2016 STLE Tribology Frontiers Conference

Nov. 13-15, 2016
Drake Hotel • Chicago

PROGRAM GUIDE

TFC Meeting App

stle
Society of Tribologists and Lubrication Engineers

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STLE is the premier technical society serving the needs of more than 13,000 individuals and 250 organizations that comprise the tribology and lubrication engineering business sector. STLE is an international organization headquartered at 840 Busse Highway, Park Ridge, Illinois. Contact us at **847-825-5536**, **info@stle.org**, **www.stle.org**. For more information, see the membership ad on page 39.

Dr. Ashlie Martini, Chair
2016 TFC Planning Committee

The future of tribology research

Dear Conference Attendee,

Welcome to Chicago, and thank you for participating in STLE's 2016 Tribology Frontiers Conference (TFC). I am very excited about the conference and am so pleased that you are here.

Here in the Windy City, the world's top tribology researchers from industry, academia and government are gathered to present their latest work. We'll spend three focused days exploring the role our science will play in solving tomorrow's most critical social and technological challenges.

The 2016 TFC provides an opportunity for you to engage in the areas of tribology research of greatest interest to you. This year the TFC Planning Committee has created nine technical tracks targeting:

1. Surfaces and Interfaces
2. Biotribology
3. Fluid Lubrication
4. Lubricants
5. Machine Elements and Systems
6. Energy/Environment/Manufacturing
7. Tribochemistry
8. Materials Tribology
9. Beyond the Cutting Edge

We also have a special mentoring session Sunday night for early careerists and anybody else who would like to brush up on their job-interviewing skills. And there are special events throughout the conference designed to help you network with your peers and establish valuable business contacts.

On behalf of STLE's board of directors and the TFC Planning Committee, thank you for being part of this year's event. We wish you an enjoyable and productive conference.

Sincerely,

Ashlie

2016 TFC Exhibition } Grand Ballroom

Hours:

- Sunday: Noon-7 pm
- Monday: 8 am-4 pm
- Tuesday: 8 am-4 pm

Registration Information

Registration is at the Grand Ballroom Foyer in the Drake Hotel.

Hours:

- Saturday: Noon – 6 pm
- Sunday: 8 am – 6:30 pm
- Monday: 7 am – 6 pm
- Tuesday: 7 am – Noon

Attendance at all TFC paper presentations, networking sessions and social events is open to anyone who is registered for the conference. See condensed schedule for time and location of individual technical committee and industry council meetings.

Badge Policy

All attendees receive a badge with their registration materials. The badge must be worn at all times and is required for admittance to TFC activities. Swapping badges is prohibited and may result in revocation of the badge.

TFC Mobile App

Find all conference details on the STLE TFC mobile app. Download from the iOS App Store or the Google Play Store. Just search for **STLE 2016** or scan the adjacent QR code.

Recording Policy

Audio or video recording is *not* permitted in TFC sessions. Audio recording is permitted in the paper sessions with advance permission of the instructor. No video of any kind is permitted in the paper presentations.

Cellular Phone Policy

In order to not disturb speakers or fellow attendees, please keep cellular telephones on vibrate and leave the room to talk.

Future Industry Meeting Dates

- **STLE 72nd Annual Meeting & Exhibition**
  May 21-25, 2017, Atlanta, Georgia
- **2017 World Tribology Congress**
  September 17-22, Beijing, China
- **STLE 73rd Annual Meeting & Exhibition**
  May 20-24, 2018, Minneapolis, Minnesota
- **STLE 74th Annual Meeting & Exhibition**
  May 19-23, 2019, Nashville, Tennessee
- **STLE 75th Annual Meeting & Exhibition**
  May 3-7, 2020, Chicago, Illinois

2016 Conference Planning Committee

Ashlie Martini – Chair
University of California Merced

David L. Burris
University of Delaware

Aaron Greco
Argonne National Laboratory

Daniele Dini
Imperial College London

Bart Raeymaekers
University of Utah

Yemi Oyerinde
Chevron Phillips Chemical Co.

Nicolas Fillot
INSA-LaMCoS

Wilfred T. Tysoe, PhD
University of Wisconsin-Milwaukee

STAY CONNECTED AT THE TFC AND TWEET #TFC2016

Tweet

If you'd like to be more involved during the Tribology Frontiers Conference and share information with fellow attendees, STLE encourages you to use Twitter to tweet noteworthy sessions, questions and any other valuable resources. Log on to Twitter (**www.twitter.com**) and tweet using **#STLE2016** hashtag. And be sure to follow STLE's twitter handle (**@STLE_Tribology**) for the latest updates throughout the conference.

Preliminary Schedule at a Glance*

Sunday, November 13, 2016

Speakers Luncheon
Noon – 12:45 pm – French Room

Welcome and Introductions
1 – 1:20 pm – Grand Ballroom

Invited Talk:
1:20 – 2:00 pm – Grand Ballroom • **J. Edward Colgate, PhD, Northwestern University:** "Surface Haptics: How Friction Modulation Lets Us Touch Virtual Worlds"

Networking Break
2 – 2:40 pm – Grand Ballroom

Technical Sessions • 2:40 – 6:00 pm

1A • Beyond the Cutting Edge – Highlights from Tribology Letters – Walton South
1B • Surfaces & Interfaces I – Walton North
1C • Materials Tribology I – Georgian Room
1D • Lubricants I – Venetian Room
1E • Biotribology – Astor Room

Student Career Mentoring Program
6 – 7:00 pm – Grand Ballroom • **Ken Pelczarski, Pelichem Associates:** "Effective Interviewing Techniques"

Student Networking Event • 7:30 – 9:00 pm – Dave & Busters

Monday, November 14, 2016

Speakers Breakfast
8 – 8:45 am – French Room

General Attendee Breakfast
8 – 8:45 am – Grand Ballroom

Invited Talk:
9 – 9:40 am – Grand Ballroom • **Professor Michael Moseler, Fraunhofer Institute of Mechanics and Materials:** "Tribo-Mechano-Chemistry: Lessons From Atomic Scale Modeling"

Networking Break (Exhibits & Posters)
9:40 – 10:20 am – Grand Ballroom

Technical Sessions • 10:20 am – Noon

2A • Materials Tribology II – Walton South
2B • Surfaces & Interfaces II – Walton North
2C • Machine Elements & Systems I – Georgian Room
2D • Lubricants II – Venetian Room
2E • Fluid Lubricants I: Squeeze film, Cavitation & Gaseous Lubrication – Astor Room
2F • Tribochemistry I – Superior Room

Lunch on Your Own
Noon – 1:20 pm

Monday, November 14, 2016

Invited Talk:
1:20 – 2:00 pm – Grand Ballroom • **Miquel Salmeron, Lawrence Berkeley National Laboratory & University of California, Berkeley:** "AFM and TEM Studies of Friction and Wear in Pt-Graphene and Pt-SiO2 Systems"

Technical Sessions • 2 – 6:00 pm

3A • Materials Tribology III – Walton North
3B • Surfaces & Interfaces III – Walton South
3C • Machine Elements & Systems II – Georgian Room
3D • Lubricants III – Venetian Room
3E • Fluid Lubrication II: Rheology & EHL – Astor Room
3F • Tribochemistry II – Superior Room

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

Networking Reception
6:30 – 8 pm – Grand Ballroom

Tuesday, November 15, 2016

Speakers Breakfast
8 – 8:45 am – French Room

General Attendee Breakfast
8:00 – 8:45 am – Grand Ballroom

Invited Talk:
9 – 9:40 am – Grand Ballroom • **Donald Hillebrand, PhD, Argonne National Laboratory:** "Advanced Vehicle Technology Research"

Networking Break (Exhibits & Posters)
9:40 – 10:20 am – Grand Ballroom

Technical Sessions • 10:20 am – Noon

4A • Materials Tribology IV – Walton South
4B • Surfaces & Interfaces IV – Walton North
4C • Machine Elements & Systems III – Georgian Room
4D • Energy/Environment/Manufacturing I – Venetian Room
4E • Fluid Lubrication II: Textured Lubricated Contacts – Astor Room

