

Tribology and Mechanics of Coatings and Surfaces Room Town & Country C - Session MC3-1-TuM

Tribology of Coatings and Surfaces for Industrial Applications I

Moderator: Osman Eryilmaz, Argonne National Laboratory, USA

8:00am **MC3-1-TuM-1 Bridging Research and Industrial Application: Advanced Coatings and Surface Treatments for Tribological Challenges, Andras Korenyi-Both [andy.korenyi-both@woodward.com]**, Woodward Inc., USA

INVITED

Surface engineering and advanced coatings are critical for addressing complex tribological challenges across diverse industrial applications, from aerospace to manufacturing. This talk provides an overview of key advancements in coating technologies, spanning decades of research and development, with a focus on linking fundamental insights to real-world applications. Highlights include the investigation of faults and failures in sprayed MoS₂ coatings on the Galileo spacecraft, which informed the development of improved PVD MoS₂ coatings through doping and layering for enhanced performance transitioning to rocket engine turbo pump gears. The transition from PVD coatings to tribomechanical deposition applications is explored, leveraging techniques such as laser surface texturing and WAM testing to bridge laboratory results with production-scale implementation. Emerging technologies, such as autocatalytic in situ diamond-like carbon formation from hydrocarbons, are also discussed, showcasing their potential to enable self-lubricating surfaces in extreme industrial environments. The application of duplex and triplex treatments is highlighted as a powerful approach to solving complex tribological problems, combining multiple surface engineering techniques to optimize performance across diverse conditions. Additional contributions include the development of high-performance coatings for forging and die-casting applications, high-temperature plasma electrolytic oxidation combined with solid film lubricants and the use of nanoparticles in liquids to enhance lubrication. Case studies like the MISSE-to-production pipeline highlight the challenges of translating terrestrial -proven coatings to flight applications, addressing the "flight history conundrum." This work demonstrates the importance of combining advanced surface engineering strategies—ranging from thin-film deposition to hybrid treatment approaches—to tackle emerging challenges in multi-fuel and dry gas environments. Collectively, these efforts underscore the value of a multidisciplinary approach to the development, characterization, and deployment of coatings and surface treatments for solutions in transportation, manufacturing, and beyond. Closing remarks include the role of solid film lubricants towards environmental stewardship.

8:40am **MC3-1-TuM-3 DLC-Based Coatings with Enhanced Cavitation Resistance for Automotive Applications, Kenny Bislin, Oerlikon Surface Solutions AG, Liechtenstein; Martin Bohley, Oerlikon Balzers Coating Germany GmbH, Germany; Christian Fleischmann, Astrid Gies [astrid.gies@oerlikon.com], Theresa Huben, Kaushik Hebbar Kannur, Felix Oelschlegel, Stefan Moser, Oerlikon Surface Solution AG, Liechtenstein; Timea Stelzig, Oerlikon AM Europe GmbH, Germany**

Since several years, automotive manufacturers focus on enhancing the engine performance while reducing the fuel consumption and therefore emissions of gasoline internal combustion engines (ICE). Consequently, the usage of high-pressure direct injection systems, already known from diesel ICEs, is increasing. In these systems, the fuel is accumulated in a central high-pressure rail and injected via injectors into the cylinder. The injection pressure has increased over time; current state-of-the-art systems operate between 200bar and 500bar. By increasing the injection pressure from 200bar to 500bar, the particle emission of the engine can be reduced by 95%. In most of the high-pressure injection systems, the injector valves consist of a ball opening and closing against a seat. Any leakage between the ball and the seat must be avoided to guarantee the lifetime of the system. In most of the current systems, the components like for example the balls are often coated with diamond-like-carbon (DLC) based coatings in order to prevent any premature wear in the systems.

However, the constantly rising injection pressures, but also the use of different fuel blends with incorporation of certain amounts of ethanol and methanol for reduced CO₂ emissions lead to drastically increased loads on the different components, especially due to severe cavitation occurring inside the injectors, exceeding sometimes the mechanical strength of common DLC coatings. The resulting wear of the injectors causes fuel

leakage into the combustion chamber and significantly reduces the lifetime of such systems.

In this study we compare the tribological performance as well as the cavitation resistance of a standard DLC coating optimized for tribological applications with a DLC coating with enhanced cavitation resistance. The tribological performance of the coatings is investigated using a translatory oscillating friction and wear test (SRV[®] from Optimol Instruments). To study the cavitation resistance of the coatings, a cavitation test bench (sonotrode tester) was employed using test procedures according to ASTM 32.

While the tribological performance of both coatings is similar, the standard DLC coating shows first indication of cavitation erosion after 90 minutes testing time, whereas the DLC coating with enhanced cavitation resistance shows first indications of cavitation resistance by a factor of 3 later and at a lower intensity. Therefore, this coating is more suitable for the application in high-pressure direct injection systems and enables the use of more environmentally friendly gasoline blends with higher ethanol or methanol share due to the drastically increased cavitation resistance.

9:00am **MC3-1-TuM-4 Surface Technologies for Geothermal Energy Applications, Oyelayo Ajayi [ajayi@anl.gov], Levent Eryilmaz, Aaron Greco, Argonne National Laboratory, USA**

INVITED

Geothermal power systems rely on equipment that must perform in exceptionally harsh environments—high temperatures, high flow rates, chemically aggressive brines containing chlorides, CO₂ and H₂S, and suspended solids. These conditions make many components susceptible to surface-initiated or surface-related failure modes. Vulnerable systems include drilling tools, casing strings, valves and piping, and rotating equipment such as pumps, motors and turbines. Under these extremes, abrasive wear, particle erosion, corrosion and mineral deposit formation can rapidly degrade performance, shorten component life. Mitigating surface-related failures is therefore essential to reliable, cost-effective construction and operation of geothermal plants. Surface engineering offers a practical, cost-effective pathway to extend service life without wholesale changes to base materials. Incumbent surface technologies used in geothermal applications include hardfacing overlays with metal-matrix composite claddings (e.g., carbide-reinforced Ni/Co systems); thermochemical conversion treatments such as boriding/boronizing that create hard, wear-resistant diffusion layers; and thermal spray coatings—HVOF, plasma and arc spray deposition to apply corrosion- and erosion-resistant alloys, cermets and ceramics. This presentation will review where and how these technologies are applied, their benefits and limitations, and the practical technical considerations that determine success. Key property and performance attributes most relevant to geothermal service—hardness, fracture toughness, coating adhesion, erosion and slurry wear rates, corrosion resistance, scaling propensity, thermal stability will be discussed. Emerging advances in surface technologies, such as functionally graded coatings, nanostructured and amorphous metal overlays, high-entropy alloy and cermet systems, will be highlighted. Gaps where further development is needed: standardized test protocols representative of geothermal conditions, long-duration field data and models that bridge laboratory results to plant performance, coatings that resist silica-rich scaling while maintaining mechanical integrity will be discussed. Together, these insights aim to highlight opportunities for surface-engineered solutions across geothermal power systems.

9:40am **MC3-1-TuM-6 Tailoring Ice Adhesion Behavior of Erosion Resistant Coatings: Tuning Surface Chemistry and Physical Properties, Olayinka Abegunde [Olayinka.Abegunde@sdsmt.edu], Nathan Madden, Grant Crawford, Forest Thompson, South Dakota School of Mines and Technology, USA; Emily Asenath-Smith, US Army Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH 03755, USA**

The mitigation of ice accretion on critical infrastructure, including aircraft components and energy installations remains a significant challenge in cold and arctic regions. Conventional de-icing methods based on thermal and chemical approaches are widely used and have been explored extensively but are inherently energy-intensive and environmentally unsustainable. Thus, passive approaches which rely on the surface properties of a material to reduce ice adhesion strength, delay ice nucleation, or repel ice accretion have gained significant attention.

This study explores the design, deposition, and characterization of durable, erosion resistant coatings engineered to minimize interfacial adhesion strength with ice in cold environments by tuning their surface chemistry, physical properties, and surface microstructure. A series of nitride-based coatings were deposited using magnetron sputtering process. Deposition

Tuesday Morning, April 21, 2026

parameters were optimized to tailor key surface characteristics, including roughness, topography, surface energy, crystallographic texture, and Young's modulus.

The surface morphology and topography were examined using scanning electron microscopy (SEM) and atomic force microscopy (AFM), while grazing-incidence X-ray diffraction (GIXRD) was employed to identify crystalline phases. X-ray photoelectron spectroscopy (XPS) provided insights into the surface chemical states and contact angle goniometry was utilized to evaluate surface wettability. The sub-zero coefficient of friction and wear rate were assessed using a low-temperature tribometer. Ice adhesion strength was quantified through a shear-testing procedure which enabled controlled growth of ice on the durable coatings.

This work provides new insights into the structure–property–performance relationship governing ice adhesion and demonstrates a pathway for scalable fabrication of durable, low-adhesion coatings suitable for extreme service conditions in the aerospace and energy sectors.oi

10:00am **MC3-1-TuM-7 2D MXene Coatings – Combining Macro-Scalesuperlubricity and Durability, *Andreas Rosenkranz* [arosenkranz@ing.uchile.cl], University of Chile** **INVITED**

MXenes nano-sheets have experienced tremendous attention in the scientific community since their discovery in 2011. In the last 5 years, the tribological research community has started to explore their friction and wear performance when used as lubricant additives, solid lubricant coatings and reinforcement phase in composites. Especially when using MXenes for solid lubrication, promising results have been verified. MXene coatings tend to demonstrate an ultra-high wear resistance being particularly beneficial for the durability and longevity of these coatings. These beneficial properties are traced back to the formation of a thin MXene-rich tribolayer. Little is known about the structural and compositional properties of these tribolayers. The underlying kinetics and driving forces are yet to be explored. More knowledge about the involved mechanisms and kinetics is urgently needed, which is expected to significantly boost this entire research topic.

Therefore, we have designed tribological ball-on-disk experiments to understand the influence of the number of layers (few- versus multi-layers), the coatings thickness and the tribological testing conditions (normal load, sliding velocity and relative humidity) on the tribofilm formation. Combined with advanced materials characterization, these tests allow us to draw some important conclusions about the involved thermomechanical aspects and underlying kinetics of the layer formation.

Based upon the experiments conducted, we verify thermomechanical and kinetic aspects of the involved tribolayer formation, which align well with the respective temporal evolution of the coefficient of friction. When exceeding a critical value of the applied normal load (Hertzian contact pressure), the formation of a stable tribolayer with beneficial friction and wear properties is not possible. More importantly, the same conclusion can be drawn when exceeding a critical sliding velocity, which clearly shows the kinetic aspect of the involved layer formation. We also verify that increasing the respective thickness of the MXene coatings does not necessarily result in more beneficial effects (low friction, low wear, and long-lasting effects). Concerning energy application, the material of choice tends to go towards mono-layer MXenes. Regarding tribological research, no scientific study has systemically addressed whether it is more beneficial to use few- or multi-layer MXenes. This contribution also sheds some light on this open question, thus giving some important guidelines and recommendation for future tribological experiments using MXenes.

