STLE Tribology Frontiers Conference

2019 STLE Tribology Frontiers Conference

Co-sponsored by the ASME Tribology Division

Tribology: The Interface of Physics, Chemistry, Materials and Mechanical Science and Engineering

October 20-23, 2019

Historic Drake Hotel on Chicago's "Magnificent Mile"

Chicago, Illinois

2019 Preliminary Technical Program as of July 8, 2019

(Subject to Change)

2019 STLE Tribology Frontiers Conference
October 20-23, 2019
The Drake Hotel
Chicago, Illinois (USA)
Preliminary Program-at-a-Glance
As of 7-03-19 – Subject to Change

Sunday, October 20, 2019

Speaker Luncheon – 12 pm – 12:45 pm – Walton North

Welcome and Introductions – 1:00 – 1:15 pm
Grand Ballroom

Plenary Session – TBD – 1:15 – 2:00 pm -
Grand Ballroom
Title: TBD

Networking Break – 2:00 – 2:40 pm

Technical Sessions – 2:40 – 6 pm

1A – Material Tribology I I	Grand Ballroom
1B – Surfaces & Interfaces 1	Walton South
1C – Fluid Lubrication I	Georgian Room
1E – Tribochemistry I	Astor Room

Meet & Greet Reception – 6 – 7 pm French Room

Monday, October 21, 2019

Speaker Breakfast – 8 – 8:45 am Walton North

General Attendee Breakfast – 8 – 8:45 am French Room

Plenary Session: TBD –9 – 9:40 am Grand Ballroom
Title: TBD

Networking Break (Exhibits & Posters) – 9:40 – 10:00 am French Room

Technical Sessions – 10:00 am – 12 noon

2A – Materials Tribology II	Grand Ballroom
2B – Surfaces & Interfaces II	Walton South
2D – ASME Workshop	Venetian Room
2E – Tribochemistry II	Astor Room

Lunch on Your Own – 12 noon – 1:20 pm

Technical Sessions – 1:20 – 3:40 pm

3A –-Materials Tribology III	Grand Ballroom
3B – Surfaces & Interfaces III	Walton South
3C – Fluid Lubrication II	Georgian Room
3E - Tribochemistry III	Astor Room

Networking Break-(Exhibits & Posters) – 3:40-4:20 pm French Room

Technical Sessions Continued– 4:20 – 6 pm

3A –-Materials Tribology III	Grand Ballroom
3B – Surfaces & Interfaces III	Walton South
3C – Fluid Lubrication II	Georgian Room
3E - Tribochemistry III	Astor Room

Poster Session – 6 - 8 pm
Networking Reception French Room

Tuesday, October 22, 2019

Speaker Breakfast – 8:00 – 8:45 am –Walton North

General Attendee Breakfast – 8:00 am – 8:45 am – French Room

ASME Tribology Award Presentations

Plenary Session - TBD– 9:00 am – 9:40 am
Grand Ballroom
Title:TBD

Networking Break (Exhibits & Posters) – 9:40 am – 10:00 am French Room

Technical Sessions - 10:00 am - 12 Noon

4A – Machine Elements & Systems II	Grand Ballroom
4B – Surfaces & Interfaces IV	Walton South
4C – Lubricants I I	Georgian Room
4D – Biotribology I	Venetian Room

Lunch on Your Own – 12:00 noon – 1:20 pm

Technical Sessions – 1:20 – 3:40 pm

5A – Energy/Environment/Manufacturing I -	Grand Ballroom
5B - Machine Elements & Systems I -	Walton South
5C – Lubricants II	Georgian Room
5D - Biotribology II	Venetian Room

Networking Break (Exhibits & Posters) 3:40 – 4 pm French Room

Technical Sessions Continued– 4 – 5:00 pm

5A – Energy/Environment/Manufacturing I -	Grand Ballroom
5B - Machine Elements & Systems I -	Walton South
5C – Lubricants II	Georgian Room
5D - Biotribology II	Venetian Room

Wednesday, October 23, 2019

General Attendee Breakfast – 8:00 am – 8:45 am – French Room

Special Plenary Symposium – Beyond the Cutting Edge: Highlights from Tribology Letters – 9 am – 12:00 pm Grand Ballroom

Featured Speakers:

9:00 am - 9:30 am
3221821: Unraveling Mysteries of Tribochemistry
Seong Kim, Pennsylvania State University, University Park, PA

9:30 am - 10:00 am
3218088: One Ring Holds and One Ring Breaks
Yip-Wah Chung, Tobin Marks, Qian Wang, Northwestern University, Evanston, IL

10:00 am - 10:15 am - **Break**

10:15 am - 10:45 am
3221447: Blowing in the Wind - On the Formation and Physical Properties of Wear Particles We Breathe
Ulf Olofsson, KTH Royal Institute of Technology, Stockholm, Sweden

10:45 am - 11:15 am
3221467: Mechano-Chemical Decomposition of Organic Friction Modifiers with Multiple Reactive Centers Induces Superlubricity of Ta-C
Michael Moseler, Gianpietro Moras, Fraunhofer IWM, Freiburg, Germany

11:15 am - 11:45 am
3219482: Insights into Hydrogel Friction
Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL

1A Grand Ballroom

Materials Tribology I

Session Chair: TBD

2:40 - 3 pm

3200052: The Tribological Performance of Shot Peened AISI5160 Steel

Xue Han, Oakland University, Auburn Hills, MI

The effect of heat treatment on wear and friction performance of AISI 5160 steel was studied. The AISI 5160 steel samples were austempered at 288°C, 316°C, 343°C, 371°C, 399°C, 427°C, and 454°C for 2 hours until the bainite transformation was complete. In addition, the influence of shot peening on the wear and friction behavior of heat treated 5160 steel was studied. The microstructure, hardness, and residual stress of specimens were studied by optical microscopy, scanning electron microscopy, Vickers micro-hardness, 3D-profiler, and X-ray diffraction. Austempering temperatures of 288°C, 316°C, and 343°C produced lower bainite with better wear behavior than austempering temperature of 371°C, 399°C, 427°C, and 454°C which produced upper bainite. Moreover, shot peened specimens had better wear behavior than non-shot peened specimens for austempered temperatures from 288°C to 371°C. Abrasive wear was the primary wear mechanism for all test specimens.

3 - 3:20 pm

3221213: Structural Change in 304L Stainless Steel near Surface Material by Micro-Impact Texturing

M. Cinta Lorenzo Martin, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL

Tribological behaviour of various materials is strongly dependent on the near surface material region. There are different ways to modify the near surface material properties, such as heat treatments, coatings and laser texturing. Other forms of near surface material modification involve mechanical actions, such as short-pinning, pattern honing and friction stir surfacing. Micro-impact texturing is another mechanical surface engineering method. The process involves hitting the surface with fine particles at high impact velocity (sand blasting). The process changes the surface morphology by creating an anisotropic micro-indents pattern on the surface. This paper presents the evaluation of near surface material changes as a result of impact texturing of austenitic 304L stainless steel. The near surface structure was evaluated by several characterization techniques such as XRD, optical microscopy and electron microscopy (SEM, EDS, and TEM). For metastable materials such as austenitic steel, impact texturing produced phase transformation and the formation of martensitic phase in the near surface material to a depth of 5-15 microns (depending on impact parameters). This phase was observed to result in 2 order of magnitude wear reduction compared to the non-textured material under dry and marginal lubrication in reciprocating sliding contact against 440C steel ball.

3:20 - 3:40 pm

3199789: Effect of Surface Texture on the Dynamic Friction Behavior of PTFE Sealing Materials

Jian Wu, Yonggang Wang, Youshan Wang, Benlong Su, Zhibo Cui, Harbin Institute of Technology, Weihai, Shandong, China

PTFE is widely used as a sealing materials due to its low friction coefficient. With the development of

surface texture technology, it is possible to improve the sealing life of PTFE under complex environments such as high pressure and oil medium. So dynamic friction test platform is developed for simulating the high pressure, oil medium environments. Then, the effects of different loads, speeds and textured surface on the dynamic friction characteristics are studied. Fluid-solid coupling simulation model of textured PTFE has been developed by ABAQUS. Results indicate that friction coefficient increases with increasement of slip speed; friction force cannot be reduced by texturing PTFE; however, the friction force of textured PTFE decreases under oil condition compared with conventional PTFE seal. The complex evolution law of surface deformation and contact in dynamic friction process have been revealed, which lays the foundation for high performance sealing materials and structural design.

3:40 - 4 pm
3209141: Self-Competing and Coupled Effect of Laser Engraved Counterface Groove Depth, Density and Directionality on Wear of Alumina PTFE
Kaisen Zhang, Hefei University of Technology, Hefei, China

Recent works found lapped counterface roughness perpendicular to the sliding direction could significantly improve debris retention and reduce the wear of an alumina PTFE solid lubricant by 70%. In this paper, we aimed to test the independent effects of roughness groove depth, density and directionality on debris retention and wear performance of a well-studied alumina PTFE solid lubricant using laser textured counterfaces. Grooves were textured parallel or perpendicular to the polymer's sliding direction and with independently varied depth and interval. A new surface directionality parameter was defined to quantify surface directionality before and after the wear test. The results suggested both groove depth and interval have self-competing effect on wear due to the in-situ grounding of the counterface topography during sliding. Groove direction, surface directionality and wear are also strongly correlated. A conceptual framework was proposed to illustrate the relations between counterface texture, polymer wear, surface directionality and counterface abrasion.

4 - 4:20 pm
3240511: Modeling Water's Role in the Initial Friction Behavior of MoS_2 Films
John Curry, Sandia National Laboratories, Albuquerque, NM, Tomas Babuska, Lehigh University, Bethlehem, PA, Brendan Nation, Sandia National Laboratories, Albuquerque, NM, Brandon Krick, Lehigh University, Bethlehem, PA, Michael Dugger, Michael Chandross, Nicolas Argibay, Sandia National Laboratories, Albuquerque, NM

The transition to steady state, or run-in, for solid lubricants is a relatively unexplored and poorly understood aspect of performance. More importantly, for many precision components such as those used in mechanisms for aerospace applications, duty cycles frequently limit all operation to the run-in phase. This talk focuses on factors that contribute to increased friction during run-in, with a focus on the role of water in the contact and in the bulk of the film over time. Friction experiments were carried out in environments from ambient conditions to UHV over a wide range of dwell times. A mechanism for water's role is discussed and a generalized model is presented to help predict aging effects of water on run-in behaviors for MoS_2 films. This work was funded by the Laboratory Directed Research and Development program at Sandia National Laboratories, a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under Contract DE-NA0003525.

Surfaces and Interfaces I

Session Chair: TBD

2:40 - 3 pm
3222390: Electrical Contact Resistance at Gold/Graphene Interfaces
Mohammad R. Vazirisereshk, Saima A. Sumaiya, Mehmet Baykara, Ashlie Martini, University of California Merced, Merced, CA

Recent studies have shown that a major limitation of graphene-based nanoscale electronic devices is electrical contact resistance (ECR) at metal/graphene interfaces. ECR nominally depends on the properties of the contact between the graphene and metal electrodes, i.e. size, shape and morphology, but is also affected by atomic-scale details in the interface. However, studies of ERC mechanisms at the atomic scale are challenging due to difficulties associated with characterization of the buried conducting interface. In this work, atomistic simulations and conductive atomic force microscopy (C-AFM) experiments are used to study ECR across the interface formed between gold islands of varying lateral size and a highly oriented pyrolytic graphite (HOPG) surface. The size and shape of the atomically-smooth interface between the gold islands and HOPG are determined via C-AFM experiments, such that variations in ECR can be directly related to the geometry of the contact. Molecular dynamics simulations are then used to model the gold islands, tip apex and near-contact HOPG, with a modification that enables electrical current to be approximated without explicitly modeling electrons. The combination of C-AFM measurements with atomistic simulations provide insight into the correlations between structural, mechanical and electrical properties of nanoscale contacts, which are of paramount importance for the design of next-generation materials and devices.

3 - 3:20 pm
3221593: A Comparison of Nanoscale Measurements and Models of Real and Nominal Contact Areas
Robert Jackson, Yang Xu, Yan Chen, Anqi Zhang, Barton Prorok, Auburn University, Auburn, AL

In this study, a new experimental method is proposed to measure the real area of contact between a ceramic sphere and an Al surface based on the adhesive transfer of the Au film and the Scanning Electron Microscope (SEM) in the back-scattered mode. A thin film of Au is sputtered on the ceramic sphere before the indentation with the Al surface. After indentation, the interfaces of the ceramic sphere and Al surface are observed by SEM. The contact area can be identified based on both the distributions of the ceramic and Au on the ceramic sphere and Al surface, respectively. The measured contact area at different nominal pressures are compared to predictions made by several popular theoretical elastic-plastic rough surface contact models.

3:20 - 3:40 pm
3200257: Verification of Three Friction Models for a Contact Patch with Uni-Axial Loading
Iyabo Lawal, Matthew Brake, Rice University, Houston, TX

Multiple contact patches exist for a given interface and the evolution of the contact patch depends on the frictional response. The surface topology, and local material properties (Elastic Modulus, etc) change in response to several variables including: loading of the interface, geometry of the interface and material properties. How interfaces in structural dynamics evolve with uni-directional reciprocating

loads is an area of Structural Dynamics with a high amount of uncertainty. [1] These combined effects illustrate the complexity of how the interface evolves with time. This work will verify three different friction models: Coulomb, Stribeck and Bouc-Wen to help predict how the contact patch topology and local material properties changes in response to known loads. AISI 304 SS is used in testing. Modelling is based on 2-D plane strain FEM (Finite Element Method) simulations with experimental validation of the incomplete contact with a flat-on-sphere tribometer.

3:40 - 4 pm

3205617: Multiscale Computational Scheme for Semi-Analytical Modeling of the Point Contact of Inhomogeneous Materials

Mengqi Zhang, Southwest Jiaotong University, Chengdu, China

Semi-analytical models (SAMs) have been developed to analyze contact problems efficiently, including those of inhomogeneous materials, based on the equivalent inclusion method. However, understanding the behavior of microscopic inhomogeneities requires SAMs of even higher efficiency. This study builds a new semi-analytical model for high-speed simulations of contacts of materials containing distributed particles of sizes orders of magnitude smaller than that of the contact radius. The domain decomposition method is applied to construct a two-level mesh set to implement multiscale computation. The macroscopic mesh uses homogenized elements that ensure a high computing efficiency in obtaining the contact pressure distribution as a boundary condition, whereas the material microstructures are modeled using the microscopic mesh, and thus the microscopic stress and strain are obtained. New influence coefficients are derived for eigenstress and eigenstrain calculations in both mesh levels and are used to calculate the eigenstress and equivalent eigenstrains. The new model is implemented to investigate the effects of particle clustering on the contact performances of composites.

4 - 4:20 pm

3253145: Simulating the Interaction between Surfactants and Iron Oxide Interfaces: From Density Functional Theory to Molecular Dynamics Simulations

Daniele Dini, Carlos Ayestaran-Latorre, James Ewen, Imperial College London, London, United Kingdom, Chiara Gattinoni, ETH Zurich, Zurich, Switzerland

Understanding the behaviour of surfactant molecules on iron oxide surfaces is important for many industrial applications. Molecular dynamics (MD) simulations of such systems have been limited by the absence of a force-field (FF) which accurately describes the molecule-surface interactions. In this study, interaction energies from density functional theory (DFT) calculations with a van der Waals functional are used to parameterize a classical FF for MD simulations of amide surfactants on iron oxide surfaces. The Original FF, which was derived using mixing rules and surface Lennard-Jones (LJ) parameters developed for nonpolar molecules, were shown to significantly underestimate the adsorption energy and overestimate the equilibrium adsorption distance compared to DFT. Conversely, the Optimized FF showed excellent agreement with the interaction energies obtained from DFT calculations for a wide range of surface coverages and molecular conformations near to and adsorbed on α-Fe2O3(0001).

