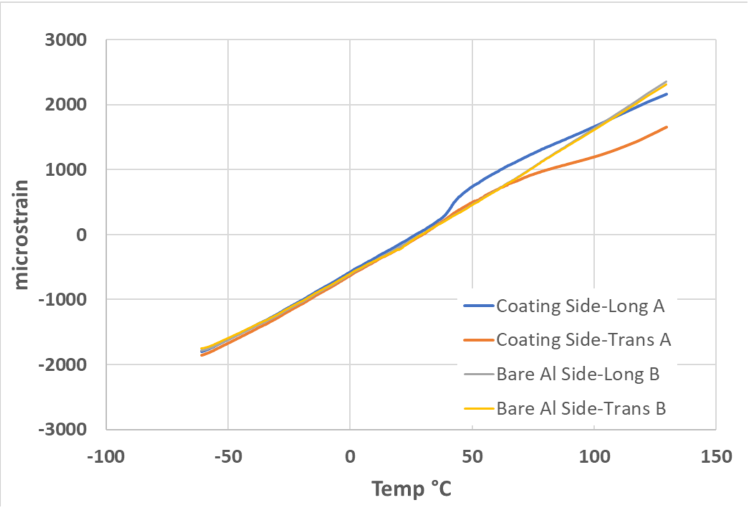
- Retested coating performance after sand blasting and/or cryo shock and saw minimal effects on:
  - Coating adhesion
  - Optical absorption
  - Dust removal efficacy



Thermal testing

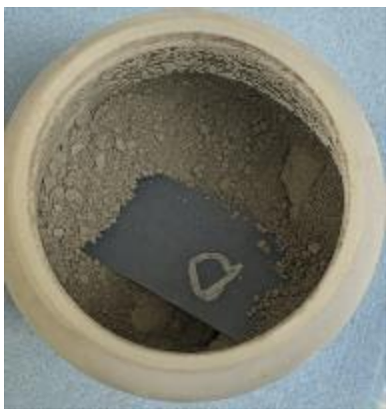
- Dynamic mechanical analysis (DMA) from -105°C -> 125°C indicates that our coating remains flexible over this temperature range
  - Higher glass transition temperature would be better
- No coefficient of thermal expansion (CTE) mismatch below 40°C with aluminum substrate

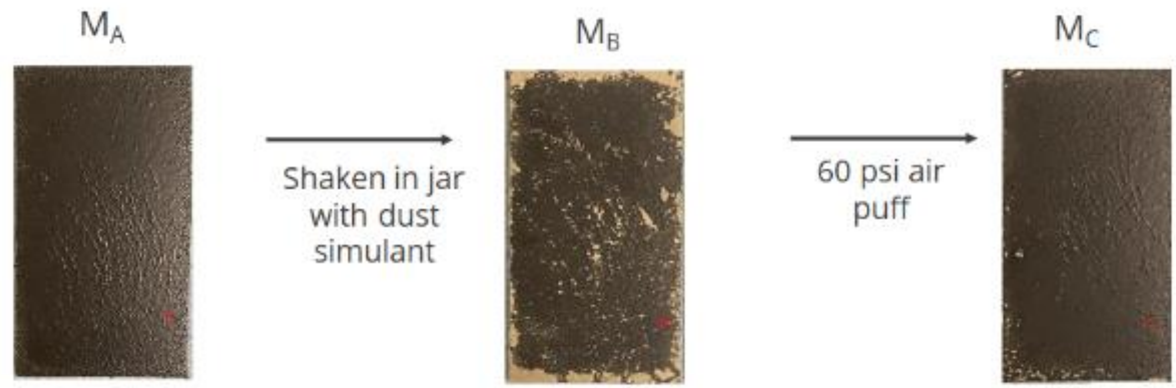




Dust adhesion testing in air

- Used Exolith LMS-1D Lunar Mare Dust simulant, baked out under vacuum
- Two metrics to evaluate: (1) passive dust mitigation, and (2) ease of dust removal





$$\mathit{Dust\ adhesion\ reduction\ efficacy} = 1 - \left(\frac{M_B - M_A}{M_A} \Big/ \frac{M_{B,bare} - M_{A,bare}}{M_{A,bare}} \right)$$

$$\mathit{Dust\ removal\ efficacy} = 1 - \left(\frac{M_C - M_A}{M_A} \Big/ \frac{M_{C,bare} - M_{A,bare}}{M_{A,bare}} \right)$$

