Wednesday Morning, May 14, 2025

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

Tribology of Coatings and Surfaces for Industrial Applications I

Moderators: Rainer Cremer, KCS Europe GmbH, Germany, **Stephan Tremmel**, University of Bayreuth, Germany

9:00am **MC3-1-WeM-4 Cyclic and Randomized Micro-Impact Tests of Coatings for Erosion Protection: Role of Multilayer Structure in Providing Damage Tolerance***, **Ben Beake [ben@micromaterials.co.uk]**,* Micro Materials Ltd, UK*; Daniel Tobola,* Lukasiewicz Research Network, Krakow Institute of Technology, Poland*; Luksaz Maj,* Institute of Metallurgy and Materials Science of Polish Academy of Sciences, Krakow, Poland*; Tomasz Liskiewicz,* Manchester Metropolitan University, UK*; Puneet Chandran,* Lukasiewicz Research Network, Krakow Institute of Technology, Poland

Coating systems for applications in machining and forming tools, and in applications where they are subject to solid particle erosive wear, are subject to high loads which can result in high wear and premature failure. To aid the design of coating systems to mitigate this with improved surface fatigue resistance, cyclic micro-impact tests have been performed on three hard multilayered coatings (TiN/TiCrN/TiN, TiN/TiCrN/10x(TiN/CrN)/TiN and 25x(Cr/CrN)) deposited by arc evaporation onto hardened tool steel and results compared to a monolayer TiN reference. To more closely replicate the statistical, and apparently stochastic, distribution of multiple impacts that occur in solid particle erosion randomized micro-impact tests were performed where multiple impacts occur with controlled energy at different (chosen) locations on the coating surface. The cyclic and randomized impact tests were both performed using a multi-sensing approach where the depth and dissipated energy were monitored for every impact improving detection of the onset of severe wear. The multilayered TiN-based coatings were more prone to chipping than the monolayer TiN in the cyclic and randomized tests. Although the 25x(Cr/CrN) coating was susceptible to radial cracking and cracking within impact craters this localized cracking relieved the impact-induced stresses and minimized the chipping failure found on the other coatings. SEM and TEM imaging has been used to investigate the impact damage phenomena.

9:20am **MC3-1-WeM-5 Effect of Bias Voltage and Temperature on the Structural and Tribo-Mechanical Properties of Chemically Complex Tisibcn Nanocomposites***, Wolfgang Tillmann,* ***Julia Urbanczyk [julia.urbanczyk@tu-dortmund.de]**,* TU Dortmund University, Germany*; Alexander Thewes,* TU Braunschweig University, Germany*; Nelson Filipe Lopes Dias,* TU Dortmund University, Germany

TiSiBCN thin films show promising properties for applications at elevated temperatures due to improved thermal stability and oxidation resistance, as well as friction-reducing characteristics.While previous studies investigated mainly the effect of the chemical composition on the thin film properties, it remains unclear how deposition parameters, such as the bias voltage and the heating power, affect the structural and tribo-mechanical properties of TiSiBCN. For this reason, the effect of the bias voltage and heating power on magnetron-sputtered TiSiBCN nanocomposites with different chemical compositions was analyzed. In the first line of investigation, the bias voltage was varied from -100, -150, and –200 V, and in the second line, the heating power was set to 2, 5, and 8 kW.

The chemical composition remains nearly unaffected by the heating power, while the bias voltage has a slight effect on the quantity of the elements. X-ray diffraction (XRD) analysis revealed a polycrystalline structure with randomly oriented crystallites, characterized by different peak shifts depending on the chemical composition. Identified crystalline phases include TiN, TiC, TiB, and TiB_2, coexisting with various amorphous phases. Transmission electron microscopy (TEM) images reveal a nanocomposite structure and changes in microstructure, such as crystallite refinement with higher bias voltage or growth, as well as further self-assembly with higher deposition temperatures, depending on the chemical composition and initial phase structure. An increased bias voltage induces residual stresses while the hardness tends to decrease. With higher heating power, internal stresses are released and the hardness increases up to 41 GPa. To explore the application potential of the TiSiBCN thin films for forming processes of aluminum alloys, the tribological behavior was evaluated against AW-6060 in tribometer tests, highlighting TiSiBCN as a promising protective coating.

