Tribology and Mechanics of Coatings and Surfaces
Room Palm 3-4 - Session MC1-2-FrM

Friction, Wear, Lubrication Effects, & Modeling II

Moderators: Pierluigi Bilotto, TU Wien, Austria, **Julien Keraudy**, Oerlikon Balzers, Oerlikon Surface Solution AG, Liechtenstein

8:00am **MC1-2-FrM-1 Electro-Tribometers and Beyond: Experimental Routes to Assess Materials and Lubricants under Mechanical and Electrical Loadings***, **Leonardo Farfan Cabrera [farfanl@tec.mx]**,* Tecnologico de Monterrey, Mexico*; Ali Erdemir,* Texas A&M University, USA*; Peter Lee,* Southwest Research Institute, San Antonio Texas, USA **INVITED**

The global energy transition, driven by the rapid electrification of mobility, wind power systems, and other advanced energy technologies, demands a deeper understanding of how electrical loading influences friction, wear, and tribochemical film formation in electrified contact interfaces. Bearings, gears, and electrical contacts in these systems are increasingly exposed to stray currents that accelerate surface degradation, lubricant breakdown, and coating failure. To address these challenges, traditional tribometers have been redesigned into electro-tribometers that integrate precise control of mechanical, electrical, and environmental parameters. This presentation highlights different platforms developed to study materials and lubricants under electrical conditions: (1) the electrified four-ball test, used to evaluate current-induced wear and lubricant degradation in concentrated point contacts; (2) the electrified pin-on-disk test, operated under controlled gas atmospheres (air, nitrogen, argon, or humidified conditions) to investigate electro-tribochemical reactions and film growth with high reproducibility; (3) the electrified Mini-Traction Machine (MTM), designed to examine traction and mixed-lubrication behavior under simultaneous rolling, sliding, and current flow; (4) the block-on-ring test, adapted to simulate and study the combined effects of mechanical loading, sliding contact, and electrical current on tribological interfaces; and (5) the electrified ball-cratering (micro-abrasion) test, adapted for localized wear and debris characterization of materials and coatings under electrical bias. Together, these experimental routes establish a unified framework for probing electro-tribochemical mechanisms, coating durability, and lubricant stability, paving the way toward standardized testing of materials, coatings, and lubricants for electromobility, wind power, and other energy conversion systems.

8:40am **MC1-2-FrM-3 Tribological Performance of Sputter-Deposited MoS_2 Coatings with Varying Process Gases***, **Tomas Babuska [tfbabus@sandia.gov]**, Alexander Mings, Steven Larson, John Curry, David Adams,* Sandia National Laboratories, USA

Sputter-deposited molybdenum disulfide (MoS_2) coatings have been used for decades in aerospace applications due to their ultra-low steady-state coefficients of friction ($\mu_{ss} < 0.05$). Developing MoS_2 coatings for demanding applications with predictable and reliable performance over time (i.e., high-quality) requires tuning the coating microstructure through process variations. In this work, we explore process-structure-property-performance relationships of pure MoS_2 solid lubricant coatings where coatings are sputter deposited using different process gases. Helium, kypton, neon, argon and xenon are used to sputter deposit MoS_2 of varying morphologies, and the impact on critical performance traits such as initial friction, run-in, and aging resistance are studied. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

9:00am **MC1-2-FrM-4 Effect of Ta Content in ta-C:Ta Coatings on the Machining Performance of Aluminum Alloy***, **Kosuke Suzuki [kousukes@mmc.co.jp]**,* Mitsubishi Materials Corporation, Japan*; Takayuki Tokoroyama, Ruixi Zhang, Noritsugu Umehara,* Nagoya University, Japan*; Shun Sato, Kenji Yumoto,* Mitsubishi Materials Corporation, Japan **INVITED**

In recent years, demand for lightweight materials in the automotive and aerospace industries has increased, leading to a growing need for machining aluminum alloys. In aluminum alloy machining, Diamond-Like Carbon (DLC) coatings—especially hydrogen-free tetrahedral amorphous carbon (ta-C) coatings—are widely used due to their excellent wear resistance and low friction, which help suppress material adhesion and tool wear caused by hard Si particles in the alloy.