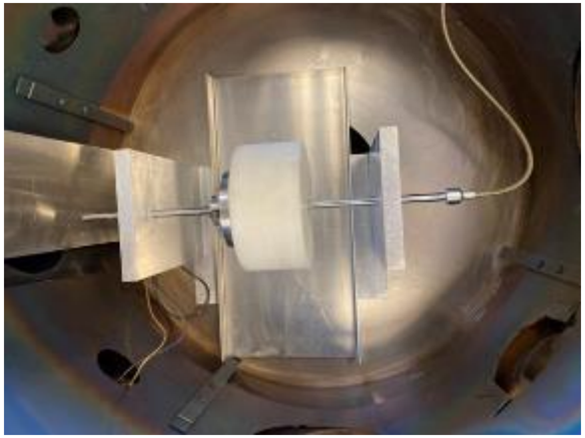
Dust adhesion in air

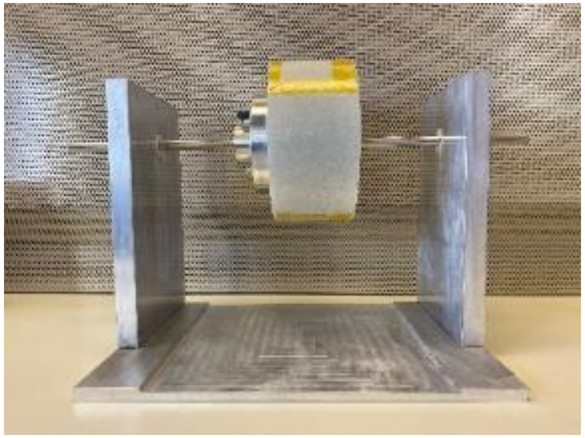
- Versus a bare substrate, our coating was effective at both:
  - Reducing initial dust adhesion by 75-94%
  - Improving dust removal efficacy by >93%
- Uncoated nylon and Teflon had lower initial dust adhesion
  - Experimented with adding static charge to substrates before testing, but were unable to do so in a reproducible fashion

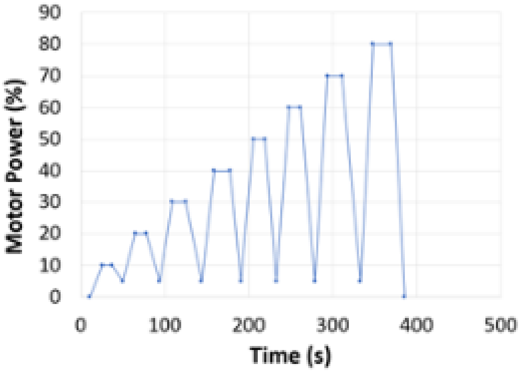
Substrate	Dust adhesion reduction	Dust removal efficacy
Nylon	75%	93%
AA2024	94%	98%
Teflon	78%	95%
Kapton	93%	95%

Dust adhesion testing in vacuum

- CU Boulder collaborators constructed rotating drum apparatus (4” OD, 2” high)
- Sample is wrapped around outside of drum
- Dust sieved onto sample
- Placed into vacuum chamber at <1e-5 torr
- Video is recorded as drum is spun at 0-1280 rpm



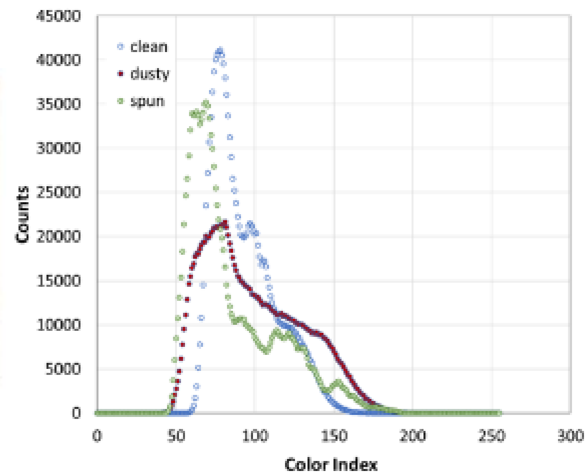




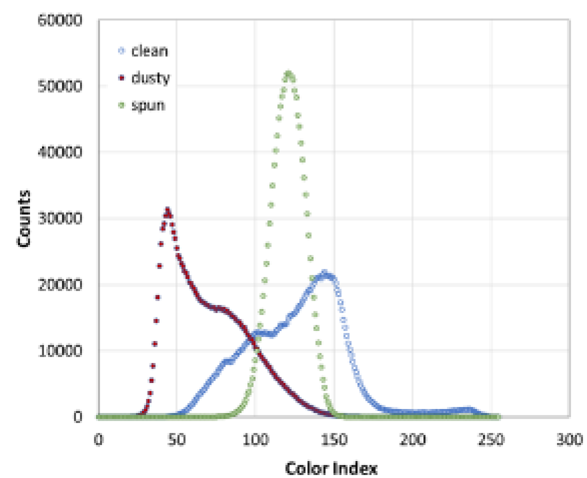
Dust adhesion in vacuum

- Image analysis complicated by:
  - Dark NPs in coating
  - Reflections from uncoated aluminum
  - Poor contrast of JSC-1A

Bare aluminum



Coated aluminum



Conclusions & Future Work

- Our coating reduces lunar dust adhesion by over 90% vs. an uncoated substrate
- Robust to environmental exposures
- Does not significantly alter absorptivity or emissivity of most substrates
- Primary application target: aluminum radiators
- Future work:
  - Improvements in characterization methods for dust mitigation in vacuum
  - Demonstration of coating function at cryogenic temperatures
  - NASA Phase II?

Questions?