9:40am **MC3-1-WeM-6 Lubrication Mechanism of CrAlN+MoWS Coatings in Gear Contacts under Dry Rolling-Sliding Conditions***, Kirsten Bobzin, Christian Kalscheuer, Max Philip Möbius,* ***Marta Miranda Marti [marti@iot.rwth-aachen.de]**,* Surface Engineering Institute - RWTH Aachen University, Germany

The use of liquid lubricants for wear and friction reduction in geared transmissions is well established. However, in applications like the food industry, liquid lubricants are undesirable due to contamination risks. A promising alternative involves applying a wear-resistant CrAlN coating incorporated with solid lubricant components, such as molybdenum, tungsten and sulfur. Previous studies demonstrated the functionality of graded CrAlN+MoWS coatings, analyzing the lubrication mechanism on flat samples using pin-on-disc method. Further studies extended this analysis to gear applications, where the coating reduced friction and wear by 88 % compared to uncoated contacts.

In this study the lubrication mechanism of PVD deposited graded CrAlN+MoWS on gears was analyzed. The coated wheels were tested against uncoated pinions under varying Hertzian pressure at pitch point, with p_{H1} = 589 N/mm^2 and p_{H2} = 1.723 N/mm^2, and circumferential speed v_{t1} = 2 m/s and v_{t2} = 8,3 m/s. After tribological testing, the gear tooth surfaces were examined using confocal laser scanning microscopy (CLSM) and energy-dispersive X-ray spectroscopy (EDX) to determine the coating distribution. Raman spectroscopy was employed to analyze the possible formation of the solid lubricant MoS_2 and WS_2 phases, as well as other friction-reducing oxides. At lower Hertzian pressures, the triboactive elements on the wheel tooth flank are effectively consumed, leading to a friction reduction compared to uncoated gear contacts. On the wheel tooth faces, the triboactive elements remain present and are identified through Raman spectroscopy as MoS_2, which could further contribute to friction reduction. On the corresponding uncoated pinions, traces of Mo, W, and S are detected, confirming the effective transfer mechanism of CrAlN+MoWS coatings in gear contacts at lower Hertzian pressure. At higher Hertzian pressures and high circumferential speeds, traces of MoS_2 are observed on the wheel tooth face, indicating the coating consumption to reduce friction and demonstrating the effectiveness of the coating under extreme testing conditions, which expand the gear's lifespan compared to uncoated gear contacts.

The results demonstrate the lubrication mechanism of the CrAlN+MoWS coating in gear contact. MoS_2 is generated at the gear contact, even under low Hertzian pressure, and is efficiently utilized within the contact zone to ensure a friction reduction. At higher speeds, these triboactive elements remain effective, continuing to enhance lubrication and reduce wear within the gear contact when compared to uncoated gears.

11:00am **MC3-1-WeM-10 Wear Protection via Triboactive CrAlMoN Coatings in Chain Drives***, Kirsten Bobzin, Christian Kalscheuer,* ***Max Philip Möbius [moebius@iot.rwth-aachen.de]**,* Surface Engineering Institute - RWTH Aachen University, Germany*; Martin Rank, Oliver Koch,* Institute of Machine Elements, Gears and Tribology - RPTU Kaiserslautern-Landau, Germany

Within chain drives, critical wear occurs between the chain pin and chain bush, leading to chain elongation. This determines the service life of a chain. Hard coatings deposited by physical vapor deposition (PVD), such as CrAlN, can effectively reduce wear. However, coating the inner surfaces of chain bushes presents economic and technological challenges. A promising alternative is the use of triboactive CrAlMoN coatings, which interact with lubricants and their additives to form protective tribofilms. These tribofilms can transfer to uncoated chain bushes, providing essential wear protection.

In this study, three chains were assembled using uncoated, CrAlN and CrAlMoN coated pins. These chains were then tested on a chain drive test bench. All chains were lubricated with grease containing sulfur additives. Analyses of the as-coated chain pins included geometry, surface roughness, coating thickness, coating morphology and compound adhesion. The chains underwent testing under medium load conditions corresponding to a power transmission of P_M = 2.3 kW and high load conditions corresponding to P_H = 9.5 kW. Wear was monitored through periodic measurements of chain elongation to determine wear rates over time. Upon completion of testing, both chain pins and bushes were analyzed for visual appearance changes, wear volume, surface topography, and remaining coating thickness. Under medium load conditions, CrAlMoN coated chains exhibited slightly higher wear rates compared to reference systems. However, under high load conditions, CrAlMoN coated chains demonstrated the lowest wear rates among all tested configurations. Notably, wear distribution between the chain pin and bush was more uniform in CrAlMoN coated systems compared to others where higher wear predominantly affected uncoated bushes.