4:20 - 4:40 pm

3257250: MD Simulations of Friction and Wear of Fuel Surrogates

Judith Harrison, US Naval Academy, Annapolis, MD, J. Schall, Oakland University, Rochester, MI, Sabina Maskey, Brian Morrow, US Naval Academy, Annapolis, MD

The application of carbon-based coatings to engine components has become increasingly more common. Coatings, such as ultrananocrystalline diamond (UNCD) and amorphous carbon (a-C:H) can have a wide-range of properties but are generally attractive due to their wear resistance. At the same time, alternative fuels, such as Catalytic Hydrothermal Conversion Jet (CHCJ), diesel (CHCD) and others are being developed. Because these fuels are complex, surrogates for these fuels have been developed so that impacts of changes in composition on properties and combustion can be studied. To date, little effort has been devoted to the study of the interactions of these fuels with engine coatings. The results of molecular dynamics (MD) simulations using both the REBO+S and the ReaxFF potentials, that examine the interaction of two- and three-component CHCJ surrogates with carbon-based engine will be presented.

4:40 - 5:20 pm

3253437: *Spotlight Presentation*: A Near-Surface Microstructure Evolution Map for CuNi Alloys under Sliding Obtained from Large-Scale Molecular Dynamics

Stefan Eder, Vienna University of Technology, Vienna, Austria, Ulrike Cihak-Bayr, Manel Rodríguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria, Daniele Dini, Imperial College London, London, United Kingdom, Carsten Gachot, Vienna University of Technology, Vienna, Austria

In this work, we study the microstructural response of five FCC CuNi alloys subjected to sliding with molecular dynamics simulations featuring tens of millions of atoms. The initial grains average 40 nm in size to ensure that plasticity is not dominated by grain boundary sliding, so our polycrystalline aggregate exhibits dislocation pile-up, twinning, and grain refinement analogous to polycrystals with much larger grains. By analyzing the depth-resolved time development of the grain size, twinning, shear, and the stresses in the aggregate, we produce a microstructure evolution map for CuNi alloys. This captures the predominant microstructural phenomena occurring for a given composition and normal pressure, and aids engineers in optimizing materials/surfaces to work within a required operating range. We compare tomographic visualizations of our atomistic model with focused ion beam images of the near-surface regions of real CuNi alloys that were subjected to similar loading conditions.

1C Georgian Room

Fluid Lubrication I

Session Chair: S. Bair, Georgia Tech, Atlanta, GA

2:40 - 3 pm

3189153: Parallel Thrust Bearings, a Comparison Between Experiments and CFD Thermoelastohydrodynamic Simulations

Michel Fillon, Anastassios Charitopoulos, Pprime, Poitiers, France, Christos Papadopoulos, National Technical University of Athens, School of Naval Architecture and Marine Engineering, Athens, Attika, Greece

Experimental studies have demonstrated that parallel surface thrust bearings are capable of supporting thrust loads, a phenomena that cannot be predicted with the use of the classic hydrodynamic lubrication theory [1]. The literature gives various explanations of the load carrying capacity of parallel thrust bearings [2]. Recent studies concluded that the main pressure build-up mechanism is the temperature deformation of the bearing pad geometry [3], but other phenomena also contribute to the load carrying capacity. On the current work the effect of the “imperfect” parallel surface will be studied,

in means of comparison of experimental results with 3D CFD ThemoElastoHydroDynamic computational models.

3 - 3:20 pm
3237963: CFD and Experimental Investigation of Spring Supported Thrust Bearings
Samuel Cupillard, Hydro-Quebec, Varennes, Quebec, Canada

Spring supported thrust bearings are equipping a wide portion of the hydraulic turbines of Hydro-Québec. Despite operating adequately most of the time, unexpected behaviors and failures occur time to time. Some elements of designs are often questioned and bring us to the fact that more knowledge is required when maintenance and repair are needed. To achieve that, a thermo-elasto-hydrodynamic (TEHD) numerical model has been developed to predict the performance of such bearings. The TEHD model enables a 2-way fluid-structure coupling in order to calculate the pad deformations. Besides, some measurement campaigns have been performed on two different types of thrust bearings equipping hydraulic machines of Hydro-Québec. The results from the numerical model are well in agreement with the experimental measurements in terms of film thickness and temperature. The measurements together with the simulations have contributed to a better understanding of the behavior of this type of thrust bearing.

3:20 - 3:40 pm
3218323: A Computational Fluid Dynamics (CFD) Investigation of Inertia Effects in the Hydrodynamic Lubrication of Journal Bearings; Static and Dynamic Performance
Troy Snyder, Minel Braun, University of Akron, Talmadge, OH

The use of computational fluid dynamics (CFD) in the analysis of journal bearing performance can widen the predictive envelope beyond the classical Reynolds equation. In this paper, CFD is used to evaluate the static and notably the dynamic performance of journal bearings at operating conditions where inertia effects are significant, and the assumptions underpinning the classical Reynolds equation cease to be valid. Linearized dynamic coefficients obtained from a transient CFD-FSI approach are directly compared with those obtained from the perturbed Reynolds equation. Inertia effects are explored through iterative modification of the Reynolds equation as well as Stokes and Navier-Stokes forms of equations. Threshold values of Reynolds numbers for which advective and temporal inertia effects can respectively be neglected, are elucidated and compared with previous investigations. At high Reynolds numbers, turbulence effects are also considered through both CFD and Reynolds equation frameworks.

3:40 - 4:20 pm
3221522: ***Spotlight Presentation:*** **Comparison of Dry and Lubricated Traction in Rolling Contacts - A Review**
Gerhard Poll, Leibniz University Hannover, Hannover, Lower Saxony, Germany

In dry rolling contacts, slip is known to be the result of elastic deformations of the contacting solid bodies when subject to tangential forces. The Coulomb friction law is commonly applied to determine the maximum traction. Thus, solid contact mechanics are governing the traction characteristics. In contrast, in lubricated contacts, fluid rheology is thought to prevail. In reality, solid body elastic deformations as a result of tangential forces also exist in lubricated contacts. and should be considered at high pressures. Also, the lubricants tend to solidify into a glassy state with increasing pressure and then need to be regarded as solid interfacial layers with elastic properties. On the other hand, the surfaces in dry contacts are often not “clean” and covered by layers with specific rheological properties. Given the fact that discussions in the scientific community have re-intensified recently, the authors intend to review the state of research regarding this topic.

4:20 - 4:40 pm

3221273: Coupling Transient Mixed Lubrication and Wear for Journal Bearing Modeling

Yanfeng Han, Guo Xiang, Jiaxu Wang, Chongqing University, Chongqing, China

A transient Mixed Lubrication-Wear coupling model (MLW coupling model) is developed to investigate the mixed lubrication and wear performances of journal bearings, and a wear experiment is performed to verify the developed numerical model. In the coupling numerical model, the transient interaction between the behavior of mixed lubrication and wear is considered by incorporating the wear depth distribution, which is determined by the developed friction fatigue wear model, into the film gap equation. The evolutions of the worn surface profile, wear rate, fluid pressure and asperity contact pressure over operating time are calculated by the developed numerical model. The simulated results demonstrate that the transient wear process affects the distribution trend of lubrication performances significantly, and a worn surface profile may exist that provides an optimal tribology performance of journal bearings. The simulated results also demonstrate that there are two wear stages, identified by initial and steady wear stage, of journal bearings under mixed lubrication condition. Furthermore, the effects of the input parameters, including the radius clearance(C), surface roughness (s), asperity curvature radius (b) and boundary friction coefficient(m_c), on the predicted mixed lubrication and wear performance are evaluated.

4:40 - 5 pm

3221275: Comparative Analysis of Groove and Dimple Shape Partially Textured Journal Bearing under Various Conditions

Anil Shinde, Annasaheb Dange College of Engineering, Ashta, Sangali, Maharashtra, India

The present study deals with comparative analysis between ellipsoidal dimple and rectangular groove shape partially textured bearing under various conditions. The performance characteristics viz. load carrying capacity; frictional torque and coefficient of friction for rectangular groove and ellipsoidal dimple shape texturing is studied numerically at the different number of array, height of texture and axial spacing between texturing. A three dimensional thin film flow analysis model of COMSOL Multiphysics 5.0 software is used to compare the static performance characteristics of different configurations of the bearing system. The numerical analysis is carried out at same textured area and textured location for all configurations. From the analysis, it is found that, ellipsoidal dimple shape texturing gives best performance as compared with other configurations.

1E Astor Room

Tribochemistry I

Session Chair: TBD

2:40 - 3:20 pm

3221348: ***Spotlight Presentation:*** **Probing and Understanding Elementary Steps in Tribochemical Reactions**

Wilfred Tysoe, UW Milwaukee, Milwaukee, WI

Tribology invesigates the effects of mechanical forces during sliding. The effect of stress on tribochemical reaction rates is described using the Bell model but obtaining a molecular understanding of the way in which an external force modifies reaction rates requires knowing the elementary steps for a simple model reaction pathway. This is illustrated for the gas-phase lubrication of copper by dimethyl disulfide where two stress-activated elementary-step reactions are identified. The first is the tribochemical decomposition of adsorbed methyl thiolate species to form gas-phase hydrocarbons and chemisorbed sulfur. In a second stress-induced reaction, surface sulfur is transported into the subsurface region of the copper. The first effect is investigated theoretically using quantum calculations and the results are compared with those for the decomposition of methyl thiolate species on a Cu(100) single crystal substrate measured by atomic force microscopy in ultrahigh vacuum.

3:20 - 3:40 pm

3253169: Reactive Simulations Deconvolute the Effects of Heat and Shear on Iron Sulfide Film Formation

Ashlie Martini, Karen Mohammadtabar, University of California Merced, Merced, CA, Stefan Eder, Nicole Dörr, AC2T, Vienna, Austria

Tribofilm formation is believed to be accelerated by multiple factors in a sliding contact, but the individual contributions of these factors are not fully understood. In this study, we use reactive molecular dynamics simulations to deconvolute the effects of heat, load, and shear force on chemical reactions between di-tert-butyl disulfide, an extreme-pressure additive, and Fe(100), a model approximation of the ferrous surfaces of mechanical components. The reaction pathway is characterized in terms of the number of chemisorbed sulfur atoms and the number of released tert-butyl radicals during heat, load and shear stages of the simulation. Chemisorption is limited by accessibility of reaction sites, so shear accelerates the reaction by facilitating movement of radicals to available sites. Analysis of tert-butyl radical release in the context of an Arrhenius-based model for mechanochemical reactions shows that shear lowers the energy barrier for reactions, implying that, in lubricated contacts, the effect of shear will be dominant at lower temperatures, which are expected to arise under moderate sliding conditions.

3:40 - 4 pm

3221533: Dynamics of Viscosity Index Improver Polymers under Shear and Confinement

Hitoshi Washizu, Soma Usui, Taiki Kawate, University of Hyogo, Kobe, Japan

Molecular dynamics of viscosity index improver polymers are investigated by multiphysics simulations. The Brownian motion of polymer segment is described by Langevin dynamics. Flow of base oil is calculated solving Navier-Stokes equation by lattice Boltzmann method. The force between the polymer segments and solvent base oil is calculated by Stokes force applying on the center of the mass of polymer segments, using the mean velocity from the fluids. Under no-shear system, the radius of gyration increases with the polymer weight increases, as is predicted, whereas the reverted dependence is found in the shear case. In bulk solution under shear, the inverted temperature dependence of the radius of gyration of polymers are found. This is due to the decreasing viscosity of the base oil due to the temperature rise. Although this behavior is not reported yet, this tendency is good for viscosity rise in the low velocity region, and do not inhibit the friction loss in the high velocity region.

In confined solution under shear, given by the movement of a solid wall, the polymer molecules moved to the solid wall direction, due to the lift force. The lift force increase with the addition of the polymer weight. This means, not only the inter-molecular force but the hydrodynamic force is important to understand the viscosity improving and adsorption process.

4 - 4:20 pm

3204786: A Quantum Chemical Study of Behavior of Boundary Lubricating Additives

Chao Zhang, Shanghai University, Shanghai, China

$Dmol^3$ module in Materials Studio 2017 software based on the density functional theory (DFT) is used at the atomic level for the calculation of the energies and structures of all reactants, products, intermediates, and transition states of a set of isomerization, decomposition, adsorption, desorption, oxidation, restortion, and polymerization reactions that engine oil friction reduction and antiwear additives may take part in under boundary lubricating condition. ZDDPs, MoDTCs, advanced environment friendly alternative lubricants and additives on surfaces of steels, other metals, and DLC coatings are employed to investigate their comprehensive effects on friction reduction and wear resistence. Comparison between the simulation results and tribological experimental data are made, and a good agreement is observed. The results of this study should provide insight on the relative significance of the various theoretical mechanisms that are believed to be at work. This approach can be a useful tool to design tribopairs, lubricants and additives.

2A Grand Ballroom

Materials Tribology II

Session Chair: TBD

10 - 10:20 am
3221832: Introducing Plasma Enhanced Atomic Layer Deposited Nitrides: A Remarkably Wear Resistant Material System
Tomas Babuska, Lehigh University, Bethlehem, PA, Alexander Kozen, Navy Research Laboratory, Welcome, MD, Mark Sowa, Veeco CNT, Boston, MA, Guosong Zeng, Lawrence Berkeley National Laboratory, Berkeley, CA, Nicholas Strandwitz, Brandon Krick, Lehigh University, Bethlehem, PA
Atomic layer deposition (ALD) is widely used in applications requiring conformal coatings that require highly controlled thickness and tight dimensional tolerances such as MEMS/NEMS, biomedical implants and aerospace components. By adding plasma, plasma enhanced-ALD allows for deposition at low sample temperatures while maintaining conformality. Plasma enhanced atomic layer deposited TiN, VN and TiVN thin films have recently shown promise as a superb tribological material, outperforming similar coatings processed by traditional PVD techniques (i.e. magnetron sputtering, cathodic-arc). TixV1-xN thin films have shown ultra-low wear rates rivaling diamond (K ~ 2x10-9 mm3/Nm and less) and low friction (µ~0.16) while still being electrically conductive, making it a promising material for not only low wear applications but for electrical contacts.

10:20 - 11 am
3221362: *Spotlight Presentation*: Reliability of Microswitches Subject to Cold and Hot Switch Cycling
Maarten de Boer, Changho Oh, Carngie Mellon University, Pittsburgh, PA, Robert Carpick, University of Pennsylvania, Philadelphia, PA

A key problem limiting progress in microelectronics is that when transistors are scaled down in size, they leak current and as such are highly energy inefficient. A potential solution is a nanoswitch, in which a gap is physically opened so that leakage is eliminated. However, much work is needed to demonstrate that such switches reliably meet a cycles-to-failure requirement. Using Pt-coated microswitches, we explore materials, process parameters, cycling conditions and environments to improve the cycle count. We report on process parameters that repeatedly achieve 300 million cycles when cold switched (contact voltage on only when switch is closed). Such switches are then tested under hot switching conditions (contact voltage always on) as a function of voltage and contaminant level. Lower voltage improves lifetime in a clean environment, but degrades it in a contaminated environment. This is attributed to a graphitic film that builds up but does not break down electrically.