10:40am **MC3-1-TuM-9 Friction and wear of composite MXene/MoS₂ coating under low viscosity fuels under reciprocating sliding, *Ali Zayaan Macknoja* [alizayaanmacknoja@my.unt.edu], *Mohammad Eskandari*, University of North Texas, USA; *Stephan Berkebile*, Army Research Laboratory, USA; *Andrey Voevodin*, *Samir Aouadi*, *Diana Berman*, University of North Texas, USA**

Friction and wear-related failures remain major challenges in moving mechanical assemblies operating under various conditions. For example, the components of fuel systems made of AISI 52100 steel are susceptible to scuffing-induced wear when operated in fuel environment. This study demonstrates the decreased friction and wear characteristics achieved by spray-coating 52100-grade steel surfaces with solution-processed multilayer Ti₃C₂T_x-MoS₂ blends. Study analyzed performance of the coating in different fuels. Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy results revealed the formation of an in-situ robust tribolayer responsible for the outstanding performance observed at high contact pressures and sliding speeds. This study has broad

implications for the development of solid lubricants that can operate under extreme conditions and low viscosity fuel environment, inspiring further research and development in this field.

Tribology and Mechanics of Coatings and Surfaces

Room Palm 5-6 - Session MC2-1-TuA

Mechanical Properties and Adhesion

Moderators: Chia-Lin Li, Ming Chi University of Technology, Taiwan ,
Michael Meindlhumer, Montanuniversität Leoben, Austria, Balila
Nagamani Jaya, Indian Institute of Technology, India

1:40pm **MC2-1-TuA-1 Mechanical and Interfacial Behavior of Liquid-Like Polymer Surfaces at Extremes**, *Megan J. Cordill* [megan.cordill@oeaw.ac.at], Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Leoben, Austria **INVITED**

Ice buildup presents significant obstacles for both power generation and air transportation in cold regions requiring effective ice protection strategies. Passive anti-icing methods, such as icephobic coatings have garnered increasing interest due to their cost-effectiveness and eco-friendliness. Effective passive ice removal requires very low ice adhesion strength values of less than 20 kPa so that the ice can be easily removed with natural forces such as wind and gravity. Recent studies have shown that liquid-like surfaces (LLS) with ice-shedding properties can be generated through the covalent attachment of linear polymer chains onto smooth substrates bearing sufficiently high hydroxyl group densities. The durable coating retains its slippery properties after exposure to laboratory conditions of icing/deicing and heating cycles, organic solvents, and acid treatment. However, little is known about mechanical stability and longevity of the LLS at relevant temperatures and wind speeds. Nanoindentation, both traditional and AFM-indentation, was used to measure the mechanical properties at various temperatures to establish a ductile to brittle transition of the coating. Additionally, scratch and wear testing were utilized to mimic scratch induced debris and removal of the LLS. As a final check, bulge testing was used to evaluate the adhesion of the ice-phobic coating to the aluminum substrate. These experiments were then compared to the same coatings subjected to various ice and wind tunnel experiments performed on a NACA 0012 aerofoil that would simulate actual conditions during take-off and landing. The combination of assessments demonstrates that the developed LLS coating is robust for wind turbine applications as well as to replace anti-icing fluids currently used for airplanes.

2:20pm **MC2-1-TuA-3 In Situ Observation of Multicracking in Thin Films and Nanostructures**, *Damien Faurie* [faurie@univ-paris13.fr], Université Sorbonne Paris Nord, France **INVITED**

Multicracking in brittle thin films on compliant substrates is a critical reliability issue in flexible electronics, optical coatings, and protective thin-film technologies. While characteristic fracture patterns have been reported for decades, the fundamental mechanisms governing crack initiation, spacing, and multiplication still remain unclear. Classical models link average crack spacing to film thickness, yet they do not account for the local stress heterogeneity and accumulation of damage that precede fracture. In this invited talk, we present an *in situ* experimental methodology that combines synchrotron X-ray diffraction with real-time optical imaging during controlled uniaxial and biaxial mechanical loading of brittle thin films (10–500 nm) supported on polymer substrates. This approach enables the simultaneous monitoring of stress evolution, diffraction peak broadening (FWHM), and crack nucleation. We show that variations in FWHM provide a quantitative diffraction signature of local stress concentration and correlate directly with the onset and multiplication of cracks. This establishes a direct link between microscopic stress heterogeneity and the formation of multicracking networks. Looking forward, we extend this methodology to lithographically patterned thin films, where periodic architectures (e.g., parallel wires, modulated-width structures, multilayered or architected interconnects) offer new degrees of freedom to tailor stress distribution and confinement effects during deformation. We will discuss how such artificial architectures can promote or suppress crack formation, enable stress redistribution, and ultimately improve thin-film reliability. Overall, this work provides a new framework to understand and engineer multicracking in thin films and opens pathways toward mechanically robust architected coatings and interconnects for next-generation flexible technologies.

3:00pm **MC2-1-TuA-5 Numerical and Experimental Evaluation of Cyclic Contact Loads on Titanium Borides**, *Hugo Alberto Pérez Terán*, GERMAN ANIBAL RODRIGUEZ CASTRO, ALFONSO MENESES AMADOR, *Felipe Nava Leana* [felnaval@gmail.com], Instituto Politécnico Nacional, Mexico; *Daybelis Fernández Valdés*, Tecnológico Nacional de México; *VICTOR MANUEL ARAUJO MONSALVO*, Instituto Nacional de Rehabilitación Luis Guillermo Ibarra Ibarra, Mexico

In this work a Ti6Al4V alloy hardened by the boriding process was evaluated by cyclic contact loads. Powder-pack boriding process was used to modify the alloy surface where two phases TiB and TiB₂ were obtained on the sample due to the boron diffusion into the substrate material. The thermochemical treatment was carried out at a temperature of 1100°C for 10, 15 and 20 h of exposure time. Titanium borides (TiB and TiB₂) formed on the surface of the Ti6Al4V alloy was confirmed by means of the XRD analysis. Berkovich nanoindentation test was conducted to determine both hardness and Young's modulus of the borided samples. Cyclic contact loads were applied on the borided sample using a MTS Acumen equipment to evaluate the quality of the titanium borides based on the damage caused on the sample surface. Finite element method was used to obtain the stress field due to cyclic contact loads. Results showed that the sample with thicker thickness because of longer treatment time showed the best mechanical behavior under cyclic contact loads.

4:00pm **MC2-1-TuA-8 Grain Boundaries and “Complexions” in Metallic Thin Films: New Insights on the Interplay of Atomic Structure, Chemistry and Material Properties**, *Gerhard Dehm* [dehm@mpi-susmat.de], Max Planck Institute for Sustainable Materials, Germany **INVITED**

Similar to surface reconstructions, grain boundaries in polycrystalline materials can undergo phase transformations (sometimes referred to as “complexion” in the literature), which alter the resulting properties. Temperature, stress, and chemical composition are the main driving forces for such transformations. Understanding and controlling such transformations allows additional control over the relationships between structure, processing, properties, and performance, especially in materials with a high content of grain boundaries.

The first part of the presentation shows examples of grain boundary phases and transitions in pure and alloyed metallic thin films. Surprisingly, grain boundary phase transitions are observed even in pure metals. The second part of the presentation focuses on electrical and mechanical properties. A workflow is presented that allows to investigate the contribution of individual grain boundary structures to electrical resistivity. The results show that the excess volume of a grain boundary is the main contributor to electron scattering in a pure fcc metal such as copper. However, impurities segregated at the grain boundary can significantly alter electron transport. This can be exploited positively, but can also be detrimental, as exemplified with two examples.

Also mechanical properties are strongly influenced by grain boundaries and their phases. While this has long been known for cases of grain boundary embrittlement, such as Bi in Cu or Ga in Al, the influence on strength and shear-coupled grain boundary motion has only recently been studied in detail and will be presented in the lecture. Finally, strategies to make use of grain boundary “complexions” for property design are discussed.

Acknowledgment: This work has been partially supported by the ERC advanced grant GB-Correlate (Correlating the State and Properties of Grain Boundaries [<https://www.mpie.de/3893203/GB-correlate>]) and the German Science Foundation DFG within the SFB 1394 Structural and chemical atomic complexity – from defect phase diagrams to material properties. Fruitful interactions with many colleagues, especially T. Brink, C. Liebscher, L. Langenohl, K. Bhat, A. Kanjilal, J. Duarte, and H. Bishara are gratefully acknowledged.

4:40pm **MC2-1-TuA-10 Many-to-one Mapping Between Stress-Strain Curves and Spherical Indentation Load-Displacement Curves**, *Santosh Thapa* [sth230@g.uky.edu], *Yang-Tse Cheng*, *Madhav Baral*, University of Kentucky, USA

The stress-strain relationship is key to understanding material behavior, yet conventional tensile testing provides only bulk-averaged properties and fails to capture local heterogeneities. Instrumented indentation testing (IIT), particularly with spherical indenter, is often assumed capable of uniquely determining stress-strain relationships from a single load-displacement curve. However, our results challenge this assumption showing that different combinations of elastic modulus, yield stress, and work-hardening exponent can produce indistinguishable indentation responses, highlighting the non-uniqueness of the inverse problem of obtaining stress-strain

Tuesday Afternoon, April 21, 2026

relation from spherical indentation load-displacement curves. Thus, the quest for obtaining local mechanical properties from spherical indentation measurements continues.

Tribology and Mechanics of Coatings and Surfaces Room Town & Country C - Session MC3-2-WeA

Tribology of Coatings and Surfaces for Industrial Applications II

Moderator: Osman Eryilmaz, Argonne National Laboratory, USA

2:00pm **MC3-2-WeA-1 Tailoring and Designing High-Performance Carbon Coatings - Insides in Recent Developments and New Approaches for Tribological Applications**, *Dominic Stangier* [dominic.stangier@oerlikon.com], Oerlikon Balzers Coating GmbH, Germany **INVITED**

The deposition of diamond-like carbon coatings is an established approach to enhance the service life of tribologically stressed components and tools for industrial applications. Due to today's challenges of reduced lubrication, increased thermal and tribological loads as well as the demand for improved performance and service life, conventional and standardized existing thin films solutions are often limited in their wear-resistance and therefore provide insufficient protection. To overcome these challenges, tailored and application-specific coating systems have gained enormous interest in the field of carbon coatings. On the one hand the efficient deposition of these coating designs requires often a combination of advanced plasma technologies, as well as on the other side the possibility of chemically doping the amorphous carbon network to adjust the property profile. In this regard, the deposition of ta-C coatings by cathodic arc evaporation was found to be an excellent solution, which allows the adjustment of mechanical properties in a broad range as well as offers the possibility to combine different plasma technologies for the deposition of functional multi-layer designs. However, the key challenge is the evaporation of the carbon cathode, which was conducted by an industrial scale arc source (APA evaporator) using a dynamic controlled electromagnetic field generated by a coil system to steer the arc spot motion and control the deposition conditions. This technology enables the modification of the tribological properties for the running-in phase and the "stationary" wear behavior by adjusting the coordination of the carbon network (sp^3/sp^2 -ratio) as well as the chemical composition. In addition, the results reveal the possibility of controlling the intrinsic residual stresses of ta-C coatings to improve the coating adhesion. Furthermore, tailoring the properties was conducted by doping small amounts of Si in ta-C coatings for increasing the thermal stability, which therefore extends the application field of the coating systems.

