Tribology Focus Topic
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Tribology Focus Topic Poster Session

TR-ThP1 Subsurface Characteristics of an Abraded Fe-0.4wt%C Martensitic Steel using Nanoindentation and Cross-Sectional TEM Techniques, *F. Katsuki*, Sumitomo Metal Industries, Limited, Japan

The present investigation of unidirectional abraded surfaces of a martensitic (0.4 wt%C) steel with silicon (1.5wt%Si), chromium (1.5wt%Cr) and molybdenum (1.9wt%Mo) addition elucidates the work hardening and the softening near the surface layer caused by abrasion, particularly its relation to the wear behavior. The abrasion testing was performed using a pin-abrasion apparatus in which a small pin of the specimen was ground on an abrasive paper at an applied load of 2.1N and sliding speed of 0.66m/s. Crushed silica particles (size: 15-67µm) were used as the abrasive medium. The abraded surfaces were examined with a nanoindentation apparatus to evaluate the variation of nanohardness with sliding time on a nanometer scale. A cross sectional transmission electron microscope (TEM) technique was also employed to clarify the structural changes in the region close to the abraded surface. It has been found that abrasion induced work hardening with sliding time was observed in the case of chromium and molybdenum addition steels. A fine dispersion of molybdenum carbide (Mo_2C) was observed in the surface of the molybdenum steel after abrasion. Mo_2C precipitates at approximately 550°C, indicates that surface and near surface temperatures would be over the carbide formation temperature by the abrasion induced frictional heating. On the other hand, the softening has been indicated to be caused by the abrasion heating leading to some tempering effects in the case of the silicon addition steel. Work hardening and softening caused by abrasion induced subsurface deformation and frictional heating respectively seem to be two processes taking place simultaneously which counteract each other's effect. Metallurgical reaction such as precipitation and temper by frictional heating has been found to play a important role in controlling the wear characteristics of steels. The influence of the alloying element addition on the wear response of the martensitic steel will be discussed.

TR-ThP2 The Lubrication Characteristics of Molybdenum Disulfide Films by RF Magnetron Sputter, *A. Kasahara*, *M. Goto, M. Tosa,* National Institute for Materials Science (NIMS), Japan*, T. Maruyama, J. Nakagawa, K. Endo*, Toyama Co., Ltd., Japan

For vacuum applications, lubricants which have low vapor pressure and good tribological performance are required. Solid lubricants have been widely adopted for vacuum applications due to their low vapor pressure. Thin film lubricants and high-temperature solid lubricants are discussed as the latest alternatives to fluorine grease. These lubricants feature lower out-gassing for clean and vacuum environments. One big drawback of solid lubrication is limited life. We investigate solid lubricant in order to develop high performance ultra-high vacuum (UHV) manipulation mechanism and high-temperature drive devices. We focused sputtering coating method and Molybdenum Disulfide (MoS_2) , since this material has been reported to be suitable in vacuum , but not well been investigated. As a first step, we have carried out basic study of MoS_2 thin film to find out suitable sputtering parameter. It was deposited on martensite stainless steel (SUS440C) substrates, using radio frequency magnetron sputter. Their tribological characteristics in UHV and high-temperature was evaluated by vacuum friction measurement system, high-temperature friction measurement system based on Bowden-Leben type and abrasion measurements by Stylus Surface Profiler.

TR-ThP3 Structure of Thin Diamond-Like Carbon Films and its Relationship to its Tribological Performance, *F.J. Flores-Ruiz*, *F.J. Espinoza-Beltran, M.O. Vazquez-Lepe, A. Herrera-Gomez*, CINVESTAV-Unidad Queretaro, Mexico

Diamond-like carbon (DLC) films are promising materials for dry-contact applications where resistance to surface damage or lubricating performance is required. In the present work, the structure of 3 and 10 nm Focus Cathodic Arc (FCA) carbon films and 3 and 10 nm plasma carbon films grown on Si(100) was studied by angle-resolved X-ray photoelectron spectroscopy (ARXPS). The concentration and distribution of sp^2 and sp^3 carbon within the film was assessed with methods described elsewhere [i]. Atomic force microscopy (AFM) with a silicon tip was used to study the friction coefficient µ on the nanoscopic scale. It is defined by the Amonton law, $\mu=F_L/F_N$, where F_N and F_L are the normal and the lateral force applied to a probe [ii]. The calculation of the normal and lateral force applied during the process of sliding the tip over the sample was done according to the methodology proposed by Carpick [iii] . The results suggest a relationship between the chemical structure and the tribological performance for each film tested. The films grown by FCA presented the best tribological performance (µ~*0.02*) compared to films grown by plasma (µ~*0.06*) indicating a direct link between the distribution of sp^2 and sp^3 carbon and the nanoescale friction coefficient. Since during the friction tests there was no evidence of damage or wear on either the surface or the tip, the conventional interpretation for the origin of friction proposed by Bowden and Tabor [iv] grossly underestimates the energy loss in the sliding process. On the other hand, the energy loss can be quantitatively explained in terms of heat generation [v]. The tribological performance analysis indicates that the friction is related to the adhesion force between tip and sample. However, the friction coefficient values do not show significant changes as the strength of adhesion varies, indicating that the value of the friction coefficient depend on the contributions of atomic bonds at the surface.