11 - 11:20 am
3216909: Formation of MoS_2 from Elemental Mo and S Using Reactive Molecular Dynamics Simulations
Rimei Chen, University of California, Merced, Merced, CA, Arben Jusufi, Alan Schilowitz, ExxonMobil, Annandale, NJ, Ashlie Martini, University of California, Merced, Merced, CA

It is generally accepted that Mo- and S- based lubricant additives reduce friction in boundary lubrication through the formation of MoS_2 during operation. However, the fundamental mechanisms of this

crystallization process are still not known, and direct experimental measurement is challenging because the process occurs between two contacting surfaces. Here, we use reactive molecular dynamics simulations to model MoS_2 formation from elemental Mo and S by compressing and heating amorphous materials. These models capture the formation and breaking of covalent bonds so that the reaction pathways leading to MoS_2 formation can be explored. We compare multiple reactive force fields for their ability to reproduce MoS_2 formation and test the sensitivity of crystallization to simulation parameters. The size and distribution of MoS_2 domains are characterized during the growth process. The simulations reveal fundamental mechanisms of MoS_2 formation and suggest conditions under which crystal growth might be optimized.

11:20 - 11:40 am
3221694: Micropitting and Fatigue Measurement of Thermoplastic Materials
Mano Chockalingam, Zhencheng Ren, Barbara Fowler, Gary Doll, The University of Akron, Akron, OH
Micropitting is a surface fatigue failure mode common in cyclically loaded contacts such as in rolling element bearings and gears.The scientific objective of this work was to study the onset and progression of micropitting and fatigue life of thermoplastic candidates for mechanical applications. When compared with metals, thermoplastics have lower frictional properties, less wear, higher corrosion resistance, and are thermally and electrically insulating. Fatigue testing was performed under similar conditions on five different thermoplastic materials on a micropitting rig (MPR). Post-test analysis included visual inspection of MPR rollers and optical interferometry to study the onset and progression of micropitting. Results indicated that the micropitting onset was more dependent upon the surface roughness of the rollers rather than the type of fiber reinforcement. It was also observed that progressive wear of the surfaces exposed underlying pores in the rollers.

2B Walton South

Surfaces and Interfaces II

Session Chair: TBD

10 - 10:20 am
3239801: The Unsatisfied Effect of Plateau Honing on the Friction and Wear of Cylinder Liners
Youngze Lee, EunSeok Kim, SungKyunKwan University, Suwon-si, Gyeonggi-do, Korea

To improve the performance of the engine, it is important to control interacting surfaces optimally in designing the surfaces of cylinder liners. The plateau honing technology has been used on the cylinder liners. It is a cross-hatch pattern of valleys for oil repository. However, the valley produced by honing functions hinders the formation of fluid dynamic pressure on interacting surfaces. The friction and wear tests with reciprocating motion were performed to compare the lubricity of sliding cylinder liner surfaces with different plateau honing marks on the different surface roughness. The effectiveness of honing marks was compared with those of different surface roughness under conditions that the oil is not supplied sufficiently. From the tests, it was found that the abrasion resistance is more affected by the surface roughness than honing marks due to asperity contacts and formation of oil films. In addition, larger and sharply wear particles worn out generally from the honing surface and leave deep wear track.

10:20 - 10:40 am

3202502: Tribology Properties and Microstructure of Sulfurized, Nitrided, and Nitrocarburized Layers Deposited in a Hollow Cathode Discharge

Minyi Zhang, Yang Li, Guangyan Chen, Yongyong He, Jianbin Luo, State Key Laboratory of Tribology, Tsinghua University, Beijing, China

The tribology characters of sulfurized layer, nitrided layer, nitrocarburized layer and sulphonitrocarburized layer were investigated and compared. The morphologies and structures of these layers were analyzed by SEM, AFM, XRD, XPS and 3D White Light Scanner. The Nano hardness of the different layers was investigated. The XPS and XRD were utilized to detect the valence states of boundary and the phase structure. The sulfurized layer is relatively porous, which is good for the tribology properties with oil lubrication. The results of SEM and AFM show that the grain size of the sulphonitrocarburized layer is much smaller than that of the sulfurized layer, the microscopic roughness as well. Dry sliding wear of different diffusion layers was carried out on ball-on-disc tester. The wear scars were investigated by SEM and 3D White Light Scanner. The result shows that the Sulphonitrocarburized layer has the lowest friction coefficient and wear loss.

10:40 - 11 am

3198783: Frictional Characteristics of Suspended MoS_2

Peng Huang, Institute of Materials, Chengdu, China

Molybdenum disulfide (MoS_2), a booming layered two-dimensional (2D) nanomaterial, has gain intensive interests for its remarkable physical properties. In this work, the friction characteristics of suspended MoS_2 are systematically investigated with atomic force microscopy (AFM). The friction on the suspended MoS_2 is much larger than that on the supported MoS_2 because of the softening bending rigidity and easier formation of puckering at the AFM tip−MoS_2 contact interface, and the difference would increases with the applied load. Similar to the supported MoS_2, the friction on the suspended MoS_2 also decreases with the increasing layers because of the enhanced bending rigidity. The friction on the suspended MoS_2 is relatively insensitive to the shapes of holes below but sensitive to the dimensions. This work can provide beneficial guidance for the diverse design requirements of MoS_2-based nanoelectromechanical devices, and is also meaningful in the application of MoS_2 as solid lubricants.

11 - 11:20 am

3221409: Effect of Environmental Vapor on the Friction at Exposed Graphene Step Edges

Zhe Chen, Seong Kim, Pennsylvania State University, University Park, PA, Arash Khajeh, Ashlie Martini, University of California Merced, Merced, CA

Graphene is considered to be an excellent coating for lubrication. However, graphene edges, which are nearly inevitable on graphene coating surfaces, have a significant effect on the lubricity of the coating by inducing much higher local friction than the graphene basal plane. In order to investigate the mechanism of the friction behavior of the exposed graphene step edge, nanoscale friction tests were performed with atomic force microscopy (AFM). Distinct friction behaviors were obtained when the test was performed in various vapors. Thus it is assumed that not only the topography change at the step edge, but also the chemical interactions among the exposed graphene edges, the AFM tip surfaces, and the vapor molecules play a significant role in the friction behavior of the exposed graphene edge. Further analysis through molecular dynamics (MD) simulations proved this assumption. This work enriches the understanding of frictional properties at atomic step edges and is helpful for the application of 2D materials as lubrication coatings.

11:20 am - 12 pm
3218530: *Spotlight Presentation*: Measuring Friction at a Single Interface with Two Independent Microtribometers: A Model Study with Alumina Spheres on Gold or Single-Crystal MoS_2
Brian Borovsky, Gabriel McAndrews, Raymond Wieser, St. Olaf College, Northfield, MN, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

Fundamental studies of micro/nanoscale friction often employ scanning probes operating at relatively low speeds (< 1 mm/s). These approaches typically rely on compliant spring-based mechanisms whose deflections are sensed electrically or optically. Over the last decade, several groups have developed an alternative approach using quartz crystal microbalances (QCM) to quantify frictional forces at solid-on-solid contacts. QCM-based techniques achieve high sliding speeds (~1 m/s) that are relevant to most practical devices. By reciprocating a probe-on-flat interface at MHz frequencies, the QCM detects lateral forces in a regime where the probe can be considered infinitely rigid. We have integrated spring-based and QCM-based measurements into a single system in order to perform well-controlled comparisons of these two distinct techniques. The interfaces examined use two model materials, polycrystaline gold and single-crystal MoS_2, against alumina microspheres. We show how integrating these complementary approaches can help bridge the gap between fundamental and practical micro/nanotribology studies.

2D — Venetian Room

ASME Session I

Session Chair: TBD

10 - 10:40 am - **ASME Presentation #1**

10:40 - 11:20 am - **ASME Presentation #2**

11:20 am - 12 pm - **ASME Presentation #3**

2E — Astor Room

Tribochemistry II

Session Chair: TBD

10 - 10:20 am
3202905: Extracting More Value from Tribofilm Images
Oluwaseyi Ogunsola, Shell Global Solutions (US) Inc., Houston, TX, Chaitanya Pradhan, Aarthi Thyagarajan, Vishal Ahuja, Nitish Nair, Shell India Markets Pvt. Ltd., Bangalore, India

Tribofilms are formed mostly through chemical bonding of oil additives to metal surfaces in an engine. Stronger and thicker tribofilms are likely to give better wear protection by preventing metal-to-metal

contact. Most test methods for tribofilm investigation generate wear images that are further analyzed to determine the thickness. Traditional methods of tribofilm thickness analysis are limited by sampling location, inability to extract tribofilm region automatically, and the lack of a quantitative metric to characterize tribofilm uniformity. This presentation features a method to derive more value out of tribofilm images from MTM SLIM experiments by automated extraction of the tribofilm region to generate thickness distribution, identification of image features e.g. tribofilm uniformity, dominant thickness, and more. These extra details will enable screening of lubricant chemistries with enhanced tribofilm attributes in ICEs and other applications with similar additive chemistry.

10:20 - 10:40 am

3221890: Sensitivity of Standard Fuel Tribological Methods to Environmental Oxygen

Stephen Berkebile, Blake Johnson, Allison Osmanson, US Army Research Laboratory, Aberdeen Proving Ground, MD

Standard tests for measuring the lubricating ability of fuels are typically conducted in air. Such standard tests will be shown to have evidence of oxidative wear, although the point of failure in recent test of a high-pressure fuel pump operated with a low viscosity jet fuel will be shown to have originated from scuffing that lacked signs of oxidative processes. The non-oxidative scuffing will be compared to the extent of steel oxidation in the High Frequency Reciprocating Rig (HFRR) diesel fuel lubricity standard. The HFRR wear for several different fuels showed evidence of significant steel oxidation, in contrast to the scuffing observed in the pump. The standard tribological methods of HFRR and Ball on Three Disks (BOTD) conducted in air will then be compared to both methods conducted in an oxygen-starved nitrogen gas environment to demonstrate the effect of the presence/absence of oxygen on fuel lubricity measurements for several different fuels.

10:40 - 11 am

3222259: Influence of Sliding Velocity and Exposure Time on the Tribologically-Induced Oxidation in High-Purity Copper

Christian Greiner, Julia Lehmann, Peter Gumbsch, Reinhard Schneider, Karlsruhe Institute of Technology, Karlsruhe, Germany

Tribo-oxidation is an often observed but far from fully understood phenomenon during friction and wear. The aim of our research is to elucidate the elementary mechanisms of tribologically-induced oxidation by paring polycrystalline high-purity copper plates with sapphire spheres. The experiments are performed at room temperature in a strictly controlled atmosphere with reciprocating linear sliding under mild tribological loading. This works aims to understand the influence of the sliding velocity and the exposure time after the tribological loading to the controlled environment on the formation of these oxide clusters. We systematically vary the sliding speed from 0.1 to 5.0 mm/s and investigate the resulting microstructure. Scanning electron microscopy techniques are used in order to reveal the fundamental mechanisms of tribologically-induced oxidation. Once understood, this will help for tailoring the materials properties in order to achieve superior tribological performance.

11 - 11:20 am

3231983: The Effect of Fuel and Soot on Tribofilm Formation from ZDDP-Containing Lubricant Oils with Different Friction Modifiers

Shusheng Xu, Paul Byron, Ardian Morina, Anne Neville, University of Leeds, Leeds, United Kingdom, Sashi Balakrishnan, BP Global Lubricants Technology, Technology Centre, Whitchurch Hill, United Kingdom

The negative impact of contamination on the tribological performance is ubiquitous of lubricants. How contaminants affect the formation of tribofilm is less well understood [1-3]. In this study, 5 wt.% gasoline or 0.5 wt.% was added to the lubricants and the effect of them on the tribochemistry was studied by using the MTL-SLIM tribometer system. The results show that the formed patched-like ZDDP tribofilms were quite different: large size for the oil with inorganic friction modifier (MoDTC) but smaller size for the oil with the organic friction modifier (Amide). When gasoline was added to the lubricating oil, the friction coefficient of the lubricant with inorganic friction modifier increased significantly (from 0.06 to 0.08) but that of the lubricant with organic friction modifier kept almost unchanged (~0.095). The lubrication mechanism of the oil with/without contamination are dicussed in terms of the viscosity, wear mechanism and tribofilm thickenss and chemical composition.

3A Grand Ballroom

Materials Tribology III

Session Chair: TBD

1:20 - 1:40 pm
3239804: Sliding Wear Assessment of Various Alloys for Pumping Applications: A Comparative Study
Ronnie Woodward, University of Strathclyde, Tillicoultry, Clackmannanshire, United Kingdom

Pumping applications require wear resistant components to ensure long operating life spans. Sliding wear is a key mechanism of damage for rotary machinery, particularly in the oil and gas sector. Components in this context frequently experience failure due to material loss and changes in geometry, so processes such as nitriding and heat treatments are applied. This improves tribological properties, however adds time and expense to the manufacturing stage. The present study focusses on examining the tribological properties of various potential alloys for pumping applications to judge their suitability in this sliding wear context. The performance of these potential alloys were compared to the results of the current heat treated and nitrided pumping materials. Nitronic 60, AISI 420, 15-5PH, AISI 4340, grey cast iron, nitrided M39T, and leaded bronze were analysed in pin-on-disc sliding wear tests. This involved sliding two samples, a pin and a disc, together while under load to create wear scars on the surface of the disc.

1:40 - 2 pm
3220430: Tribological Behavior and Electron Work Function of Engineering Coiled Tubing Steels
Dongyang Li, J.Q. Li, University of Alberta, Edmonton, Alberta, Canada, Liu Yang, Wuhan Polytechnic University, Wuhan, China, D.G. Wang, G.B. Guo, China University of Petroleum-Beijing, Beijing, China, Daolun Chen, Ryerson University, Toronto, Ontario, Canada

Coiled tubing (CT) steel is widely used in the oil and gas industry. Although CT steels of different grades show similar microstructures within a narrow compositional range, their tribological performance can be quite different. Due to their limited composition range and similar microstructures, it is not easy to have clear clues for tailoring CT steels with fundamental understanding. We investigated mechanical and tribological properties of several CT steels and analyzed their microstructures. To understand the underlying mechanism responsible for their performance, electron work functions (EWF) of the CT steels were analyzed using a Kelvin probe. EWF reflects the atomic bonding stability and thus the atomic bonding strength and electrochemical stability of materials. Results of the study show that the wear resistance of CT steels increases as the EWF increases, corresponding to an increase in atomic bonding strength. The connection between the work functions and the tribological properties of the CT steels is discussed. It is demonstrated that the work function can provide supplementary information for material modification with fundamental understanding.

2 - 2:20 pm

3204869: Promoting the Formation of Core-Shell Structured Carbides in High-Cr Cast Irons by Boron Addition

Jiaqi Li, Dongyang Li, University of Alberta, Edmonton, Alberta, Canada

High chromium cast irons (HCCIs) have long been used in oil sand, mining, and manufacturing industrial sectors due to its high resistance to wear, corrosion and corrosive wear. HCCIs are composed of hard carbides and ferrous matrix, resulting in high hardness and reasonably good toughness. However, the misfit stress at the carbide/matrix interface due to lattice mismatch may lower the resistance of HCCIs, especially those with higher carbon concentrations and coarse primary carbides, to wear involving impact and large variations in contact stress which increase the risk of interfacial failure.
Recent studies show that core(M_7C_3)-shell($M_{23}C_6$) structured carbides (CSSCs) are present in 45-series (Fe-45%Cr-%C) HCCIs, which helps minimize the misfit stress at the interface between carbide and matrix, thus enhancing the wear resistance of the material. However, such core-shell structured carbide was observed only in 45-4 HCCIs. It is of importance to understand the mechanism responsible for the formation of the CSSCs for maximized benefits. In this study, we conducted thermodynamics analysis to explore the possibility of producing CSSCs through alloying elements. With the guidance of thermodynamic calculation, we were successful to form CSSCs by alloying with boron, confirmed by experiments. For further information, we conducted first-principles calculations to evaluate the effect of the core-shell structured carbides on its resistance to interfacial debonding.