Lunch on Your Own
Noon – 1:20 pm

Technical Sessions • 1:20 – 6:00 pm

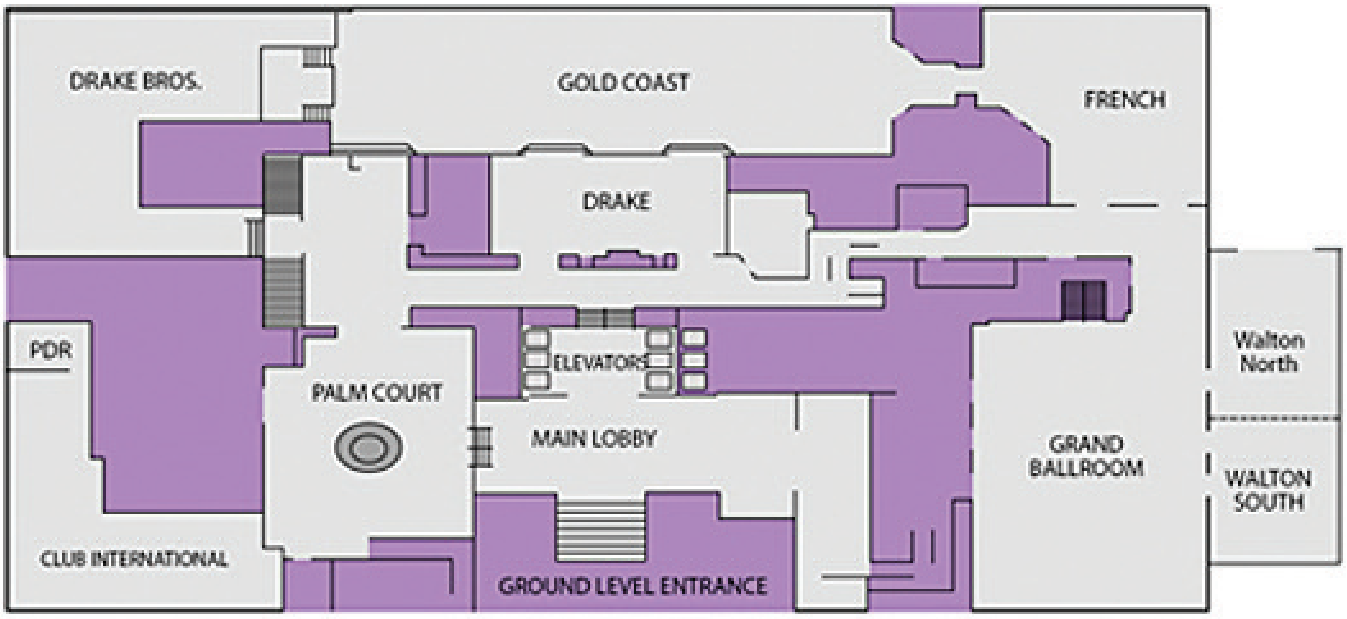
5A • Materials Tribology V – Walton South
5B • Surfaces & Interfaces V – Walton North
5D • Energy/Environment/Manufacturing II – Venetian Room

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

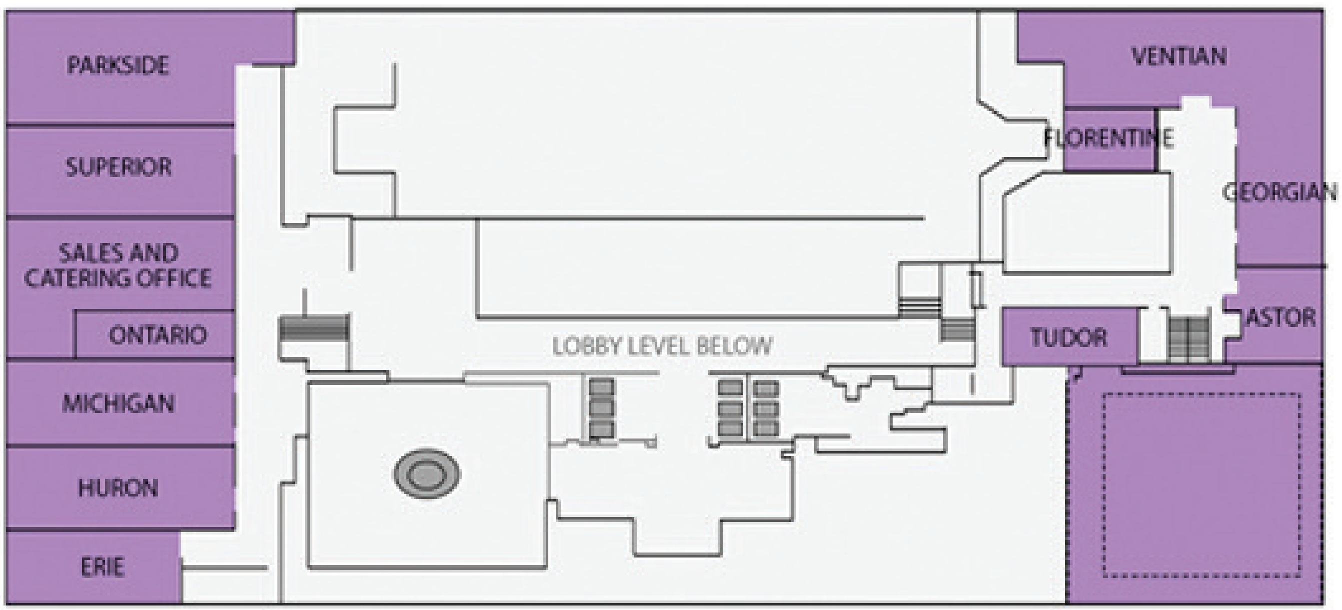
*As of 11/1/16 – Subject to Change

HISTORIC DRAKE HOTEL

140 E Walton Place, Chicago, IL 60611



Lobby Level



Mezzanine Level

SUNDAY

Speakers Luncheon
Noon – 12:45 pm – French Room

Student Career Mentoring Program
6 – 7 pm – Grand Ballroom – TLT Career Coach columnist Ken Pelczarski, "Effective Interviewing Techniques"

Student Networking Event
7:30 – 9 pm – Dave & Busters Entertainment Center
1030 N. Clark Street, Chicago

MONDAY

Speakers Breakfast
8 – 8:45 am – French Room

General Attendee Breakfast
8 – 8:45 am – Grand Ballroom

Networking Reception
6:30 – 8 pm – Grand Ballroom

TUESDAY

Speakers Breakfast
8 – 8:45 am – French Room

General Attendee Breakfast
8 – 8:45 am – Grand Ballroom

ALL DAYS

Networking Breaks
15-minute breaks scheduled daily in the mornings and afternoons. In addition to networking with your peers, be sure to visit with exhibiting companies in the Grand Ballroom.

Invited Speakers

The Tribology Frontiers Conference is honored to have four world-renowned invited speakers. Please make time in your conference itinerary to hear their presentations.

Sunday, 1:20 – 2 pm } Grand Ballroom
Dr. J. Edward Colgate, Northwestern University: "Surface Haptics: How Friction Modulation Lets Us Touch Virtual Worlds"

Monday, 9 – 9:40 am } Grand Ballroom
Professor Michael Moseler, Fraunhofer Institute of Mechanics and Materials: "Tribo-Mechano-Chemistry: Lessons From Atomic Scale Modeling"

Monday, 1:20 – 2 pm } Grand Ballroom
Miquel Salmeron, Lawrence Berkeley National Laboratory & University of California, Berkeley: "AFM and TEM Studies of Friction and Wear in Pt-Graphene and Pt-SiO2 Systems"

Tuesday, 9 – 9:40 am } Grand Ballroom
Dr. Donald Hillebrand, Argonne National Laboratory: "Advanced Vehicle Technology Research"

Awards will be presented at the Monday evening Networking Reception.

ASME Mayo D. Hersey Award

- **Izhak Etsion**
  Technion – Israel Institute of Technology

  The Mayo D. Hersey Award is bestowed on an individual in recognition of distinguished and continued contributions over a substantial period of time to the advancement of the science and engineering of tribology.

ASME Burt L. Newkirk Award

- **Aaron Greco**
  Argonne National Laboratory

  The Burt L. Newkirk Award is given to an individual who has not passed his/her 40th birthday on July 1 of the year in which the award is conferred and who is an ASME member at the time of nomination. It is given to one who has made notable contributions to the field of tribology in research or development as evidenced by important tribology publications.

ASME Marshall B. Peterson Award

- **Harmandeep Khare**
  University of Pennsylvania

  The Marshall B. Peterson Award is given biennially in recognition of early-career achievement in research as demonstrated by papers published in scientific journals of ASME and promise for pursuit of research in tribology. It is preferred, but not required, that the awardee's research emphasis be on material aspects of tribology, e.g., wear, friction materials and solid lubricants. At the time the award is given (October of even-numbered years), the nominee's age shall be less than 30 years.

ASME Journal of Tribology Best Paper Award

"Rotordynamic Morton Effect Simulation with Transient, Thermal Shaft Bow." Authors:

- **Xiaomeng Tong, Texas A&M**
- **Alan Palazzolo, Texas A&M**
- **Junho Suh, Texas A&M**

Keynote Session I – Grand Ballroom

1 – 1:20 pm Welcome & Introductions

1:20 – 2 pm Surface Haptics: How Friction Modulation Lets Us Touch Virtual Worlds, p. 9
Dr. J. Edward Colgate, Northwestern University, Evanston, IL

