Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room Golden State Ballroom - Session EP-ThP

Tribology and Mechanical Behavior of Coatings and Engineered Surfaces (Symposium E) Poster Session

EP-ThP-2 Atmospheric Pressure Plasma Deposition of Low Friction Coatings on Engineering Thermoplastics: The Plasma-Process-Structure in the Versatile Spray Coating Technique as Basis of Commercial Applications,
***Dietmar Kopp (dietmar.kopp@joanneum.at)**, J. Lackner, R. Kaindl, W. Waldhauser,* Joanneum Research Forschungsgesellschaft GmbH, Austria*; M. Stummer,* INOCON, Austria*; A. Coclite,* Graz University of Technology, Austria

Deposition strategies to obtain low friction and wear resistant coatings on 3D-printed, rough polyamide 12 (PA, nylon) surfaces were developed by atmospheric pressure plasma deposition. Dry lubricants such as MoS_2 and graphite were fed as powder material to the DC plasma torch by INOCON Technologie GmbH, applying parameter sets that would not thermally damage the heat sensitive polymers. In general, microtribological characterization indicates that especially high influence on the coating performance is given by the coating composition and thickness. Pure MoS_2 coatings are quickly worn, especially on roughness tips (mean substrate roughness R_a up to 20 µm), exposing the substrate locally and leading to friction coefficients similar to PA12 and rather limited potential of wear protection. Compound coatings with graphite within a MoS_2 matrix provide huge potential for wear protection (>20 times less penetration depth) even in the case of exposing PA12 to roughness tips, due to the transfer of lubricating carbon into these exposed areas. If the thickness is sufficiently high, missing wear of tips results in low-friction behavior with friction coefficients <0.1 (thus, 4 times lower than for uncoated PA12).

EP-ThP-3 The Influence of Boron in Thick AlTiN and AlCrN Coatings Deposited by Bipolar HiPIMS to Control Residual Stress and Improve Tribomechanical Properties,
***Adrián Claver (adrian.claver@unavarra.es)**,* Institute for Advanced Materials and Mathematics (INAMAT2), Universidad Pública de Navarra (UPNA), Spain*; I. Fernandez,* Nano4Energy SL, Spain*; J. Endrino,* Nano4Energy SL, University Loyola, Sevilla (Spain), Spain*; J. Santiago ,* Nano4Energy SL, Spain*; J. Fernández Palacio,* Centre of Advanced Surface Engineering, AIN, Spain*; J. García,* Institute for Advanced Materials and Mathematics (INAMAT2), Universidad Pública de Navarra (UPNA), Spain

Thick PVD coatings provide wear protection, improving thermal and abrasion resistance during machining operations[1]. In order to improve tool life, multiple attempts have been made to increase the thickness beyond 5 um [2]. However, ion bombardment during film growth usually induces high compressive stress in thick films, resulting in adhesive failure of coated tools in tribological applications. In this work, we investigated how to reduce high stress levels in thick AlTiN- and AlCrN- based coatings [3] (up to 10 µm) by incorporating boron to the metal nitride structure. The composition and microstructure of the coatings were characterized using Glow Discharge Optical Emission Spectrometry (GDOES), Scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD). The stress of the coatings was determined by curvature method and compared with the results derived from XRD analysis. Nano-hardness, scratch tests and pin-on-disk tests were carried out to study the tribological properties of the coatings. Machining tests were performed to validate in service performance of the coatings. The results show that standard AlTiN and AlCrN are hard and dense coatings but highly stressed. However, the incorporation of boron induces a nanocomposite type structure, formed by nanocrystalline domains and boron-rich amorphous regions. As a result, stress is reduced, while thermal stability, elasticity and fracture toughness are enhanced.