2:20 - 2:40 pm

3210133: Microstructure Characterization of Incoloy 800H Subjected to Fretting at 750°C in Air and Helium

Ahmed Darwish, K. Linga Murty, Jacob Eapen, North Carolina State University, Raleigh, NC, Arman Ahmadi, Farshid Sadeghi, Purdue University, West Lafayette, IN

In this work, we investigate the fretting behavior of Incoloy 800H in a simulated very high temperature reactor (VHTR) environment, and analyze the microstructural changes due to fretting through electron microscopy and spectroscopic methods. Fretting experiments are conducted on Incoloy 800H using Bruker UMT Tribolab with a ball-on-flat configuration. The results from Raman spectroscopy analysis show the presence of oxides such as Cr_2O_3, $FeCr_2O_4$, Fe_2O_3, and Fe_3O_4 during fretting tests conducted in an air environment; as expected, both chromium and iron oxides are observed. Chromium oxide (Cr_2O_3) provides excellent corrosion protection and its stability is of critical importance to the alloy performance. The presence of other oxides may indicate competing mechanisms that can possibly erode or reduce the efficacy of the protective chromium oxide layers. Electron microscopy analyses also show interesting differences in the wear zone with air and helium environments.

2:40 - 3 pm

3203221: Effect of Mo and B Additives on Hardness and Wear Resistance of Cu-Ni Alloy

Runfang Hou, D.Y. Li, University of Alberta, Edmonton, Alberta, Canada

Due to its corrosion resistance, conductivity, and modifiable mechanical properties, Cu-Ni alloy has

found a wide variety of applications, especially in the marine environment. It is highly desired if the mechanical strength and wear resistance of Cu-Ni alloy can reach a level comparable to that of steel. In this study, Cu-Ni alloy samples with Mo, B, and combinations of Mo and B were made using an arc melting furnace. The samples were annealed at 600°C for 4 hours and characterized with scanning electron microscopy, optical microscopy and X-Ray diffraction techniques. Wear resistances of the samples were evaluated using a pin-on-disk wear tester and wear track was analyzed by optical profilometry. It was demonstrated that the Mo and B additives were effective in strengthening the Cu-Ni alloy while retaining desired corrosion resistance. In particular, the combination of Mo and B additives was more effectively than a single additive to harden the alloy, leading to considerably elevated wear resistance. The modified Cu-Ni alloy samples show their hardness comparable to that of normalized low carbon steel. The volume loss of the Cu-Ni alloy with, e.g., 2% B and 2% Mo, caused by wear was reduced by 35% and 55% when tested in air and 3% NaCl solution, respectively. The mechanism for the improvements will be discussed. Mo and B additives have demonstrated their great promise as new alloying elements to modify Cu-Ni alloys.

3 - 3:20 pm

3221365: Optimization and Contact Reliability of TiN-Coated Microswitches

Maarten de Boer, Changho Oh, Carnegie Mellon University, Pittsburgh, PA

Titanium nitride (TiN) is of interest as a material in MEMS and NEMS switches due to its high hardness, low surface energy, good electrical conductivity and resistance to chemical oxidation. We optimize process parameters to attain low electrical resistivity (60 microohm*cm) and acceptable residual stress. Because surface stoichiometry of binary metal compounds may depend on mechanochemical effects, we cycle test in controlled O_2, N_2, Ar and N_2:C_6H_6 gas environments. Of these, O_2 yielded short lifetimes (~100 cycles), while N_2 and Ar gave equivalent results (~10^5 cycles). The N_2:C_6H_6 environment enabled the longest lifetimes (≥17 million cycles) at the expense of increasing electrical contact resistance. The cycle count limit in N_2 and Ar was investigated and traced to a weak microstructure that develops at corners of the contacting surfaces. If such corners are avoided in future designs, TiN-coated switches likely can survive to much higher cycle counts.

3:20 – 3:40 pm

3200682: Abrasive Wear of Cryogenically Treated Commercial Wrought and as-Built by Electron Beam Melting Ti-6Al-4V

Paulo Herrera, Everth Hernández-Nava, Tom Slatter, The University of Sheffield, Sheffield, United Kingdom, Rob Thornton, University of Leicester, Leicester, United Kingdom

The effect of deep cryogenic treatment (DCT) on wear resistance has been variously established for a number engineering alloys, but light alloys, such as wrought and electron beam melting (EBM) obtained Ti6AL4V, have not been investigated similarly. In this work, the abrasive wear resistance of Ti6AL4V samples obtained commercially and by EBM, were characterized. Each type of material was divided in two classes, being one of those test groups in the as received condition and the other one submitted to cryogenic treatment. These materials were tested using an ASTM-G65 based 'rubber wheel' wear test rig and Vickers hardness. Overall, titanium samples in wrought condition did not present a significant difference after abrasive wear testing as average wear volumes are similar with minimal scatter in the results. EBM Ti6Al4V however, showed a significant change in volume. The resistance of EBM obtained Ti6AL4V is very much lower than the wrought equivalent regardless of the level of DCT.

3:40 – 4 pm – Break

Surfaces and Interfaces III

Session Chair: TBD

1:20 - 1:40 pm
3225040: Aqueous Gel Adhesion
George Degen, Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

An understanding of mucoadhesion--adhesion between a mucous membrane and another surface—is important for pharmaceutical and biomedical fields, yet there are relatively few models describing contact mechanics of mucous layers. The Winkler model has shown promise for describing adhesive contact mechanics of soft, thin hydrogel layers, but experimental studies of model systems relevant to mucoadhesion are needed. Hydrogels (synthetic aqueous gels) are inexpensive and easily synthesized models for biological surfaces, including mucous membranes. Hydrogels can be used to study high water content gels, including the relationships between permeability, osmotic pressure, and polymer mesh size. The hydrogel mesh size, defined as the average distance between neighboring polymer chains, has been previously measured by small angle X-ray scattering. The mesh size is known to be strongly influenced by the water content of the gel. Here, we describe the impact of water content on the adhesion of thin hydrogel films. We demonstrate that the adhesion between fully swollen (equilibrated) and unswollen (non-equilibrated) hydrogel films submerged in a good solvent (water) increases with the difference in osmotic pressure between the films. These experimental findings agree with theoretical predictions relating the adhesion force to differences in osmotic pressure and are relevant to understanding adhesion of natural (mucosal) and synthetic (hydrogel) systems.

1:40 - 2 pm
3221407: In-Situ Observation of Heat Generation Behavior with Different Combinations of Additives during Scuffing
Kazuyuki Yagi, Yasuo Matsuzaki, Joichi Sugimura, Kyushu University, Fukuoka, Japan

In the current study, in-situ observation of heat generation behavior was conducted during scuffing with different combinations of additives. A contact area was created between a rotating sapphire disc and a stationary steel pin. The contact area was captured over the sapphire disc. A monochromatic high speed camera, which could detect light in a wide range of wavelength between visible and near-infrared, was employed to capture the contact area during scuffing. Several types of lubricants with different combinations of additives were tested for scuffing tests. Heat generation behavior during scuffing and its dependence on lubricants are discussed.

2 - 2:20 pm
3221540: Effect of Strain on Polymeric Contact Electrification Magnitude, Polarity, and Distribution
Jon-Erik Mogonye, Stephen Berkebile, Daniel Cole, US Army Research Laboratory, Aberdeen Proving Ground, MD

With the explosion in proposed triboelectric devices, and recent investigations into macro-strain and charge domains in contact-electrified insulators, there is renewed interest in contact charge phenomena. In the present study we investigated polymeric induced contact-electrified surface

potential distributions by scanning Kelvin probe microscopy using atomic force microscopy. Three polymers of varying rank in the empirical triboelectric series – polycaprolactam, polyethylene terephthalate, and fluorinated ethylene propylene – were strained and contacted with polyethylene. We observed magnitude and polarity of the resultant surface potentials to depend on the degree of plastic strain. Furthermore the surface potential between unstrained and strained samples demonstrated polarity switching, with increasing strain generally resulting in more negative potentials. Nano to micro scale distributions of surface potentials were observed to be unipolar for all strains and polymers. The dependence of these local surface potential distributions on topography and local properties examined through phase imaging and modulus mapping will be discussed.

2:20 - 2:40 pm

3202340: Friction Coefficient and Lubricant Film Thickness Determination under Different Sliding-Rolling Conditions Influenced by Surface Porosity in Sintered Material

Guido Boidi, Daniele Dini, Amir Kadiric, Imperial College London, London, United Kingdom, Francisco Profito, Izabel Machado, University of São Paulo, São Paulo, Brazil

This work explores the possibility to exploit different manufacturing techniques to obtain superior performances in lubricated point contacts. The effect of surface pores in sintered material was evaluated based on frictional behavior under different sliding-rolling conditions and lubrication regimes. Furthermore, lubricant film thickness was measured using interferometry technique. Powder metallurgy samples were manufactured to obtain different porosity and pores characteristics both on disc and ball specimens. Test results showed that the decrease of porosity generally improves tribological performances and low porosity surfaces can promote friction reduction if compared to non-porous reference material in specific configurations and operating with similar specific lubricant thickness values. This project contributes to understanding how random micro-irregularities could change lubricant conditions, potentially increasing the efficiency of mechanical systems.

2:40 - 3 pm

3208780: Modeling of Iron Fines Formation in Cold Rolling Processes Using Material Point Method

Melkamu Awoke Mekicha, University of Twente, Enschede, Netherlands

Surface cleanliness of a cold rolled sheet metal is important for product performance and aesthetic reasons. Iron fines, which are produced as a result of the roll asperities ploughing through the strip surface in the roll bite, are one of the main factors that contaminate strip surface. Predicting iron fines formation is critical to tailor strip cleanliness to a desired specification. In this work, we study the formation of iron fines by modelling the wear behavior of a single roll asperity sliding over the strip surface using a Generalized Interpolation Material Point Method. The roll asperity is modelled as a rigid ellipsoidal indenter and the strip as a smooth-soft substrate. The influence of several parameters such as the geometry of the roll asperity, adhesion, the length of the scratch, strip material behavior and interfacial shear strength of the roll-strip contact interface on iron fines formation are investigated numerically and discussed.

3 - 3:20 pm

3224495: Numerical Simulation of Transmiitable Torque in Rotating Magnetorheological Fluid Device with Different Surface Texture

Chiranjit Sarkar, Indian Institute of Technology Patna, Patna, Bihar, India

The influences of wall surface texture on transmitted torque performance of magnetorheological (MR) fluid have been experimentally found out by different researchers [1-3]. In this paper, the effect of the surface textures of the friction plate on the transmitted torque performance has been numerically

investigated under the conditions of different working radius and applied magnetic flux (T). Here, the rotating plates with three types of surface texture are proposed and modeled . Rotating machinery laminar flow module based on Bingham model has been implemented to obtain the relationship among the surface texture of the friction plates, applied magnetic flux, working radius and the transmitted torque performance using COMSOL Multiphysics 5.3a software. The results show that the transmitted torque is significantly influenced by the working radius and surface texture of the friction plate, and the maximum transmitted torque is obtained at the maximum working radius and with plane friction plate

3:20 - 3:40 pm
3221349: Exploration on the Lubrication Regime of Water Lubricated Rubber Bearings Considering the Worn Interface Wettability
Wei Feng, Yanfeng Han, Jiaxu WANG, Junyang Li, Ke Xiao, Chongqing University, Chongqing, China

The purpose of this paper is to study the effect of worn interface wettability on the lubrication performance of water-lubricated rubber bearings. The boundary lubrication can be identified when the water-lubricated rubber bearing is subjected to a low speed and heavy load conditions. And the worn interface of water lubricated rubber bearings is superhydrophobic, which is disadvantageous for water film formation. Therefore, the UV irradiation was used to improve the superhydrophobicity into superhydrophilic of the worn interface. The experimental results demonstrated that the superhydrophilic can enhance the formation ability of water film, which will reduce friction and wear caused by asperity contact at boundary lubrication condition. However, the wear increases with the further increasing time, because of the superhydrophilic surface is worn.

3:40 - 4:20 pm - **Break**

4:20 - 4:40 pm
3218007: Hydrodynamic Lubrication Model of the Piston-Cylinder Interface from a Piston Pump
Blake Johnson, Army Research Laboratory, Chicago, IL

A hydrodynamic tribological model has been developed that analyzes the major phenomena involved in the piston-cylinder interface of a fuel pump. The model used the Successive-Over-Relaxation method (SOR) to solve the Reynolds Equation of the fluid. The contact area was adjusted and re-meshed throughout the simulation to account for the motion of the piston in and out of the cylinder. Asperity contact was considered using the Greenwood Tripp boundary friction model. Elastic deformation of the piston and cylinder was estimated using Lamé Equations. The temperature within the interface was estimated, and fluid properties were updated based on the localized fluid temperature and pressure. Based on an input of component geometry, mechanical properties, roughness, fluid properties, and pump operating conditions, the model outputted the following conditions throughout the pumping cycle: distribution of fluid pressure and film thickness, piston misalignment and eccentricity, and viscous and solid friction forces. Model results were compared to various tribological tests and real pump tests run with a range of fuel fluid properties.

4:40 - 5:20 pm
3222456: ***Spotlight Presentation:*** **Non-Linear Dynamical Effects in Frictional Energy Dissipation for Atomistic Friction Model**
Motohisa Hirano, Hosei University, Koganei, Tokyo, Japan

The non-linear dynamics in friction is studied from an atomistic point of view. The study of the Frenkel-Kontorova model with kinetic energy terms has found the two distinct different regimes appear in the parameter space specifying the model: the superlubricity and the friction regimes. Depending on the parameters such as initial velocity and the interfacial potential amplitude, we have found the novel frictional property in which the mean sliding velocity initially does not change for a while, but it suddenly drops at unexpected time and later the sliding speed recovers for some period, consequently the mass center sliding velocity shows Brownian motion. This paper discusses the mechanism of the sliding speed's sudden drop, i.e., the catastrophe of the breakdown of the superlubricity from the viewpoints of nonlinear oscillation. The problem of what triggers the catastrophe is studied by examining whether the chaotic vibration exists in the dynamic Frenkel-Kontorova model.

3C	Georgian Room

Fluid Lubrication II

Session Chair: G. Poll, Institute of Machine Design and Tribology, Leibniz University Hannover, Hannover, Lower Saxony, Germany

1:20 - 1:40 pm
3193545: Combined Effect of Viscosity Variation and Porous Wall on Squeeze Film Conical Bearing Operating with Rabinowitsch Fluid Model
Amit Rahul, Indian Institute of Technology(ISM), Dhanbad, Jharkhand, India

In this study, the effect of viscosity variation of non-Newtonian lubrication on squeeze film characteristics with porous and Rabinowitsch fluid for conical bearings is analyzed. The modified Reynolds equation representing the characteristics of non-Newtonian fluid with viscosity variation on the porous wall followed by the cubic stress law condition is invoked. For lubricant flow in a bearing clearance and in a porous layer Morgan–Cameron approximation is considered. A small perturbation technique is used to compute the pressure generation using modified Reynolds equation of lubrication. Approximate analytical solutions have been obtained for the squeeze film pressure, load-carrying capacity, squeeze film time, and center of pressure. The outcomes are displayed in diagrams and tables, which show that the effect of viscosity variation and porous wall on the squeeze film lubrication of conical bearings decreases film pressure, load-carrying capacity, and response time for the Newtonian case in comparison to the non-Newtonian case.