However, under more severe machining conditions, further improvements in coating performance are required to extend tool life, especially in terms of wear resistance and delamination resistance. One of the representative approaches for such performance enhancement is the addition of transition metal elements to DLC coatings, and numerous studies have been reported in this area. Among these, tantalum (Ta) is known to form strong covalent bonds with carbon and is expected to achieve both mechanical strength and improved adhesion strength through the reduction of residual compressive stress.Nevertheless, studies on its influence on machining performance remain limited.

In this study, tantalum-doped ta-C (ta-C:Ta) coatings with varying Ta contents were fabricated, and the correlation between Ta content and coating properties, as well as its effect on the drilling performance of aluminum alloy (ADC12), was systematically evaluated.

For each coating, microstructural analysis and residual stress measurements were conducted, along with ball-on-disk friction tests and scratch tests. Additionally, aluminum alloy cutting tests were performed to evaluate wear resistance and cutting force. As a result, the friction coefficient and specific wear rate tended to increase with higher Ta content in the friction tests. On the other hand, the scratch tests showed an increase in critical load, and a correlation between critical load and residual compressive stress was confirmed. Observations of the scratch marks revealed that ta-C:Ta coatings exhibited smaller delamination areas compared to undoped ta-C coatings. The dispersed structure of TaC nanocrystals observed in the ta-C:Ta coatings is suggested to suppress delamination propagation and contribute to improved toughness.

In the cutting tests, the coating containing 1.1 at.% Ta demonstrated the best wear resistance and lowest cutting force by significantly suppressing chipping while maintaining resistance to abrasive wear. These results suggest that controlling residual stress through appropriate Ta addition and enhancing toughness via fine TaC structures are effective strategies for improving tool life in aluminum alloy machining.

9:40am **MC1-2-FrM-6 Tailoring Titanium Nitride Thin Film on Magnesium Substrate to Improve Adhesion and Tribological Performance***, **Thiago Gontarski [thiago.gontarski@pucpr.edu.br]**, Bruno Pereira,* Pontifícia Universidade Católica do Paraná, Brazil*; Richard Chromik,* McGill University, Canada*; Ricardo Torres, Paulo Soares,* Pontifícia Universidade Católica do Paraná, Brazil

Magnesium (Mg) alloys are attractive materials for biomedical, automotive, and aerospace applications due to their low density and high specific strength. However, their poor wear and corrosion resistance remain major limitations for long-term use. In this work, titanium nitride (TiN) thin films were deposited on Mg-Y-RE magnesium alloy using magnetron sputtering to improve adhesion and tribological performance. Two main variables were investigated: (i) the substrate bias voltage, comparing DC and pulsed modes, and (ii) the presence of a graded TiN interlayer. The coatings were characterized by X-ray diffraction (XRD) to analyze the crystalline structure, scanning electron microscopy (SEM) for surface morphology, and energy-dispersive spectroscopy (EDS) for chemical composition. Mechanical properties were evaluated by nanoindentation to determine hardness and elastic modulus, while adhesion was assessed through scratch testing. Tribological performance was examined using a ball-on-plate tribometer, and the wear scars were quantified by white light interferometry (WLI) to calculate the wear volume. The results indicate that the optimal configuration for enhancing both adhesion and tribological properties is the combination of pulsed bias with a graded TiN architecture. These findings highlight the importance of tailoring both bias voltage and film architecture to optimize the mechanical and tribological behavior of TiN-coated magnesium alloys.

10:20am **MC1-2-FrM-8 Mxene Based Functionalisation of Ceramic Coatings Produced by Plasma Electrolytic Oxidation of Light Alloys***, **Tess Knowles [tess.knowles@manchester.ac.uk]**, Aleksey Rogov, Nicolas Laugel, David Lewis, Aleksey Yerokhin,* University of Manchester, UK

Plasma electrolytic oxidation (PEO) is an advanced surface treatment method used to produce stable barrier oxide coatings on light alloys. This coating technique is advantageous due to its simplicity and environmental benefits compared to relative methods such as anodising and promising for applications across many sectors including aerospace, automotive and biomedical. However, conventional PEO coatings have limitations to many areas of performance as they can only do so much as a passive protective layer. For this reason, it is important to further engineer the coating system to enhance the most beneficial behaviours and improve coating functionality.