2:40pm **MC3-2-WeA-3 Advanced Coating and Surface Techniques in Modern Automotive Tribology**, *Sung Chul Cha*, Hyundai Motor Group-Hyundai Kefico, Republic of Korea; *Kyoungh Il Moon*, *Hae Won Yoon*, KITECH, Republic of Korea; *Jongkuk Kim*, KIMS, Republic of Korea; *Gi-Hoon Kwon* [kgh9900a@kitech.re.kr], KITECH, Republic of Korea

This paper presents low-friction coating technologies for automotive tribology applied over the past 20 years. In the era of eco-friendly vehicles, particularly electric vehicles (EVs), it is essential to develop suitable coating technologies. Hyundai Motor Group has forecasted mobility trends for 2035: strong HEVs will account for 23% in 2035 (16% in 2024), plug-in HEVs 26% (8%), and battery EVs 38% (13%). By 2035, eFuel capacity is expected to increase from 3 billion liters to 100 billion liters. Global coating companies are developing technologies using hybrid process, low temperature coating process for polymer material, high ionization and high speed. Oerlikon-Balzers has introduced ta-C coatings for polymer materials, as well as MoN and ta-C coatings for automotive components. As a major research institution, Fraunhofer IWS in Germany presented Si- and B-doped ta-C coatings for applications up to 500 °C. RWTH Aachen University's IOT developed coatings with a graded structure, consisting of S-rich and Mo-rich layers on CrAIN, to achieve low friction on plastic substrates. Recent developments in low-friction coatings presented at ICMCTF were analyzed, and the findings are included in this work. In Korea, R&D efforts focus on developing ultra-low friction coatings for extreme conditions, such as those found in EV components. Current coatings exhibit a coefficient of friction (CoF) of 0.05, while ultra-low friction coatings (CoF 0.01) include nitrides and ta-C doped with elements such as ZrCuSi, ZrMoTi, MoZrTiSi, and ZrMoTiCuSi. To address the corrosion issues of SiO-DLC caused by bioethanol fuels, ta-C coatings have been successfully applied, demonstrating high hardness (66 GPa), low friction (CoF 0.05), thermal resistance up to 500 °C, and excellent corrosion resistance. Furthermore, to enhance the frictional performance of coatings, electrochemical polishing

technique (DLyte) has been employed, resulting in a significant reduction in surface roughness (Ra from 0.4 μm to 6 nm).

3:00pm **MC3-2-WeA-4 Development and Evaluation of TiAlVSiCN Coatings for Automotive Applications**, *Jianliang Lin* [jlin@swri.org], Southwest Research Institute, San Antonio Texas, USA

To increase the fuel efficiency of diesel engines or enhance the performance of racing vehicles, reducing the friction of moving components, such as piston rings and valvetrain parts, is critical, particularly at low engine speeds and loads. Therefore, there is a strong need to develop novel, low coefficient of friction (COF), and robust tribological coatings. In this research, low friction titanium–aluminum–vanadium–silicon–carbon–nitride (TiAlVSiCN) nanocomposite coatings were developed by sputtering Ti-6Al-4V targets in a reactive gas mixture using high power impulse magnetron sputtering (HiPIMS). The chemistry and microstructure of the TiAlVSiCN coatings were tuned by varying the gas flow rate. The tribological behavior of the coatings deposited on stainless steel coupons was evaluated using ball-on-disk and block-on-ring wear tests in SAE 10W-30 engine oil (no additives). The TiAlVSiCN coatings with thicknesses in the range of 6-10 μm exhibited tunable hardness in the range of 15–35 GPa, and the lowest COF of 0.03 and wear rate of $4.8 \times 10^{-9} \text{ mm}^3 \text{ N}^{-1} \text{ m}^{-1}$ under lubricated conditions. The optimized coating, offering the best combination of low COF and wear resistance, was deposited on piston rings and further evaluated using a TE 77 bench test. Its performance was compared with an OEM diamond-like carbon (DLC) coating and a traditional low friction TiSiCN coating. The TiAlVSiCN coating demonstrated superior performance compared to both the OEM DLC and TiSiCN coatings in terms of sliding friction, smooth run-in behavior, galling resistance, and wear resistance. The TiAlVSiCN coating was subsequently applied to piston rings and tested in an internal combustion engine. The results of the engine tests, in comparison with OEM DLC coatings, will be updated.

3:20pm **MC3-2-WeA-5 New Carbon High Productivity / Low Temperature Coater with New Temperature Measurement and New Colour Coating**, *Markus Esselbach* [markus.esselbach@oerlikon.com], Oerlikon, Liechtenstein

Despite the long legacy of carbon coatings in the PVD world, there are still many possibilities to stretch the boundaries of what is possible. With the new coating platform INSPIRA Carbon Mega we were able to develop a new PVD / PACVD coating machine reducing significantly machine production costs and coating temperature at the same time. A new, fast temperature measurement that allows an accurate in situ temperature indication on the turning part during process will be presented and gives a new dimension of insights in the design of coating process ensuring not to overheat sensitive substrates even in short periods of the process. The machine can provide the whole range of smooth carbon coatings from WCC to DLC to hydrogen free DLC coatings with up to 40 GPa hardness with low dependence on loading geometry. Additionally, a new black coating with extremely low L-Value and high hardness is available on this machine and will be presented.

3:40pm **MC3-2-WeA-6 Evaluation of Boriding as a Post-Treatment to Improve the Thermal Stability and Tribological Performance of Weld-Repaired Tool Steels**, *Cesar Resendiz Calderon* [resendiz.cesar@tec.mx], *Leonardo Farfan Cabrera*, Tecnologico de Monterrey, Mexico; *Enrique Campos Silva*, Instituto Politecnico Nacional, Mexico; *Edgar Ravelo Santos*, *Mateo Roux Reyna*, *Sebastian Garcia Barragan*, Tecnologico de Monterrey, Mexico

Metal deposition processes for component repair are gaining attention as a practical alternative to replacement. Yet, welding-based methods can alter microstructures and reduce mechanical integrity, especially in high-carbon steels. Such effects are critical in components exposed to elevated temperatures and demanding service conditions. In this study, the effectiveness of boriding as a post-conditioning treatment to improve wear resistance and reduce tribological heterogeneity is investigated, with special attention to its stability under long-term high-temperature exposure. A repair process based on welding was simulated on AISI H13 tool steel. AISI 308L austenitic stainless steel and ERNiFeCr-2 alloys were used as filler materials for the restoration using the GTAW technique. After metal deposition, a pack-boriding treatment was applied to form a continuous boride layer over the repaired surfaces. Half of the borided samples were exposed to 700 °C for 240 h to evaluate their thermal stability. Surface hardness, coating adhesion, and tribological performance were characterized before and after thermal exposure, both in the repaired and non-repaired regions, using nanoindentation, scratch testing, and dry reciprocating sliding tests. Surface damage and wear mechanisms were analyzed by scanning electron microscopy, and the wear volume was

Wednesday Afternoon, April 22, 2026

quantified through optical profilometry. Boriding proved effective in reducing mechanical property mismatches between the base and repaired regions and in enhancing the tribological performance of repaired H13 steel, even after prolonged high-temperature exposure. The treatment was particularly beneficial for samples repaired with stainless steel filler metal.

Tribology and Mechanics of Coatings and Surfaces Room Palm 3-4 - Session MC1-1-ThA

Friction, Wear, Lubrication Effects, & Modeling I

Moderator: Klaus Boebel, Oerlikon Surface Solution AG, Liechtenstein

1:20pm **MC1-1-ThA-1 Tribological Behavior of New and Green Surface Treatments of Anodized Aluminum Alloys**, *Marc Schmittbuhl*, Ecole Centrale de Lyon - LTDS, France; *Gilles Auregan, Jacoboni Alex*, Safran Landing Systems, France; *Joffrey Tardelli*, IRT-M2P, France; **Marjorie Cavarroc-Weimer** [*marjorie.cavarroc@safrangroup.com*], Safran Tech, France; *Vincent Fridrici*, Ecole Centrale de Lyon - LTDS, France

Light and high-performance aluminum alloys are widely used in aeronautical equipments manufactured by Safran Landing Systems. Many parts require sulfuric anodic oxidation surface treatments combined with a sealing step to protect them from corrosion during service. Compliance with chemicals regulations has led to the replacement of traditional sealing baths using chromates (hexavalent chromium) or nickel salts [1] with a combination of an impregnation bath consisting of trivalent chromium (Cr(III)) and fluorozirconates (Zr(IV)), followed by sealing bath with silicates additives [2]. Although these new treatments maintain good corrosion resistance, their tribological behavior differs and thus raises new issues, particularly with regard to friction in screw assemblies.

The objective of this study is to understand friction behavior and wear mechanisms of the new treatments through tribological tests and characterizations of the aluminum oxide layer.

Various configurations of surface treatments were studied, all on 2024 aluminum alloy oxidized by sulfuric anodization:

- Historical treatments sealed with water containing nickel salts
- New-generation treatments including Cr(III)/Zr(IV) impregnation and sealing with water containing silicate salts
- New-generation treatments including only the impregnation step or the sealing step

Flat samples are treated with each configuration and then tested in linear reciprocating tribological conditions in contact with the flat face of a cylindrical 100Cr6 steel pin. The experimental conditions are defined to approximate the conditions of screw fastening assemblies (number of cycles, contact conditions, kinematics, etc.).

The evolutions in friction coefficient for the different configurations are analyzed. Different features of the initial treatment and wear scars on both samples are characterized by means of topography (interferometry and roughness), microscopy (optical and SEM), chemistry (EDX and Raman spectroscopy), and mechanics (hardness). It allows us to identify the parameters influencing friction behavior and wear mechanisms.

Differences in coefficient of friction are related to changes in interface features. Examination of the wear tracks reveals different wear patterns, which can be explained by the effect of the impregnation of new generation treatments on friction.

[1] L. Hao, B. Rachel Cheng, "Sealing processes of anodic coatings – Past, present, and future". *Metal Finishing*, Vol. 98, p. 8-18, 2000.

