Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room San Diego - Session E3

Tribology of Coatings for Automotive and Aerospace Applications

Moderators: Sébastien Guimond, Oerlikon Balzers, Oerlikon Surface Solutions AG, Nicolas Argibay, Sandia National Laboratories, Pantcho Stoyanov, Pratt & Whitney, USA

1:50pm **E3-2 Bending Fatigue Property Enhancements of Metallic Substrates by Thin Film Metallic Glass Coatings*, Chia-Hao Chang*, *J Chu,* National Taiwan University of Science and Technology, Taiwan

Thin film metallic glasses (TFMGs) possess extraordinary mechanical properties such as high strength, high toughness, large elastic limit as well as excellent wear and corrosion resistances. Thus, they have attracted industrial interests for the potential applications with their superior mechanical properties. In this presentation, 200-nm-thick TFMG and TFMG/ceramic multilayer coatings were deposited on the 316L stainless steel, Ti6Al4V alloy and ZK60 Mg alloy specimens using radio frequency magnetron sputtering system for four-point-bending fatigue test at room temperature. Fatigue properties of either TFMG-coated or TFMG/ceramic multilayer-coated samples were improved significantly. The hardness of TFMGs and multilayer, their excellent adhesion to the substrate, and the resulting reduction in surface roughness are believed to account for the enhanced fatigue characteristics.

2:10pm **E3-3 Optimization of the Tribological Contact between Piston Ring and Cylinder Wall with Oxide Coatings***, C Bohnheio, P Ernst, P Luethy,* Oerlikon Metco AG, Switzerland*; J Ramm, H Rudigier,* ***Florian Seibert****, B Widrig,* Oerlikon Surface Solutions AG, Liechtenstein

Strategies to further improve the efficiency of modern combustion engines resulted in the development of so called downsized engines operating at higher power densities and operation temperatures. This implies improved stability of material surfaces in the contact between piston ring and cylinder wall. The piston group contributes also significantly to the energy loss in the powertrain of a combustion engine. Therefore, reduced friction losses are another demand in engine development. The selection of appropriate coatings for the piston ring and the liner surface may respond to both challenges.

Two coating technologies were investigated: physical vapour deposition (PVD) for the piston rings and atmospheric plasma spray (APS) for the cylinder bore surfaces. In a first step, these coatings were applied to test substrates and investigated by a reciprocating wear test (SRV®). The tests were performed under dry and lubricated conditions and for room temperature and temperatures up to 160°C. Wear of the coating and the ball (counter-part) was measured by confocal microscopy. It could be shown that the tribological contact between hard PVD and APS oxide coatings and the alumina counter-part did not only show excellent wear behavior for different surface finishing, but had also the highest stability for elevated temperatures. In a next step, the most promising coating combinations were tested in a motorbike engine configuration and compared with standard materials like CrN for the piston ring and a number of standard coatings for the liner. The tests demonstrated for one oxide-oxide combination an increase of the power output of the engine by 1.5%.

2:30pm **E3-4 Mechanical Characterization of the Glaze Layer formed by Fretting Wear in a Ceramic versus Metallic Alloy Contact***, A Viat,* ***Gaylord Guillonneau****, S Fouvry,* Ecole Centrale de Lyon, France*; G Kermouche,* Ecole des Mines de Saint-Etienne, France*; J Michler,* Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

In a simplified aeronautic blade disk contact, between ceramic and Haynes 25 (cobalt-based alloy) flats, high temperature fretting wear induces third body formation. This third body, called "glaze layer", is created from compacted and sintered debris. Nanocrystalline structure and composition have been described in a previous paper [1]. The glaze layer adhering on both alloy and ceramic counterparts contains counterface material, as observed for ductile contacts [2]. However, the glaze layer does not behave like a ductile material at first sight: under ambient temperature, it is brittle and harder than the two respective substrates.

In-situ SEM micropillar compression at temperatures between ambient and 500 °C have been performed in the glaze layer and its substrates in cross section. This approach focuses on the mechanical behavior at temperatures where the glaze layer is created and is operational for wear protection. The device used is an Alemnis/EMPA high temperature SEM micro-tester [3]. Micropillar compression enables to obtain directly the mechanical response of material surfaces in terms of elasticity, yield stress / hardness and work hardening. Also, the deformation behaviour can be directly observed by SEM images. Firstly, the tribological contact and the device used for in-situ microcompression will be presented. Then the mechanical properties will be detailed and discussed in terms of elasticity and plasticity as a function of temperature. Finally, a discussion about the relation of the glaze layer mechanics with its formation and lubricious properties is proposed.