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EP-ThP-5 Optimized a-SiC_x:H Intermediate Layers for Well-adhered a-C:H Thin Films on Ferrous Alloys,
V. Piroli, J. Weber, M. Goldbeck, UCS, Brazil*; F. Cemin,* UNICAMP, Brazil*; A. Michels,* UCS, Brazil*; F. Alvarez,* UNICAMP, Brazil*; **Carlos Figueroa (cafiguer@ucs.br)**,* UCS, Brazil

Hydrogenated amorphous carbon (a-C:H) thin films have been gaining much attention among new technologies due to their low friction coefficients and high wear resistance. However, the low adhesion of the couple a-C:H thin film / ferrous alloy is still an ongoing challenge. The use of Si-containing interlayers not only minimizes residual stress and provides chemical affinity but also these intermediate layers can be obtained by cheap PECVD technologies. Nevertheless, high temperatures in the interlayer's deposition process, e.g., 300 °C [1], do not allow massive applications due to the degradation of previous substrate's heat treatment. This work aims to study the adhesion of a-C:H thin films on AISI 4140 steel, with an a-SiC_x:H interlayer, by using relatively low a-SiC_x:H deposition temperatures to enable the scale production of well-adhered a-C:H/a-SiC_x:H/steel structures.

Samples of AISI 4140 steel were treated in a low-cost pulsed-DC PECVD equipment with electrostatic confinement. The a-SiC_x:H interlayer was deposited for 10 min using a tetramethylsilane (TMS) / Ar vapor mixture. During the interlayer's deposition, the temperature varied between 85 °C and 200 °C, according to the process. The a-C:H film was deposited using an acetylene (C_2H_2) / Ar gas mixture for 60 min at 80 °C.

The thin films were characterized by FEG-SEM, optical microscopy, XPS and scratch test. Cross-section FEG-SEM allowed observing three well-defined regions in the sandwich structure: the a-C:H film (top layer), the a-SiC_x:H film (intermediate layer) and the steel (bottom layer). One can observe an exponential decay of the defects density by increasing the interlayer's deposition temperature. XPS determined the content of oxygen present in the a-C:H/a-SiC_x:H interface, which varied between 1.5% (for 85 °C) and 0.5% (for 200 °C). The critical scratch loads (Lc), obtained from the scratch test, varied from 4.3 N (for 85 °C) to 5.9 N (for 175 °C). To date, samples with Si-containing interlayers produced from hexamethyldisiloxane (HMDSO), TMS or tetraethoxysilane (TEOS) at 500 °C presented maximum a-C:H critical loads of 3.4 N, 0.4 N and 0.3 N, respectively [2]. Finally, the use of relatively low temperatures on the deposition of well-adhered, with minimum oxygen content a-C:H/a-SiC_x:H/steel structures represents a new finding. The results of this research could facilitate industrial production of coatings with a more affordable market price.

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EP-ThP-6 A Deep Neural Network for Pattern Optimization of Microtextured Surfaces in Lubricated Contacts,
*A. Silva, **Veniero Lenzi (veniero.lenzi@fisica.uminho.pt)**, L. Marques,* University of Minho, Portugal

The reduction of friction between moving parts in contact in mechanical equipment is fundamental in order to reduce wear, increase equipment efficiency and reduce the use of lubricant. It is well-known that the treatment of surfaces through micro-texturing allows for an improvement of the tribological performance of the contact, however it is not clear how to find the optimal texturing pattern that provides the best friction reduction.

In this work, we designed a deep neural network (DNN) that can predict the Stribeck curve of a lubricated contact, starting solely from the knowledge of the initial texture. The DNN has been trained using a in-house developed finite elements method solver for the Reynolds equation that correctly treats the cavitation problem by using the iterative inexact Newton algorithm. The training set for the DNN consisted of randomly generated patterns of dimples with fixed depth and radius.

Our DNN is capable of calculating Stribeck curves in milliseconds with a mean square error lower than 0.5 % when compared to curves obtained with the direct solver. This enabled us to solve the inverse problem, that is finding the optimal texturing given a Stribeck curve, by means of a search within the solution space obtained using the DNN.

EP-ThP-7 e-Poster Presentation: Tribological Behavior of Lamellar Solid Lubricant Coatings in Low Viscosity Hydrocarbons*, **Euan Cairns (euancairns@my.unt.edu)**, A. Ayyagari,* University of North Texas, USA*; S. Berkebile,* US DEVCOM Army Research laboratory, USA*; D. Berman, S. Aouadi, A. Voevodin,* University of North Texas, USA