[2] N. Chahboun, D. Veys-Renaux, E. Rocca, "Sealing mechanism of nanoporous alumina in fluorozirconate salt containing solutions". *Applied Surface Science*, Vol 541, 2021

1:40pm **MC1-1-ThA-2 Mapping Property Spaces of Combinatorially Deposited Nanocrystalline Alloy Coatings**, *John Curry, Frank DelRio, Tomas Babuska* [*tfbabus@sandia.gov*], *Justin Hall, Kyle Dorman, David Adams, Nathan Brown, David Montes de Oca Zapian, Scotty Bobbitt, Michael Chandross*, Sandia National Laboratories, USA; *Filippo Mangolini, Camille Edwards*, University of Texas at Austin, USA

INVITED

Nanocrystalline alloys continue to gain interest as a promising class of alloys with exceptional mechanical, tribological and catalytic properties among many other intriguing functional properties. Even within simpler binary metallic alloy systems, relative pairings and composition ratios of each alloy can be varied to produce a wide range of alloys with different microstructures/phases and performance characteristics. The ability to rapidly screen the properties and performance of these alloy systems enables the discovery of new alloy compositions tailored to diverse application spaces. This work outlines test methodologies and results for rapidly assessing friction coefficients, tribofilm/wear scar topography, alloy hardness/modulus, resistivity, composition, and structure/density of binary

Thursday Afternoon, April 23, 2026

alloy systems. Pt-Au, Pt-Ni and Cu-Ag alloy systems are the focus of current studies, each deposited through combinatorial deposition methods with ~ 336 individual samples per alloy spanning their full range of binary composition space. DFT and EAM-X calculations of adsorption and segregation energies are also discussed. Results show many compositions exist with diverse mechanical properties, tribological performance and mechanochemical phenomena. Application of FAIR data principles during data generation and organization will also be discussed. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

2:20pm **MC1-1-ThA-4 From Green Lubricant to Liquid Precursor for Hard, Multi-Functional Coatings**, **Mohammad Eskandari** [*mohammadeskandari@my.unt.edu*], *Diana Berman, Ali Zayaan Macknojia*, University of North Texas, USA

The development of sustainable, high-performance protective coatings via simple, scalable, and environmentally harmless methods is a significant challenge in materials science. This study introduces a new approach for surface engineering by polymerizing very-high viscosity *Orychopragmus violaceus* (OV) seed oil into a hard, multifunctional coating directly on a steel surface. OV seed oil, noted for its exceptional thermal stability, due to its unique triglyceride (TAG) estolide fatty acid structure, was used as a liquid precursor to form a hard protective film on 52100 bearing steel. The coating was synthesized in-situ through a simple, thermal curing process at moderate temperatures (200-250°C). Optimization of the steel-oil interface using surface activation was found to be advantageous for achieving excellent adhesion and film smoothness.

Comprehensive characterization revealed the formation of a uniform, amorphous, carbonaceous thin film with a controllable thickness. The coating exhibited a great hardness and an elastic modulus, as measured by nanoindentation, and demonstrated excellent adhesion through scratch testing. Under pin-on-disk reciprocal tribological testing against 52100 counterbody, the coating provided a low and stable coefficient of friction and specific wear rate, showing around an order of magnitude improvement in the tribological performance. Furthermore, potentiodynamic polarization tests in a 3.5% NaCl solution revealed a dramatic improvement in corrosion resistance compared to the uncoated 52100 steel.

This study presents a successful, cost-effective method for creating a hard, lubricious, and corrosion-resistant coating from a sustainable, green precursor. This in-situ formation process offers a promising alternative to conventional vacuum deposition techniques and opens new insight for the development of next-generation materials for high-performance lubrication and surface protection.

2:40pm **MC1-1-ThA-5 Promise and Pitfalls of Tribological Coatings in Electric Vehicle Applications**, **Ali Erdemir** [*aerdemir@tamu.edu*], *Gugyeong Sung, Seungjoo Lee, Merve Komurlu, Henry Papesh, Cagatay Yelkarasi*, Texas A&M University, USA; *Leonardo Farfan*, Tecnologico de Monterrey, Mexico

INVITED

Electric vehicles (EVs) hold great promise for a green, reliable, and economically viable mobility for this century and beyond [1]. However, their long-term reliability is threatened by significant challenges related to critical materials and severe tribological issues triggered by higher torque, load, speed, and temperature conditions [2]. In particular, the shift to a torque-centric drivetrain, combined with extreme contact pressures and shear forces, can accelerate wear, fatigue, and scuffing failures. This situation is further exacerbated by the presence of frequent electrical discharges at the rolling/sliding contact interfaces, which cause severe surface damage and lubricant breakdown. In this talk, we will give a comprehensive overview of these critical issues and stress the need for more advanced materials and coatings that can significantly improve tribological performance and, consequently, the reliability of future EV systems. Specifically, we will highlight the crucial roles of highly electrically insulating Diamond-Like Carbon (DLC) [3] and/or conducting transition metal nitride coatings in enhancing the friction, wear, and scuffing performance of future EV drivetrains.

[1] K. Holmberg and A. Erdemir, The impact of tribology on energy use and CO2 emission globally and in the combustion engine and electric cars, *Tribology International*, 135 (2019) 389-396.

[2] "Electric Vehicle Tribology: Challenges and Opportunities for a Sustainable Transportation Future", *Leonardo Farfan-Cabrera and Ali Erdemir, Eds.*, Elsevier, Amsterdam, 2024, ISBN: 9780443140747

[3] L. I. Farfan-Cabrera, J. A. Cao-Romero-Gallegos, S. Lee, M. U. Komurlu, and A. Erdemir, 2023, Tribological behavior of H-DLC and H-free DLC

Thursday Afternoon, April 23, 2026

coatings on bearing materials under the influence of DC electric current discharges, *Wear*, 522(2023)204709.

3:20pm **MC1-1-ThA-7 Behavior of Nb-Doped Molybdenum Disulfide Coatings Under Electrified Tribological Tests**, *Miguel Rubira Danelon*, University of São Paulo, Brazil; *Newton Kiyoshi Fukumasu*, Institute of Technological Research, Brazil; **Roberto Martins de Souza** [robertosouza@usp.br], *André Paulo Tschiptschin*, University of São Paulo, Brazil

Adaptive coatings have been shown to extend the lifespan of mechanical systems exposed to magnetic, thermal, and electrical disturbances by modulating their properties. In electric vehicle powertrains, stray currents are known to accelerate the degradation of bearings and gears. Coatings based on transition-metal dichalcogenides, such as molybdenum disulfide, provide excellent solid lubrication and wear resistance. However, structural defects can facilitate the formation of MoO₃ in humid environments, thereby undermining low-friction performance. Doping TMDs with transition metals enhances their mechanical properties, promotes the formation of amorphous structures with greater integrity, and allows bandgap tuning, enabling modulation of their properties via an electric current. In this study, Nb-doped MoS₂ coatings were deposited onto H13 tool steel substrates using balanced pulsed DC magnetron sputtering. Tribological testing involving electro-stimulation employed a reciprocating ball-on-plane apparatus with an AISI 52100 sphere, a normal load of 30 N, a 5 mm stroke, and a frequency of 0.28 Hz. Three electrical conditions (positively and negatively charged, and no current) were evaluated under both continuous and intermittent current-contact modes, with applied currents ranging from 100 to 1500 mA. Coating morphology and composition were characterized by scanning electron microscopy with energy-dispersive spectroscopy (SEM/EDS), and Raman spectroscopy was used to analyze the films before and after testing. Mechanical properties were assessed through instrumented nanoindentation. Results indicated that passing current reduced the coefficient of friction under both continuous and intermittent modes, achieving reductions of up to 50% relative to the non-electrified condition. This reduction is attributed to recrystallization of Nb:MoS₂ during sliding with an electrified contact. Wear behavior, however, was influenced by current direction, with positively charged counterbodies exhibiting greater wear than negatively charged counterbodies. It is proposed that opposite current polarities induce distinct tribolayer formation and elemental segregation (Mo, S, Nb), which maintains low friction but differentially affects wear. Overall, Nb-doped MoS₂ demonstrates current-responsive tribological behavior characterized by friction reduction and polarity-dependent wear mechanisms.

4:00pm **MC1-1-ThA-9 Calibrated Friction Measurements Using a New Interferometric Atomic Force Microscope**, *Joel Lefever* [joel.lefever@oxinst.com], *Aleksander Labuda*, *Roger Proksch*, Oxford Instruments, USA

Measuring lateral force is critical for friction measurements on tribological materials ranging from bearings in engines to 2D materials. The atomic force microscope (AFM) is one important tool for frictional measurement on the scales of both microns and nanometers. Conventional optical beam deflection (OBD)-based AFMs are difficult to calibrate, with most calibration methods requiring cumbersome sample exchanges which may disturb the alignment of the chip and detection beam, while simultaneously introducing substantial uncertainty.

We introduce a method for performing lateral force measurements using an AFM with a quadrature phase differential interferometer (QPDI) detector in addition to a traditional optical beam detector (OBD), which furthermore provides a new means to perform a direct calibration of the lateral sensitivity. The detection spot may be placed on the centerline of the cantilever, using QPDI for height feedback while using OBD for friction measurement. In this configuration crosstalk from the lateral signal into the normal signal is eliminated, which reduces the effects of friction and topography on the applied load and is useful for macroscopic relief. Alternatively, by positioning the interferometric detection spot along one edge of the cantilever, the AFM takes advantage of the detector's low noise floor to observe stick-slip friction at scan rates that would be difficult or impossible with optical beam AFMs. The results demonstrate clearly resolvable stick-slip friction over a range of tip speeds up to 2 μm/s and additionally show the variation of friction with applied load. Because this calibration technique can be performed *in situ* without sample exchanges, it also allows calibration to be performed in enclosed environments, for example to enable changing humidity. Furthermore, with some

modifications, all of these methods can also be performed in liquid, which is useful for characterizing tribofilm growth and other phenomena.

4:20pm **MC1-1-ThA-10 Effects of Mo-N-Cu Doping on Microstructural, Mechanical, and Tribological Properties of Thick Ta-C Coatings for Cryogenic Applications**, *Young-Jun Jang* [yjjang@kims.re.kr], *Jae-Il Kim*, *Ji-Woong Jang*, *Jongkuk Kim*, Korea Institute of Materials Science (KIMS), Republic of Korea

INVITED

The introduction of environmental regulations and the growing use of renewable energy have altered the operating temperature (111 K) of mechanical components used for transporting cryogenic fluids such as hydrogen, liquid nitrogen, and liquefied natural gas. In cryogenic environments, where lubrication fluids or special lubricants are unavailable, adhesive, abrasive, fatigue, and delamination wear can occur; hence, suitable materials for such conditions are essential. Various solutions have been proposed, including hybrid ceramic bearings combining hard ceramics and alloy steel, or protective coatings such as diamond-like carbon. Among these, tetrahedral amorphous carbon coatings exhibit excellent hardness and wear resistance, yet their performance in cryogenic environments is limited due to difficulties in forming low-friction tribo-films, which are hindered by thermal and chemical reactions in atmospheric conditions. Furthermore, ta-C coatings with surface hardness above 40 GPa can cause severe wear imbalance due to hardness differences with base materials (e.g., SUS 316L stainless steel, 1.75 GPa). The mismatch between the thermal expansion coefficients of the coating and substrate also increases delamination wear at lower temperatures. Excessive hardness additionally leads to reduced fracture toughness, low-temperature brittleness, fatigue, and fracture, thereby degrading coating functionality. For sliding components such as valves or bearings to maintain efficiency under cryogenic conditions, a modified ta-C coating that preserves the mechanical and tribological advantages of ta-C while accommodating thermal and structural stresses is required. This study explores Mo-N-Cu-doped tetrahedral amorphous carbon (Mo-N-Cu-ta-C) coatings synthesized using simultaneous filtered cathodic vacuum arc and unbalanced magnetron sputtering under air (296 K) and liquid nitrogen (77 K) environments. The resulting 1 μm-thick coating comprised nanocomposite Mo carbide and nanolayered Cu structures. Compared with undoped ta-C, Mo doping reduced counterpart wear by 82%, Cu doping enhanced fracture toughness by 22%, and decreased disk wear by 86%. Nitrogen addition promoted phase separation, strengthening the synergistic effects of Mo and Cu to achieve balanced wear. Cu and N₂ further minimized thermal expansion and strain mismatches between the coating and substrate at reduced temperatures, mitigating thermal stress and improving cryogenic reliability. At 296 K, the Mo-N-Cu-ta-C coating exhibited superior adhesion, controlled toughness, and stable wear behavior while maintaining reliable performance in LN₂.