References

[1] Viat A, De Barros Bouchet M-I, Vacher B, Le Mogne T, Fouvry S, Henne J-F. Nanocrystalline glaze layer in ceramic-metallic interface under fretting wear. Surf Coat Technol.

[2] Rigney D.A., 2000. "Transfer, mixing and associated chemical and mechanical processes during the sliding of ductile materials", Wear 245, pp 1-9

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2:50pm **E3-5 Sequence of Stages in the Microstructure Evolution in Copper under Reciprocating Tribological Loading***,* ***Christian Greiner****,* Karlsruhe Institute of Technology (KIT), Germany **INVITED**

Tailoring the surface properties of a material for low friction and little wear has long been a goal of tribological research. Since the microstructure of the material under the contact strongly influences tribological performance, the ability to control this microstructure is thereby of key importance. However, there is a significant lack of knowledge about the elementary mechanisms of microstructure evolution under tribological load. To cover different stages of this microstructure evolution, high-purity copper was investigated after increasing numbers of sliding cycles of a sapphire sphere in reciprocating motion. Scanning electron and focused ion beam (FIB) microscopy were applied to monitor the microstructure changes. A thin tribologically deformed layer which grew from tens of nanometers to several micrometers with increasing number of cycles was observed in cross-sections. By analyzing dislocation structures and local orientation changes in the cross-sectional areas, dislocation activity, the occurrence of a distinct dislocation trace line and the emergence of new subgrain boundaries could be observed at different depths. These results strongly suggest that dislocation self-organization is a key elementary mechanism for the microstructure evolution under a tribological load. The distinct elementary processes at different stages of sliding identified here will be essential for the future modelling of the microstructure evolution in tribological contacts.

3:30pm **E3-7 Effect of Test Atmosphere on the Tribological Behaviour of the Fluorinated Tetrahedral Amorphous Carbon (ta-C-F) Coatings against Steel***,* ***MuhammadZafarUllah Khan****, S Bhowmick, A Alpas,* University of Windsor, Canada

Carbon based coatings exhibit low coefficient of friction (COF) in sliding contact against steel, but the resulting COF is highly sensitive to environmental conditions. This study examines the tribological properties of a fluorinated tetrahedral amorphous carbon (ta-C-F)coating containing 12 at. % F (ta-C-F) tested against a 52100 grade steel at 2.0 N and 5 cm/s in ambient air (53% RH), in dry oxygen and in dry N_2 atmospheres with relative humidity reduced to less than 4%. The ta-C-F coating exhibited low and stable steady state COF (μ_s) under ambient (0.25), dry oxygen (0.27) and N_2 (0.22) atmospheres conditions. It was suggested that a carbonaceous transfer layer passivated by F atoms was responsible for low and stable μ_s under all testing conditions as revealed by X-ray photoelectron and micro-Raman spectroscopy. However, the running-in COF (μ_R) varied with the testing atmosphere. The highest running-in COF (μ_R = 0.56) was observed under ambient condition which was reduced to 0.48 in dry oxygen and 0.40 in N_2. The presence of N_2 played an important role in stabilizing carbonaceous transfer layer by limiting the formation of abrasive iron oxide particles.

3:50pm **E3-8 Laser-based Process for Polymeric Tribological Coatings on Lightweight Components***, **Hendrik Saendker**, J Stollenwerk,* Fraunhofer Institute for Laser Technology, Germany*; P Loosen,* Chair for Technology of Optical Systems TOS, Germany

Multiple applications, especially in the automotive sector and in mechanical engineering, are predominantly affected by friction and wear stress and, therefore, represent a substantial challenge for the components being used. Oftentimes, the endurance and the efficiency of these components can be enhanced by means of application-specific tribological coatings. For engine components like pistons or bearing shells made of light metals like Aluminum, current coatings based on sliding lacquer do not meet increasing requirements, particularly regarding temperature resistance and wear protection. Coatings based on high-temperature resisting thermoplastic polymers like PEEK (polyether ether ketone) represents an alternative to conventional tribological coatings. An outstanding challenge results from using temperature-sensitive Aluminum alloy which show structural changes above temperatures of 140 - 180°C, hence below the melting temperature of PEEK of approximately 340°C. In Comparison to conventional oven processes, laser-based processes provide a reduced thermal load of the workpiece. Therefore, the investigated coating process comprises four consecutive steps: a laser-based pre-treatment of the components (1), the preparation of a hydrous dispersion based on PEEK powder (2), the deposition of the dispersion by e.g. spray coating (3), and the melting of the PEEK powder by means of laser radiation (4).