1:40 - 2 pm
3203707: Experimental Research about the Effect of Carbon Black on Noise in Oscillatory Parallel Plate Squeeze Oil Film
Xu Liu, Xiaoyang Chen, Rongyu Kang, Xuejin Shen, Shanghai University, Shanghai, Shanghai, China, Ben NI, Ford Motor Company, Dearborn, MI

It was found that the irregular typewriter noise of engine main bearing will be effectively reduced after adding the carbon black in lubricant oil. The oscillatory parallel plate squeeze oil film test apparatus which could collect different kinds of signals including sound pressure, displacement, vibration acceleration, force, and pictures of cavitation simultaneously during the test running was used to experimental study the relationship between carbon black, cavitation and noise. It was shown that the presence of carbon black can significantly reduce the generation of noise from the experiments. And this suppression effect becomes stronger as the concentration increases. The experimental results also show that the carbon black with small particle size has better noise reduction effect. After being left for a long

time, the suppression effect of carbon black was weakened. However, the small particle size carbon black still has a better noise reduction effect after leaving same setting time. By combining the data obtained by the displacement sensor and pictures taken from high speed camera, the volume change of the cavitation volume in the period of noise generation could be obtained. The results showed that maximum area and volume of cavitation gradually decrease as the carbon black concentration increases, which shows that the carbon black has a certain inhibitory effect on the development of cavitation and thus reduces the noise generation.

2 - 2:20 pm

3203791: Making the Case for Nano Technology Lubricants

Michael Hagemann, Evonik Resource Efficiency GmbH, Darmstadt, Germany

Nanostructured materials are predicted to become an important lubricant additive class due to their extraordinary tribological properties. These include high load bearing capacities, very low friction (reaching even super lubricity) and anti-wear properties. In spite of their advantages and intense academic research this additive class is still not well established nor widely used in industry. Dispersion stability and filtration properties are seen as the main hurdles for industrial application of nanostructured materials as lubricating oil additives. This talk will analyze the hurdles that future product developments must overcome and propose respective solutions. While most research work focusses on one solid material, this talk will consider particles of different chemical nature and compare respective properties. The talk will consider two different particle natures: materials that are solid lubricants by themselves, like the metal sulfides of Tungsten and Molybdenum, and materials that do not belong to this class, like the oxides of Silicon and Titanium.

2:20 - 3 pm

3212737: ***Spotlight Presentation:*** **The Rheological Assumptions of Classical EHL: What Went Wrong?**

Scott Bair, Georgia Tech, Atlanta, GA

The field of elastohydrodynamic lubrication (EHL) now has two very different approaches to the problem. In the first, the classical approach, the pressure dependence of viscosity has from the beginning been quite different from that which is measured in viscometers. This rather odd situation resulted from a desire to analyze the response of the liquid film without the complication and labor of viscometer measurements. Instead, the viscosity was extracted from the observed behavior of the film itself. Two assumptions regarding the pressure, temperature and shear dependence of viscosity have been essential to the way that classical EHL developed over the last forty years.

1. The liquid in the inlet zone responds in Newtonian fashion.
2. The shear stress versus shear rate relationship of the liquid has the same functional form as the average shear stress versus average shear rate obtained from a traction curve.

The new, quantitative, approach employs transport properties measured in instruments (such as viscometers) which do not rely upon these assumptions. There has been a rapid succession of advances in understanding of film forming and of friction under the new approach. This paper compares the assumed viscosities with accurate measurements and explores the history of and possible motivations for the efforts to reject primary measurements.

3 - 3:40 pm

3221151: ***Spotlight Presentation:*** **Base Oil Friction Prediction under Severe Conditions from Molecular Dynamics Simulations**

Nicolas Fillot, Alejandro Porras-Vazquez, Laetitia Martinie, Philippe Vergne, INSA-LaMCoS, Villeurbanne, France

Film thickness prediction in elastohydrodynamic (EHD) lubrication regime benefits nowadays from efficient semi-analytical formula. This is still not the case for EHD friction because several physical behaviors interact simultaneously (fluid rheology, thermodynamics, shear heating, etc.). To identify the key mechanisms responsible for lubricated friction at the molecular scale, Molecular Dynamics simulations are proposed. The material studied is a commercial base oil of which the chemical composition is determined. At equilibrium (without shear), the thermodynamic state of the lubricant is identified. Under pressure, temperature and shear, friction evolves in different ways according to the thermodynamics state of the lubricant, from shear rate-dependent to shear rate-independent friction. The calculated friction is then confronted to experimental results obtained from a ball-on-disc apparatus. As shown by [1] and [2] on pure liquids, independently of surface effects, the numerical prediction, though at very high shear rate, proves to be a very good extrapolation of experimental results also for this commercial base oil.

3E	Astor Room

Tribochemistry III

Session Chair: TBD

1:20 - 1:40 pm
3202767: Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM
Kerry Cogen, Hitesh Thaker, Infineum USA L.P., Linden, NJ, Alison Pawlicki, Nikolay Borodinov, Olga Ovchinnikova, Oak Ridge National Labratory, Oak Ridge, TN

In vehicle transmissions, antiwear tribofilms form from lubricating fluids on rolling / sliding contacting surfaces and serve to control friction and protect surfaces from wear and fatigue. Understanding the mechanism of antiwear film formation and how to tune surface chemistry to control functionality is essential for development of next generation transmission fluids. Here, we developed a unique multimodal AFM methodology to understand initial film formation from different phosphorus-containing lubricants in-situ. We combined Friction Force Microscopy (FFM) to capture the spatial details of friction over the surface as the tribofilm forms and evolves and Nano Infrared Spectroscopy AFM (NanoIR-AFM) to understand the chemistry of the film. We demonstrate the formation of antiwear tribofilms on steel surfaces, the effect of lubricant formulation on how these films evolve in-situ, and the differences in chemistry between these films.

1:40 - 2 pm
3220845: Wear-Assisted Corrosion of Cu-Ni Alloys in HCl and NaCl Solutions
Mingyu Wu, D.Y. Li, University of Alberta, Edmonton, Alberta, Canada

Abstract: Corrosive wear is a complex destructive process, which involves pure wear, pure corrosion, wear-assisted corrosion and corrosion-assisted wear. The damages caused by the individual sub-processes can be evaluated if the wear-assisted corrosion or the extra corrosion caused by wear is determined. In order to tailor the material for improved performance, the mechanism for wear-assisted corrosion needs to clarify, since it alters with the corrosive medium. In this work, an electrochemical sliding wear technique was applied to acquire the current signals of Cu-Ni alloy during processes of sliding wear and stirring only (no contact between the sample and moving counter-face) in HCl (pH=3)

and 3.5 wt. % NaCl solutions, respectively. We also looked into the corrosion behavior of the Cu-Ni alloy using polarization test, SEM and XPS techniques. Results showed that the direction and magnitude of changes in corrosion current caused by stirring and sliding wear were quite different in these two solutions, which were explained based on the corresponding changes in the surface condition involving the formation of surface oxide film. By monitoring respective variations in corrosion current densities during stirring and wear, the role of oxide evaluation in affecting the wear-corrosion synergy can be analyzed.
Keywords: Cu-Ni alloy; Wear-corrosion synergy; Corrosion product film; Stirring; Electrochemical sliding wear

2 - 2:20 pm

3222849: Effect of Ambient Chemistry on Friction at the Basal Plane of Graphite

Arash Khajeh, Ashlie Martini, University of California, Merced, Merced, CA, Zhe Chen, Seong Kim, Pennsylvania State University, University Park, PA

Graphite has been widely used as a solid lubricant for many years due to its layered structure which enables ultra-low friction. However, the lubrication performance of graphite and other layered materials is affected by ambient conditions and previous studies have shown significant differences between frictional behavior in various gas environments. Here we study the effect of gaseous hydrocarbon species in the environment on the nanoscale friction of graphite. Experiments performed using atomic force microscopy revealed that the presence of different hydrocarbon molecules can affect friction on the basal plane. To understand these results, we developed a reactive molecular dynamics simulation of a graphite substrate and a sliding silica tip in the presence of pentanol and phenol molecules. The results were analyzed in terms of the registry of the chemical species relative to graphite and chemical interactions between the species and both the tip and graphite. The findings of this research provide insight into the critical role of environment chemistry on friction of layered materials.

2:20 - 2:40 pm

3200511: Tribofilm Characterization by Surface Enhanced Raman Spectroscopy with Plasmonic Sensor

Hiroshi Tani, Renguo Lu, Shinji Koganezawa, Norio Tagawa, Kansai University, Suita-shi, Osaka, Japan, Kyohei Kijima, Graduate School of Kansai University, Suita-shi, Osaka, Japan

Raman spectroscopy is a useful tool to analyze tribofilms formed on wear track surfaces after friction or wear tests. However, its sensitivity is not sufficient enough for characterization of extremely thin tribofilms (thickness of several nanometers to several tens of nanometers). In this study, we developed a plasmonic sensor for SERS of the tribofilms (Fig. 1); we investigated tribofilms generated from lubricant additives by X-ray photoelectron spectroscopy (XPS) and SERS with the plasmonic sensor, and compared the results. The Raman signal intensity significantly increased when the plasmonic sensor was used. In addition, several peaks related to P and S, originating from the additive, were observed in the spectrum recorded from inside the wear track using the plasmonic sensor. Moreover, the spectrum showed several peaks assigned to FeS2, P-O-P bonds, and PO4 structures. Finally, we investigated the tribofilm samples by XPS. The spectra showed peaks corresponding to P, S, and Zn, as well as the PO4 structure. Thus, these results indicate that the sensitivity of SERS performed with the plasmonic sensor is similar to that of XPS.

4A Grand Ballroom

Materials Tribology IV

Session Chair: TBD

10:00 am - 10:20 am

3221674: Tribological and Corrosion Performance of TiO_2-Doped NiW Coatings on Carbon Steel Substrates

Arindam Paul, Kandisi Anyabwile, Brian Musial, Barbara Fowler, Gary Doll, University of Akron, Akron, OH

In this study, NiW and TiO_2 doped NiW coatings were developed and electrodeposited by a pulsed reverse current technique on AISI 52100 steel rods and rollers. Their tribological performances were evaluated in rolling and mixed mode contact using 3 ball on rod and micropitting rigs, respectively. The tests were carried out in boundary lubricated conditions with two mineral oils having the same viscosities; one was fully additized and the other without any additives. Results of the tribological testing revealed that the incorporation of TiO_2 into the NiW matrix significantly enhanced the wear resistance while the W in the coating had beneficial synergies with the sulfur-based additives in the oil. Polarization testing by electro-impedance spectroscopy indicated that while the addition of TiO_2 to the NiW decreased the corrosion resistance of NiW, the TiO_2-doped NiW coating still imparted a significant amount of corrosion resistance to carbon steel substrates.

10:20 - 10:40 am

3220613: Ultra-low Wear as a Statistical Transfer Process: A Case Study on Transfer Film Fluctuation Using Alumina PTFE

Wei Sun, Jiaxin Ye, Xiaojun Liu, Kun Liu, Hefei University of Technology, Hefei, Anhui, China

Previous studies showed an ultra-low wear ($k\sim10^{-7}$ mm^3/Nm) alumina-PTFE solid lubricant forms an extremely adherent and tenacious transfer film with a native wear rate of $\sim10^{-9}$ mm^3/Nm. The mechanism for the 100x wear rate discrepancy between the bulk and transfer film remains unclear. In this study, we measured the evolution of the transfer film topography using contact and non-contact profilometry and found continuous counterface abrasion even after a persistent transfer film was formed. Apparent transfer film thickness increased with decreased wear rate and plateaued after the bulk composite reached steady state low wear sliding. The results strongly suggested a balancing mechanism at the sliding interface. A statistical third-body transfer and back-transfer adhesive wear model was proposed which directly correlates surface energy/adhesibility and debris size to the direction and probability of third body adhesion. Wear rate simulation based on the model agrees reasonably with the experimental results.

10:40 - 11 am

3196518: Tribological Behavior of Fiber Reinforced PA66 Material under High Contact Pressure, Sliding and Grease Lubricated Conditions

Takeshi Kunishima, Vincent Fridrici, Philippe Kapsa, LTDS Laboratoire de Tribologie et Dynamique des Systèmes, Ecully, France, Yasuharu Nagai, Takanori Kurokawa, Hirokazu Arai, JTEKT Corporation, Kashihara, Japan

Polyamide66 is widely used for sliding parts. Reinforcement fibers are usually added to increase its strength. In this work, we investigated the tribological mechanisms of fiber reinforced Polyamide66 in contact with metallic material under grease lubrication. In the first stage of sliding, breakage and dropping out of fibers occurred and micro scratches were generated, and finally peeling off of resin occurred. Creep deformation was higher just after peeling off; however wear increased with sliding time. In addition, by increasing molecular mass, wear resistance was improved. This was because toughness of composite was increased, and fatigue properties related to repeated stresses were increased. Wear of metallic cylinders was also investigated. A decrease in wear of both composite and metal is observed when the molecular mass of resin is increased. In addition, it was confirmed that wear of composite is dominated by the hardness of fiber itself.

11 - 11:20 am
3221846: Fabrication of Porous Alumina-IF-MoS2 Self- Lubricant Composite and Its Tribological Behavior
Abdul Salam, Tsinghua University, Beijing, China

The solid lubricant MoS2 immersed into pores of Alumina matrix can improve lubrication efficiency in the template and maintain the exceptional mechanical properties of the matrix. Alumina ceramics are good candidates for the composite because they have high hardness, high compressive strength, and high resistance to chemical corrosion. In this study, Porous Alumina-IF-MoS2 matrix was fabricated as self-lubricant composite. Porous Alumina ceramics was produced using Graphite Powder as pore forming agent while fullerene like molybdenum dislusfide was synthesized by thermal decomposition of Ammonium thiomolybdate ((NH4)2MoS4) in choice of solvents followed by Annealing in tubular furnace. The MoS2 characterized by Field emission scanning electron microscope (FESEM) and Transmission electron microscope (TEM) show that fullerene like structures formed into pores and on surface of the composite. The friction and wear test results reveal that the composite displayed excellent tribological properties. In addition, IF-MoS2 synthesized in pores of Alumina ceramic can improve self-lubrication efficiency in the composite.

11:20 - 11:40 am
3222382: Optimization of Operating Parameters Governing the Tribological Behavior of Carbon-Carbon Composite Brake Material.
Eslam Ramadan, Tarek Abd El-Badia, Amro Youssef, Ahmed Hussien, Military Technical College, Cairo, Egypt

Carbon carbon composites are used worldwide in high-end braking systems. The system is modeled as stator and rotor under contact. This paper discuss the tribological behavior for c/c composite. The parameters under investigation are reducing the weight loss, increasing service life. Design of experiment is carried out using taguchi method for optimizing the number of experiments. Response surface method is then used to obtain insight about the best combination of operating parameters. Operating parameters were optimized for reducing weight loss based on L9 taguchi orthogonal array design with three input parameters: applied load, rotational speed and time. Finding out the influence of input parameters on two responses (weight loss, coefficient of friction change). Analysis of variables was carried out using anova and regression equations for every response developed. Wear and friction properties of c/c composite were investigated by performing a dry sliding wear using disk on disk abrasive wear test. The Results showed that for weight loss the time at which contact between stator disk and rotor disk was the dominant factor on weight loss then the applied load come in second rank and finally the rotational speed. For friction coefficient the applied load was the dominant factor then

speed and then the time.

