Tribology and Mechanical Behavior of Coatings and Engineered Surfaces

Room Town & Country B - Session E3-TuM

Coatings for Automotive and Aerospace Applications

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8:40am **E3-TuM-3 Thermomechanical Stability of Hard DLC Coatings Produced by HiPIMS-DOMS***, **João Carlos Oliveira (joao.oliveira@dem.uc.pt),*** University of Coimbra, Portugal*; A. Vahidi,* University of Coimbra, Iran (Islamic Republic of)*; F. Ferreira, R. Serra, A. Cavaleiro,* University of Coimbra, Portugal

DLC films are very resistant to abrasive and adhesive wear making them suitable for applications that experience extreme contact pressure. For this reason, they are one of the most promising solutions for application in piston´s rings of internal combustion engine (ICE). However, recent trends in the automotive industry, such as reduced engine sizes and turbocharging, require higher operating temperatures and loads, which the classical DLC films deposited by magnetron sputtering cannot withstand. High Power Impulse Magnetron Sputtering (HiPIMS) has been actively investigated for hard DLC deposition. In HiPIMS, a large fraction of sputtered atoms is ionized, thanks to 2–3 orders of magnitude higher plasma densities than in classical magnetron sputtering. However, in the standard HiPIMS process based on Ar, the ionized fraction of C is very low (few percent), due to the low carbon ionization cross section by electron impact.

In previous work, the authors have shown that adding Ne to the plasma up to 50 % results in the deposition of denser and smoother DLC films, with improved tribological properties and increased hardness. In this work, the thermal stability of DLC films deposited in Ar-Ne discharge gas by Deep Oscillation Magnetron Sputtering (DOMS), a variant of HiPIMS, was investigated. In a first step, the thermal stability of the films by annealing up to 700 ºC in a protective atmosphere. The structure of the DLC films deposited without Ne in the discharge gas was stable up to 500 ºC, while clear signs of graphitization were detected at higher temperatures by Raman spectroscopy. The stability of the film up to 500 ºC was confirm by pin-on-disk tests and nanoindentation at room temperature after annealing. The structure of the DLC films deposited with Ne in the discharge gas was stable up to annealing at 700 ºC as shown by Raman spectroscopy. However, the hardness of the films decreases from 25 to 20 GPa upon annealing at 700ºC, while the specific wear rate increases from 0.5 to 1.25 x 10^{-16} m^3/Nm. The thermal stability of the DLC films was also characterized by pin-on-disk tests at high temperature. The coatings were tested up to 400 ºC in ambient atmosphere. Adding Ne to the deposition plasma resulted in an increased thermal stability by 50 ºC for the film deposited with a mixed Ne + Ar discharge gas.

9:00am **E3-TuM-4 Static and Dynamic Friction Assessment Using Novel High Temperature Tribometer***, **Marwan Azzi (marwan.azzi@polymtl.ca),*** Polytechnique Montreal, Canada*; E. Bitar-Nehme,* Tricomat inc, Canada*; J. Sapieha,* Polytechnique Montreal, Canada*; l. Martinu,* Polytechnique Montréal, Canada

Tribology in extreme environments has recently gained significant interest in the aerospace and energy generation communities, largely due to the increased demand for development of durable and more efficient engineering components with an increased performance beyond the current limits. For instance, the next generation gas turbine engines are required to reduce fuel consumption and pollution emission by significant amount which requires a step change in the design and operating environment of the mechanical systems (e.g. higher temperature and contact pressure).

In the present work, a novel experimental test rig has been developed to rigorously investigate the evolution of the static and dynamic friction as well as the wear resistance of a tribological contact exposed to high temperatures (HT) for long period of time. Pin-on-Flat configuration has been adopted in the design with the flat sample being mounted in a furnace that heats up to 800oC. Here, we present an approach to assess static and dynamic friction, and we illustrate it by the results obtained on several materials including stainless steel and Inconel substrates with TiN- and CrN-based vacuum coatings deposited by magnetron sputtering. The measurements showed that a number of sliding cycles is necessary to reach a stable static and dynamic coefficient of friction (CoF). These sliding cycles could be performed uni-directionally or bi-directionally with no effect on the steady-state value of CoF. In addition, it was found that the HT exposure time with closed and stationary tribological contact increases significantly the static CoF which might be related to processes such as diffusion that take place at the interface. The HT tribological testing combined with detailed microstructural characterization of the wear scar (SEM, EDS and Raman spectroscopy) allowed to determine the friction and wear mechanisms. The oxide layer formed at HT was found to play a crucial role in the evolution of HT static friction.