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[ii] G. Amonton, "De la resistance cause´e dans les machines". Mem. Acad. R. A, **275** (1699).

[iii] R. W. Carpick, "Scratching the Surface: Fundamental Investigation of the Tribology with the Atomic Force Microscopy". Chemical Reviews, 97, pp. 1163 (1997).

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[v] J. Luo, Y. Hu, S. Wen (Editors), "Physics and Chemistry of Micro-Nanotribology." ASTM-International, West Conshohocken, PA, USA. Chapter 9, pp. 167 (2009).

TR-ThP4 Tribological Investigations of Octadecylphosphonic Acid (ODP) and Octadecyltrichlorosilane (OTS) Self-Assembled Monolayers: A Comparative Study of MEMS-type Interfaces, *N. Ansari,* Auburn University*, S. Barkley,* Luther College*, C. Bouxsein, M. Deram, N. Eigenfeld,* Saint Olaf College*, O. Matthews,* Luther College*, A. Poda, W.R. Ashurst,* Auburn University*, B.P. Borovsky,* Saint Olaf College*, **E.E. Flater***, Luther College

Microelectromechanical systems (MEMS) are critically-limited by interfacial phenomena such as friction and adhesion. One strategy to reduce friction between MEMS surfaces is to coat them with molecularly-thin self-assembled monolayer (SAM) coatings. Historically, silicon MEMS have been coated with silane-based SAMs, such as octadecyltrichlorosilane (OTS). However, continued progress in the development of MEMS may require new material systems to be employed. Therefore, in this study, we have investigated the frictional properties of octadecylphosphonic acid (ODP) monolayers deposited on aluminum oxide surfaces, across speed regimes. Measurements using an atomic force microscope (AFM) and separately using a nanoindenter-quartz crystal microbalance system were performed each with a microsphere-terminated probe. This allows for a comparative study between different velocity regimes using contacts with similar sizes, pressures, surface roughnesses, and interfacial chemistries. AFM colloidal probe friction measurements indicate that for a bare tip sliding on various substrates, ODP-coated alumina surfaces exert a lower friction force than either bare or OTS-coated alumina substrates. We also observed strong evidence of transfer of the ODP molecules to the tip when the tip is uncoated. The results presented in this study are significant contributions towards our goal of better understanding the frictional properties of phosphonate SAMs in pursuit of alternative MEMS materials.

TR-ThP6 The Effect of Test Parameters on the Tribocorrosion Behavior of Multilayers, *M. Flores*, *O. Jiemnez, J. Garcia, E. Rodriguez,* Universidad de Guadalajara, Mexico*, L. Huerta*, Universidad Nacional Autononoma de Mexico

The multilayer coatings can improve the corrosion and wear resistance of materials for biomedical applications. The tribocorrosion behavior of TiALN and $TiAlPt_xN$ coatings and $TiAlPt_xN$-$TiAlPt_x$ multilayers immersed in a corrosive environment was investigated. The coatings were deposited on 316L stainless steel and Ti6Al4V alloys by magnetron sputtering. The period thickness of multilayers was 300 nanometers and the total thickness was 3.6 microns. In order to evaluate the influence of the environment, the corrosion was studied using open circuit potential (OCP) measurements and potentiodynamic polarization techniques in saline and a Ringer ´s solutions. For the tribocorrosion test a counterbody of Alumina with 10 mm diameter was used. The loads used were from 1 to 5 N, the oscillating frequencies were 1Hz to 5 Hz. The electrochemical noise measurements were performed during, and after the sliding and scratch tests. The structure and composition of multilayers were studied by means of XRD, XPS and RBS techniques. It was found that the codeposition of Pt and TiAlN-TiAl multilayer can improve the wear-corrosion resistance of materials for biomedical applications.The tribocorrosion behavior results in terms of the coefficient of friction showed a dependence against the force and the sliding frequency.