4B	Walton South

Surfaces and Interfaces IV

Session Chair: TBD

10 - 10:20 am
3254398: Different Textures Creationf for Study of Their Roles on Tribodynamics of Radial Ball Bearing
Eshwar Chandra Vidyasagar Koyyana, Indian Institute of Technology Delhi, South West Delhi, India

Rolling bearings normally operated under starved lubricating conditions due to synergistically pushing aside and throwing out of grease from the balls' tracks on the races. This yields low inherent damping capacity of rolling bearing, which makes it prone to vibrations and consequently resulting in poor performance. In this situation, it needed to somehow maintain the presence of lubricant at the races for improving the tribodynamics of bearings. Recently surface textures have emerged as a viable technology for developing clean and green technologies. Globally great explorations are being conducted by the researchers for enhancing the tribo-dynamics of conformal and counter conformal contacts. The objective of this paper is investigate the tribological (wettability, nano-hardness, surface topography of races and balls, wear of balls, temperature rise) and vibration (in time and frequency domains) performances of test radial ball bearings (SKF-BB1B420206) using the textures. Nanosecond pulsed Nd: YAG laser was used in creating the textures. Dimple area density has been kept around 15%. Two inductive proximity probes and one S-type load cell were used for measuring the vibrations and frictional torques of conventional and textured bearings, respectively. Comparisons of experimental results achieved with different textures have been done for demonstrating the encouraging findings.

10:20 - 10:40 am
3199174: EHL Simulation Model for an Abstracted Piston-Bushing Test Bench
Achill Holzer, Markus Gärtner, Katharina Schmitz, RWTH Aachen University, Aachen, Germany

In addition to the experimental tribological investigations on the single piston test rig, an analysis of the same system will be carried out using a multibody simulation. This includes, according to the degree of abstraction of the model, the lubricated contacts piston/bushing, slipper/swash plate and slipper/piston through an elastohydrodynamic (EHL) contact model. Effects, such as forces due to the multibody dynamics, the deformation of the components, the pressure build-up in the lubricating gap by hydrodynamics and contact pressure behavior have to be taken into account. Simulations will be done using FIRST, a commercial computer program. The calculation of tribological problems using multibody simulation models, in which lubricated contact points are represented by EHL couplings can be regarded as an established method. In this context reference is made to the numerical analysis of plain bearings. The focus is on the calculation of the piston/bushing contact.

10:40 - 11 am
3203688: Discrete Convolution and FFT with Summation of Influence Coefficients (DCS-FFT) for Three-Dimensional Periodic Contact Problems

Linlin Sun, Ning Zhao, Northwestern Polytechnical University, Xi'an, Shannxi, China, Qian Wang, Northwestern University, Evanston, IL, Mengqi Zhang, Southwest Jiaotong University, Chengdu, China

Many contact problems must be treated as periodic problems, such as the contact of cylinders with rough surfaces and inhomogeneities, whose structural feature in contact is confined in a finite domain in one direction but extended infinitely in the other direction. Reported in this presentation is a novel numerical model for simulating the contact involving machined cylindrical components containing inhomogeneities. Due to the stochastic nature of asperity and inhomogeneity distributions, the cylinder is divided into N number of segments in the length direction while taking the roughness and inhomogeneities in one such segment as representatives. Following the suggestions by Liu et al, the periodic convolution is used in the length direction, while the cyclic convolution is used in the non-periodic direction; the solution is processed through Fast Fourier transform and the method is named DCS-FFT. The accuracy of the DCS-FFT algorithm is examined by comparison of the numerical results for a cylindrical contact with the corresponding analytical solution, and its efficiency is compared with that of two other FFT-based algorithms. The developed method is implemented to study the influence of inhomogeneities on subsurface stress distributions with/without the periodic length-direction extension and superposition of inhomogeneity ICs.

4C Georgian Room

Lubricants I

Session Chair: TBD

10 - 10:20 am
3224443: Investigation of Protic Ionic Liquids Used as Lubricants
Patricia Iglesias, Rochester Institute of Technology, Rochester, NY
In the recent decade, ionic liquids (ILs) have shown great potential as lubricants or lubricant additives. Currently, the most commonly used ILs are aprotic (APILs) and contain halogen elements in their anions. However, the halogen-containing ILs are detrimental to our environment since the hydrogen halide will corrode the contacting materials when the halogen-containing ILs are exposed to the moisture. In addition, APILs are also very expensive because of their complex synthesis route. Contrary to APILs, protic ionic liquids (PILs) are another subset of ILs, which can be easily produced through proton transfer from a Brønsted acid to a Brønsted base. PILs possess a wide range of properties and tunable structures which make them ideal alternatives to APILs. In this research, three kinds of novel PILs, which were synthesized from the same acid but different bases with varying basicity, were studied as lubricants. All PILs reduced the friction coefficient comparing to the mineral oil (MO) and mineral oil with own additives (MOA), and a maximum friction reduction of 68, 73, and 51 % were obtained respectively relative to MO.

10:20 - 10:40 am
3198236: Tribological Properties of Cyano-Based Ionic Liquids as Lubricant Additives
Shouhei Kawada, Shinya Sasaki, Masaaki Miyatake, Tokyo University of Science, Tokyo, Japan

Ionic liquids are salts consisting of cation and anion that exist as liquid phase at room temperature. They have been used as novel lubricants, because of their attractive properties, such as low vapor pressure, high thermal stability, and high oxidation stability. Moreover, these properties can be controlled by changing the ion pairs. Thereby, solubility against base oils is able to enhance. It is well known that trihexyl(tetradecyl)phosphonium cation achieve high solubility. This investigation evaluated tribological properties of ionic liquids, which consist of this cation and cyano-based anion. Trihexyl(tetradecyl)phosphonium tricyanomethane ([$P_{6,6,6,14}$][TCC]) and trihexyl(tetradecyl)phosphonium dicyanoamide ([$P_{6,6,6,14}$][DCN] were used as lubricant additives and dioctyl sebacate (DOS) was used as base oil. DOS + ionic liquids exhibited smaller wear volume compared with DOS only. In addition, they showed stable friction behavior under high temperature.

10:40 - 11 am

3202880: Low-Toxicity Ionic Liquids as Additives for Environmentally-Friendly Lubricants

Jun Qu, Xin He, Huimin Luo, Teresa Mathews, Oak Ridge National Laboratory, Oak Ridge, TN

In this study, low-toxicity ionic liquids (ILs) are being developed as potential additives for environmentally friendly lubricants (EALs), specifically for hydraulics. Candidate ILs were designed and synthesized based on Lubricant Substance Classification list (LuSC-list) and then screened by their oil solubility and corrosivity. Selected ILs were blended at 0.5% concentration into a polyalkylene glycol (PAG), an oil soluble PAG (OSP), and a mineral base oil and their tribological performance was tested under boundary lubrication of steel-steel sliding. Several ILs exhibited superior friction and wear behavior to the traditional ZDDP, particularly when used in the PAG and OSP. This suggests better compatibility of the ILs with polar oils, which was later confirmed by tribofilm characterization. Acute and chronic toxicity tests that exposed Ceriodaphnia dubia, a common aquatic bioindicator species, demonstrated that selected candidate ILs are significantly less toxic than ZDDP. This work opens new avenues for developing ILs for EALs.

11 - 11:20 am

3202801: Innovations in High Performance, Environmentally Acceptable Lubricants (EALs): A Real World Perspective

Mark Miller, Biosynthetic Technologies, Indianapolis, IN

Green initiatives are everywhere. Bio-fuels, wind energy, renewable fibers are just a few of the environmental initiatives that have recently made headlines. Meanwhile some of the greatest innovations have been in the development and utilization of high performance, environmentally acceptable lubricants (EALs). This paper focuses on the innovations, features, benefits, strengths and limitation of the different types of EALs. It explores classification of base fluids and additives as well as the requirements of finished lubricants. It compares the performance of conventional petroleum products and biolubricants. The different definitions of environmental acceptability why that is important will be explored. The regulatory driving forces will be identified as well as the requirements for each. The considerations for choosing the type of EAL that is most applicable to specific applications will be studied. Finally, the best maintenance practices to ensure long fluid and equipment life will be discussed.

11:20 - 11:40 am

3220956: Road to Ultra-Low Viscosity 0W Oils: Quantifying Frictional Benefits for Crankshaft Bearings

Priyanka Desai, Shell Global Solutions (US) Inc., Houston, TX, Konstantinos Kalogiannis, Omar Mian, MAHLE Engine Systems (UK) Ltd., Rugby, United Kingdom, Francesco Manieri, Tom Reddyhoff, Imperial College London, London, United Kingdom, Mainwaring Robert, Shell Global Solutions (UK) Inc., London, United Kingdom

Shell and MAHLE have worked together to explore the frictional and engine fuel economy benefits offered by ultra-low viscosity oils within the SAE 0W grade envelope. Using the Journal Bearing Machine, we have evaluated the impact of various prototype lubricants such as SAE 0W-8 and 0W-4, using polymer coated journal bearings operated across a range of speeds, loads and temperatures. Additionally, we report the consequences of these choices for their wear and seizure tolerance, highlighting the constraints on engine operation required to realise the economy benefits whilst retaining a 'close to the edge but safe' design ethos.

11:40 am - 12 pm
3205580: Experimental Investigation of the Mechanical and Surface Properties of Submicrometer Spherical Carbon Particles Used to Enhance Oil Tribological Performance
Abdullah Alazemi, Kuwait University, Safat, Kuwait

The mechanical, surface, and chemical properties of spherical carbon nanoparticles were examined experimentally in this study. Carbon spheres with less than a micrometer in diameter were previously proven to reduce friction and wear when used as oil additives. In this work, chemical analysis of these carbon nanoparticles was performed using field emission scanning electron microscopy (FE-SEM) and the results clearly demonstrated that those spherical nanoparticles consist of a pure carbon. Also, atomic force microscopy (AFM) was utilized to extract 2D and 3D topographic images of the carbon nanoparticles as well as to estimate their modulus of elasticity. Furthermore, wettability analysis and viscosity measurements of oil and carbon spheres mixture was performed.

4D Venetian Room

Biotribology I

Session Chair: A. Pitenis, University of California, Santa Barbara, Santa Barbara, CA
Session Vice Chair: A. Dunn, University of Illinois, Urbana, IL

10 - 10:40 am
3200311: *Spotlight Presentation*: Contact Mechanics and Articulation of the Frictional Latch Mediating Function of the Snap Maneuver in Elaterid Beetles
Alison Dunn, Lihua Wei, Ophelia Bolmin, Aimy Wissa, University of Illinois, Urbana, IL, Marianne Alleyne, University of Illinois at Urbana-Champaign, Urbana, IL

Effective energy storage and release is required for survival of insects. Elaterid beetles, known familiarly as 'click' beetles or 'skipjacks,' respond to physical stimulus is by an audible and tangible snap, executed within the hinge between their body segments with no external leverage required. This is similar to the explosive power release of the mantis shrimp and the trapjaw ant. The aim of this study is to use recorded images of the snap maneuver to identify the function of the friction latch at the hinge. Scanning electron microscopy (SEM) was used to identify the geometry of the anatomy of the interface. A peg protrudes from the prothorax, and mates against a lip on the mesosternum in a 'brace' position just before the snap initiates. High-speed x-ray video reveals a rotation of the peg locally against the lip just before snap, which appears to redistribute the reaction forces. The slight angle change simultaneously orients the force more laterally to overcome friction, and decreases the normal force at the interface, allowing for slip. This new understanding allows for more sophisticated modeling of the contact area and local contours which support the load throughout the critical slip event.

10:40 - 11:20 am
3221833: *Spotlight Presentation:* Evolutionary Routes to Damage Tolerant Materials: Unique Microstructure and Fracture Properties of Enamel in the Grinding Dentition of the Hadrosaurid Dinosaur
Brandon Krick, Tomas Babuska, Tomas Grejtak, Lehigh University, Bethlehem, PA, Gregory Erickson, Stephen Kuhn-Hendricks, Florida State University, Tallahassee, FL, Mark Norell, American Museum of Natural History, New York, NY, Soumya Varma, Yi Lee, Siddhartha Pathak, University of Nevada, Reno, Reno, NV

Grazing horses and bovids (mammals from cattle family) possess file-like grinding dentitions with enamel crests primarily composed of hard, yet brittle hydroxyapatite. Grazing mammals repeatedly ingest pebbles, which create frequent, high-stress contacts that should promote fracture, cracking and wear; however, this dental material is composed of a complex prismatic architecture that resists fracture and controls damage. Hadrosauroid dinosaurs evolved analogous grinding dentitions yet possess simpler aprismatic wavy enamel. We test the hypothesis that these served the same function through comparative fracture and tribological experimentation. Both tissues turn and channel steer cracks, localizing damage and inhibiting crest spalling. Preservation of fracture properties in fossil enamels, many of which are not found in living animals, allows exploration of past form and function and provides a novel source for biomimetically inspired next-generation ceramics.

11:20 am - 12 pm
3225042: *Spotlight Presentation*: Cells Sense and Respond to Frictional Shear Stress
Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

The body's first line of defense against the external world is primarily composed of epithelial cells. These cells and the soft tissues they comprise often bear significant stresses under large strains, conduct complicated mass and heat transport functions, and continuously restructure, remodel, and rebuild in response to physical challenges, insults, and injuries. The body manages these challenges through high water content gel layers, which are continuously secreted by all moist epithelial cells. These gel networks may be thought to act as mechanical fuses under shear forces, thereby protecting the underlying epithelia. The tribology of mucinated cellular monolayers has revealed that cells are capable of producing strong pro-inflammatory signaling molecules, or cytokines, following excessive shear stresses. Recent studies used a series of progressively stiffer hydrogel probes (by decreasing water content) to impart shear stresses of 40, 60, and 80 Pa under identical normal forces against cell monolayers. This work revealed that higher shear stresses under identical normal force conditions led to an increase in apoptotic cells in the monolayer. These findings suggest that mitigating frictional shear stress could be a viable design strategy for soft implantable devices.

5A	Grand Ballroom

Energy/Environment/Manufacturing I

Session Chair: B. Gould, Argonne National Laboratory, Lemont, IL
Session Vice Chair: L. Alhadeff, University of Sheffield, Rotherham, United Kingdom

1:20 - 2 pm

3221703: ***Spotlight Presentation:*** **The Influence of Material Properties on the Formation of Subsurface Bearing Failures with Microstructural Alterations.**

Benjamin Gould, Aaron Greco, Nicholaos Demas, Argonne National Laboratory, Lemont, IL

White etching cracks (WECs) have been identified as a dominant mode of premature failure within wind turbine gearbox bearings. Though WECs have been reported in the field for over a decade, the conditions leading to this failure, and the process by which this failure culminates, are both highly debated. Because of this, the development of benchtop tests capable of accurately recreating these failures at an accelerated rate are difficult to come by. Recent work has identified inclusions containing both an aluminum oxide component as well as a manganese sulfide component as preferential initiators of these failures. These inclusions are prevalent in larger bearings but sparse in standard benchtop test samples. The present work investigates the formation of WECs using special samples manufactured from a WT bearing, and shows the cleanliness of the test specimen plays a drastic role in the formation of these failures.

