Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room San Diego - Session E1-1-ThM

Friction, Wear, Lubrication Effects, and Modeling II

Moderators: Nazlim Bagcivan, Schaeffler Technologies GmbH & Co. KG, Germany, **Carsten Gachot**, Vienna University of Technology, **Tomas Polcar**, Czech Technical University in Prague, Czech Republic

8:40am **E1-1-ThM-3 Sliding Wear Resistance of Nickel Boride Layers on Inconel 718 Superalloy***, I Campos-Silva,* Instituto Politecnico Nacional Grupo Ingeniería de Superficies, México*; **Alan Daniel Contla-Pacheco,*** Instituto Politecnico Nacional, Grupo Ingeniería de Superficies, México*; U Figueroa-Lopez,* Tecnologico de Monterrey-CEM, Mexico*; J Martinez-Trinidad, A Ruiz-Rios, M Ortega-Aviles,* Instituto Politecnico Nacional Grupo Ingeniería de Superficies, México

New results about the wear resistance of nickel boride layers under dry sliding conditions were estimated in this work. For this purpose, an Inconel 718 superalloy was borided using the powder-pack process at two different conditions to estimate the influence of the nickel boride layer thicknesses on the sliding wear resistance. The first condition was at 1173 K with 2 h of exposure (B1), while 1223 K with 6 h of exposure was used for the second condition (B2). A flat-uniform nickel boride layer was developed at the surface of the borided Inconel 718 superalloy with a layer thicknesses ranged between 19 to 50 microns according to the boriding conditions. The microstructure of the nickel boride layer consisted of a mixture of Ni_4B_3, Ni_2B and Ni_3B phases with a presence of a diffusion zone beneath the layers. Otherwise, the indentation properties such as hardness, Young's modulus and the distribution of residual stresses across the boride layer-substrate system were estimated for both boriding conditions.

The sliding wear tests were performed on both boriding conditions and over the untreated material (Inconel 718 superalloy), using a ball-on-flat configuration comprised with an alumina ball of 6 mm diameter as a counterpart, in which a constant load of 20 N was employed with different sliding distances between 50 to 200 m. In addition, during the wear tests, the friction coefficient was monitored for the overall set of experimental conditions.

As it expected, the presence of the nickel boride layers at the surface of the Inconel 718 superalloy enhanced the wear resistance than that of the untreated material. However, for the B2 condition, an increase of the nickel boride layer thickness produced a more wear-resistant layer, in which the values of the wear rate remained constant for the entire set of sliding distances, in contrast with the results estimated for the B1 condition. Finally, the failure mechanisms developed over the surface of the wear tracks for the borided Inconel 718 superalloys (B1 and B2 conditions), and untreated material were discussed and correlated as a function of the friction coefficients and the mechanical properties estimated by indentation tests.

9:00am **E1-1-ThM-4 A Study of the Wear Mechanism of PTFE: The Effects of Temperature and Environment on its Mechanical and Tribological Properties***, **Vilayvone Saisnith**, V Fridrici,* Ecole Centrale de Lyon, LTDS - Université de Lyon, France

Polytetrafluoroethylene (PTFE) coatings are widely employed in various industrial applications due to their low coefficient of friction, low surface energy, good chemical and high temperature resistances. However, PTFE exhibits relatively weak mechanical strength and its wear resistance (particularly in abrasion conditions) has been a critical issue which needs to be understood and to be overcome. In the present work, we set up a methodology to obtain a measure of the durability of PTFE coatings. Experiments to study the effect of both temperature (from room temperature to 180°C) and environment (dry, in water and in an oil) on the mechanical and tribological properties of PTFE have been carried out. The interactions between temperature and environment are also investigated. Scanning Electron Microscopy (SEM) was used to investigate the worn surfaces and debris and thus understand the wear mechanisms under various conditions. As expected, experimental results showed that the tribological resistance of PTFE significantly decreases with increase in temperature. In addition, the coefficient of friction exhibits no significant difference as a function of the environment. The morphological study of wear debris observed after tests at different temperatures and the measurements of mechanical properties of the coating by nano-indentation at different temperatures helped us understand the various wear mechanisms occurring during these tests. In particular, the higher wear observed in an oil environment could be attributed to a different tribological behavior of the transfer film on the abrasive counterbody, with its ease of formation and regeneration.

9:20am **E1-1-ThM-5 Harness Intrinsic Friction in Transition Metal Dichalcogenides***, **Antonio Cammarata**,* Czech Technical University in Prague, Czech Republic*; T Polcar,* University of Southampton, UK

One of the main difficulties in understanding and predicting frictional response is the intrinsic complexity of highly non-equilibrium processes in any tribological contact, which include breaking and formation of multiple interatomic bonds between surfaces in relative motion. Moreover, under tribological conditions, local charge accumulation may take place and produce a tribological response different than that of the corresponding neutral structure.