Tribology and Mechanics of Coatings and Surfaces Room Town & Country A - Session MC-ThP

Tribology and Mechanics of Coatings and Surfaces Poster Session

MC-ThP-1 Evaluation of Stress Field in a Borided Inconel 718 Superalloy Under Dry Sliding Wear, *Alan Daniel Contla Pacheco, Iván Campos Silva*, Instituto Politécnico Nacional, Mexico; *Arturo Ocampo Ramírez*, Universidad Veracruzana, Mexico; *Daybelis Fernández Valdés*, Tecnológico Nacional de México; *GERMAN ANIBAL RODRIGUEZ CASTRO, Felipe Nava Leana [felnaval@gmail.com], ALFONSO MENESES AMADOR*, Instituto Politécnico Nacional, Mexico

In this work, the wear resistance of Inconel 718 superalloy hardened by the boriding process was evaluated by means of dry sliding. A powder-pack boriding process was used to modify the alloy surface in which nickel borides were obtained in the sample due to the boron diffusion into the substrate material. The thermochemical treatment was carried out at a temperature of 950 °C for 2 and 6 h of exposure time. The Ni₂B, Ni₄B₃ and Ni₃B intermetallic compounds formed on the surface of the Inconel 718 superalloy were confirmed by XRD analysis. Berkovich nanoindentation tests were conducted to determine both hardness and Young's modulus of the borided samples. The dry sliding wear tests were performed on the surface of the borided sample using an alumina ball with diameter of 6 mm, a constant load of 20 N and distances of 50, 100, 150 and 200 m. Wear coefficient was obtained by the Archard's model. The finite element method using mesh nonlinear adaptivity was used to obtain the stress field during the wear test. Results of the failure mechanisms over the worn tracks showed that the sample with thicker thickness had better wear resistance.

MC-ThP-3 Tribological and Corrosion Performance of Alloy 718 coated with WC/Co Applied by HVOF, *Nathalia Kappaun Vieira [nathaliakapp@hotmail.com]*, PUCPR, Brazil; *Steffen Aicholz*, Oerlikon Balzers, Brazil; *Michelle Sostag Meruvia, Paulo Soares, Ricardo Diego Torres*, PUCPR, Brazil

Nickel-based superalloys, such as Inconel 718 and Inconel 625, are widely used in oil and gas industry due to their mechanical and Chemical properties. The extraction and processing environments involve high temperatures, high pressures, and corrosive environments. Nickel alloys offer high mechanical strength at elevated temperatures, and excellent resistance to corrosion and oxidation, ensuring safety and a longer service life for components that use them. Inconel 718 has high corrosion resistance, but its application is limited due to low hardness and wear resistance. One method of solving this problem is to combine heat treatment with application of coatings. The present work carried out a comparative study of the tribological and tribocorrosive properties of nitride Inconel 718 and Inconel 718 with a WC/Co coating, applied by the HVOF method, which was chosen due to the obtention of a dense layer with low porosity, improving the wear resistance of the material. The surfaces were characterized using X-ray diffractometry (XRD), microhardness, and scanning electron microscopy (SEM) techniques. The tribological, tribocorrosive, and corrosive properties were evaluated in five environments: (a) Distilled water saturated with CO₂; (b) distilled water with sodium chloride; (c) distilled water saturated with H₂S; (d) distilled water with sodium chloride and saturated with CO₂; (e) distilled water with sodium chloride, CO₂ and H₂S. Where in the end the surfaces will be compared across three requirements: i) corrosion current and potential, ii) wear rate, iii) wear rate considering the synergistic effect of tribocorrosion.

MC-ThP-4 Influence of Coating Thickness and Bias Voltage on Cracking Behavior of TiAlCrN PVD Coating, *Kirsten Bobzin, Christian Kalscheuer [kalscheuer@iot.rwth-aachen.de], Wenting Xu*, Surface Engineering Institute - RWTH Aachen University, Germany

Physical Vapor Deposition (PVD) TiAlCrN coatings show outstanding mechanical properties, thermal stability and oxidation resistance. Therefore, TiAlCrN coatings exhibit great potential to be deposited on cutting tools in order to minimize wear during cutting operations. Both the coating thickness and the bias voltage applied during the PVD process can influence the cracking behavior of the coating, which in turn affects the machining capacity and lifetime of the cutting tools. In this study, TiAlCrN coatings with thicknesses of $s = \sim 2.2 \mu\text{m}$, $\sim 2.8 \mu\text{m}$ and $\sim 3.8 \mu\text{m}$ were deposited on cemented carbide WC-Co substrates under a constant applied bias voltage of $U_b = -80 \text{ V}$. In addition, TiAlCrN coatings were deposited with

different applied bias voltages of $U_b = -60 \text{ V}$, -80 V and -100 V at a constant thickness of $s = \sim 2.8 \mu\text{m}$. The cracking resistance was evaluated using nanoscratch tests with constant forces of $F = 250 \text{ mN}$, 500 mN and 750 mN . A conical diamond indenter was used for the nanoscratch tests. Nanoscratches were analyzed for cracks on the surface and in cross-section for coating deformation using scanning electron microscopy (SEM). Additionally, the depth of the nanoscratches were measured with confocal laser scanning microscopy (CLSM). In this study, thicker coatings exhibit better cracking resistance. With increasing thickness, the permanent deformation is reduced. In addition, the coating deposited with a bias voltage of $U_b = -100 \text{ V}$ exhibits the lowest deformation. The results reveal valuable insights in the cracking behavior of TiAlCrN coatings. These findings can contribute to enhancing the machining performance and the lifetime of cemented carbide tools through targeted coating design.

MC-ThP-5 Enhancing Corrosion Resistance and Tribological Performance of Inconel 718 through Plasma Nitriding and CrAlN/DLC Coatings for Oilfield Applications, *Heloisa Scalabrin [heloisa.scalabrin@pucpr.edu.br], Michelle Sostag Meruvia, Paulo Soares, Ricardo Diego Torres*, Pontifícia Universidade Católica do Paraná (PUC-PR), Brazil

Oil and gas environments are highly corrosive due to the presence of H₂S, CO₂, and chloride ions, which accelerate material degradation through both chemical and mechanical mechanisms. This study investigates the impact of plasma nitriding on the tribological performance, adhesion, and corrosion resistance of CrAlN/DLC coatings deposited on Inconel 718 substrates. The goal is to develop an alternative surface treatment suitable for extreme oilfield conditions.

The Inconel 718 specimens were aged at 760 °C for 6 hours. Three groups were analyzed: (i) nitrided Inconel 718, (ii) nitrided Inconel 718 with CrAlN/DLC coating, and (iii) Inconel 718 with CrAlN/DLC coating without nitriding. Characterization was conducted using nanoindentation to assess mechanical properties, pin-on-disk testing for wear evaluation, and scratch testing for adhesion. The tribocorrosion performance was evaluated in a simulated oilfield environment. Structural and phase integrity of the coatings were analyzed using Raman spectroscopy and X-ray diffraction (XRD), while surface morphology and failure mechanisms were examined via scanning electron microscopy (SEM).

Plasma nitriding enhances surface hardness and promotes the formation of a diffusion layer, which improves coating adhesion and compatibility with the substrate. This combination reduces friction and wear under tribocorrosive conditions. Additionally, DLC deposition lowers friction coefficients and wear rates, further enhancing resistance to tribocorrosion. Preliminary results indicate that nitriding significantly increases surface hardness and coating adhesion. XRD analysis confirms the structural integrity of CrAlN/DLC coatings after exposure, supporting the proposed surface treatment as a multifunctional solution for harsh oilfield environments.

MC-ThP-6 High Temperature Stability of Different Diamond-Like Carbon Thin Films, *Daniel Pözlberger [daniel.poelzberger@tuwien.ac.at]*, Institute of Materials Science and Technology, TU Wien, Austria; *Julien Keraudy, Klaus Böbel*, Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein; *Tomasz Wojcik, Philip Kutrowatz*, Christian Doppler Laboratory for Surface Engineering of High-performance Components, TU Wien, Austria; *Carsten Gachot*, Institute of Design Engineering and Product Development, Research Unit Tribology, TU Wien, Austria; *Helmut Riedl*, Institute of Materials Science and Technology, TU Wien, Austria

The transition to a more energy-efficient world requires innovative solutions, with materials science and tribology playing critical roles. Improving lubrication and reducing wear are essential for lowering the carbon footprint, conserving energy, and meeting climate targets. While conventional liquid lubricants perform well under many conditions, extreme environments, such as high or cryogenic temperatures, high contact pressures, vacuum, or radiation, demand the use of solid lubricants combined with advanced materials. However, many solid lubricants, including MoS₂, MXenes, and graphite, oxidize rapidly above approximately 400 °C, limiting their applicability. Developing self-lubricating materials that also provide excellent corrosion and wear resistance is, therefore, crucial. Among solid lubricating coatings, diamond-like carbon (DLC) is one of the most established. Yet, its performance at high temperatures above 400 °C remains questioned, as DLC coatings are suspected to degrade under such conditions. A systematic comparison and extreme condition testing that links tribological performance to coating properties is still missing.

This study investigates different DLC-based thin film materials, classifying them by dominant mechanisms, application ranges, and performance.

Several DLC coatings are compared, including non-hydrogenated DLC (a-C), hydrogenated DLC (a-C:H), hydrogenated DLC with an oxide former (a-C:H:Si:O), and tetrahedral amorphous carbon (ta-C). These coatings, which vary in mechanical properties and sp_2/sp_3 ratios, were tribologically tested at different temperatures and loads. Subsequent surface characterization included nanoindentation, Raman spectroscopy to analyze the effects of graphitization after thermal exposure, and X-ray photoelectron spectroscopy. Further insights into the limits of carbon as a solid lubricant are provided through high-resolution characterization techniques such as high-resolution transmission electron microscopy.

In summary, this work highlights the potential of advanced DLC coatings for solid lubrication. It highlights the need for a deeper understanding of their mechanisms and the design of innovative coatings to enable future high-performance applications.

