PERFORMANCE ASSESSMENT OF SOLID POLYMER LUBRICANTS AND HARD COATINGS FOR DUST-CONTAMINATED BEARING APPLICATIONS. J. Sorrell[1,3], and A. A. Polycarpou[2,3], [1]jes4214@utulsa.edu, [2]andreas-polycarpou@utulsa.edu, [3]Department of Mechanical Engineering, The University of Tulsa, Tulsa, OK 74104, USA.

Environmental factors during lunar activities pose a great technical challenge that must be overcome prior to successful extended operations in a lunar environment. Of these factors lunar regolith disturbance via anthropogenic activities is the greatest challenge to the reliability of tribological components[1]. Prior art has shown lunar regolith particles within tribological contacts lead to premature failure[2–4]. Furthermore, sealing elements are subject to premature failure and degradation in a lunar environment as well. Lunar regolith ingress is expected under the harsh environmental conditions regardless of sealing elements. Assessing the ability of tribological contacts to withstand the intrusion of these particles is crucial for extending the service life of these components. Polymeric coatings and hard coatings are both potential choices for dust tolerant bearing surfaces. ATSP polymer composites have proven performance benefits when exposed to lunar regolith simulants in both cryogenic and high temperatures. Additionally, hard coatings such as diamond-like carbon (DLC) and titanium molybdenum disulfide (Ti-MoS_2) have shown tolerance to dust in extreme environmental conditions[5–7].

There is a lack of prior work comparing hard coatings against polymeric soft coatings in the presence of harsh abrasives. This work is an assessment of DLC, Ti-MoS_2, and PS400 hard coatings tested against themselves and an aromatic thermosetting copolyester (ATSP) vitrimer in the presence of fine lunar regolith simulant at room temperature (*Figure 1*). The goal of this testing was to provide data for downselection of hard-hard and hard-soft tribopairs, focusing on their ability to eject or thrash lunar regolith dust and resist abrasion.

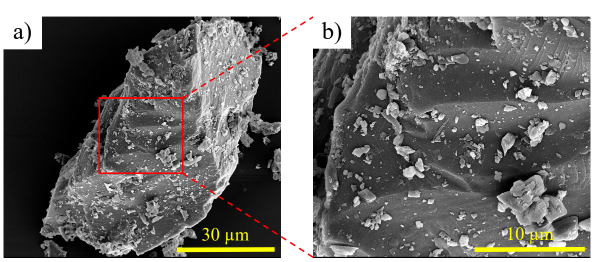

Figure 1. LHS – 1D Lunar dust simulant, extra fine lunar highlands simulant with mean particle size of 7 µm and max size of 35µm at a) 1,500X and b) 5,000X.

DLC and Ti-MoS_2 averaged low friction (COF ~0.18) in self-tests, thick DLC (0702) had intermediate COF of ~0.23 in self-tests, while DLC vs ATSP averaged a higher but stable COF (~0.26-0.30) (*Figure 2*). Soft counterfaces yielded more consistent performance (SD <0.125) and avoided unstable high-energy run-in (~3 min/~45 m). ATSP paired with PS400 resulted in improved abrasion performance, ~60% reduced pin wear compared to PS400 self-test (*Figure 3*), and a stabilized COF in the presence of dust (*Figure 2*).

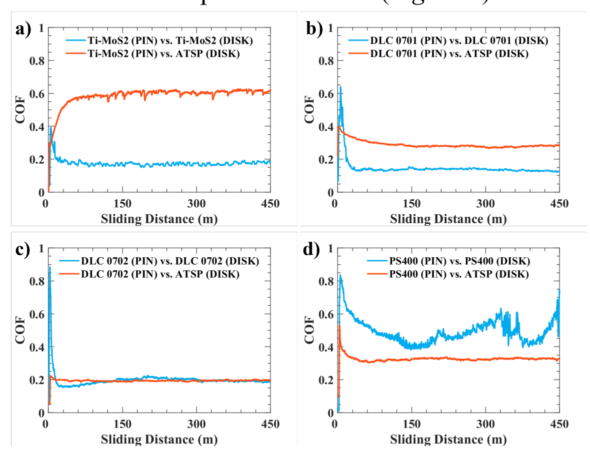

Figure 2. In-situ COF results of a) Ti-MoS_2, b) DLC 0701, c) DLC 0702, and d) PS400 hard coatings tested against themselves and against ATSP coated 440C steel disks.

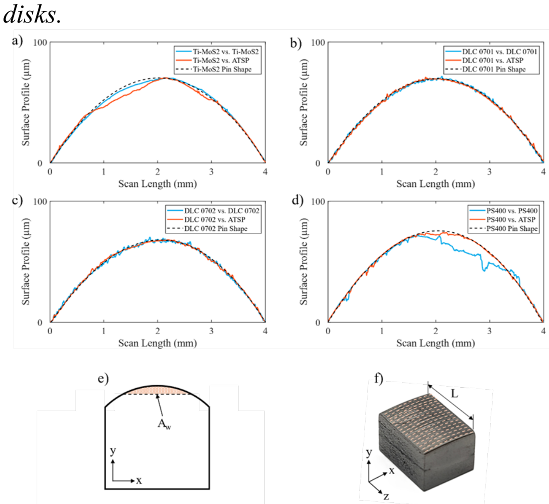

Figure 3. Curved pin profilometric scan data referenced to initial pin shape for a) Ti-MoS_2, b) DLC0701, c) DLC0702, and d) PS400 tribopairs. Graphics of e) cross-sectional wear area (A_w) and f) section path and pin length (L) are shown.

