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

Tribology of Coatings and Surfaces for Industrial Applications II

Moderators: Osman Eryilmaz, Argonne National Laboratory, USA, **Stephan Tremmel**, University of Bayreuth, Germany

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 Germany 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 electro-magnetic 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 [sungchul.cha@hyundai-kefico.com],* Hyundai Motor Group- Hyundai Kefico, Republic of Korea*; Kyoung Il Moon, Hae Won Yoon,* KITECH, Republic of Korea*; Jongkuk Kim,* KIMS, 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 CrAlN, 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 $4.8x10^{-9}$ $mm^3N^{-1}m^{-1}$ 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 Combining laser-textured dimples and AlCrN coating to reduce wear on AISI M2 steel***, Iker Alfonso [iker.alfonso@unavarra.es], Adrian Claver, Jose Antonio Garcia,* Universidad Pública de Navarra, Spain*; Iban Quintana,* Tekniker, Spain*; Iñaki Zalakain,* Universidad Pública de Navarra, Spain

Tool degradation remains a major challenge in precision metal forming, where punches and dies are exposed to high pressures and temperatures leading to accelerated surface wear. A common strategy to mitigate this is the application of hard ceramic coatings, such as CrN, TiN, AlCrN, or DLC, deposited by Physical Vapor Deposition (PVD). Additionally, Laser Surface Texturing (LST) has emerged as a promising technique to improve tribological behavior by creating micro-features like dimples, which can trap debris and act as lubricant reservoirs. The combination of both techniques has shown promising benefits, although further optimization is still required.

This work explores the combination of femtosecond laser surface texturing (LST) and AlCrN coating as a promising strategy to reduce wear on fine blanking tools. Dimple textures with a diameter of 50 µm, a depth of 15µm and a surface coverage of 10%, 15%, and 20% were fabricated on AISI M2 steel. After the fabrication of the textures an AlCrN coating of 1.5 µm thickness was deposited via HIPIMS. SEM images of the surface confirmed the proper coating coverage of the dimples and the study of the cross-section revealed a suitable film growth. Nanoindentation and scratch tests showed 33 GPa hardness and good adhesion. Contact angle measurements indicated that the as-prepared surfaces were oleophilic, while increasing the textured area density led to a progressive shift toward higher hydrophobicity. Ball-on-disk tests demonstrated that an initial lubricant supply of 0.05 mL was sufficient to maintain a stable separation lubricant film under loads of 10, 30 and 50 N, resulting in friction coefficients between 0.10 and 0.15 regardless of textured area density. Long-term tests performed for 20000 cycles revealed a clear improvement in wear resistance, with the wear coefficient k decreasing from 2.99E-06 m^3/Nm to 8.02E-08 m^3/Nm when applying the AlCrN coating on textured samples. SEM/EDX analysis of the wear tracks indicated reduced degradation of the dimples in the case of the AlCrN-coated samples, and no significant chemical interaction with the alumina ball. Results suggest that applying a tribological coating is the primary approach to mitigate wear, while further work is needed to explore the potential of surface textures as wear debris traps and lubricant reservoirs.

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 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.

Author Index

Bold page numbers indicate presenter