An area that PEO is often used is for enhancement of wear resistance of aluminium alloys in sliding contact applications. PEO coatings must be modified to adapt tribological behaviour to changing environment, temperature and loading conditions. In these situations the main option is to add adaptive lubricants to the oxide coating to reduce friction and improve the overall performance of the component, some common examples being graphite or molybdenum disulphide based solid lubricants. These are capable of vastly reducing the friction coefficients [1] but encounter limitations under increased loading as they can delaminate due to weak interlayer bonding [2], with detrimental effects on coating longevity.

To address this problem, we investigate the application of MXene based solid lubricants on PEO coated Al alloys. MXenes are an innovative class of 2D inorganic materials with increased bonding strength between the layers of transition metal compounds making up their structure. To improve the compatibility between the PEO base and MXene top layer, in the first part of our work, we optimise the surface characteristics and properties of the PEO coating, adapting the surface texture and porosity to allow for better adherence and retention of the dry lubricant in sliding tribological contacts. Subsequent experiments include reciprocating sliding wear tests against steel and ceramic substrates, under hertzian contact pressures up to 1 GPa in dry and wet environments. The tribological behaviour and wear mechanisms are investigated by confocal microscopy, Raman spectroscopy and cross-sectional microanalysis. The key factors influencing the adaptive tribological performance of MXene-functionalised PEO coating systems are discussed with recommendations on further research directions made.

References

[1] A. Shirani, *et. al.*, *Surface and Coatings Technology*, **2020**, *397*,126016.

[2] M. Lin, *et. al.*, *Tribology International*, **2021**,*154*, 106723.

10:40am **MC1-2-FrM-9 Experimental Investigation of Friction, Wear, and Dielectric Behavior of Hybrid Polymer Nanocomposites for Insulated Bearings with Machine Learning Assisted Optimization***, **Unnati Joshi [unnatiajoshi@gmail.com]**, Anand Joshi, Vishal Mehta, Jaivik Pathak, Pranav Rathi,* Parul University, India

The present research reports the development and comprehensive investigation of polymer based hybrid nanocomposites composed of Graphene Oxide (GO) and Copper Oxide (CuO) nanoparticles reinforced Polyether ether ketone (PEEK), designed for multifunctional efficacy in advanced high speed electromechanical system applications, including insulated bearings. The objective was to improve the friction-wear characteristics and dielectric properties of the base PEEK polymer. The suitability of the hybrid nanocomposites for insulated bearing applications were evaluated by examining the dielectric constant, dielectric loss, wear rate, and coefficient of friction. Structural and morphological properties were characterized using SEM, EDS, XRD, and FTIR. In this study, the friction, wear and dielectric properties of PEEK based nanocomposites containing 5 wt% Graphene Oxide and varying Copper Oxide nanoparticle contents (1 to 5 wt%) were experimentally investigated. Among all the compositions that were examined, the nanocomposite containing 5 wt.% GO and 5 wt.% CuO nanoparticles demonstrated the highest R^2 value of 88% for wear resistance and 93% for coefficient of friction, thereby validating its optimal performance level and operational stability. The simultaneous enhancements that result from the combination of CuO and GO are indicative of improved surface strength. Furthermore, the machine learning regression models, including Random Forest, XGBoost, and Extra Tree, have exhibited exceptional predictive capabilities for wear and friction forces. The Extra Tree model, in particular, achieved near-perfect accuracy (R^2 = 0.9999) and identified load as the most influential factor. Also, the dielectric constant (ε') and dielectric loss (ε") were predicted and modelled using these machine learning models. The analysis demonstrated that the highest ε' was achieved at 2 wt% Copper Oxide as a result of increased interfacial polarisation, while the most stable dielectric loss (ε") was achieved at 3 and 4 wt% Copper Oxide. The Extra Trees algorithm consistently exhibited superior predictive accuracy and generalisation capability among all the models. This demonstrates that the wear resistance, coefficient of friction, and dielectric behaviour of the composites, were substantially influenced by the synergistic interaction between Graphene Oxide and Copper Oxide nanoparticles. This research advances durable, high performance insulating materials for next-generation electromechanical systems, supporting SDG 9. It also promotes SDG 12 by supporting the design of affordable, durable materials that reduce material waste and enhance industrial component energy efficiency.

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