2 - 2:40 pm

3221746: ***Spotlight Presentation*****: Tribology in the Triboelectric Nanogenerator: Assessing Durability Issues**

Anne Neville, Abdel Dorgham, Joshua Armitage, Leeds University, Leeds, United Kingdom

The triboelectric effect (or contact electrification) has long been understood as the process of electrical charge transfer resulting from the mechanical contact of material surfaces [1]. The underlying mechanisms that contribute have been the subject of much research [2,3] and applications have been developed in order to harness and control this charge transfer for a variety of purposes [4]. This paper will focus on the development of quantitative methodologies for characterising the triboelectric properties of materials on the macroscale and assessing the topography and surface chemistry effects of materials as a function of time as their surfaces evolve [5,6]. The methodology in question involves the development and construction of a novel test apparatus, capable of replicating and analysing the electrical output and tribological properties of a scaled-up triboelectric nanogenerator (TENG). This allows for tribological parameters to be correlated with triboelectric properties such as contact potential difference, induced current and charge polarity for different material pairings, both insulating and conductive. The change in surface topography and the development of transfer films will be the focus of this paper; assessing the "tribology" aspects of TENGs and the evolution of triboelectric properties with time.

2:40 - 3 pm

3222555: Contact of Lithium Metal-Separator-Cathode in a Li-Battery

Xin Zhang, Qian Wang, Northwestern University, Evanston, IL, Stephen Harris, Lawrence Berkeley National Lab, Berkeley, CA

The use of Li metal electrodes would greatly increase the energy density of rechargeable Li batteries, but formation of complex Li metal structures (referred to as "dendrites") on the metal surfaces leads to battery failure, which has precluded their use. Recent experiments suggest that these dendrites can be suppressed when pressure is applied to the Li electrode, but there are no measurements or calculations to estimate what pressures are actually generated. This presentation reports a semi-analytical method (SAM) based three-dimensional (3D) contact model, for trackling the mechanical behaviors of realistic anode-separator-cathode interfaces in a Li metal battery, in which: (1) both the Li-anode and cathode surfaces are rough; and (2) both the Li-anode and separator are treated as deformable materials under contact. The proposed model is implemented to analyze the influences of separator thickness, electrode roughness, material properties on the contact stresses of the Li electrode.

3 - 3:20 pm

3198817: Tool Coatings and Their Influence on the Length of Steady-State Wear Region for Micro End Mills

Lisa Alhadeff, Matthew Marshall, Tom Slatter, University of Sheffield, Rotherham, United Kingdom, David Curtis, Advanced Manufacturing Research Centre, University of Sheffield, Sheffield, United Kingdom

Micro-tool wear is harder to monitor than macro tool wear, with frequent tool failure due to chipping or shaft failure. This leads to high costs and inefficient processes. The aim of this work is to elongate the steady state region of the wear curve for micro-end-mills (µ-mills). Tool wear during slot machining with 500µm µ-mills was examined. The length of the steady state region (the working life of the tool) was used to evaluate the ability of various coatings to extend tool life. The relationship between wear mechanisms and the shape of the wear curve was examined. The results demonstrate that it is possible to engineer µ-mills to increase their steady state life, leading to longer and more stable tool life. The predictability this affords allows tool paths to be modified to account for changing tool geometry. This work presents the first attempt to directly manipulate the wear curve for µ-mills, analysing the wear mechanisms taking place over tool life to explain wear behaviour.

5B	Walton South

Machine Elements and Systems I

Session Chair: TBD

1:20 - 1:40 pm

3196900: Overview of Morton Effect Related Simulation and Experiments

Alan Palazzolo, Texas A&M University, College Station, TX

This phenomenon prevents some industrial machines such as compressors and turbines from attaining their design speeds and loads due to increasing levels of vibration at a constant speed. The mechanism for this anomaly is shaft bow occuring at fluid film bearings as a result of asymmetrical heating of the journals due to synchronous vibration. The authors have compiled and extensive publication record for their analytical, simulation and experimantal work related to the Morton effect. The results show that extensive, high fidelity modeling is required to reliably predict the Morton effect and devise means to suppress it. This include modeling of tilt pad bearing pad flexibility and thermal expansion along with journal centrifugal and thermal growths, and thermal deflection and vibration of complex shafting. Morton effect involves both long (thermal) and short(vibration) time constants which poses a special challenge for keeping code execution under practical limits for industrial applications. The presentation will present modeling methods, computation algorithms to reduce run time, experimental results and correlations with predicted results.

1:40 - 2 pm

3198828: Belt-Drive Mechanics: Energy Losses in the Presence of Detachment Waves

Michael Varenberg, Yingdan Wu, Michael Leamy, Georgia Institute of Technology, Atlanta, GA

The dissipative rolling friction force in a simple belt-drive system is estimated both experimentally and

computationally while taking into account the detachment events at the belt-pulley interface. Shear traction is estimated based on measurements of the shear strain along the contact arc. It is shown that the dissipative force can be approximated by taking the difference between the shear traction and the load carried by the belt. A model is developed for analyzing the contributions of different components to this dissipative force by considering both the volumetric and surface hysteresis losses. The computed rolling friction force is found to be in good agreement with that estimated based on the experiments. It is also found that while the shear- and stretching-induced energy losses contribute the most to the dissipation in the belt drive system, the losses associated with the Schallamach waves of detachment make up a considerable portion of the dissipation in the driver case.

2 - 2:20 pm

3203928: Influence of Run-in Procedures on the Efficiency and Anti-Wear Performance of Hydraulic Pumps

Achill Holzer, Katharina Schmitz, RWTH Aachen University, Aachen, Germany

Systematic investigations of the tribological effects based on different abstraction levels are planned. Using a disc-disc tribometer, as the highest level of abstraction, an optimal run-in procedure is identified. This tribometer will be adapted to the new requirements in order to be able to map different run-in procedures. To have a better understanding of the tribological effects, various regular metallurgical analyses, like structural investigations and micro indentation tests will be carried out. Run-in procedures have a substantial influence on the operating life of all kind of tribological contacts. A better understanding of the effects of the first hours of use, especially parameters like normal load, relative velocity, temperature and additives can have a significant impact on the overall operating life of the pump. If an average service life of 10.000 hours is expected, this leads to significant energy savings due to the higher degree of efficiency.

2:20 - 2:40 pm

3195796: Small Diameter NiTi Alloy Balls for Bearing Applications

Christopher DellaCorte, Samuel Howard, NASA, Cleveland, OH

Nickel-rich Ni-Ti alloys are emerging as bearing materials that can impart enhanced resilience (high static load capability) for rolling element bearings. This is achieved because the high elastic range and relatively low elastic modulus of NiTi superelastic materials reduces stresses and increases the resiliency of ball-race contacts. Recent success in the manufacturing of small diameter NiTi-Hf alloy balls has enabled the assembly and testing of small (12.7mm) bore “hybrid” bearings which utilize steel races and NiTi alloy balls. These bearings can potentially exhibit static load (dent) capacity three to five times greater than an all steel bearing. In this presentation, the manufacturing and long term (10 000hr) bearing life test results of “hybrid” steel-NiTi alloy bearings is reviewed and discussed.

2:40 - 3 pm

3221305: Internal Loading Distribution in Statically Loaded Ball Bearings Subjected to a Combined Radial, Thrust, and Moment Load, including the Effects of Temperature and Fit

Mario Ricci, INPE, São José dos Campos, São Paulo, Brazil

A numerical procedure for internal loading distribution computation in statically loaded, single-row, angular-contact ball bearings, subjected to a known combined radial, thrust, and moment load, is used to find the load distribution differences between a loaded unfitted bearing at room temperature, and the same loaded bearing with interference fits, which might experience radial temperature gradients between inner and outer rings. For each step of the procedure it is required the iterative solution of Z +

3 simultaneous nonlinear equations – where Z is the number of the balls – to yield exact solution for axial, radial, and angular deflections, and contact angles. Numerical results are shown for a 218 angular-contact ball bearing.

3 - 3:20 pm

3197292: Cage Dynamic Analysis of High-Speed Angular Contact Ball Bearings

Xiaoyang Chen, Tao Zhang, Shanghai University, Shanghai, China

Based on the dynamic model and the working conditions of parched elastohydrodynamic lubrication of high-speed angular contact ball bearings, the cage forces and motions are investigated under the two conditions of the outer ring fixed inner ring rotation and the inner and outer rings rotation in reverse. By the force decomposition, the influences of the forces on the cage motion are obtained, and the mechanism of cage whirl is explained. It is found that the centrifugal force generated by cage mass center whirl is the main driving force for maintaining the whirl radius, and the friction forces of ball/cage pocket and cage/guide ring maintain the whirl speed. The collision forces of ball/cage pocket and cage/guide ring contacts bear the cage centrifugal force and the proportion they bear affects the wear rate of cage pocket and guide surface. The simulation results of the cage whirl were verified by a cage dynamic performance test.

3:20 - 3:40 pm

3203780: Experimental Study on Cage Dynamic Characteristics of Angular Contact Ball Bearing in Unstable Working State

Shijin Chen, Xiaoyang Chen, Qingqing Li, Shanghai University, Shanghai, China, Jiaming Gu, Shanghai Tian An Bearing Co. Ltd, Shanghai, China

During the acceleration and deceleration processes of the bearing, the kinetic relationship of collision and the friction between the cage and the rolling element is complex, which has an important influence on the dynamic characteristics and stability of the rolling bearing and its cage. In this paper, experimental investigation of dynamic motions of a cage was carried out on the processes of startup and shutdown in a ball bearing. It was shown that acceleration and deceleration of the bearing inner ring have a significant effect on the movement of the cage. During the startup process, there is a critical speed. When the inner ring speed is lower than the critical speed, the cage mass center swings along the guide land within a range of 70°. Above the critical speed, the cage mass center enters a circular whirl trajectory, and the greater the acceleration, the higher the critical speed. It is interesting that during the shutdown process, the inner ring speed does not continuously decrease, but goes through three stages: rapid reduction phase, stability or even small increase phase and slow decrease phase. In the rapid deceleration phase, the cage mass center trajectory is a circle, and its diameter is equal to the guiding clearance. After that, the cage mass center trajectory is also circular, but the diameter is smaller than the guiding clearance, or swings within the guide clearance. Both acceleration and deceleration process, the cage skidding is very serious.

3:40 - 4 pm - **Break**

4 - 4:20 pm

3221881: Novel Tribo-Dynamic Methodology of Deep Groove Ball Bearing under Extreme Speeds of Electric Drives

Mahdi Mohammadpour, Loughborough University, Loughborough, United Kingdom

More stringent automotive emission legislations introduce new technical challenges to the engineering

and scientific community. In order to meet these legislations, many manufacturers introduce hybrid or pure electric powertrain systems. In order to maximize the efficiency of electric part and optimize its packaging, modern electric drives are designed to operate at ultra-high rotational speeds in excess of 10000 rpm and consequently, relatively lighter load. This new range of operating condition brings new challenges in terms of efficiency, durability and Noise-Vibration and Harshness (NVH). New experimental techniques and numerical methods are required to analyze tribological conjunctions under abovementioned conditions. This paper presents a novel combination of experimental measurement and multi-physics numerical methods to study the tribo-dynamic behavior of deep groove ball bearings under operating conditions of modern electric drives. Using the proposed methodology, the effect of axial preload on the tribo-dynamics of the bearing is investigated.

4:20 pm - 4:40 pm

3237646: Thermal Analysis of an Aro-Engine Cylindrical Roller Bearing Using Thermal Network Approach

Rami Kerrouche, Azzedine Dadouche, Mahmoud Mamou, National Research Council Canada, Ottawa, Ontario, Canada, Salah Boukraa, Institute of Aeronautical and Space Studies, University Saad Dahlab of Blida 1, Blida, Algeria

High-speed rolling element bearings for aircraft engines are custom-made components and operate under high temperatures due to the elevated rotational speeds and loads. Therefore, understanding the various heat generation sources and mechanisms is worth investigating to accurately quantify power losses within the bearing. In this context, a parametric study is established to determine and locate the power losses inside an aero-engine cylindrical roller bearing. Then a thermal network model based on Ohm's law is developed in order to estimate the temperatures of bearing elements. A series of experiments carried out on a high-speed rolling-element bearing test rig will also be presented to validate the theoretical predictions such as bearing temperatures and power loss at specific operating conditions.

4:40 - 5 pm

3253142: Experimental and Simulation Analysis of Textured Connecting-Rod Big-End Bearings for Friction Reduction

Francisco Profito, University of São Paulo, Sao Paulo, Brazil, Sorin-Cristian Vladescu, Tom Reddyhoff, Daniele Dini, Imperial College London, London, United Kingdom

Journal bearings have wide application, especially the big- and small-end bearings that link up the connecting-rod to the crankshaft and piston of internal combustion engines (ICEs), respectively. On the account of the extensive applications of journal bearings in ICEs and its great impact on the engine mechanical efficiency, coupled with the challenges imposed by several technological trends aimed at improving the engine fuel economy, the use of increasingly lower viscosity oils and the grows of start-stop systems, the development of novel tribological solutions for improving the bearings' performance and reliability is mandatory. In this context, a potential alternative for optimising the performance of engine bearings is the application of surface texture. Therefore, the present contribution is aimed at investigating, through experimental and numerical simulation analyses, the effect of different texture configurations on the friction behaviour of connecting-rod big-end bearings.

Lubricants II

Session Chair: TBD

1:20 - 1:40 pm

3214279: Gap and Shear Rate Dependence of Viscoelasticity of Lubricants with Polymer Additives Sheared in Nano Gaps

Shintaro Itoh, Kenji Fukuzawa, Ryosuke Aoki, Hedong Zhang, Naoki Azuma, Nagoya University, Nagoya, Aichi, Japan, Yasushi Onumata, JXTG Nippon Oil & Energy Corporation, Yokohama, Japan

To reduce fuel consumption of cars, it is effective to reduce friction loss by lowering viscosity of engine oil and transmission oil. On the other hand, this leads to a decrease in load capacity, which means that the sliding gap narrows and wear and seizing easily occur. Therefore, there is a need for a lubricant design that does not break the oil film even in a minute gap while achieving a reduction in the viscosity of the lubricating oil. It was reported that polymer additives that have been used as a viscosity index improver form an adsorption layer on solid surface and contribute to the reduction of friction force and the improvement of wear resistance in the boundary lubrication regime. The sliding gap when such an adsorption film exhibits lubricity must be on the order of nanometers, which is about the same as the thickness of the adsorption layer. In this study, we measured the viscoelastic properties specific to the adsorption layer of polymer additives sheared in the nano gaps by using the fiber wobbling method and found their unique dependence on the shearing gap and the shear rates.

1:40 - 2 pm

3220856: Novel IF-WS_2 Dispersed Particle Performance in Metalworking Fluid Applications

George Diloyan, Manish Patel, Nanotech Industrial Solution, Lake Charles, LA

Inorganic fullerene like tungsten disulfide (IF-WS_2) particles are known to be high performing friction reducer, anti-wear and extreme pressure additive for various lubricant applications. They are not only suitable for conventional lubrication conditions rather can be used in extremely harsh conditions such as high / low temperature, high pressure and high shock. Performance of the particles depends on size, shape and concentration as well as surface chemistry. Proper surface engineering of the IF-WS_2 particles using appropriate surfactants / dispersion chemistry is important for stability and performance of particles in polar and nonpolar media. We have develop high concentration IF-WS_2particle dispersions in polar and nonpolar media. The current work present that IF-WS_2 base fluid that significantly improve the lubricity, anti-wear and extreme pressure properties of MQL, drawing fluid, forging fluid, synthetic and semi-synthetic metalworking fluids. Our extended experiments further showed that particles not only improve the tribological properties and cooling efficiency rather it reduces the corrosive properties of water. A systematic studies on anti-corrosion performance of particles was conducted. There is ongoing research to explore the additional properties of IF –WS_2 particle along with tribological properties.