MC-ThP-7 The Impact of Nitriding Parameters on the Tribological and Corrosion Behavior of Inconel 718, Gabriel Queiroz Carara, Heloisa Scalabrin, Cesar Neitzke, Michelle Meruvia, Paulo Soares, Ricardo Torres [ricardo.torres@pucpr.br], PUCPR, Brazil

The mechanical and tribological properties, along with the corrosion resistance of plasma-nitrided Inconel 718, were evaluated at nitrided treatment temperatures of 400°C and 500°C. The treatments varied in duration, lasting 1 hour, 2 hours, or 4 hours, and utilized gas compositions of 5% N₂ / 95% H₂ and 25% N₂ / 75% H₂ at a pressure of 530 Pa. Microstructural characterization was conducted using X-ray diffraction. For mechanical characterization, Vickers hardness measurements were performed using a force of 245.2 mN. The tribological properties were assessed through a reciprocating wear test involving an Inconel 718 and cemented ball pair, from which the wear rate was determined. Corrosion resistance was evaluated through potentiodynamic polarization testing. The results indicated that treatment at 400°C led to the formation of the expanded austenite phase, while the samples nitrided at 500°C formed the CrN phase. As anticipated, increasing the nitriding parameters resulted in a progressive increase in sample hardness—from 4.5 GPa for untreated samples to 9.75 GPa for those treated at 500°C with 25% N₂ for 4 hours. A notable reduction in the coefficient of friction was observed in all nitrided samples compared to the non-nitrided specimen, with the samples treated at 500°C exhibiting the lowest friction coefficient values. Additionally, the wear rate saw a significant decrease when comparing nitrided samples to non-nitrided ones.

MC-ThP-9 Effect of Sodium Tungstate on the Wear and Corrosion Behavior of Micro-Arc Oxidation Coatings on AZ31 Magnesium Alloy, Yueh-Lien Lee [yuehlien@ntu.edu.tw], National Taiwan University, Taiwan

Magnesium alloys offer advantages such as low density and high specific strength, but their practical application is often limited by insufficient wear and corrosion resistance. Micro-arc oxidation (MAO) is a promising surface treatment for modifying surface characteristics of magnesium alloys. In this study, MAO coatings were formed on AZ31B magnesium alloy using a silicate-based electrolyte, with and without the addition of boric acid.

Coatings were prepared in a boric-acid-free electrolyte and in electrolytes containing 2 g/L and 5 g/L boric acid, respectively. The influence of boric acid addition on coating morphology, discharge behavior, and wear- and corrosion-related characteristics was examined. The results indicate that the presence of boric acid alters the MAO discharge behavior and coating formation, leading to observable differences in coating compactness and surface features. Variations in wear response and electrochemical impedance behavior were observed among the coatings prepared under different electrolyte conditions.

At higher boric acid concentrations, changes in discharge intensity were associated with increased coating porosity, which influenced wear and corrosion behavior. Additional electrolyte modification was explored to assess the effect of conductivity on coating characteristics. These results provide preliminary insight into the role of boric acid in controlling MAO coating formation and wear-corrosion behavior on AZ31B magnesium alloy.

MC-ThP-10 Advantages of Ultra-High Vacuum Tribology, Esteban Braitman [ebraitm@hotmail.com], Sven Kelling, Rickmer Kose, Sentys Inc., USA

Tribological behavior—friction, wear, and adhesion—depends strongly on the local environment. In air, adsorbed water, oxygen, and organics form boundary films that dominate contact mechanics; reducing pressure thus these films and shifts interactions toward intrinsic solid-solid processes. Ultra-high vacuum (UHV, below 10⁻⁹ mbar) effectively removes physisorbed monolayers on laboratory timescales, exposing atomic-scale adsorption,

chemisorption, cold-welding, and intrinsic wear mechanisms otherwise masked at higher pressures. UHV tribology is therefore critical for vacuum-service industries (space mechanisms, semiconductor tools, accelerators, vacuum MEMS), yet remains rare because of specialized chambers, rigorous bakeout, vacuum-compatible instrumentation, and long pumpdown cycles. Commercial UHV tribometry options are limited; **PREVAC** currently offers a commercial UHV tribometer reaching ~10⁻⁹ mbar. This review synthesizes UHV studies, compares UHV, HV, and atmospheric results for common materials and coatings, and issues practical recommendations to improve industrial uptake and reproducibility.

MC-ThP-11 Influence of Boriding Time on the Wear Behavior and Structural Stability of Ti6Al4V Under Simulated Physiological Conditions, J. A. Nieto-Sosa [jnietos2100@alumno.ipn.mx], M. A. Melo-Pérez, I. Arzate-Vázquez, L. A. Moreno-Ruiz, Instituto Politécnico Nacional, Mexico; E.E. Vera-Cárdenas, Tenológico Nacional de México/Instituto Tecnológico de Pachuca, Mexico; G. A. Rodríguez-Castro, J.A. Andraca-Adame, Josué Escobar-Hernández, Instituto Politécnico Nacional, Mexico

This work evaluates the tribological performance of Ti6Al4V alloy modified via powder pack boriding for potential use in high-load biomedical implants. The study investigates the mechanical response and structural stability of biphasic TiB₂/TiB layers exposed to two distinct simulated physiological environments: Hanks' solution and Simulated Body Fluid (SBF), providing a comprehensive insight into the performance of these surfaces in ionic media. Mechanical characterization revealed that the boriding process at 1100 °C for 5 and 20h significantly increases surface hardness, reaching a range of 1900 to 3600 HV for the titanium boride phases. Interfacial integrity was assessed via Rockwell C adhesion tests (VDI 3198), showing a transition from HF3 to HF4 as treatment time increased to 20 h. This shift reflects a highly compressed and hardened surface state that maintains structural integrity without coarse delamination during mechanical contact. The reciprocating sliding results highlighted a reduction in the steady-state Coefficient of Friction (CoF), dropping from 0.40 for the untreated alloy to 0.22 (5 h) and 0.12 (20 h). A significant contrast was observed between the biological fluids: SBF proved to be more aggressive than Hanks' solution, inducing a 15% increase in the specific wear rate (k) and higher signal tortuosity due to increased ionic activity and chloride-mediated interaction. Despite this, the 20 h condition (28.2 μm thickness) achieved a 97.6% reduction in k (1.60 ×10⁻⁶ mm³/Nm) compared to the untreated reference (61.87 mm³/Nm). Morphological analysis via optical profilometry confirmed that the boride layers do not fail by traditional material removal. Instead, they exhibit a sinking-in effect, where the hard ceramic layer is pressed into the thermally softened substrate. This mechanism was quantified through the Plastic Deformation Ratio (PDR), which decreased from 0.33 in the untreated alloy to 0.05 in the 20 h condition. These findings demonstrate that a 20 h boriding treatment is critical to providing the necessary load-bearing capacity and dimensional stability required for orthopedic applications in iogenic environments.

MC-ThP-12 Vapor Deposition Coatings for Hard Chrome Replacement in Advanced Mechanical Components, Giacomo Bernardelli [256293@studenti.unimore.it], Luca Lusvardi, Giovanni Bolelli, Università degli Studi di Modena e Reggio Emilia, Italy; Alessio Bassano, Leonardo S.p.A., Italy

Metallic chromium coatings produced by electrochemical deposition starting from hexavalent chromium oxide (CrO₃) are widely employed due to their excellent mechanical and tribological properties. However, Cr⁶⁺ substances have been classified cancerogenic for many years. Therefore, according to European Union REACH regulation, they cannot be used in Europe without a temporary authorization. Chrome platers must apply for reauthorization before the old one expires. In this context, in collaboration with Leonardo S.p.A. alternative deposition technologies are being investigated to replace Cr⁶⁺ plating for mechanical components currently treated with this process. A further challenge in this path towards safety and sustainability is imposed by the European Union through a list of Critical Raw Materials (CRMs), which combine raw materials of high importance to the EU economy and of high risk associated with their supply. Therefore, the alternative coatings materials used with hexavalent Cr-free deposition processes should also exclude CRMs.

The selected technology is PVD in a MS configuration, using Cr targets to obtain Cr-based films. The substrate is a quenched and tempered alloy steel comparable to that used in the final application. The primary goal of the work was to get reasonably thick coatings (>10 μm) on planar samples and then refining the coating architecture to improve mechanical and

Thursday Afternoon, April 23, 2026

tribological performance. Specifically, a comparison is made between two sample sets fabricated using the same deposition technique, with variations in the process parameters.

Nanoindentation and scratch testing were used to analyse mechanical characteristics and adhesion and ball-on-disc tests were used to examine tribological behaviour. A rather dense coating structure was identified by morphological investigations, obtaining high hardness values (about 1300 HV), surpassing those of ordinary hard chromium. Excellent adherence was shown in scratch testing, and no coating delamination was seen within the applied load range (20 mN–30 N). Ball-on-disc tests against Al_2O_3 balls showed relatively low wear rates in the range of 10^{-6} to 10^{-7} mm³/N·m and a relatively low friction coefficient (~0.4).

These results are encouraging toward the improvement of the coating architecture and the development of a deposition technology which could be applied by the company to achieve a complete replacement of hexavalent chromium in their applications.

MC-ThP-14 Temperature-Driven Tribofilm Evolution in Oscillating Sliding Contacts Revealed by Advanced Surface Characterization, Florian Pape, Bruker Inc., USA; Alexander Dulebo, Udo Volz, **Ude D. Hangen** [ude.hangen@bruker.com], Bruker Nano GmbH, Germany

Tribofilms are essential for reducing friction and wear in mechanical systems, directly influencing efficiency and component lifetime. To investigate additive-driven tribofilm formation, oscillating sliding tests were conducted on a Bruker UMT TriboLab using a 6 mm 100Cr6 steel ball against silicon and steel substrates. A base oil with 5% ZDDP, known for promoting phosphate-based tribolayers, and 1 wt% graphene platelets was used to study friction behavior and film growth.

Experiments were run on pristine silicon under a 2 N normal load, 2 mm stroke, 2 Hz frequency, for 15 minutes at temperatures of 25–30°C, 70°C, and 100°C. The resulting wear tracks were examined using complementary Bruker instruments. A stylus profiler quantified topographical changes and tribofilm height variations. Mechanical properties of the resulting layers and its friction were characterized with high spatial resolution using the Bruker Hysitron TI-990 Tribolndenter. Nanoscale mapping of surface structures and mechanical contrast was performed on a Bruker Dimension Icon AFM operating in PeakForce QNM mode, enabling visualization of additive-derived features inside and outside the wear scars.

This combined characterization approach provides detailed insights into how ZDDP and graphene additives influence tribofilm formation under oscillating contact, supporting the development of more effective lubricant systems for advanced tribological applications.