This observation suggests that the formation and transfer of protective tribofilms in CrAlMoN systems contribute significantly to enhanced wear resistance under high stress conditions. Analysis after high-load testing revealed that CrAlMoN coated pins retained substantial coating thickness within the wear areas of the pin.The findings indicate that triboactive CrAlMoN coatings hold considerable promise for reducing wear in high-performance chain drives by forming protective tribofilms during tribological operation that can be transferred to uncoated chain bushings.

11:20am **MC3-1-WeM-11 Tribological Contact Formation on PVD-Coated Tools***, **Aljaz Drnovsek [aljaz.drnovsek@ijs.si]**, Peter Panjan, Matjaž Panjan, Miha Čekada,* Jožef Stefan Institute, Slovenia **INVITED**

Tools surface topography changes dramatically after PVD coating deposition. Various topographical imperfections on the coating surface can negatively impact the quality of the coating and, in some cases, cause the failure of the coating. The imperfections in coated forming tools initiated over a decade of research into the phenomena associated with coating surfaces, particularly the growth defects.

I will present results related to the formation of the coating topography and how it depends on factors such as substrate material, ion etching, and deposition processes. The topographical features of the coating significantly influence oxidation, corrosion, and especially the tribological behavior of PVD coatings.

The influence of the coated surface on the formation of a tribological contact has been the focus of several studies, as the contact area between two sliding bodies is not constant with time. Initially, only the asperities which appear as growth defects are in real contact with the counter body. Under load, these asperities can fracture, spall, and produce small particles. The real contact area is increasing sharply before it stabilizes. In terms of friction, we recognize this behavior as the running-in period. The coefficient of friction increases in this period until it reaches a steady state value. It is still poorly understood how this transition from the run-in to the steady state friction occurs and, more importantly, how the growth defects affect the tribological performance. The role of defects in the formation of the tribological contact changes depending on counter body materials and operating temperature. The latter was studied recently. The results indicate that in the case of the TiAlN coating, the highest wear was measured during the room temperature test. Conversely, the wear during the running-in phase and steady-state friction were low at elevated temperatures initially, but as the temperature increased, the wear rate rose, which can be attributed to increased tribological oxidation and fatigue.

The growth defects on the coating surface played a significant role in the friction and wear behavior, as they were a primary source of wear particles and the first spots of oxidation on the coating. The measurements suggest that the running-in phase depends mainly on the asperities density at room temperature tests. In contrast, at high temperatures, they attributed to the formation of a stable tribological oxide layer in the wear track, which elongates the running-in period and protects the coating underneath.

12:00pm **MC3-1-WeM-13 Effect of Transition Metals (Nb, V, and Ta) Doping on the High-Temperature Mechanical and Tribological Properties of CrYN Coatings***, Gokhan Gulten, Banu YAYLALI, Mustafa YESILYURT, Yasar TOTIK,* Atatürk University, Turkey*; Justyna Kulczyk Malecka, Peter Kelly,* Manchester Metropolitan University, U.K.*; **Ihsan EFEOGLU [iefeoglu@atauni.edu.tr]**,* Atatürk University, Turkey

This study aims to develop a high temperature wear resistant coating for AISI 316L. As a functional coating, CrYN coatings with added niobium, tantalum, and vanadium (a-C:H:Nb/Ta/V) were deposited using a closed-field unbalanced magnetron sputtering (CFUBMS) system. The Taguchi L9 orthogonal array approach was used to test and systematically change a variety of parameters in order to achieve the optimal coating properties. The microstructural properties of the coatings were examined using a scanning electron microscope (SEM), while X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) analysis were conducted to determine crystallographic and surface chemistry properties, providing a detailed understanding of the coating structure. Nanoindentation tests were performed to determine mechanical properties, yielding precise measurements of hardness and elasticity. The adhesion of the coatings was measured through scratch tests at varying temperatures (400, 600, and 800 °C) and room temperature. The tribological characteristics of the a-C:H:Nb/Ta/V coatings were assessed using a high-temperature pin-on-disc tribometer, examining their wear resistance and frictional behavior under ambient air and at varying temperatures (400, 600, and 800 °C). These comprehensive analyses reveal the potential of the a-C:H:Nb/Ta/V coatings for applications requiring enhanced surface properties, offering superior tribological performance across different temperature conditions.

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