2 - 2:20 pm

3220432: Effect of Nano-MQL Using Graphene Nanoplatelets as Cutting Fluid on Lubrication during Grinding of Nimonic 90

Pirsab Attar, Sudarsan Ghosh, P. Venkateswara Rao, Indian Institute of Technology, Delhi, New Delhi, Delhi, India

The mineral-based metal working fluids are used to reduce the friction and temperature generated

during the machining and grinding. However, the metal working fluids are considered as unsustainable during machining and grinding processes due to its high operating and disposal cost, susceptibility to environmental pollution, health-related issues amongst the workers, and high energy consumption. On the other hand, minimum quantity lubrication (MQL) technique is widely used in machining and grinding due to its ability to lubricate and cool the grinding zone by less consumption of cutting fluid. Moreover, the selection of cutting fluid additives for the formulation of water-based nanofluid using graphene nanoplatelets (GnP) under MQL mode is not dangerous in view of environmental and ecological aspects. To fulfil the sustainability criteria, the experiments have been conducted on Nimonic 90 superalloy under dry and MQL environments. Further, the surface integrity of the ground surface has been studied using Surface Profilometer and Stereo Zoom Microscope (SZM). The results obtained during nano-MQL grinding using GnP shows that the grinding forces have been reduced significantly, and the surface quality has been improved compared to dry grinding of Nimonic 90 superalloy.

2:20 - 2:40 pm

3253709: Elastohydrodynamic Friction of Lubricant Blends

Tom Reddyhoff, P. Deshpande, W.Montgomery, Imperial College London, London, United Kingdom
M Welch, Natural History Museum, London, UK

Understanding the origins of friction in elastohydrodynamically lubricated (EHL) contacts is of great practical importance, since it is this friction that determines the power loss and therefore the efficiency of many machine components. This is, however, not straightforward, since, unlike film thickness which is determined in the inlet; traction arises from the central region of the EHL contact. Here, due to the extreme conditions of high strain rates (up to 10^8 s-1) and pressures (up to 3 GPa), the lubricant behaves in a highly non-Newtonian fashion. An additional factor is that a lubricant must also provide sufficient film thickness, so that simply reducing viscosity is of limited effectiveness. This presentation will report on a new approach to understand and improve the EHL friction performance, in a way that links the molecular composition of a lubricant to its viscosity and EHL friction behaviour. The approach uses in situ FTIR and Raman spectroscopy measurements of different chemical blends to shed light on molecular changes that occur during shearing under pressure. This data is then compared to EHL friction and film thickness measurements, carried out on conventional EHL tribometers. The results show how a lubricant can be formulated to reduce EHL friction without impacting film thickness.

5D Venetian Room

Biotribology II

Session Chair: S. Radice, Rush University Medical Center, Chicago, IL
Session Vice Chair: Q. Yang, George Washington University, Sterling, VA

1:20 pm - 1:40 pm

3204055: Design and Optimization of a Finger-Surface Tribometer with Constant Normal Load Control

Sitangshu Chatterjee, Maricarmen del Toro, Xinyi Li, Yuan Ma, M. Hipwell, Texas A&M, College Station, TX

The finger-device interaction has been an area of interest among researchers in haptics. Due to the dependence of friction force and friction coefficient on the normal load, it is essential to maintain a controlled constant normal load when studying the effect of other parameters including humidity and

surface texture on friction. A typical practice is to use visual feedback to control the normal load. In our work, a novel reciprocating tribometer was designed that can control the normal load using a precision vertical stage. A control algorithm was developed and optimized to drive the vertical stage based on the feedback from the force transducers. Comparison between the presented tribometer and visual feedback normal force control showed that the tribometer could achieve a normal load with a standard deviation of 7.5% - 18.7%, whereas the standard deviation of visual feedback based normal load control is measured to be 16.3% - 33.1%.

1:40 - 2 pm
3204039: Study of Human Fingertip Friction with Controlled Relative Humidity
Xinyi Li, Cheng Lai, Sitangshu Chatterjee, Yuan Ma, M. Hipwell, Texas A&M, College Station, TX

Understanding the friction mechanisms between human fingertips and contacting surfaces is crucial for haptics and robotics. The presence of condensed water, sweat and sebum can affect the friction between fingertips and contacting surfaces. Previous studies primarily focused on the effects of moist conditions of fingertips or the contacting surface with limited variation with respect to environmental relative humidity. However, the moisture of fingertips can only qualitatively describe the phenomenon. Therefore, relative humidity was designed to be controlled in this paper to better quantify the moist condition and to simulate real-life environments. In this experiment, an environmental chamber enclosed tribometer was used to measure the fingertip frictional force under relative humidity ranging from 20% to 80%. Experimental results showed that an increasing relative humidity from 30% to 70% leads to an increase in the coefficient of friction. This observation is consistent with our hypothesis on the effect of capillary in friction.

2 - 2:20 pm
3201213: Modeling Capillary Behavior in Finger-Device Interfaces
Yuan Ma, M. Hipwell, Texas A&M, College Station, TX

Understanding tribology in finger-device interfaces is crucial for the field of haptics, which finds widespread application in consumer electronics, virtual reality and Internet of Things. Many experimental and theoretical analyses have been carried out to characterize the friction force and its relationship with other factors including topography, deformation, adhesion and electro-adhesion. While it has been stated in previous studies that capillary can potentially affect friction force, there have been limited reports on quantifying or modeling of the capillary in the finger-device interface, partially due to the complicated geometry of the contact interface. In this paper, a multi-physics model of the finger-device interface is built, incorporating both mechanical deformation and capillary formation and distribution due to sweating. The simulation result demonstrates how water redistributes in the contact interface after sweat secretion and furthermore, explains why different surfaces feel differently when touched by fingers.

2:20 - 2:40 pm
3218979: Molecular Dynamics Simulations of Amplitude Modulation Atomic Force Microscopy Probing Hydrophilic and Hydrophobic Self-Assembled Monolayers in Water
Quanpeng Yang, Xiaoli Hu, Warren Nanney, Tao Ye, Ashlie Martini, University of California, Merced, Merced, CA

Amplitude modulation atomic force microscopy (AM-AFM) is widely used as a tool for measuring surface topography and properties in nanotribological studies. In some cases, samples (such as bio-materials) need to be probed in a liquid environment, which introduces challenges for interpreting AM-AFM measurements due to the complexity of interaction forces in liquids. In this study, using molecular dynamics (MD) simulations combined with AM-AFM experiments, we studied imaging mechanisms for the nanoscale pattern formed by hydrophilic and hydrophobic self-assembled monolayers (SAMs) in water. The image contrast observed in the experiments was analyzed in terms of the amplitude-distance relationship obtained using MD simulations of AM-AFM. These results were further interpreted using the distribution of water on the surfaces and tip-SAM-water interactions. The atomic-scale information from the simulations provides a mechanistic understanding of the interactions responsible for AFM image contrast in liquid environments.

2:40 - 3 pm

3221408: Dynamic Viscoelasticity of Hydrated Phospholipid Polymer Brush Measured by Fiber Wobbling Method

Shintaro Itoh, Shoko Aoyama, Yuu Higashisaka, Kenji Fukuzawa, Hedong Zhang, Naoki Azuma, Nagoya University, Nagoya, Aichi, Japan

2-methacryloyloxyethyl phosphorylcholine (MPC) has a molecular structure in which a phospholipid (phosphorylcholine group) and a methacryloyl group are linked. A phosphorylcholine group is a molecular structure present on a cell membrane surface. When methacryloyl groups polymerize, they are called MPC polymers. By coating with MPC polymer, the chemical composition is similar to the cell membrane surface, so it is possible to realize a biocompatible surface with excellent protein adsorption suppression and antithrombotic properties. When it was applied to artificial joints, it was reported that they have wear resistance and lubricity as well as biocompatibility. This is explained as a hydration lubrication realized by the MPC polymer retaining water. Kyomoto et al. reported the polymer brush film of MPC showed especially low friction. In this study, to elucidate the detailed mechanism of the lubricity of the hydrated MPC polymer brush film, we measured the shear gap dependence of its dynamic viscoelasticity by using the fiber wobbling method.

3 - 3:20 pm

3220591: The Effect of Hyaluronic Acid on the Tribocorrosion of CoCrMo- and AHNS- Alloys in Simulated Inflammatory Environments

Simona Radice, Spencer Fullam, Alfons Fischer, Markus Wimmer, Rush University Medical Center, Chicago, IL

Orthopedic implants are locally exposed to corrosive environments during joint inflammation, due to locally released hydrogen peroxide (H_2O_2). Interactions among hyaluronic acid (HA) of the synovial fluid, H_2O_2 and metallic surfaces play a role in the tribocorrosion behavior of the implant.
This work aimed to compare the corrosion and fretting behavior between an established CoCrMo-alloy and an emerging Austenitic High Nitrogen Steel (AHNS) alloy, in synovial-like solutions containing proteins, HA, and different molarities of H_2O_2. The AHNS showed overall a higher corrosion resistance than CoCrMo. In 30 mM H_2O_2, the corrosion rate of CoCrMo was higher with HA than without HA, while for the AHNS the corrosion resistance did not decrease. Results from the fretting tests are not available yet. Our preliminary results suggest that HA accelerates corrosion of CoCrMo implants in the presence of 30 mM H_2O_2. They also encourage further research on the AHNS alloy for orthopedic applications.

3:20 - 3:40 pm

3200208: The Tribological Properties of Methyl Cellulose as a Model Oviductal Fluid

Anjana Kothandaraman, Amir Hajiyavand, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

Infertility is a massive global problem! Those affected suffer a tremendous amount of psychological and emotional stress. The viscosity of the oviductal fluid (mucus) may provide important information regarding the success rate of the spermatozoa reaching the oocyte and subsequent fertilisation. A Methyl Cellulose (MC) based model mucus was developed, which has previously been reported as an ideal in-vitro sperm motility fluid. Their physical properties were evaluated, further to which a tribological analysis was conducted using a mini-traction machine (MTM) of different concentrations of the model mucus. As the viscosity of the model mucus is increased with higher concentrations of MC, a reduction of the traction coefficient is observed. This is a favourable condition for oocyte transport, however may negatively affect sperm rheotaxis. These results suggest that a balance in the physical and tribological properties of the mucus is essential to provide the favourable conditons for successful fertilisation.

6A Grand Ballroom

Beyond the Cutting Edge

Session Chair: TBD

Session Starts at 9 am

9 - 9:30 am
3221821: Unraveling Mysteries of Tribochemistry
Seong Kim, Pennsylvania State University, University Park, PA

Unlike thermal, photochemical, and electrochemical reactions which are initiated by electronic excitation or transition within or among reactant molecules under the influence of heat, light, or electrical bias, tribochemical reactions are initiated by mechanical actions imposed onto the molecules by the solid surface. Here, the key question is how mechanical energy of moving solid surfaces is channeled into reaction coordinates of molecules presence at the tribological interface. We have addressed this question through carefully designed experiments and collaborations with computational groups. This talk will focus on the effects of chemical structures of the adsorbed molecules that are being sheared at the interface as well as the roles of surface chemistry of solid substrates and surrounding gas environments.

9:30 - 10 am
3218088: One Ring Holds and One Ring Breaks
Yip-Wah Chung, Tobin Marks, Qian Wang, Northwestern University, Evanston, IL

We present results on the use of two types of P- and S-free cyclic compounds as additives to polyalphaolefin (PAO) for boundary lubrication. The first type is a series of thermally stable alkyl-cyclens whose unusual molecular structure leads to their strong multi-dentate adsorption onto oxide-covered steel surfaces. This unique attribute results in significant friction reduction not only when compared with PAO, but also with a fully formulated lubricant, especially at elevated temperatures. The second type is a series of highly strained cyclic compounds soluble in PAO, such as cyclopropanecarboxylic acid. Under stress and frictional heating, they decompose to form oligomeric tribofilms, providing significant reduction in friction and wear. This approach represents a unique strategy to providing on-demand lubrication and wear control.

10 - 10:15 am - **Break**

10:15 - 10:45 am
3221447: Blowing in the Wind - On the Formation and Physical Properties of Wear Particles We Breathe
Ulf Olofsson, KTH Royal Institute of Technology, Stockholm, Sweden

Emissions are a drawback of road transport. Particles generated by traffic originate not only from the engine exhaust emissions, but also from wear processes occurring in brakes and between tires and the road surface. Particles smaller than 10 µm in diameter can enter the human body, and the smaller the particle size, the deeper the particle can penetrate. The wear particles generated from the transport sector altogether sum up to 50% by mass of the total ones, and its relative contribution is expected to increase due to the legislation driven reduction of aerosols from vehicle combustion processes. To get an idea of the importance of the wear generated aerosols, just consider that if emissions from disc brake systems were reduced by 67 wt%, on vehicles circulating in Europe, this would reduce the overall PM_{10} emissions from road traffic by 6–20%. Recent laboratory studies on wear generated particles from disc brake contacts are summarized here.

10:45 - 11:15 am
3221467: Mechano-Chemical Decomposition of Organic Friction Modifiers with Multiple Reactive Centers Induces Superlubricity of Ta-C
Michael Moseler, Gianpietro Moras, Fraunhofer IWM, Freiburg, Germany

Superlubricity of tetrahedral amorphous carbon (ta-C) coatings under boundary lubrication with organic friction modifiers is important for industrial applications, but the underlying mechanisms remain elusive. Here, combined experiments and simulations unveil a universal tribochemical mechanism leading to superlubricity of ta-C/ta-C tribopairs. Pin-on-disc sliding experiments show that ultra- and superlow friction with negligible wear can be achieved by lubrication with unsaturated fatty acids or glycerol, but not with saturated fatty acids and hydrocarbons. Atomistic simulations reveal that, due to the simultaneous presence of two reactive centers (carboxylic group and C=C double bond), unsaturated fatty acids can concurrently chemisorb on both ta-C surfaces and bridge the tribogap. Sliding-induced mechanical strain triggers a cascade of molecular fragmentation reactions releasing passivating hydroxyl, keto, epoxy, hydrogen and olefinic groups. Similarly, glycerol's three hydroxyl groups react simultaneously with both ta-C surfaces, causing the molecule's complete mechano-chemical fragmentation and formation of aromatic passivation layers with superlow friction.

11:15 - 11:45 am
3219482: Insights into Hydrogel Friction
Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL

Biological tribosystems, including the oral cavity, the corneal epithelium and the cartilage, enable diverse functions of the human body by maintaining extremely low coefficients of friction via mucous gel layers and a water-based lubricant. Their tribological properties are often investigated using structurally similar hydrogels. Hydrogels offer the advantage that their microstructure can be easily modulated to enable systematic studies of the effect of microstructure on frictional properties. We have studied the dynamic and static frictional response of poly(acrylamide) hydrogels with varying microstructure over a wide range of loading conditions by colloidal probe lateral force microscopy. A comprehensive model for dynamic friction has been developed based on the viscoelastic behavior of hydrogels. We also propose a phase diagram for static friction and contact ageing, which should be universal for hydrogel-like materials, like those present in biological tribosystems.

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