Proceedings of the 3rd International Conference of Theoretical and Applied Nanoscience and Nanotechnology (TANN'19)
Ottawa, Canada – June, 2019
Paper No. TANN 141
DOI: 10.11159/tann19.141

Nanocrystalline MoS_2 Wear Mechanics by Friction Force Microscopy

Peter Serles[1], Guillaume Colas[2], Jason Tam[3], Jane Howe[3], Aurélien Saulot[4], Tobin Filleter[1]
[1]Department of Mechanical & Industrial Engineering, The University of Toronto
5 King's College Road, Toronto, ON, Canada
PSerles@mie.utoronto.ca, Filleter@mie.utoronto.ca
[2]FEMTO-ST institute - Department of Applied Mechanics, Université Bourgogne Franche-Comté
CNRS, 24 Chemin de l'Epitaphe, 25000 Besançon, France
[3]Department of Materials Science and Engineering, The University of Toronto
184 College St, Toronto, ON, Canada
[4]Université de Lyon, LaMCoS, INSA-Lyon, CNRS UMR 5259, France

Extended Abstract

Molybdenum-disulphide has been used as a lubricant for the space industry for more than 50 years[1], [2]. Yet, despite this history, the tribological (friction and wear) behaviour of this lubricant remains poorly understood and hard to predict for long space journeys where maintenance is not an option. The complexity of the lubricating, wear, and breakdown mechanics has led to ongoing challenges in planning lifetimes of these coatings and has resulted unexpected failure of satellites, rockets, and telescopes costing billions of dollars over the past several decades[3]–[5]. As humanity looks to increasingly longer space travel missions such as the Lunar Gateway and Mars Exploration Programs, fundamental understanding of MoS_2 lubricant mechanics are critical to creating predictable mission performance.

A lack of in-situ detection for wear mechanics has been a limiting factor in understanding the evolution and breakdown of lubricants across a wide range of applications. While most wear tests simply inspect the condition of the virgin and post-mortem lubricant[6]–[8], friction force microscopy (FFM) offers the ability to generate both lateral and topographic atomic force microscopy (AFM) signals aiding in understanding both the wear and friction parameters in unison and in-situ. This technique, along with custom application-specific AFM cantilevers, has been used to identify the wear mechanics of two space-qualified nanocrystalline MoS_2 coatings which present drastically contrasting tribological behaviour based on their underlying structures.

The first coating consists of a purely nanocrystalline structure while the second consists of nanocrystals embedded in an amorphous matrix. The amorphous matrix coating has been shown to demonstrate lower average friction and wear behaviour as compared with the purely nanocrystalline coating contrary to conventional wisdom. This is attributed to the constructive effects of the composite amorphous and crystalline phases while the nanocrystalline structure is shown to actually inhibit the intrinsic lubricating ability of MoS_2 van der Waals lamellae. Additionally, the mechanics of tribofilm development and run-in are dependent on the structure helping to identify specific parameters contributing to long-term wear and lubricating performance.

While the composite amorphous-nanocrystalline lubricant demonstrates better average friction and wear resistance, internal stresses are shown to build to the point of catastrophic fracture resulting in erratic and unpredictable wear behaviour. While acceptable for low-precision applications, the lower performing but stable behaviour of the nanocrystalline coating would be better suited for most high-precision applications. This structural tribological understanding allows the structure of the lubricant to be tailored directly to the end-use space mechanism.

References

[1] V. R. Johnson and G. W. Vaughn, "Investigation of the mechanism of MoS2 lubrication in vacuum," *J. Appl. Phys.*, vol. 27, no. 10, pp. 1173–1179, 1956.
[2] R. D. Brown, R. A. Burton, and P. M. Ku, "Long-duration lubrication studies in simulated space vacuum," *ASLE Trans.*, vol. 7, no. 3, pp. 236–248, 1964.
[3] M. Rayman and Jet Propulsion Laboratory/NASA, "Dear Hand-Me-Dawns," 30-Nov-2013.

[4] Space Exploration Technologies Corp. (SpaceX), “The Why and How of Landing Rockets,” 15-Jun-2015.
[5] R. Cowen, “The wheels come off Kepler,” *Nature*, vol. 497, no. 7450, pp. 417–8, 2013.
[6] Y. L. Su and W. H. Kao, “Tribological behaviour and wear mechanism of MoS2–Cr coatings sliding against various counterbody,” *Tribol. Int.*, vol. 36, no. 1, pp. 11–23, 2002.
[7] T. W. Scharf, P. G. Kotula, and S. V. Prasad, “Friction and wear mechanisms in MoS2Sb2O 2Au nanocomposite coatings,” *Acta Mater.*, vol. 58, no. 12, pp. 4100–4109, 2010.
[8] J. He, X. Zhu, P. Cosemans, J. P. Celis, W. Lauwerens, M. Van Stappen, L. M. Stals, “Different tribological behavior of MoS2 coatings under fretting and pin-on-disk conditions,” *Surf. Coatings Technol.*, vol. 163–164, pp. 422–428, 2002.