**TR-ThP7 Tribological Properties of Electron Beam Excited Plasma Nitrided Surfaces*, P. Abraha*, *J. Miyamoto*, Meijo University, Japan

Tribological properties play significant role on the performance of tool steel surfaces. Here, application of electron beam excited plasma nitriding and its effect on tribological properties is described. The technique eliminates the formation of the brittle and rough compound layer that is common in nitriding processes. The hardening process is done through diffusion of the plasma species in to the subsurface of the treated material without altering the initial surface finish. The applications of the process can be in areas of hard coating where adhesion of the coating material with the tool steel is of significant importance.

The experimental tool steel material is SKD 61 with a chemical composition of 0.36% C, 5.05% Cr, 1.21% Mo, 0.83% V, 0.92% Si, 0.43% Mn, 0.008% P, >0.001% S, Fe bal. The sample was heat treated, hardened and triple tempered to a hardness of 630 Hv. The sample was then treated in a nitrogen plasma produced by a beam current of 8 A under a working pressure of 0.4 Pa. The temperature was set at 500 degrees centigrade throughout the treatment time. The experimental set up includes bias terminals that reduce the ion density within the vicinity of the tool steel material. This is done to reduce nitriding due to ion and increase the chance of nitriding due to neutral species within the plasma. The cross sectional hardness distributions and wear measurements of the nitrided tool steels were examined to determine the mechanical and tribological surface properties. The surface has no trace of the compound layer that is usually observed in the ion nitriding processes. This is also confirmed from the X-ray Diffraction peaks, as there is no visible Fe_3N and Fe_4N peaks observed. These results are attractive as they open new areas of application especially in the coating industry where adhesion remains to be the limiting factor in lots of the hard coatings that protect cutting and forming tools against wear.

**TR-ThP8 Parameter Optimization of Ion Plated Nickel-Copper-Silver Lubrication*, M. Danyluk*, *A. Dhingra*, University of Wisconsin Milwaukee

In this paper we present a connection between argon ion flux with ion mixing and rolling contact fatigue (RCF) life of a thin solid nickel-copper-silver film lubrication on ball bearings tested in high vacuum. Using a Langmuir probe we measure plasma properties and ion flux and then calculate plane stress within the film during deposition using a validated model found in the thin film science literature. Experiments reveal that there is an inverse relationship between ion flux and RCF life for most deposition voltage and pressure combinations tested, specifically, 15.5 to 18.5 mTorr and 1.5 to 3.5 kV. For voltages up to 2.5 kV, RCF life decreases as deposition voltage and ion flux increase. Experiments also confirm that as ion flux increases deposition rate decreases due to sputter removal from the ball surface. For voltages between 2.5 and 3.5 kV interlayer mixing and contamination of the 100 nm thick coating reduces RCF life even as ion flux decreases with decreasing process pressure within a constant power process. At ion energy greater than 2.5 keV and ion flux above 10^{15} cm^{-2} s^{-1}, SRIM results suggest elemental mixing of copper and nickel at the interface and this is confirmed using Auger Electron Spectroscopy (AES) on steel and Si_3N_4 5/16” diameter balls.

**TR-ThP9 Shear-induced Tribofilm Formation: Boron Containing Molecules on Copper*, B.P. Miller*, *O.J. Furlong, W.T. Tysoe*, University of Wisconsin Milwaukee

The push for greener lubricants has steered focus away from compounds containing sulfur and phosphorus. The tribological chemistry can depend critically on the nature of the substrate so that a good lubricant additive for one type of surface may not be applicable to another. In particular, the lubrication of sliding copper-copper interfaces in electrical motors provides a challenge due to the requirement for a conducting interface. Boron containing molecules have been proposed as potential green lubricants since environmentally safe boric acid is a prominent decomposition product in the presence of water. The following investigates the chemistry and frictional properties of alkoxy dioxaborolane (borolane) on copper surfaces in ultrahigh vacuum (UHV) to determine the precursor at room temperature that can potentially form a tribofilm needed for the lubrication of sliding copper-copper contacts. Temperature programmed desorption (TPD) and X-ray photoelectron spectroscopy (XPS) experiments provide the background information for investigating the frictional properties of borolane. A sliding copper-copper interface is exposed to borolane under UHV conditions, and a significant reduction in friction is found from the clean-surface values. A lasting tribofilm persisted even after the borolane dosing was stopped, and carbon was found on and below the surface in the wear scar region by *in-situ* Auger spectroscopy. Because the interfacial temperature rise under the experimental conditions used to measure friction is <1 K, the tribofilm formation is shear- and not thermal-induced

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