2 – 2:40 pm – BREAK

	Session 1A Tribology Highlights	Session 1B Surfaces & Interfaces I	Session 1C Materials Tribology I	Session 1D Lubricants I	Session 1E Biotribology
Location	**Walton South**	**Walton North**	**Georgian Room**	**Venetian Room**	**Astor Room**
TIME					
2:40 pm	Mechanisms Behind the Environmental Dependence of the Tribological Properties of Amorphous Carbon Coatings, Robert Carpick, p. 9	Contact Analysis Over A Heterogeneous Elastic-Plastic Body For Rolling Contact Fatigue Prediction, Thibaut Chaise, p. 10	Electrodeposition of Nanocrystalline Zinc on Steel for Enhanced Resistance to Corrosive Wear, Qingyang Li, p. 12	Effect of Molecular Chemical Structures on Shear Properties of Nanometer-Thick Liquid Lubricant Films … Takayuki Kobayashi, p. 14	Cell Monolayers Under Pressure: Fluid Flow in Contact, Kyle Schulze, p. 16
3 pm		Applying Analytical Roughness Models to Real Surfaces: Reconstructing the Power Spectral Density From … Tevis Jacobs, p. 10	A Comparison of the Wear Resistance Between Reactive Plasma Sprayed Nano- and Micron- structured … Yanchun Dong, p. 12	An Improved Model for Describing the High-pressure High Shear Stress Behaviour of Polymer-base Oil Solutions, Pauline Cusseau, p. 14	Tribological Rehydration: Directly Observing the Loss and Recovery of Interstitial Fluid, Axel Moore, p. 16
3:20 pm	Tribology Influences Rheology Influences Tribology: Microscopic Mechanism for Shear-thickening of Non-Brownian Suspensions, Juliette Cayer-Barrioz, p. 9	Dry and Lubricated Contact Mechanics Between Soft Linearly Viscoelastic Solids … Carmine Putignano, p. 11	Tribological Properties of PDA/PTFE Coating Under Lubricated Condition, Yang Zhao, p. 13	Determination of Rheological Properties of Composite Base Fluid for Lubricants, M. Cinta Lorenzo Martin, p. 14	Broadband Nature of Energy Dissipation in Articular Cartilage, Melih Eriten, p. 16
3:40 pm		A Solution of Rigid Perfectly Plastic Cylindrical Indentation Based on Slip Line Theory, Robert Jackson, p. 11	Tribological Properties of Carbon Nano-fiber Film on SiC Surface, Hiroshi Tani, p. 13	Super-Arrhenius Piezoviscosity: An Essential Component of Elastohydrodynamic Friction Missing … Scott Bair, p. 15	Relationship of Skin Friction Characteristics with Finger Moisture, JinHwak Park, p. 16
4 pm	Driving Mechanochemical Wear on Graphene Using Local Stress and Heat, Jonathan Felts, p. 9	Using Ultrasound For Monitoring Frictional Contacts, Xiangwei Li, p. 11	Ultra-low Friction of Polyethylenimine / Graphene Oxide Lamellar Coatings in Various … Prabakaran Saravanan, p. 13	Rheology of an Ionic Liquid with Variable Carreau Exponent – A Full Picture by Molecular Simulation … Philippe Vergne, p. 15	
4:20 pm		Study on the Rolling Contact Fatigue Properties of Composite Oxide Ceramics, Yuichi Endo, p. 11	Preparation and Tribological Properties of Graphene/Ni Based Composite Coatings, Jianliang Li, p. 13	A Methodology to Investigate the Adhesion Properties and Tackiness of Industrial Greases, Emmanuel Georgiou, p. 15	
4:40 pm	In-situ Viscosity Measurement of EHD Lubricants, Janet Wong, p. 10	Loading Rate Optimization for Minimizing Dynamic Effects in Quasi-static Contact Modeling, Xi Shi, p. 12	Coefficient of Friction of TiN and MoS_2 Thin Film Coatings on Aluminum, Omer Ahmed, p. 14	Temperature dependence of Viscosity of Poly-Alpha-Olefins Sheared in a Nanometer-size Gap, Shintaro Itoh, p. 15	
5:00 pm	Mesh Size Control of Friction in Soft Matter Interfaces, Angela Pitenis, p. 10	Contact Analysis of a Three-dimensional Porous Photonic Crystal … Fengtong Ji, p. 12			
5:20 pm		Analysis of Frictional Slip, George Adams, p. 12			

Keynote Session I } Grand Ballroom

1 – 1:20 pm | Welcome & Introductions

1:20 – 2 pm | Surface Haptics: How Friction Modulation Lets Us Touch Virtual Worlds

Dr. J. Edward Colgate, Northwestern University, Evanston, IL

Imagine reaching into a handbag for a key fob, finding it amidst clutter, grasping it and pressing "unlock," all without looking. That is an example of haptic perception. Now imagine extracting your cellphone, unlocking it, and opening an app, also without looking. Not as easy! In this talk, I'll introduce "surface haptics," which aims to give that cellphone controllable tactile properties such as buttons and sliders you can feel. How can a finger on a flat piece of glass feel a shape or texture? We approach this problem by controlling the frictional forces on the fingertip, modulating them in accordance with the finger's movement. I'll describe two friction modulation techniques – transverse ultrasonic vibrations and electrostatic fields; explain how friction modulation can be combined with lateral vibrations to create propulsive forces; and illustrate various ways in which lateral forces may be used to create the illusion of texture, events, and even 3D shape.

2 – 2:40 pm • Break • Grand Ballroom

Session 1A } Walton South

Beyond the Cutting Edge: Highlights from Tribology Letters I

Session Chair: W. Tysoe, Chemistry and Biochemistry, UW-Milwaukee, Milwaukee, WI

2:40 – 3:20 pm | Mechanisms Behind the Environmental Dependence of the Tribological Properties of Amorphous Carbon Coatings

Robert Carpick, University of Pennsylvania, Philadelphia, PA, Medard Komlavi Dzidula Koshigan, Ecole Centrale de Lyon, Ecully cedex, France, Filippo Mangolini, University of Leeds, Leeds, United Kingdom, John Brandon McClimon, University of Pennsylvania, Philadelphia, PA, B. Vacher, Sandrine Bec, Julien Fontaine, Ecole Centrale de Lyon, Ecully cedex, France

Amorphous carbon films are used as solid lubricants in a range of applications. However, one limitation is their environmental sensitivity. Silicon oxide-doped amorphous hydrogenated carbon films (a–C:H:Si:O) exhibit increased stability in extreme environments relative to amorphous hydrogenated carbons (a–C:H). We aim to develop fundamental understanding of the environmental impact on the tribology of a–C:H:Si:O. Upon sliding a–C:H:Si:O film against steel, two friction regimes occur: high friction in high vacuum or low pressures of oxygen or hydrogen gas, and a low friction regime at higher gas pressures (oxygen pressure >10 mbar, or hydrogen >50 mbar). Scanning electron microscopy revealed that the tribological behavior of a-C:H:Si:O is governed by environmentally-dependent adhesive junctions behavior at the sliding interface. At low gas pressures, material transfer from the steel pin to the a–C:H:Si:O flat occurs. At higher gas pressures, a tribofilm forms on the steel countersurface. Raman and near edge X-ray absorption spectroscopy demonstrate that when sliding in the higher gas pressure (low friction) regime, a surface layer with an elevated fraction of sp2-bonded carbon atoms forms. These changes indicate that these gases favor the release of the adhesive junctions by dissociatively reacting with the mechanically-stressed sp2 carbon-rich surface layer. We will discuss the impact of these results in considering the design and function of other solid lubricant coatings.

3:20 – 4 pm | Tribology Influences Rheology Influences Tribology: Microscopic Mechanism for Shear-thickening of Non-Brownian Suspensions

Juliette Cayer-Barrioz, LTDS-CNRS UMR5513, Scully, France

A simple model, supported by rheology and friction measurements as well as contact-dynamics simulation is proposed to link the transition from continuous to discontinuous shear thickening in dense granular pastes to distinct lubrication regimes in the particle contacts, is proposed. We identify a local Sommerfeld number that determines the transition from Newtonian to shear-thickening flows, and then show that the suspension's volume fraction and the boundary lubrication friction coefficient control the nature of the shear-thickening transition, both in experiments and simulations.

4 – 4:40 pm | Driving Mechanochemical Wear on Graphene Using Local Stress and Heat

Jonathan Felts, Shivaranjan Raghuraman, Texas A&M University, College Station, TX

Here we investigate the chemical dynamics of local graphene oxide reduction through the application of local temperature and stress using a heated atomic force microscope (AFM) tip. Specifically, a silicon AFM cantilever with an embedded Joule heater applies both local stress and heat to chemically functionalized graphene surfaces during tip sliding. The friction of the graphene sheet depends linearly on chemical group concentration, so monitoring friction force provides an *in situ* measure of chemical functionality on the surface over time. We demonstrate bond cleavage of oxygen, fluorine, and hydrogen from graphene using force alone. We then investigate both local temperature and force during tip sliding on graphene oxide. Monitoring friction over time for tip temperatures between 310 – 355 C and a load of 40 nN provides the kinetics of the reduction process, with an activation energy for bond scission of 0.7 ± 0.3 eV. Measurement noise contributed significantly to error and precluded determination of reaction order. In an effort to reduce measurement time and error, we introduce a new technique which measures friction during a linear temperature ramp between 50 – 450 C, providing an activation energy 0.62 ± 0.07 and a reaction order n ~ 1. It was further shown that applied force non-linearly reduces the observed activation barrier. The results are compared to bulk measurements from the literature as well as the current prevailing models of mechanochemical reactions.

4:40 – 5:00 pm | In-situ Viscosity Measurement of EHD Lubricants

Janet Wong, Jon Dench, Imperial College London, London, United Kingdom

Lubricants are indispensable for the efficient operation of many machines. In the Elastohydrodynamic lubrication (EHD) regime, lubricants often experience high normal pressure (> 1 GPa) and high shear rate (~ 10^7 s^{-1}). The conditions lubricants are exposed to may impact on their rheology, so that their in-contact behaviour may be significantly different from their behaviour in bulk conditions. While various rheological models have been developed to predict lubricant response in service conditions, corresponding experimental data is rare. Recently we have developed a fluorescence-based technique that allows local viscosities of a lubricant in an EHD contact to be measured in situ. The technique involves the use of a type of fluorescence dye, called molecular rotor, whose fluorescence lifetime depends on the viscosity of its surroundings. Using glycerol and IGEPAL as model lubricants, we have shown that the local viscosity of a lubricant in an EHD contact is heterogeneous. Local viscosity is the highest around the centre of the contact. The distribution of local viscosity roughly follows that of normal stress. We have also shown that the newly developed technique is capable of detecting shear thinning of the lubricant. The technique developed will be a very useful tool in promoting better understanding on lubricant rheological and the information provided will be invaluable to validating commonly used rheological models.