To understand the physical nature of the microscopic mechanism of friction and design new tribologic materials, we conducted a systematic quantum mechanic investigation at the atomic scale on prototypical Transition Metal Dichalcogenides at different charge content and applied external load. We combined group theoretical analysis and phonon band structure calculations with the characterisation of the electronic features using non-standard methods such us orbital polarization and the recently formulated bond covalency and cophonicity analyses. We proposed a phonon-mode based method, named Normal-Modes Transition Approximation, to identify possible sliding paths from only the analysis of the phonon modes of the stable geometry and to tune the corresponding sliding energy barriers. We formulated guidelines on how to engineer intrinsic friction at nanoscale, and finally applied them to design a new Ti-doped MoS_2 phase with expected improved tribological properties.

Finally, thanks to the general formulation of our approaches, the present outcomes can be promptly used to finely tune physical properties for the design of new materials with diverse applications beyond tribology such as tuning of Metal-Insulator transitions, dielectric response, Second Harmonic Generation, phase matchability, and ionic conduction among others.

9:40am **E1-1-ThM-6 Static Friction at High Temperature: from Methodology to Severe-Service Valve Application***, **Thomas Schmitt**, J Schmitt,* Polytechnique Montréal, Canada*; É Bousser,* École Polytechnique de Montréal, Canada*; M Azzi,* Tricomat, Canada*; F Khelfaoui, V Najarian, L Vernhes,* Velan*; J Klemberg-Sapieha,* Polytechnique Montréal, Canada

An international effort is being made to increase the thermodynamic efficiency of thermal power plants up to 50%. To achieve this goal, the temperature and pressure of the steam powering the turbines must be increased up to 760°C and 35 MPa. For such grueling application, Metal-Seated Ball Valves are usually the preferred solution for safety valves. Their sealing surfaces being inherently protected in both open and closed positions, they can be exposed to long periods of immobility in harsh environments. Consequently, new materials are being developed to withstand this new application, driving the development of new equipment and methodologies to characterize these materials under severe conditions.

To investigate this specific static contact, a new tribometer has been developed to measure the coefficient of static friction (μ_s) between a pin and a plane up to a 800°C and after several hours of immobility. In parallel, a methodology was established to simulate the contact condition in a valve consisting of Stellite 6 and hard chrome plating. The evolution of the static coefficient of friction was measured according to three parameters: the contact pressure (P_c), the temperature (T_c) and the holding time (t_c). The microstructure, chemical composition, and topography of the contact was then analyzed.

The study revealed that μ_s was not affected by the contact condition at RT. However, at higher temperatures, the coefficient of static friction depended on both contact pressure and holding time. Particularly, at 800°C, the friction behavior was characterized by an increase in μ_s as a function of holding time up to values greater than 1. In addition, much more pronounced adhesive damage was observed compared to other testing temperatures. The above observations were attributed to the evolution of the contact as a function of the testing conditions. In particular, the formation of a mixed oxide inside the contact seemed to have a major influence on the tribological response of the system. Finally, an adhesion mechanism was proposed to explain the origin of the evolution of the static coefficient of friction.

10:00am **E1-1-ThM-7 Coating Development, Characterization and Application-oriented Tests**, ***Lars Pleth Nielsen**, K Almtoft, B Christensen, S Louring,* Danish Technological Institute, Denmark*; H Ronkainen, T Hakala,* VTT Technical Research Centre of Finland, Finland*; D Drees,* FALEX Tribology, Belgium **INVITED**

Developing new coatings and bringing them out of the R&D phase into actual applications is not an easy task. The presentation illustrates how we have developed new coatings based on reactive sputtering processes utilizing different plasma techniques, HiPIMS, pulsed DC and DC magnetron sputtering. The HiPIMS platform was used to develop a very hard TiB_2 coating characterized by having a low residual stress level. Pulsed DC magnetron sputtering was used to deposit a stable 50 µm thick amorphous Al_2O_3 coating for CERN's next generation superconducting magnets. Finally, DC magnetron sputtering was used to deposit different types of low friction carbon-based coatings tailored for different applications such as a low-friction coating for dental application and a Si-containing a-C:H:Si coating revealing increased hardness and improved temperature stability as compared to a-C:H.

The developed coatings were characterized by SEM, nanoindentation, RBS, XPS, GDOES, XRD, etc. The presentation will provide examples of model tests including different types of wear tests as e.g. pin-on-disk, reciprocal sliding tests, scratch testing as well as more application-oriented tests that might be more useful when bringing new coatings into industrial applications.

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