Transitioning to multi-fuel capability of modern combustion engines has generated need for new sources of effective lubrication inside fuel pump assemblies. Low-viscosity fuels pose a tribological challenge when used in fuel injection systems, as they provide lower lubricity when compared to conventional diesel fuels, leading to degradation of service life of fuel pump and injection system components. Lamellar solid lubricants (MoS_2, WS_2, graphite, h-BN) may become a good secondary source of lubrication when applied to such components as coatings. However, their tribological behavior in fuel environments is unknown. In this report, we compared sliding wear performance of lamellar solid lubricant coatings applied by burnishing onto the surface of yttria-stabilized zirconia (YSZ) coating and tested in ethanol and dodecane environments. The results showed that the tribological behavior of the solid lubricants depends on their composition and environment. MoS_2-based coatings provide the best performance when compared to hexagonal BN, graphite, and WS_2, when tested in a high-frequency reciprocating sliding against steel counterpart. The coefficient of friction of MoS_2 in dodecane is 0.08 for the first 5,000 cycles, while for other solid lubricants it is above 0.1. Possible lubrication mechanisms are discussed, where interactions between fuel molecules and the lamellar lubricant structure as well as oxidations processes may affect the lubrication mechanisms. The discussions of these mechanisms are supported with SEM/EDS and Raman spectroscopy analyses of the tribological contacts

EP-ThP-10 Mechanical Behaviour and Effects of Cu/Ni Nanolaminate Coatings on the Fatigue Properties of Welded Steel Specimen*, **Jakob Brunow (jakob.brunow@tuhh.de)**, M. Rutner,* Hamburg University of Technology, Institute for Metal and Composite Structures, Germany

Nanostructured metal multilayers have been known to possess exceptional material properties regarding strength, magnetism, radiation resistance, fatigue resistance, corrosion resistance and abrasion resistance. Since there are a lot of governing factors for the material properties of nanostructured metal multilayers (NMMs), i.e. global composition, local composition, used metals and interface strength, NMMs can be tailored to specific needs. [1]

Cu/Ni NMMs have seen special interest in the scientific community for the wide variety of possible applications and the possibility to synthesize with a single-bath electrodeposition process. [2]

Current research at the University of Hamburg is focusing on the strengthening of welded steel structures against fatigue, by coating the surface with a nanostructured Cu/Ni-metal laminate patch. [3] The findings are in accordance with other studies that studied the fatigue properties of Cu/Ni nanolaminate coatings. [4]

The surface roughness is measured with AFM before and after fatigue loading. The nanolaminate Cu/Ni coating on the fractured fatigue samples are examined with serial FIB cross sectioning. Subsequently a TEM-lamella is taken from the crack tip to investigate the crack initiation and assess the fracture mechanisms of the Cu/Ni NMM. The Cu-layers experience multi-crack formation and the initial multi-cracks are arrested at the interfaces. The Ni layers bridge those cracks and each layer ruptures individually, resulting in a distinctive crack pattern.
The lifetime enhancement of the welded sample are linked to the fracture mechanism of the NMM and can thus be attributed to the following five mechanisms: reduced surface roughness, micro-crack bridging, energy dissipation, crack arrest at interfaces and changes in surface tribology. [5]

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EP-ThP-11 Nanoindentation Spectrometry*, **Esteban Broitman (esteban.daniel.broitman@skf.com)**,* SKF B.V., Netherlands

The precise knowledge of material microstructures is of vital importance to understand their mechanical and tribological performance. Standard microstructural characterization, carried out by optical and electron microscopy together with X-ray diffraction, is usually correlated to the hardness determined by Rockwell or Vickers indentation at macro- and microscale, and nanoindentation at nanoscale.

In the first part of the presentation, the background of a novel statistical nanoindentation technique to measure hardness and Young's modulus of materials is described [1]. We indicate how experiments are designed, and how the distribution of the hardness and modulus of elasticity determined from the nanoindentation observations are deconvoluted to generate hardness histograms that reflect unique characteristics (fingerprints) of each coating or bulk material. We show how the statistical deconvolution analyses gives an estimate of the microstructural constituents, their volume fraction and corresponding plastic and elastic properties at nanoscale. In the second part, numerous examples on different kind of coatings and bulk materials are presented to illustrate the usefulness of the novel technique.

We demonstrate that, by using nanoindentation as a novel tool for static nanomechanical spectrometric analysis of coatings and bulk materials, a fundamental understanding of the relation between local microstructure (phases and their size) and local material response during elastic and plastic deformation can be obtained.

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