5 – 5:20 pm | Mesh Size Control of Friction in Soft Matter Interfaces

Angela Pitenis, Juan Urueña, Kyle Schulze, Andrew Cooper, Thomas Angelini, W. Gregory Sawyer, University of Florida, Gainesville, FL

Soft, permeable sliding interfaces in aqueous environments are prevalent in nature. Although nature's ability to provide high lubricity in a poor lubricant (water) has not been well understood, it is hypothesized that protective entangled networks on the sliding surfaces facilitate lubrication. Synthetic hydrogels are excellent model materials for fundamental soft matter and biotribology studies of these biotribofilms due to their high water content, permeability, and tunable mesh size (ξ), which controls all material and transport properties. Polyacrylamide (pAAm) hydrogels have consistently produced low friction in a twinned (Gemini) sliding configuration under low sliding speeds, low contact pressures, macroscopic contact areas, in ultrapure water at room temperature. Remarkably, large mesh size and correspondingly very soft hydrogels exhibit superlubricity ($\mu < 0.005$) under specific sliding conditions. As scaling laws fail to predict this behavior based on contact area and polymer concentrations in the interface, friction and interfacial dissipation are likely not driven by chain-chain contact. The more likely source of dissipation is the viscous shearing of a fluid layer that is ~1 mesh size in thickness. Different friction behaviors have emerged by varying the sliding speed over four orders of magnitude. These domains are determined partly by polymer relaxation timescales, which are in turn controlled by the solvent viscosity within the hydrogel mesh.

Session 1B } Walton North

Surfaces & Interfaces I

Session Chair: Robert Jackson, Auburn University, Auburn AL

Session Vice Chair: Thibaut Chaise, INSA Lyon, Villeurbanne, France, Kwassi Amuzuga

2:40 – 3 pm | Contact Analysis Over A Heterogeneous Elastic-Plastic Body For Rolling Contact Fatigue Prediction

Thibaut Chaise, INSA Lyon, Villeurbanne, France, Kwassi Amuzuga, Daniel Nelias, INSA-Lyon, Villeurbanne, France

Raceways may contain heterogeneities, either soft ones, like porosities, or hard ones, like carbides. The presence of such heterogeneities in bodies in contact may have a drastic effect on the contact pressure but also on the plastic flow, either under normal load, where the presence of the heterogeneity may cause sufficient over stress to pass the material's yield limit or during over loading occurrences, where the plastic flow and consequent residual stresses will be modified by the presence of the defect. The study proposed here aims at determining some of the key parameters that may lead to rolling contact fatigue when heterogeneous bodies are involved. Based on the use of a semi analytical method, that allows fast computations of problems where plasticity, contact and heterogeneous behaviors are fully coupled, the influence of heterogeneities size, properties and a few other hardening parameters on the problem for multiple rolling cycles are studied.

3 – 3:20 pm | Applying Analytical Roughness Models to Real Surfaces: Reconstructing the Power Spectral Density From Surface Topography Measurements

Tevis Jacobs, Subarna Khanal, Abhijeet Gujrati, University of Pittsburgh, Pittsburgh, PA, Till Junge, Lars Pastewka, Karlsruhe Institute of Technology, Karlsruhe, Germany

Surface topography is a critical factor for mechanical and tribological properties of materials. Recent analytical models of roughness show that adhesion, contact stiffness, and friction depend on the nature of roughness across many length scales. The power spectral density (PSD) is the mathematical instrument that describes surface roughness as a function of scale. A quantitative, accurate PSD is necessary to validate and apply these analytical roughness models. However, this is currently limited by: (A) inconsistencies in the calculation of the PSD; (B) bandwidth-limits of conventional surface metrology; and (C) instrumental artifacts at the nanoscale. We show that experimentally-determined PSDs suffer three types of systematic error. We demonstrate strategies for detection and mitigation of these artifacts, to ensure accurate and reliable PSDs. Additionally, a novel web-based application has been created and made available for general use which computes accurate PSDs and assesses the limits of their reliability. Finally, we report the first comprehensive roughness characterization of an ultrananocrystalline diamond (UNCD) surface over the range from Angstroms to centimeters. This range of characterization enables quantitative comparison with rough-surface adhesion models. Taken together, this work advances the prediction and control of properties of real-world surfaces based on their topography.

3:20 – 3:40 pm | Dry and Lubricated Contact Mechanics Between Soft Linearly Viscoelastic Solids: Numerical Methodologies and Experiments

Carmine Putignano, Daniele Dini, Imperial College London, London, United Kingdom

Engineering polymers are widely widespread as smart engineering solutions thanks to the interesting combination of good mechanical and chemical properties, in terms of resilience, elasticity, durability, with an extremely low density. However, design of rubber and rubber-based components need a really careful examination of their mechanical properties. Indeed, viscoelastic dissipation is the key feature marking their complicated mechanical behavior since it is strictly related to the choice of suitable rubber-based materials for each application. Tires, V-belts, rollers, seals are only examples of components where damping effects have to be accounted for as the most important target parameters. Here, we review a variety of numerical methodologies that have been developed to deal with the sliding and rolling contact mechanics of viscoelastic solids, either in steady-state and in transient conditions. The study is conducted both in dry and lubricated conditions. A variety of experimental tests is, finally, presented to validate the numerical outcomes.

3:40 – 4 pm | A Solution of Rigid Perfectly Plastic Cylindrical Indentation Based on Slip Line Theory

Robert Jackson, Aman Sharma, Auburn University, Auburn, AL

During indentation it is often important to determine the relationship between the average pressure and the yield strength. This work uses slip line theory to determine this relationship for the case of a rigid cylinder indenting a frictionless perfectly plastic half-space (i.e. no hardening). The results show that the ratio between the average contact pressure and the yield strength decreases as the depth of indentation is increased. Note that the slip-line analysis does not include the effects of pile-up or sink-in deformations. However, the slip-line theory has also been compared to data generated using the finite element method (FEM). The theory and the FEM results appear to agree well.

4 – 4:20 pm | Using Ultrasound For Monitoring Frictional Contacts

Xiangwei Li, R Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

Contact of rough surfaces is present in almost all engineering applications. Engineers are interested in knowing the frictional conditions at contact interfaces. Recently, Contact Acoustic Nonlinearity (CAN) [1] has drawn much interest due to its great potential in Non-destructive evaluation. It has been noticed analytically that when high power bulk shear ultrasound propagates through a compressed rough contact interface, higher odd order harmonics (3ω, 5ω, etc.) are generated in both transmitted and reflected waves [2, 3]. The nonlinear nature of stick-slip phenomenon in friction may be the source of nonlinearity. In this study, nonlinearity due to the interaction of shear ultrasonic wave with frictional contact interface is investigated. Harmonic generation by a normally incident shear wave is evaluated experimentally using the high frequency nonlinear ultrasonic technique, combined with analytical approach to understand the nonlinearity generation and its dependence on externally applied load, friction coefficient and interfacial stiffness. Experiment results show that the ratio of fundamental frequency amplitude to the third harmonic drops when pre-applied stress rises, which suggests that harmonic generation may occur at lightly loaded contact interface where 'stick-slip' motion can take place. Further work is required to assess the nonlinearity originating from the frictional contact interface and how it can be used to measure friction coefficient.

4:20 – 4:40 pm | Study on the Rolling Contact Fatigue Properties of Composite Oxide Ceramics

Yuichi Endo, Yasuyuki Shimizu, Koji Ueda, Nobuaki Mitamura, NSK Ltd., Fujisawa-shi, Kanagawa, Japan

Ceramics have superior qualities compared to bearing steel, such as lower density, higher hardness, etc. Therefore, ceramics are used as a bearing material in various applications. Silicon nitride can be considered as a standard ceramic bearing material based on their superior rolling contact fatigue life and load resistance properties. However, silicon nitride has some problems in mass production process. The challenge results the cost of silicon nitride ball is considerably expensive. It has been observed that by using oxide ceramic material as a raw material above problem can be solved and cost can be kept lower. To achieve excellent rolling contact fatigue properties and get a reliability of oxide ceramics as a bearing material, composite of different oxide ceramics was developed, which consists of alumina and zirconia. By combining two oxide ceramics, it was considered to make the compressive residual stress higher and improve toughness, consequently, better rolling contact fatigue properties compared to conventional oxide ceramics. Optimization of microstructure was carried out by reviewing the whole production process. The bearing fatigue life of newly developed ball is good when compared with calculated fatigue life and fatigue life of silicon nitride. The failure pattern is concentric flaking, which is similar to silicon nitride and bearing steel. This study also investigated the effect of residual stress and toughness on the fatigue life of oxide ceramic composite.