9:20am **E3-TuM-5 Study of the a-C:H Coating Wear Behaviour in Boundary Lubricated Tribological Contacts Using Raman-Based Profilometry (Virtual Presentation)***, **Ardian Morina (A.Morina@leeds.ac.uk),*** University of Leeds, UK*; N. Xu,* University of Leeds, UK , UK **INVITED**

While for ferrous boundary lubricated tribological systems, it is relatively well established that the tribofilms formed from lubricant additives determine friction and wear performance, the effect of lubricant additives on DLC coating wear performance and mechanisms is still not clear. The ability to quantify coating thickness as a function of testing time has the potential to provide new insights on the correlation between tribofilm formation and coating wear, enabling improved lubricant and coating designs.

In this paper, the development of a novel method for measuring coating thickness at the nanoscale level, with the potential to be used for in-situ wear measurement during the test, will be reported.The method is based on using a Raman-active coating underlayer as a sensor of the coating thickness.In this approach, the a-C:H coating is considered a light attenuating layer of the silicon underlayer. The method has been used to study the a-C:H coating wear rate from dry and a boundary lubricated system using molybdenum dialkyldithiocarbamate (MoDTC) additive. A two-stage wear progression mechanism has been proposed for the first time to clarify the detrimental effect of MoDTC-derived tribofilm on a-C:H wear by combining detailed structure and composition analysis. The results have also been supported by post-test Raman spectroscopy, optical profilometer, EELS and TEM analysis.

Keywords: wear measurement, coating, additives, Raman, solid-liquid lubricating

10:00am **E3-TuM-7 Erosion Resistance of TiAlN Coatings for Aerospace Applications***, **Zeliha Idil Kara (e194125@metu.edu.tr),** S. Ozerinc,* Middle East Technical University, Turkey

Aircraft engine components are subjected to extreme conditions of stress and temperature, resulting in challenging materials requirements. An additional issue is erosion taking place in the air intake since the stochastic nature of the erosion makes the surface susceptible to the formation of micro-cracks, which can cause premature failure that can be catastrophic for the whole aircraft. An effective route to increase the resistance of the components against these harsh environments is the application of wear-resistant coatings. TiN & TiAlN-based coatings produced by physical vapor deposition are commonly preferred due to their low thickness, the ability to effectively coat complex shapes, and the additional advantage of providing resistance to corrosive environments. This study evaluated the characteristics and the performance of TiAlN PVD thin film coatings with an emphasis on erosion performance. Microstructural and mechanical characterization combined with erosion and corrosion testing provided insight into the performance of these coatings under the above explained harsh conditions. Single-layer (≈10 µm thick) TiAlN coatings were applied on the titanium substrates by the cathodic arc deposition method. The microstructure of the coatings was investigated by SEM and X-ray diffraction. The mechanical properties were determined by nanoindentation testing. The adhesion of the coating was examined by scratch tests performed according to EN ISO 20502 in a 10 to 50 N loading range. Solid particle erosion tests were performed according to ASTM G76 by using two different angles of particle impingement of the TiAlN thin film coating. Lastly, salt spray tests were performed according to ASTM B117 to quantify the corrosion resistance of the coatings. The results show that the TiAlN coatings have a high density and exhibit a cubic crystal structure with nanograins. The hardness and elastic modulus of the coatings were in agreement with the previously reported literature values. The erosion tests showed that the coatings dramatically reduce the erosion rate compared to uncoated specimens. The uncoated specimens showed severe surface roughness and crack formation whereas the coated surfaces were intact. Overall, the results demonstrate the effectiveness of the TiAlN coatings in reducing erosion and corrosion, making them suitable for aircraft engine applications. Future studies will focus on the further optimization of the coating composition and morphology for superior mechanical performance.

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