The current investigations are primarily focused on the investigation of the influence of different pre-treatments on the adherence of the coating and the influence of different temporally temperature profiles during laser melting on the properties of the coatings, e.g. relative density, crystallinity, surface roughness and structural changes of the base material. The pre-treatments comprise the processing of the component by means of pulsed laser radiation. For the laser melting of the PEEK powder, different lasers operating in the continuous wave mode are used.

By means of this new coating process, dense and adherent tribological coatings can be applied on Aluminum substrates. The adherence is significantly increased by the laser-based pre-treatment of the metallic substrates.

4:10pm **E3-9 Long-term Tests of Tribological Properties of HVOF-sprayed WCCoCr Carbide Coatings of Ultra-fine Powders with a View to Applying Them to Sliding Rings of Mechanical Seals***, **Aleksander Iwaniak**, R Swadzba,* Silesian University of Technology, Poland*; G Wieclaw,* Certech Sp. z o.o., Poland*; L Norymberczyk,* ANGA Uszczelnienia Mechaniczne Sp. z o.o., Poland

This paper describes tests aimed at exploring the tribological properties of thermal-sprayed coatings. The coatings were deposited onto the face areas of cylindrical metallic specimens whose shape approximated that of sliding rings used in mechanical seals. Long-term (over 400 hours of continuous operation) frictional wear tests of the coated samples were performed at a specialized workstation simulating the operation of a mechanical seal. The wear of the specimens was evaluated by 3D scanning. After the tests, the specimen surfaces were examined by means of a 3D profilometer and a scanning electron microscope (SEM, EPMA). The tests show that WCCoCr coatings sprayed using ultra-fine powders (less than 10 µm) ensure the effectiveness of a friction pair and are characerised by a low degree of frictional wear in comparison with coatings sprayed using powders having coarser particles (25 µm). The highest degree of wear was identified for CrCNiCr-type coatings. The tests indicate that metallic sliding rings covered with WCCoCr carbide coatings of ultra-fine particle powders can be used in certain types of mechanical seals in which solid tungsten carbide (WC) rings are currently used.

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4:30pm **E3-10 Role of Oxygen in High Temperature Sliding Behaviour of W Containing Diamond-like Carbon (W-DLC)***, S Bhowmick, M Lou, A Alpas, **MuhammadZafarUllah Khan**,* University of Windsor, Canada

W-containing diamond-like carbon (W-DLC) coating is of interest to the manufacturing industry, as they showed low coefficient of friction (COF) against aluminum at elevated temperatures. The low COF values at 400 ˚C (0.18) and 500 ˚C (0.12) could be attributed to the formation of the transfer layers made of lubricious tungsten oxide WO_3. However, at intermediate temperatures between 100 ˚C and 300 ˚C, a high COF of 0.60 was recorded. In this work, the friction reduction mechanisms of W-DLC coatings were investigated in dry oxygen atmosphere and studied as a function of testing temperature up to 500 ˚C against an Al alloy. The purpose of maintaining an oxygen rich environment was to increase the propensity of WO_3 formation at the sliding surfaces. An average steady state COF (μ_s) of 0.11 was observed at 25 ˚C and low friction values were maintained up to 500 ˚C where μ_s was 0.13. Micro-Raman and X-Ray photoelectron spectroscopy (XPS) revealed that at room temperature the transfer layers were rich in carbon, whereas between 100 ˚C to 500 ˚C the transfer layers primarily consisted of tungsten oxide. The presence of sufficient oxygen in testing atmospheres led to the formation of tungsten oxide rich transfer layers which reduced the COF between 100 ˚C to 500 ˚C. This work shows the importance of compositional characterization and study of mechanisms of transfer layer formation during sliding friction of 319 Al tested against W-DLC coatings.

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