4:40 – 5:00 pm | Loading Rate Optimization for Minimizing Dynamic Effects in Quasi-static Contact Modeling

Xi Shi, Yunwu Zou, Shanghai Jiao Tong University, Shanghai, China

The explicit finite element method (FEM) has been one of the most popular approaches in the field of quasi-static nonlinear analysis. However, a higher loading rate usually results in significant dynamic effects in the simulation thus a compromise between them is in need. In this study, a new criterion for proper loading time determination is presented. The major point of this criterion is that the dynamic effects can be negligible if the curve of total strain energy versus loading displacement is monotonously increasing without fluctuation in the initial loading and intermediate stages, but not including the unloading stage due to the effect of elastic release. In addition, its first derivative is smooth without bulging or multi-peak behavior in the whole loading process. The validity has been verified by two contact problems. The first one involves the sliding interaction of two identical elastic-plastic spherical asperities. Compared to the conventional energy ratio criterion (by keeping the ratio of kinetic energy to strain energy less than 5%), the proposed criterion improved the computation efficiency by 86% without affecting computational accuracy, and it can be further improved by 60% with the utilization of local mass scaling. For the second one, the Hertz contact of two hemispheres was considered due to its representative of contacts with small and elastic deformation, and the simulation results also show an improvement of 80%.

5:00 – 5:20 pm | Contact Analysis of a Three-dimensional Porous Photonic Crystal Indented and Scratched by a Rigid Sphere

Fengtong Ji, Longqiu Li, Tianlong Li, Yao Li, Harbin Institute of Technology, Harbin, China

Photonic crystal which is consisted of periodic nanostructures can be used in optoelectronic and optical devices. Prediction and characterization of mechanical properties are crucial to optimize the structure of the photonic crystal in order to sustain mechanical stresses in engineering application. In this study, a finite element model is established, in which a deformable photonic crystal with periodic structure is indented and scratched by a rigid sphere, respectively, to investigate the mechanical properties of photonic crystal, such as Young's modulus and hardness. The effect of indentation depth, pore size, crystal lattice constant and porosity on the mechanical properties of photonic crystal are presented. It shows that the material properties and the porosities have great effect on the mechanical properties of photonic crystal.

5:20 pm – 5:40 pm | Analysis of Frictional Slip

George Adams, Northeastern University, Boston, MA

Damage due to fretting fatigue is initiated due to frictional slip near the edges of the interface between two connected materials. Unfortunately the stress analysis of structures which includes these frictional slip zones is quite a bit more complicated than it is for a perfect bond, often making it impractical to include in a comprehensive finite element model of the complete structure …

Session 1C } Georgian Room

Materials Tribology I

Session Chair: Melih Eriten, University of Wisconsin – Madison, Madison, WI

Session Vice Chair: Gustavo Molina, Georgia Southern University, Statesboro, GA

2:40 – 3 pm | Electrodeposition of Nanocrystalline Zinc on Steel for Enhanced Resistance to Corrosive Wear

Qingyang Li, Hao Lu, University of Alberta, Edmonton, Alberta, Canada, Maozhong An, Harbin Institute of Technology, Harbin, Heilongjiang, China, Dongyang Li, University of Alberta, Edmonton, Alberta, Canada

In order to increase the resistance of electrogalvanized steel to corrosive wear, nanocrystalline zinc coating was electrodeposited onto the steel substrate using a sulfate bath with polyacrylamide as grain refiner. Corrosive wear tests were performed in a simulated seawater solution to evaluate the performance of the nanocrystalline zinc coating with its grain size around 40 nm, in comparison with that of coarse-grained zinc coating. It was demonstrated that material loss of the coarse-grained zinc coating having its grain size around 5 m was three times as large as that of the nanocrystalline one. The considerably higher corrosive wear resistance of the nanocrystalline zinc coating benefited from its smoother surface, higher hardness and elastic modulus, decreased adhesive force and lowered electron work function. The superior performance of the nanocrystalline coating is largely ascribed to its increased mechanical strength due to nanocrystallization and higher surface activity (corresponding to a lower work function) which improved the passivation capability and helped form a more protective corrosion product layer or oxide scale. Detailed analyses were conducted towards clarification of the mechanism responsible for the improvements.

3 – 3:20 pm | A Comparison of the Wear Resistance Between Reactive Plasma Sprayed Nano- and Micron- structured FeAl 2O 4-Al 2O 3-Fe Coatings

Yanchun Dong, Dianran Yan, Jianxin Zhang, Yong Yang, Hebei University of Technology, Edmonton, Alberta, Canada, Dongyang Li, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada

Reactive plasma spray is a process combining simultaneous synthesis and deposition of reaction products, which is often used to fabricate ceramic-matrix and metal-matrix composite coatings with elevated toughness and strength. In this work, wear resistances of nanostructured and microstructured FeAl2O4-Al2O3-Fe composite coatings, made by spraying composite powders of Fe2O3 and Al with different sizes, were investigated. The objectives of this study are to study the microstructure-property relationship and to evaluate the effectiveness of nanostructure in enhancing the wear resistance of the composite coating. Results of the study show that the nanostructured FeAl2O4-Al2O3-Fe composite coatings possess a more homogeneous microstructure, which is stronger and tougher, resulting in markedly raised wear resistance. The mechanism responsible for the improvement in the wear resistance is clarified.

3:20 – 3:40 pm | Tribological Properties of PDA/PTFE Coating Under Lubricated Condition

Yang Zhao, Min Zou, University of Arkansas, Fayetteville, AR

The objective of this work is to investigate the effect of liquid lubrication on the tribological properties of the Polydopamine (PDA)/polytetrafluoroethylene (PTFE) coating under severe operation condition. The wear process of a PDA/ PTFE coating in lubricated condition was tested under 1.5 GPa contact pressure in a rotatory oscillating motion using a ball-on-disk configuration of the UMT-2 tribometer. A normal load of 15 N was applied with the sliding speed of 0.1 m/s. A 3D laser scanning microscope was used for high resolution 3D imaging of the wear track and the counterface. The effect of PTFE coating thickness on the durability of the PDA/PTFE coating was investigated and the electrical contact resistance (ECR) signal was used to detect coating failure. It was found that PDA/PTFE coating exhibits good tribological properties in fully synthetic oil (5W20). The coating decreased the COF for about 9% and the wear for about 42% compared to those of the bare samples without coating. The results also show that the PDA coating itself did not provide any tribological property improvement.

3:40 – 4 pm | Tribological Properties of Carbon Nano-fiber Film on SiC Surface

Hiroshi Tani, Kansai University, Suita, Osaka, Japan, Masahiro Yamashita, Graduate School of Kansai University, Osaka, Japan, Renguo Lu, Shinji Koganezawa, Norio Tagawa, Kansai University, Suita, Osaka, Japan

Silicon carbide (SiC) is well known as a ceramic material which has superior friction and wear resistance characteristic in the water. That is familiar as a material for sliding bearings and mechanical seals. However, the abnormal wear occasionally occurs on a dry sliding condition or in ultra-pure water. Then, we studied the tribological properties of the carbon nano-fiber (CNF) film on the surface of sintered SiC in order to reduce the abnormal wear. The CNF film on a sintered SiC surface was easily generated by the SiC surface decomposition process, which a sintered SiC was heated to 1150 °C in high vacuum for 24 hours. The generated CNF has the porous structure and was consisted of the carbon with rich sp2 structure. The combination of CNF film on SiC plate and that on SiC pin were evaluated in dry and water environments by the pin-on-plate friction test. As the results, we confirmed that the combination of CNF films on SiC plate and that on pin showed the lower friction in dry and wet condition than the combination of SiC plate and pin. The wear area on the CNF pin was reduced by 30 % compared to the SiC pin.

4 – 4:20 pm | Ultra-low Friction of Polyethylenimine/ Graphene Oxide Lamellar Coatings in Various Atmospheres

Prabakaran Saravanan, Hiryoshi Tanaka, Joichi Sugimura, International Institute for Carbon-Neutral Energy, Fukuoka, Japan

Multilayer polyethylenimine / graphene oxide (PEI/GO)n thin films (n = 5, 10, or 15 bilayers) were coated onto steel substrates via layer by layer (LbL) assembly, and the tribological properties investigated in various gas environments. The steady-state coefficient of friction (COF) in air (with H_2O ca. 140 ppm) was reduced from ~0.89 for bare steel to ~0.17 with the coating. The lowest coefficient of friction achieved in hydrogen and vacuum was ~0.04 and ~0.08 and, respectively. Ultra-low friction was achieved in nitrogen environment (COF < 0.01) for (PEI/GO)15. The tribological behavior of thicker 10 and 15 bilayer coatings was significantly better than for 5 bilayer film in all environments, whilst the wear life was improved up to 200 times. Superior frictional behavior is observed in dry environments (H2, N2 (<2 ppm H_2O) and vacuum) compared with air (~140 ppm H_2O). The specific friction mechanism includes formation of hollow carbon nanoparticles on the friction surfaces in dry environment resulting in a much lower contact area, as evidenced by electron microscopy. Density functional theory (DFT) simulations revealed that interaction between layers depending on the gas environment; in humid conditions hydrogen bonding results in strong interaction between the layers. In dry gas environments repulsive forces facilitate separation of the layers by frictional forces, and the subsequent formation of characteristic nanostructures.

4:20 – 4:40 pm | Preparation and Tribological Properties of Graphene/Ni Based Composite Coatings

Jianliang Li, Minglu Xue, Jinhang LI, Xiaoyuan Chi, Nanjing University of Science and Technology, Nanjing, China

Graphene as a two-dimensional crystalline material has been used in novel nanomaterials due to its unique electronic,mechanical and thermal properties.It can be used in the forms of solid films, lubricant additives in the oil and composite. In this paper, the graphene sheets were prepared by using chemical redox methods. The graphene/nickel based composite coatings were prepared on steel surface by using double pulse electrodeposition process. The morphologies of composite coatings were observed by optical metallographic microscope and SEM. The phase and composition were analyzed by XRD and EDS. Its tribological properties were tested by rubbing against GCr15 pin. The morphology and composition of wear track were analyzed by EDS. The influence of different reduced temperature, different reduced time and the amount of redactor were compared. Adding graphene can decrease the average crystallite size of the composite electroplating film and increase the hardness of the composite coating. The electro - deposited graphene/nickel based composite coating with low oxygen addition has better properties of friction and wear. Besides, among graphene with different layers, single layer graphene has better properties of friction and wear.