Tribology and Mechanics of Coatings and Surfaces

Room Palm 3-4 - Session MC1-2-FrM

Friction, Wear, Lubrication Effects, & Modeling II

Moderator: Klaus Boebel, Oerlikon Surface Solution AG, Liechtenstein

8:20am **MC1-2-FrM-2 Active Friction and Wear Control in a-C:Cr Films: Electrical Current and Polarity Effects on Catalytic Graphitization**, **Newton K. Fukumasu** [newton.fukumasu@usp.br], **Miguel R. Danelon**, University of São Paulo, Brazil; **Abrar Faiyad**, **Ashlie Martini**, University of California Merced, USA; **Cherlio Scandian**, Federal University of Espirito Santo, Brazil; **Roberto M. Souza**, University of São Paulo, Brazil

Diamond-Like Carbon (DLC) films are established protective coatings for severe contact conditions, yet their tribological response under active electrical currents involves under-explored physical mechanisms. This study investigates the friction and wear behavior of Cr-doped (a-C:Cr) and undoped a-C films under reciprocating sliding with simultaneous electrical current passage. Tests were performed in dry conditions, using AISI 52100 steel balls against coated glass substrates under anodic (positive plane) and cathodic (negative plane) polarizations, applying a 10 N normal load, 4 mm stroke, and a constant current of 100 mA for the electrified cases. While undoped DLC exhibited inert behavior, resulting in a friction coefficient (COF) of 0.15 regardless of electrical conditions, Cr-doped films demonstrated a friction reduction, down to 0.05, and significant responsiveness to the applied current. Although instrumented indentation and microscopy indicated slightly lower hardness and more visible wear marks for a-C:Cr compared to the undoped film, the tribological behavior is attributed to a local shear-induced phase transformation mechanism. Raman spectroscopy of the a-C:Cr wear tracks under cathodic polarization revealed an intense 2D peak, characteristic of ordered, multilayer graphene-like structures. This result provides evidence that Cr catalytically lowers the activation energy for graphitization, activated by local heating and electron flow. Conversely, anodic polarization resulted in clean wear tracks and stable low friction, suggesting a distinct equilibrium between tribofilm formation and oxidative removal. Reactive Molecular Dynamics simulations supported these findings, elucidating atomistic pathways where Cr clusters facilitate bond rehybridization under combined shear and electrochemical stress. These results demonstrate that the tribological performance of a-C:Cr can be actively tuned, enabling "on-demand" low-friction regimes through electrically assisted catalytic graphitization.

8:40am **MC1-2-FrM-3 Tribological Performance of Sputter-Deposited MoS₂ 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 (MoS₂) coatings have been used for decades in aerospace applications due to their ultra-low steady-state coefficients of friction ($\mu_{ss} < 0.05$). Developing MoS₂ 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 MoS₂ solid lubricant coatings where coatings are sputter deposited using different process gases. Helium, krypton, neon, argon and xenon are used to sputter deposit MoS₂ 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** [kosukes@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

Friday Morning, April 24, 2026

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.

10:20am **MC1-2-FrM-8 Effects of Silver Nitrate Additives on the Antibacterial and Corrosion Behaviors of Plasma Electrolytic Oxidized AZ31 Magnesium Alloy**, **Bo-Xuan Zheng** [rick910823@gmail.com], **Chuan-Ming Tseng**, Ming Chi University of Technology, Taiwan, Republic of China

AZ31 magnesium alloy exhibits excellent biodegradability and biocompatibility, making it a promising candidate for temporary biomedical implants. Nevertheless, its rapid degradation and insufficient corrosion resistance severely limit its direct clinical application. In this study, the bioceramic composite coatings on AZ31 magnesium alloy were prepared by using plasma electrolytic oxidation (PEO) under bipolar power mode in alkaline solutions with sodium phosphate, sodium silicate, potassium fluotitanate and silver nitrate (AgNO₃) additions. The effect of AgNO₃ content on antibacterial and corrosion behaviors of PEO coatings on AZ31 magnesium alloy was investigated. The microstructural characterizations of the AgNO₃-incorporated PEO coatings were identified by XRD, SEM-EDS and EPMA. The adhesion and wear resistance of PEO coatings were evaluated using scratch testing and pin-on-disk wear tests, respectively. The potentiodynamic polarization measurements were conducted to evaluate the corrosion behaviors of PEO coatings in simulated body fluid (SBF) solutions. The antimicrobial properties of PEO coatings were carried out by measuring the numbers of *Escherichia coli* bacterial colony after various incubation durations. The XRD patterns reveal that the PEO coatings are mainly composed of MgO (inner layer) and Mg₂SiO₄ (outer layer). Cross-sectional SEM-EDS mapping images confirm that Ag elements are well dispersed near surface of PEO coatings. The highest adhesion strength (~36 N) and the lowest wear rate ($5.5 \times 10^{-6} \text{ mm}^3/\text{N m}$) can be achieved for the PEO coating with 0.2 g/L AgNO₃ incorporated. However, the potentiodynamic polarization curves display that the PEO coatings, as compared to AZ31 magnesium alloy, exhibit higher corrosion resistances in SBF solutions. Furthermore, the PEO coating with 0.2 g/L AgNO₃ addition shows the optimal corrosion resistance due to its lowest corrosion current density ($1.07 \times 10^{-8} \text{ A/cm}^2$). Furthermore, the antibacterial efficiency of the PEO coatings is significantly improved with increasing AgNO₃ additives. More interestingly, all the PEO coatings with various AgNO₃ incorporated exhibit a 100% antibacterial efficiency to *Escherichia coli* after incubation in 45 minutes. In summary, the adhesion, wear resistance, antibacterial efficiency and corrosion resistance of PEO coatings on AZ31 magnesium alloy can be pronouncedly improved by AgNO₃ additions, highlighting their potential for biodegradable implant applications.

Keywords: PEO, AZ31, Silver nitrate, Corrosion resistance, SBF.

Friday Morning, April 24, 2026

Tribology and Mechanics of Coatings and Surfaces

Room Town & Country B - Session MC3-3-FrM

Tribology of Coatings and Surfaces for Industrial Applications III

Moderators: Osman Eryilmaz, Argonne National Laboratory, USA, Volker Weinhacht, Fraunhofer IWS, Germany

8:00am **MC3-3-FrM-1 High-performance ta-C-based coatings for tribological applications deposited by laser-arc technique, Volker Weinhacht [volker.weinhacht@iws.fraunhofer.de], Frank Kaulfuss, Stefan Makowski, Falko Hofmann, Fabian Härtwig, Martin Zawischa, Fraunhofer IWS, Germany** **INVITED**

Tetrahedral amorphous carbon (ta-C) coatings are increasingly used in tribological contacts and can be found in numerous industrial applications due to their wear resistance caused by super hardness in combination with generally low friction. Fraunhofer IWS has developed a deposition technique for stable industrial coating processes for ta-C using a pulsed, laser-triggered arc discharge on graphite cathodes. The laser-arc technique can be combined with plasma filtering to reduce the density of particle-induced defects in the ta-C coatings. In addition to the further development of plasma filter technology, IWS has currently focused on the development of doped ta-C(:X) coatings by using graphite composite cathodes. In this contribution, it will be shown how doping affects the deposition behavior as well as the structure and properties of the grown ta-C:X coatings. Special emphasis is placed on the tribological properties using various engine oils and alternative, environmentally friendly lubricants.

8:40am **MC3-3-FrM-3 The Development of Amorphous-Based Multi-Component Alloys for the Nanocomposite Coatings and their Properties, Kyoung Il Moon [kimoona@kitech.re.kr], Gi hoon Kwon, Hae Won Yoon, Byoungho Choi, Kyong jun An, Korea Institute of Industrial Technology, Republic of Korea; Sung Chul Cha, Hyundai Motor Group-Hyundai Kefico, Republic of Korea**

While modern industries are becoming more sophisticated, diversified, and globalized, they require the development of smart materials with multifunctionality, high mechanical properties, and extreme durability. Also they could be prepared environmentally friendly and energy efficiently. At the same point of view, the smart coating materials capable of simultaneously expressing various mechanical properties or opposite properties such as high hardness with high toughness, high electricity with high corrosion resistance are attracting attention as versatile and useful materials in the future. In particular, there is an urgent need to develop a novel coating material capable of stably maintaining microstructures and mechanical properties in various external environments, unlike conventional coating materials whose properties and structures are easily changed by some harsh environments. To get these kinds of objects, the coating material with multi-components is essential. But if the materials should be prepared with one phase with multi-components, they could have only one property. So, nano-composites with various phases should be formed to realize the various properties. So, it is necessary to develop a coating layer composed of various components that could be formed into various phases and more complex structures with multifunctional properties.

In this study, various single alloy target materials with various compositions based on the Zr-Cu amorphous materials have been prepared by powder metallurgy methods such as atomization, mechanical alloying, and Spark Plasma Sintering (SPS). The various nanocomposite coatings could be prepared by using single alloying targets. The most important property is the composition of the target material could be transferred to the coating layers. The properties of as-prepared nanocomposite coatings will be summarized in this presentation including the coating's performance under conditions that simulate EV drivetrain environments.

9:20am **MC3-3-FrM-5 Effect of Boriding on the Surface Hardness and Wear Resistance of Low Carbon Steel Fabricated by Wire Arc Additive Manufacturing (WAAM), Abraham Molina-Sanchez [A01363512@tec.mx], Cesar David Resendiz-Calderon, Leonardo Israel Farfan-Cabrera, Christian Ricardo Cuba-Amesquita, Tecnológico de Monterrey, Mexico**

Wire and Arc Additive Manufacturing (WAAM) enables the production of large-scale, geometrically complex components at a significantly lower cost compared to other additive manufacturing (AM) technologies. It offers extensive material availability, including low-carbon steel, which is widely used in mechanical and structural components. However, due to its low hardness and corrosion resistance compared to other steels, its use is limited in high-demand environments. This study evaluates the effect of

boriding on the surface hardness and wear resistance of low-carbon steel fabricated using the WAAM technique. WAAM-built low-carbon steel plates were printed layer by layer to complete 60 layers per sample using ER70S-6 steel wire (0.8 mm diameter). The parameters included a welding voltage of 19.7 V, 67 A current, 5 mm/s travel speed, and a shielding gas of 100% CO₂ supplied at 15 L/min. These samples were subjected to a boriding process wherein a sealed container with Ekabor 2 powder as the boron donor was used, heated at 950°C for 3 hours, and cooled at room temperature. A boride layer with an average thickness of $93.5 \pm 32.6 \mu\text{m}$ composed of FeB and Fe₂B phases was formed, as confirmed by X-ray diffraction (XRD). The adhesion of the boride layer on the as-built (AB) samples was evaluated using a progressive scratch test, and nanoindentation revealed an increase in hardness with no significant changes along the material deposition direction. Dry-sliding tests measured the coefficient of friction (CoF) between AB and borided samples, and a considerable wear volume decrease of 20% was observed with the boride layer, as measured by optical profilometry. These results demonstrate no significant changes along the build direction in phase composition, hardness, or tribological behavior, indicating that boriding is an effective surface treatment for enhancing wear resistance in WAAM-fabricated low-carbon steel.