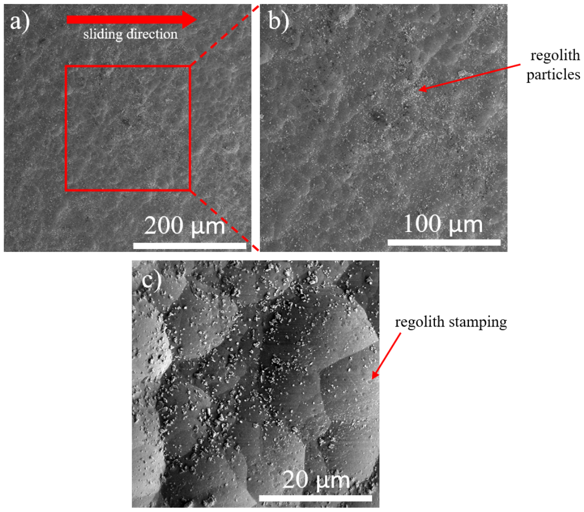

Figure 4. SEM images of DLC 0702 disk after self-tested at a) 250X, b) 500X, and c) 2500X.

Surface analysis of the samples after testing confirmed that hard-hard tribopairs pulverized the dust particles resulting in an initial high energy run-in followed by a stable regime for the remainder of testing. *Figure 4* shows the SEM images of fractured and pulverized dust particles after the DLC 0702 self-test. In contrast, the hard-soft tribopairs maintained a higher friction equilibrium due to the soft coatings capturing the dust particles and forming an abrasive pad (*Figure 5*). The formation of the abrasive pad did increase friction for most tribopairs; however, it did not necessarily increase wear. The DLC hard coatings were able to withstand the abrasive pad effect of the embedded regolith due to their high hardness and abrasion resistance.

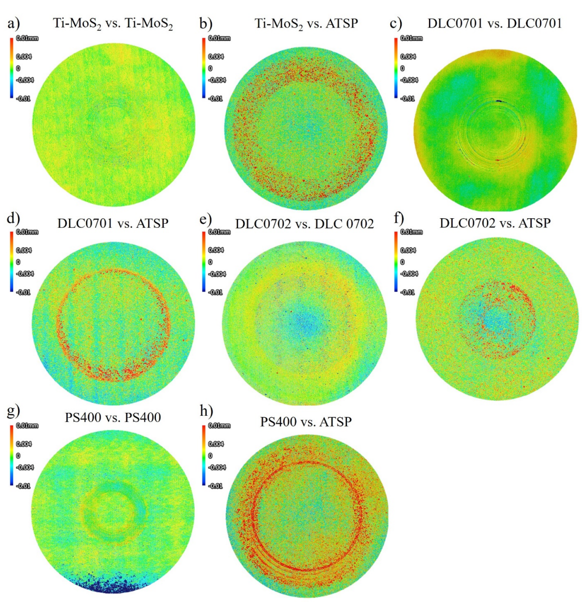

Figure 5. 3D optical profilometric data of tested 25.4 mm radius disks for all tribopairs (a-h).

These results demonstrate the feasibility of combining hard coatings with polymer coatings for extreme space applications. Additionally, they highlight the importance of understanding tribopair contact dynamics within third body abrasive environments. Future work could benefit from further material testing and analysis in cryogenic and high temperature environments as well as incorporate rolling-sliding interactions such as in roller element bearings.

References

[1] J.E. Colwell, S. Batiste, M. Horányi, S. Robertson, S. Sture, Lunar surface: Dust dynamics and regolith mechanics, Reviews of Geophysics 45 (2007). https://doi.org/10.1029/2005rg000184.

[2] R. Kobrick, K. Budinski, K. Street, D. Klaus, Three-Body Abrasion Testing using Lunar Dust Simulants to Evaluate Surface System Materials, in: American Institute of Aeronautics and Astronautics, 2010. https://doi.org/10.2514/6.2010-6077.

[3] K. Bashandeh, V. Tsigkis, P. Lan, A.A. Polycarpou, Polymer composite coatings subjected to sliding wear under simulated lunar temperature and dust conditions, Wear 546–547 (2024) 205360. https://doi.org/10.1016/j.wear.2024.205360.

[4] N. Afshar-Mohajer, C.-Y. Wu, J.S. Curtis, J.R. Gaier, Review of dust transport and mitigation technologies in lunar and Martian atmospheres, Advances in Space Research 56 (2015) 1222–1241. https://doi.org/10.1016/j.asr.2015.06.007.

[5] V. Tsigkis, P. Lan, A.A. Polycarpou, Dynamic tribo-pair of PS400 and DLC for planet Venus application, Tribology International 164 (2021) 107237. https://doi.org/10.1016/j.triboint.2021.107237.

[6] V. Tsigkis, A.A. Polycarpou, Chemical and mechanical analysis of hard coatings exposed under the supercritical CO2 Venus atmospheric surface conditions, Adv. Space Res 73 (2024) 4378–4390. https://doi.org/10.1016/j.asr.2024.01.023.

[7] R.L. Fusaro, M. Siebert, Comparison of several different sputtered molybdenum disulfide coatings for use in space applications, in: Proceedings of the 36th Aerospace Mechanisms Symposium, 2002.