4:40 – 5:00 pm | Coefficient of Friction of TiN and MoS_2 Thin Film Coatings on Aluminum

Omer Ahmed, Ahalapitiya Jayatissa, Sorin Cioc, University of Toledo, Toledo, OH

Surface coatings are extensively applied to improve the mechanical properties and/or the aesthetics of a surface. This research presents a tribological study of various TiN (Titanium Nitride) and MoS_2 (Molybdenum Disulfide) coatings on Aluminum (Al) samples, deposited by Physical Vapor Deposition (PVD). The thickness of these films ranges from 300 to 350 nm, categorized as thin films. The TiN coatings were obtained using RF magnetron sputtering and MoS2 were coated using evaporation deposition. The key parameter to control the properties of coatings are gas passed, radio frequency (RF), current applied, and pressure in the vacuum chamber. TiN being an extremely hard ceramic material has superior properties than Aluminum substrate, thus improving the surface and tribological properties. For further improvement of the frictional properties of the material, the substrate is also coated with MoS2, known to be a solid lubricant. The coefficient of friction is measured using a Pin on Disc tribometer with a steel pin. The speed was constant at 115 rpm with a load of 0.215N. The detailed tribological properties obtained before and after coatings are presented in the paper. The results showed a substantial decrease in the coefficient of friction, thus proving that TiN and MoS2 coatings are feasible in real life applications where low coefficient of friction is essential for projected performance.

Session 1D } Venetian Room

Lubricants I

Session Chair: Patricia Iglesias Victoria, Rochester Institute of Technology, Rochester, NY

Session Vice Chair: Laura Pena Paras, Universidad de Monterrey Engineering, Garza Garcia, Nuevo, Mexico

2:40 – 3 pm | Effect of Molecular Chemical Structures on Shear Properties of Nanometer-Thick Liquid Lubricant Films: A Coarse-Grained Molecular Dynamics Study

Takayuki Kobayashi, Hedong Zhang, Kenji Fukuzawa, Shintaro Itoh, Nagoya University, Nagoya, Japan

For molecular level design aimed at high performance nano-lubrication, it is essential to understand how chemical structures of lubricant molecules affect their shear properties when confined in nanoscale gaps between solid surfaces. In this study, shear properties of three types of perfluoropolyether lubricant molecules (Z, Zdol, and Demnum), which differ in end group polarity and backbone structure, were investigated using coarse-grained (CG) molecular dynamics (MD) simulations. We developed CG molecular models that reproduce the structural properties of the lubricant molecules derived from all-atom MD simulations. Using the models, we conducted MD simulations in which the three types of lubricant films 2.0 nm thick were sheared between carbon surfaces with random roughness. Two types of surfaces differing only in the correlation length of roughness were used. We found that, for the surface with the short correlation length, there was almost no interfacial slip and the shear stress increased with increasing viscous resistance between the lubricant molecules due to the end group polarity or the backbone rigidity. For the surface with the long correlation length, severe interfacial slip occurred, and as a result the shear stress was nearly independent of the backbone rigidity, but it was larger for polar than for nonpolar lubricant molecules because the strong interactions between the polar end groups and the solid surface slightly suppressed the interfacial slip.

3 – 3:20 pm | An Improved Model for Describing the High-pressure High Shear Stress Behaviour of Polymer-base Oil Solutions

Pauline Cusseau, LaMCoS/Total, Villeurbanne Cedex, France, Philippe Vergne, LaMCoS, Villeurbanne, France, Fanny Briand, Total, Solaize, France

The development of high-performance lubricants in order to decrease engine friction and then reduce fuel consumption remains a major challenge for oil manufacturers. Additives are introduced to improve the base oil properties. Among them, the Viscosity Index Improvers (VIIs) are used to reduce the dependency of the lubricant's viscosity on temperature, in order to maintain an acceptable lubrication in harsh conditions. This work focuses on understanding the role and action of the VIIs in engine lubricants through the study of their high pressure rheological behaviour. Therefore, simplified lubricants – composed of VII and base oil only – are first characterised under realistic engine conditions. Experiments are carried out on two non-commercial high pressure devices. The first one is a falling-body viscometer which measures the low-shear viscosity from atmospheric pressure to 800 MPa and up to 120°C. The second one is a high pressure Couette rheometer which provides the shear stress vs. shear rate variations for pressures from 200 to 400 MPa and temperatures from 30 to 60°C. The viscosity variations with temperature, pressure and shear stress are then represented by different models, for which the time-temperature-pressure superposition principle was applied. The goal is to improve the existing models and to obtain a reliable estimation of the rheological behaviour of the polymer-base oil solutions at high shear stress.

3:20 – 3:40 pm | Determination of Rheological Properties of Composite Base Fluid for Lubricants

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

The drive for higher efficiency lubricants in various mechanical systems such as ICE, gearbox, etc., often lead to the use of lower viscosity basefluids. As we approach the cusp of ultralow viscosity era in lubricant formulation, the need for composite basefluids consisting of mixture of fluid with different molecular structures is a necessity. There is thus a need for fast and adequate determination of rheological properties, especially the viscosity measurement of some low-viscosity basefluids. This paper presents an overview of methods and experimental results of viscosity measurement of some low-viscosity basefluids. Plausible pathways forward for effective and efficient determination of rheological properties of composite fluids are also discussed.

3:40 – 4 pm | Super-Arrhenius Piezoviscosity: An Essential Component of Elastohydrodynamic Friction Missing from Classical EHL

Scott Bair, Georgia Tech, Atlanta, GA, Laetitia Martinie, Philippe Vergne, Univ Lyon, INSA Lyon, CNRS, LaMCoS – UMR5259, Villeurbanne, France

Ninety years of high pressure viscometer measurements with many different types of viscometers have shown that faster-than-exponential (super-Arrhenius) pressure dependence of viscosity is universal for glass-forming liquids. Dielectric spectroscopy at elevated pressure also yields super-Arrhenius response in the primary relaxation time dependence on pressure. In contrast, classical elastohydrodynamic lubrication (EHL) has gone to great lengths to ignore this phenomenon, including fictionalized accounts of the results of viscometry. As a result of this, classical EHL is unable to quantitatively account for the most important property affecting friction. Some observed liquid response to shear stress at high pressure can be explained with the measured super-Arrhenius pressure dependence.

4 – 4:20 pm | Rheology of an Ionic Liquid with Variable Carreau Exponent – A Full Picture by Molecular Simulation with Experimental Contribution

Philippe Vergne, Nicolas Voeltzel, INSA Lyon, Villeurbanne, France, Laurent Joly, ILM, Université Lyon 1, Villeurbanne, France, Nathalie Bouscharain, Nicolas Fillot, INSA Lyon, Villeurbanne, France

The rheological behavior of an ionic liquid was investigated by means of molecular dynamics simulations with experimental contribution, under conditions close to those found in the elastohydrodynamic and the very thin film lubrication regimes. The molecular model was applied to nearly 200 temperature-pressure-shear rate cases, without any parameter adjustment. Experiments were conducted on a rheometer and a high-pressure falling body viscometer. This unique combination of numerical and experimental tools has enabled the full description of the ionic liquid rheological response to extreme conditions of temperature, pressure and shear rate. In the linear domain, a very good consistency between the two computational approaches (non-equilibrium molecular dynamics, equilibrium molecular dynamics via the Green-Kubo formalism) and the experiments was obtained on the Newtonian viscosity. Compared with a conventional lubricant of almost identical Newtonian viscosity, the pressure-viscosity coefficient of the ionic fluid is much lower, its variations with temperature remaining, however, very similar. The application of the time-temperature-pressure superposition principle and the regression to the Carreau equation for describing the non-linear domain have revealed, for the first time, significant variations in the exponent of the Carreau model which have been correlated with the changes in temperature and pressure.

4:20 – 4:40 pm | A Methodology to Investigate the Adhesion Properties and Tackiness of Industrial Greases

Emmanuel Georgiou, Dirk Drees, Falex Tribology NV, Rotselaar, Belgium

Lubricative greases are extensively used in various industrial and technological applications ranging from machinery equipment, automotive components, and even in electrical contacts, with the aim to decrease frictional forces and to protect these components from wear damage. Their performance is strongly dependent on their interaction properties like adherence to the substrate, cohesion or consistency, and tackiness. However, despite the large applicability of greases, very little has been reported on how to efficiently determine and quantify these properties. This issue is continuously attracting more industrial interest as the complexity in the formulation of greases is continuously evolving and this makes it even harder for end-users to differentiate between the many available greases in the market and to select the one that fits better to their application. This presentation shows how we established a methodology, based on approach-retraction curves, for objective measurement of adhesion and tackiness of industrial greases. The definitions of pull-off force and tackiness are explained and measured. A first study was made on effects of measurement parameters such as retraction speed, grease film thickness, substrate roughness and counter material composition, and an evaluation of the repeatability for a range of products shows that the method can be used to put a number on the tackiness of a grease.