10:20am **MC3-3-FrM-8 Ultralow Wear, Conductive Plasma-Enhanced Atomic Layer Deposited Metal Nitrides, Brandon Krick [bkrick@eng.famu.fsu.edu], Florida State University, USA** **INVITED**

Bold page numbers indicate presenter

— A —

Abegunde, Olayinka: MC3-1-TuM-6, **1**
 Adams, David: MC1-1-ThA-2, **7**; MC1-2-FrM-3, **12**
 Aicholz, Steffen: MC-ThP-3, **9**
 Ajayi, Oyelayo: MC3-1-TuM-4, **1**
 Alex, Jacoboni: MC1-1-ThA-1, **7**
 An, Kyong jun: MC3-3-FrM-3, **13**
 Andraca-Adame, J.A.: MC-ThP-11, **10**
 Aouadi, Samir: MC3-1-TuM-9, **2**
 ARAUJO MONSALVO, VICTOR MANUEL: MC2-1-TuA-5, **3**
 Arzate-Vázquez, I.: MC-ThP-11, **10**
 Asenath-Smith, Emily: MC3-1-TuM-6, **1**
 Auregan, Gilles: MC1-1-ThA-1, **7**

— B —

Babuska, Tomas: MC1-1-ThA-2, **7**; MC1-2-FrM-3, **12**
 Baral, Madhav: MC2-1-TuA-10, **3**
 Bassano, Alessio: MC-ThP-12, **10**
 Berkebile, Stephan: MC3-1-TuM-9, **2**
 Berman, Diana: MC1-1-ThA-4, **7**; MC3-1-TuM-9, **2**
 Bernardelli, Giacomo: MC-ThP-12, **10**
 Bislin, Kenny: MC3-1-TuM-3, **1**
 Bobbitt, Scotty: MC1-1-ThA-2, **7**
 Böbel, Klaus: MC-ThP-6, **9**
 Bobzin, Kirsten: MC-ThP-4, **9**
 Bohley, Martin: MC3-1-TuM-3, **1**
 Bolelli, Giovanni: MC-ThP-12, **10**
 Broitman, Esteban: MC-ThP-10, **10**
 Brown, Nathan: MC1-1-ThA-2, **7**

— C —

Campos Silva, Enrique: MC3-2-WeA-6, **5**
 Campos Silva, Iván: MC-ThP-1, **9**
 Cavarroc-Weimer, Marjorie: MC1-1-ThA-1, **7**
 Cha, Sung Chul: MC3-2-WeA-3, **5**; MC3-3-FrM-3, **13**
 Chandross, Michael: MC1-1-ThA-2, **7**
 Cheng, Yang-Tse: MC2-1-TuA-10, **3**
 Choi, ByoungHo: MC3-3-FrM-3, **13**
 Contla Pacheco, Alan Daniel: MC-ThP-1, **9**
 Cordill, Megan J.: MC2-1-TuA-1, **3**
 Crawford, Grant: MC3-1-TuM-6, **1**
 Cuba-Amesquita, Christian Ricardo: MC3-3-FrM-5, **13**
 Curry, John: MC1-1-ThA-2, **7**; MC1-2-FrM-3, **12**

— D —

Danelon, Miguel R.: MC1-2-FrM-2, **12**
 Dehm, Gerhard: MC2-1-TuA-8, **3**
 DelRio, Frank: MC1-1-ThA-2, **7**
 Dorman, Kyle: MC1-1-ThA-2, **7**
 Dulebo, Alexander: MC-ThP-14, **11**

— E —

Edwards, Camille: MC1-1-ThA-2, **7**
 Erdemir, Ali: MC1-1-ThA-5, **7**
 Eryilmaz, Levent: MC3-1-TuM-4, **1**
 Escobar-Hernández, Josué: MC-ThP-11, **10**
 Eskandari, Mohammad: MC1-1-ThA-4, **7**; MC3-1-TuM-9, **2**
 Esselbach, Markus: MC3-2-WeA-5, **5**

— F —

Faiyad, Abrar: MC1-2-FrM-2, **12**
 Farfan Cabrera, Leonardo: MC3-2-WeA-6, **5**
 Farfan, Leonardo: MC1-1-ThA-5, **7**
 Farfan-Cabrera, Leonardo Israel: MC3-3-FrM-5, **13**
 Faurie, Damien: MC2-1-TuA-3, **3**

Fernández Valdés, Daybelis: MC2-1-TuA-5, **3**; MC-ThP-1, **9**
 Fleischmann, Christian: MC3-1-TuM-3, **1**
 Fridrici, Vincent: MC1-1-ThA-1, **7**
 Fukumasu, Newton K.: MC1-2-FrM-2, **12**

— G —

Gachot, Carsten: MC-ThP-6, **9**
 Garcia Barragan, Sebastian: MC3-2-WeA-6, **5**
 Gies, Astrid: MC3-1-TuM-3, **1**
 Greco, Aaron: MC3-1-TuM-4, **1**

— H —

Hall, Justin: MC1-1-ThA-2, **7**
 Hangen, Ude D.: MC-ThP-14, **11**
 Härtwig, Fabian: MC3-3-FrM-1, **13**
 Hebbbar Kannur, Kaushik: MC3-1-TuM-3, **1**
 Hofmann, Falko: MC3-3-FrM-1, **13**
 Huben, Theresa: MC3-1-TuM-3, **1**

— J —

Jang, Ji-Woong: MC1-1-ThA-10, **8**
 Jang, Young-Jun: MC1-1-ThA-10, **8**

— K —

Kalscheuer, Christian: MC-ThP-4, **9**
 Kappaun Vieira, Nathalia: MC-ThP-3, **9**
 Kaulfuss, Frank: MC3-3-FrM-1, **13**
 Kelling, Sven: MC-ThP-10, **10**
 Keraudy, Julien: MC-ThP-6, **9**
 Kim, Jae-Il: MC1-1-ThA-10, **8**
 Kim, Jongkuk: MC1-1-ThA-10, **8**; MC3-2-WeA-3, **5**
 Kiyoshi Fukumasu, Newton: MC1-1-ThA-7, **8**
 Komurlu, Merve: MC1-1-ThA-5, **7**
 Korenyi-Both, Andras: MC3-1-TuM-1, **1**
 Kose, Rickmer: MC-ThP-10, **10**
 Krick, Brandon: MC3-3-FrM-8, **13**
 Kutrowatz, Philip: MC-ThP-6, **9**
 Kwon, Gi hoon: MC3-3-FrM-3, **13**
 Kwon, Gi-Hoon: MC3-2-WeA-3, **5**

— L —

Labuda, Aleksander: MC1-1-ThA-9, **8**
 Larson, Steven: MC1-2-FrM-3, **12**
 Lee, Seungjoo: MC1-1-ThA-5, **7**
 Lee, Yueh-Lien: MC-ThP-9, **10**
 Lefever, Joel: MC1-1-ThA-9, **8**
 Lin, Jianliang: MC3-2-WeA-4, **5**
 Lusvarghi, Luca: MC-ThP-12, **10**

— M —

Macknoja, Ali Zayaan: MC1-1-ThA-4, **7**; MC3-1-TuM-9, **2**
 Madden, Nathan: MC3-1-TuM-6, **1**
 Makowski, Stefan: MC3-3-FrM-1, **13**
 Mangolini, Filippo: MC1-1-ThA-2, **7**
 Martini, Ashlie: MC1-2-FrM-2, **12**
 Martins de Souza, Roberto: MC1-1-ThA-7, **8**
 Melo-Pérez, M. A.: MC-ThP-11, **10**
 MENESES AMADOR, ALFONSO: MC2-1-TuA-5, **3**; MC-ThP-1, **9**
 Meruvia, Michelle: MC-ThP-7, **10**
 Meruvia, Michelle Sostag: MC-ThP-5, **9**
 Mings, Alexander: MC1-2-FrM-3, **12**
 Molina-Sanchez, Abraham: MC3-3-FrM-5, **13**
 Montes de Oca Zapiain, David: MC1-1-ThA-2, **7**
 Moon, Kyoung Il: MC3-2-WeA-3, **5**; MC3-3-FrM-3, **13**
 Moreno-Ruiz, L. A.: MC-ThP-11, **10**
 Moser, Stefan: MC3-1-TuM-3, **1**

— N —

Nava Leana, Felipe: MC2-1-TuA-5, **3**; MC-ThP-1, **9**
 Neitzke, Cesar: MC-ThP-7, **10**

Nieto-Sosa, J. A.: MC-ThP-11, **10**

— O —

Ocampo Ramírez, Arturo: MC-ThP-1, **9**
 Oelschlegel, Felix: MC3-1-TuM-3, **1**

— P —

Pape, Florian: MC-ThP-14, **11**
 Papesh, Henry: MC1-1-ThA-5, **7**
 Paulo Tschipschin, André: MC1-1-ThA-7, **8**
 Pérez Terán, Hugo Alberto: MC2-1-TuA-5, **3**
 Pözlberger, Daniel: MC-ThP-6, **9**
 Proksch, Roger: MC1-1-ThA-9, **8**

— Q —

Queiroz Carara, Gabriel: MC-ThP-7, **10**

— R —

Ravelo Santos, Edgar: MC3-2-WeA-6, **5**
 Resendiz Calderon, Cesar: MC3-2-WeA-6, **5**
 Resendiz-Calderon, Cesar David: MC3-3-FrM-5, **13**
 Riedl, Helmut: MC-ThP-6, **9**

RODRIGUEZ CASTRO, GERMAN ANIBAL:

MC2-1-TuA-5, **3**; MC-ThP-1, **9**

Rodríguez-Castro, G. A.: MC-ThP-11, **10**

Rosenkranz, Andreas: MC3-1-TuM-7, **2**

Roux Reyna, Mateo: MC3-2-WeA-6, **5**

Rubira Danelon, Miguel: MC1-1-ThA-7, **8**

— S —

Sato, Shun: MC1-2-FrM-4, **12**
 Scalabrin, Heloisa: MC-ThP-7, **10**
 Scalabrin, Heloisa: MC-ThP-5, **9**
 Scandian, Cherlio: MC1-2-FrM-2, **12**
 Schmittbuhl, Marc: MC1-1-ThA-1, **7**
 Soares, Paulo: MC-ThP-3, **9**; MC-ThP-5, **9**; MC-ThP-7, **10**

Sostag Meruvia, Michelle: MC-ThP-3, **9**

Souza, Roberto M.: MC1-2-FrM-2, **12**

Stangier, Dominic: MC3-2-WeA-1, **5**

Stelzig, Timea: MC3-1-TuM-3, **1**

Sung, Gugyeong: MC1-1-ThA-5, **7**

Suzuki, Kosuke: MC1-2-FrM-4, **12**

— T —

Tardelli, Joffrey: MC1-1-ThA-1, **7**
 Thapa, Santosh: MC2-1-TuA-10, **3**
 Thompson, Forest: MC3-1-TuM-6, **1**
 Tokoroyama, Takayuki: MC1-2-FrM-4, **12**
 Torres, Ricardo: MC-ThP-7, **10**

Torres, Ricardo Diego: MC-ThP-3, **9**; MC-ThP-5, **9**

Tseng, Chuan-Ming: MC1-2-FrM-8, **12**

— U —

Umehara, Noritsugu: MC1-2-FrM-4, **12**

— V —

Vera-Cárdenas, E.E.: MC-ThP-11, **10**
 Voevodin, Andrey: MC3-1-TuM-9, **2**
 Volz, Udo: MC-ThP-14, **11**

— W —

Weihnacht, Volker: MC3-3-FrM-1, **13**
 Wojcik, Tomasz: MC-ThP-6, **9**

— X —

Xu, Wenting: MC-ThP-4, **9**

— Y —

Yelkarasi, Cagatay: MC1-1-ThA-5, **7**
 Yoon, Hae Won: MC3-2-WeA-3, **5**; MC3-3-FrM-3, **13**
 Yumoto, Kenji: MC1-2-FrM-4, **12**

— Z —

Zawischa, Martin: MC3-3-FrM-1, **13**
 Zhang, Ruixi: MC1-2-FrM-4, **12**
 Zheng, Bo-Xuan: MC1-2-FrM-8, **12**