4:40 – 5:00 pm | Temperature dependence of Viscosity of Poly-Alpha-Olefins Sheared in a Nanometer-size Gap

Shintaro Itoh, Yuya Ota, Kenji Fukuzawa, Hedong Zhang, Nagoya University, Nagoya, Japan

Using low-viscosity lubricants is effective to reduce friction loss in automobile engines. Since a load capacity decreases by using low-viscosity lubricants, design of hydrodynamic and elastohydrodynamic lubrication must include unique characteristics of lubricants in a narrower gap width down to nanometer size. It is known mechanical properties of lubricants confined in nanometer-size gap (nano-gaps) are quite different from those in a bulk state. Typically, the viscosity enhancement and the solidification occur. However, temperature dependence of viscosity in the nano-gaps has not been clarified. In this study, we developed highly sensitive viscosity measurement method that can determine the lubricant's temperature dependence of viscosity in the nano-gaps. As a sample lubricant we used poly-alpha-olefins (PAOs), which is a synthesized oil that has high viscosity index in the bulk state. For the viscosity measurement, we used a fiber wobbling method (FWM), which we developed in our previous study. We redesigned the setup to introduce the temperature-controlling unit into the system. As a result of measurement, at 25 degree centigrade, PAOs showed viscosity enhancement when they were confined in the gap less than 20 nm. On the other hand, the enhancement of viscosity was suppressed at 50 degree centigrade. Therefore, at the nano-gaps, the viscosity reduction due to temperature increase was larger than that in the bulk state.

Session 1E } Astor Room

Biotribology

Session Chair: Kyle Schultze, University of Florida, Gainesville, FL

Session Vice Chair: Axel Moore, University of Delaware, Millsboro, DE

2:40 – 3 pm | Cell Monolayers Under Pressure: Fluid Flow in Contact

Kyle Schulze, Stephen Zehnder, Juan Urueña, Angela Pitenis, W. Gregory Sawyer, Thomas Angelini, University of Florida, Gainesville, FL

Tissue cell monolayers collective behavior like many soft matter systems is directly tied to number density fluctuations. These density fluctuations are limited to out of plane motion and volume change of the cell due to no in-plane free space for the cells to spread. It has been observed that to accommodate these changes in cell volume fluid may move between cells. The resistance to this flow has not yet been measured. An in situ method allows for directly measuring the area of contact in a local region of a cell monolayer indented under a known load. By measuring the applied load and the contact area as a function of time the permeability and compressive modulus of the cells may be determined. The cells are found to be highly permeable and capable of driving fluid from cell to cell as they fluctuate in volume.

3 – 3:20 pm | Tribological Rehydration: Directly Observing the Loss and Recovery of Interstitial Fluid

Axel Moore, Brian Graham, Christopher Price, David Burris, University of Delaware, Newark, DE

Cartilage achieves its unusual tribological properties through a unique mechanism known as interstitial lubrication. Unfortunately, periods of rest (static loading), which account for 90% of our day, cause fluid exudation and the loss of interstitial lubrication. It was recently shown that interstitial lubrication can be maintained and recovered via a novel mechanism known as tribological rehydration. Tribological rehydration is thought to be the flow of hydrodynamically pressurized bath fluid back into the articular cartilage. To visualize this process and the path of fluid flow, a custom tribometer was mounted over a confocal microscope and a cocktail of fluorescent molecules was added to the surrounding bath solution. The uptake and penetration of the fluorescent molecules was imaged in-situ for unloaded, static, and dynamic conditions. These findings demonstrate that 1) fluid is driven back into cartilage during tribological activity, 2) fluid uptake initiates at the contact edge and then migrates toward the center and 3) tribologically meaningful fluid films are unlikely to exist.

3:20 – 3:40 pm | Broadband Nature of Energy Dissipation in Articular Cartilage

Melih Eriten, Ahmet Usta, University of Wisconsin-Madison, Madison, WI

Fluid-filled matrix of collagen and proteoglycan fibers constitutes the structural backbone of articular cartilage. By the cooperative action of fluid and solid matrix, articular cartilage achieves effective load transmission and lubrication across long bones. Mechanical loading triggers fluid-solid and solid-solid interactions within cartilage, and causes broadband energy dissipation. Thanks to viscous fluid diffusion and viscoelastic matrix deformations, both poroelastic and viscoelastic relaxations contribute to the energy losses. In this work, we study the dissipative properties of porcine cartilage across multiple length and temporal scales. First, we design contact patches to induce frequency-dependent dissipation at different length scales. We show that contact patches with optimum geometry can yield rate-independent broadband damping. In the presence of those findings, we demonstrate that poroelastic materials inspired by the articular cartilage response can be tailored towards desired energy dispersal and dissipation. Moreover, we study the nature of energy losses in porcine cartilage with varying degree of collagen and proteoglycan depletion, and show that variations in solid matrix integrity can also be exploited to obtain broadband damping.

3:40 – 4 pm | Relationship of Skin Friction Characteristics with Finger Moisture

JinHwak Park, Young-Ze Lee, Minseob Kim, SKK University, Suwon, Republic of Korea

Humans have five senses emotion in visual, auditory, olfactory, gustatory, and tactile senses. However, the tactile sense is most important among other senses. Because many products touched by human skin. We studied many factors that determine the friction characteristics. Among the many human factors we focused on the moisture of the skin. Especially the effect of moisture on finger skins on the frictional behavior was investigated to find the parameters to understand the tactile sensibility. We examined moisture of experimenter skin and grouped the peoples by moisture average value. The experimenters run slides test finger on the samples. According to the results, the variation of frictional forces during sliding tests was affected by the moisture contents of the finger. Firstly, coefficient of friction are change according to moisture of the finger. And the some stick-slip have occurred was confirmed. Secondary, we confirmed two phenomenon that small coefficient of friction and soft stick-slip occurred from dry skin. Also, When we tested, analyzed the frequency of between sample roughness and human factors. So we will confirm the relationship of friction characteristics between oil and moisture.

Student Mentoring Program } Grand Ballroom

6 – 7 pm

Effective Interviewing Techniques

Ken Pelczarski, Pelichem Associates

9 – 9:40 am

Keynote Session II – Grand Ballroom

Tribo-Mechano-Chemistry: Lessons From Atomic Scale Modeling, p. 20

Professor Michael Moseler, Fraunhofer Institute for Mechanics of Materials, Freiburg, Germany

9:40 – 10:20 am

NETWORKING BREAK (Exhibits & Posters) – Grand Ballroom

	Session 2A Materials Tribology II	Session 2B Surfaces & Interfaces II	Session 2C Machine Elements & Systems I
Location	Walton South	Walton North	Georgian Room
10:20 am	Enhancing Tribological Properties of Aluminum by Graphene as an Oil Additive and Reinforcements, Emad Omrani,, p.20	Effect of Coupled Stresses on Nanoscale Interface, Gustavo Brunetto,, p. 21	Performance of Small Bore 60NiTi Hybrid Ball Bearings: Preliminary Life Test Results, Christopher DellaCorte, p. 22
10:40 am	Investigation of the Compatibility Between Anti-wear Additives and Non-ferrous Bearing Alloys, Yan Zhou, p. 20	Studying Wear at the Asperity Scale, Peter Jacobs,, p. 21	Influence of Manufacturing Processes and Related Residual Stresses on the Bearing Life Time, Gerhard Poll, p. 22
11 am	Tribological Effects of Alumina-Nanofluids on Heat-exchanger Materials: Assessment of Jet-speed and Test-time Factors, Gustavo Molina, p. 20	Micromechanical Origins of Adhesive Wear Mechanisms: From Asperity Smoothing to Debris Creation, Ramin Aghababaei, p. 21	Using Multiple Ultrasonic Echoes for Measurement of Surface Films and Coating, Rob Dwyer-Joyce, p. 22
11:20 am	Comparison of Sooty Oil Tribological Behaviours Under Different Lubrication Regimes, Lawal Abdulqadir, p. 21	Computational Investigations into Macroscale Superlubricity Enabled by Ensembles of Low-dimensional Lubricants, Subramanian Sankaranarayanan, p. 22	Gaining Insight into Wind Turbine Gearbox Bearing Failures using Ultrasonic Measurements, Thomas Howard, p. 23

	Session 2D Lubricants II	Session 2E Fluid Lubricants I	Session 2F Tribochemistry I
Location	Venetian Room	Astor Room	Superior Room
10:20 am	Overview of Fundamental Research Sponsored by the Department of Energy, Vehicle Technologies Fuels & Lubricants Programs, Michael Weismiller, p. 23	Conditions of Lift-off in Squeeze Film Levitation, Noel Brunetiere, p. 24	In-Situ Modeling of Tribochemical Reaction Pathways and Kinetics, Wilfred Tysoe, p. 25
10:40 am	Phenyl/Fluoro Siloxane Fluids with Enhanced Lubrication Properties, Manfred Jungk, p. 23	Dampening Performance of a Squeeze Film Damper in the Presence of Gaseous Cavitation, Carmen Cioc, p. 24	Tribological and Corrosion Studies of Al 20 3 and Al 20 3-TiO 2 Multilayer Thin Films Growth by Atomic Layer Deposition, Polyana Alves Radi, p. 26
11 am	Permeation of Hydrogen Into Steel Under Rolling Contact in Various Gas with Additive Free Oils, Hiroyoshi Tanaka, p. 23	Study on Air Bearing Characteristics of a New Type Inner Rotor Spindle Motor for HDD, Masayuki Ochiai, p. 25	Study of Molybdenum Dialkyldithiocarba - mate (Mo-DTC) Friction Reduction and Wear Resistance by Structure-Oriented Lumping (SOL) Method, Chao Zhang, p. 26
11:20 am	Prediction of the Frictional Properties of Halogen-free Ionic liquids in Elastohydro - dynamic Contacts, Patricia Iglesias Victoria, p. 24	Spiral Groove Face Seals Behaviour in Liquid Lubricated Applications, Mathieu Rouillon, p. 25	
11:40 am	Study of Potential of Waste Cooking Oils as Bio Based Lubricant, Dedison Gasni, p. 24	Cavitation Algorithms for Tangential Slip/no-slip Boundary Conditions, Guy Bayada, p. 25	Ab Initio Investigation of Tribochemistry Mechanisms in Solid and Boundary Lubrication, M. Clelia Righi, p. 26
Noon	Lunch On Your Own	Lunch On Your Own	Lunch On Your Own

1:20 – 2 pm

Keynote Session III – Grand Ballroom

AFM and TEM Studies of Friction and Wear in Pt-Graphene and Pt-SiO2 Systems, p. 26

Miquel Salmeron, Lawrence Berkeley National Laboratory, Berkeley, CA

TIME	Session 3A Materials Tribology III	Session 3B Surfaces & Interfaces III	Session 3C Machine Elements & Systems II
Location	Walton North	Walton South	Georgian Room
2 pm	Highly Effective Wear Resistance Capability of Various Carbon Nanofillers in PTFE Not Transported to FEP Matrices, Thierry Blanchet, p. 27	Molecular Mechanisms of Lubrication, Roland Bennewitz, p. 28	Experiments and Simulations of Polymer-Basestock Solutions for Hydraulic Applications, Paul Michael, p. 31
2:20 pm	Elastomer vs. Ceramic in Cyclically Loaded Contact: What Wears Less?, Michael Varenberg, p. 27	Tribochemical Reactions of Adsorbed Organic Molecules and Formation of Highly-efficient Polymeric Lubricant Films at Sliding Solid Interfaces: Part 1 – Experiment Study, Xin He, p. 28	Formulation and Validation of a Mixed-TEHD Model for the Lateral Lubricating Interfaces in External Gear Machines, Divya Thiagarajan, p. 31
2:40 pm	Humidity Dependence of Atomic-scale Friction Between Nanoasperities and Graphite, Zhijiang Ye, p. 27	Tribochemical Reactions of Adsorbed Organic Molecules and Formation of Highly-efficient Polymeric Lubricant Films at Sliding Solid Interfaces: Part 2 – Computational Study, Jejoon Yeon, p. 29	Improvement of Scuffing Load Capacity of Gears by Running-in – Top or Flop?, Thomas Lohner, p. 31
3 pm	Break	Break	Break
3:40 pm	Strain Hardening: Can It Affect Abrasion Resistance?, Wilian Labiapari, p. 27	Molecular Dynamics Investigation of the Friction Reduction Mechanisms of Carbon Nanoparticles Confined Between Iron Surfaces, James Ewen, p. 29	Self-lubricating Ni-based Laser Hardfacings For High Temperature Sliding Contacts, Hector Torres, p. 31
4 pm	Identification of Strain-stress History Leading to Tribological Transformed Micro-structure: Use of High Pressure Torsion Modeling, Aymen Ben Kaabar, p. 28	Effect of Core-shell Chemistry of Metal Nanoparticles on Achieving the Superlubricity at Macroscale in Graphene-Nanoparticle System, Diana Berman, p. 29	Reciprocating Seal Friction: Transition From Dry Regime to Full Film Lubrication, Matthias Wangenheim, p. 32
4:20 pm	Compositions and Hardness Values, Meisam Nouri, p. 28	Understanding the Behavior of Ionic Liquids at Carbonaceous Surfaces, Rosa Espinosa-Marzal, p. 29	
4:40 pm		Stress-promoted Thermal Activation in Tribology, Hugh Spikes, p. 30	
5 pm		Measurements of Liquid-Mediated Adhesion between Contacting Rough Surfaces, Amir Rostami, p. 30	
5:20 pm		Contrast Mechanisms on Nanoscale Subsurface Imaging in Ultrasonic-AFM, Philip Egberts, p. 30	
5:40 pm		In-situ Generation of W-S Tribofilms Using Functionalized Surfaces and Green Additives, Manel Rodriguez Ripoll, p. 30	

TIME	Session 3D Lubricants III	Session 3E Fluid Lubricants II: Rheology & EHL	Session 3F Tribochemistry II
Location	**Venetian Room**	**Astor Room**	**Superior Room**
2 pm	Catalytic Antioxidants – Novel Substituted N,N'-Diarylphenylenediamine Derivatives as Potential Lubricant Additives, Abhimanyu Patil, p. 32	Dynamics and Thermodynamics of Lubricants in Flow: A Molecular and Tribological Approach, Yingying Guo, p. 34	Challenges in Advancing Slideway Lubrication Technology, David Racke, p. 37
2:20 pm	On the Flow of Lubricating Greases: A Computational Fluid Dynamics Approach, Lars Westerberg, p. 32	Refrigerants as ILubricants: From Molecular Dynamics Characterization to the Applicability at the Contact Scale, Stéphane Tromp, p. 34	Influence of Organic Sulfate and Phosphate Additives on Tribochemical Decomposition of Hydrocarbon Oil on Nascent Steel Surfaces, Yoshinori Fukushima, p. 37
2:40 pm	Phosphonium-Based Ionic Liquids as Additives of Mineral Oils in Steel-Steel Contacts, Patricia Iglesias Victoria, p. 33	Disjoining Pressure and Diffusion Equation for Submonolayer Liquid Film, Kyosuke Ono, p. 35	Effect of Hydrogen and Oxygen Partial Pressure on the Tribochemistry of Silicon Oxide-containing Hydrogenated Amorphous Carbon, Filippo Mangolini, p. 37
3 pm	**Break**	**Break**	**Break**
3:40 pm	Novel Borate Ester Additives with Superior Tribological Performance, Giovanni Ramirez, p. 33	Experimental Observation of Lubricant Flow in EHL Contacts Under High Sliding Conditions, Milan Omasta, p. 35	Investigation of Adsorption Kinetics and Nanoscale Tribological Properties of Fatty Amines as Organic Friction Modifiers in Engine Lubrication, Prathima Nalam, p. 38
4 pm	Tribological Performance of Functionalized Nanoparticles in Oils and Mechanism of Tribofilm Formation Under Boundary Lubrication, Vinay Sharma, p. 33	Surface Roughness Effects on a Border of Mixed Rolling-sliding EHL Contact, Petr Sperka, p. 35	Growth Observation of ZnDTP Tribofilms on Different Nitrided Surface Layers and Evaluation of Their Antiwear Performances, Saiko Aoki, p. 38
4:20 pm	Influence of Contact Conditions on the Interaction Between MoS2 Nanotubes and Oil Additive, Manel Rodriguez Ripoll, p. 33	Lubricant Film Thickness in Compliant Contacts Using Optical Interferometry, Hugh Spikes, p. 35	Tribo and Tribocorrosion Studies on Low Hydrogenated DLC Films Deposited on Ti6Al4V Using PECVD-DC Pulsed with Additional Cathode System, Polyana Alves Radi, p. 38
4:40 pm	Tribological Properties of Metalworking Fluids with Halloysite Clay Nanotube Additives, Laura Peña Parás, p. 34	A Fully-Coupled Finite Element Model for the Solution of Thermal Elastohydrody - namic Lubrication Problems, Wassim Habchi, p. 35	Studying the Tribocorrosion Behavior of Duplex Stainless Steels in Chloride Media Using Spatially Resolved Friction and Electrochemical Measurement, J. Michael Shockley, p. 38
5 pm	The Tribological Characteristics of Brass Lubricated with Oil-Based ZnO Nanofluid, Chuanlin Tao, p. 34	Heavily Loaded Point EHL Contacts for Functionally Graded Elastic Materials. Part 1: Dry Contacts, Ilya Kudish, p. 36	
5:20 pm		Heavily Loaded Point EHL Contacts for Functionally Graded Elastic Materials. Part 2: Lubricated Contacts, Ilya Kudish, p. 36	
5:40 pm		Transient Elastohydrodynamic Analysis of Line Contact Under Load and Speed Impulse, Shriniwas Chippa, p. 36	

Keynote Session II } Grand Ballroom

9 – 9:40 am | Tribo-Mechano-Chemistry: Lessons From Atomic Scale Modeling

Professor Michael Moseler, Fraunhofer Institute for Mechanics of Materials, Freiburg, Germany

Elevated stresses and shear rates in the buried interface between two sliding bodies drive chemical reactions and the formation of exotic phases that are not accessible by conventional thermo-chemistry. The resulting tribomaterials are essential for the function of tribological systems in academia and industrial applications. Experimental studies of tribomaterials are still restricted to an ex-situ characterisation by highly resolved TEM and spectroscopic techniques allowing only for speculations about the underlying processes. This contribution will present examples for a complementary approach that employs atomic scale models and simulations to elucidate the mechano-chemistry in sliding contacts and mechanisms that govern the formation of tribomaterials in metals, ceramics and carbon hard coatings. For some cases the impact of the tribomaterial on friction and wear will be discussed.

9:40 – 10:20 am • Break • Grand Ballroom

Session 2A } Walton South

Materials Tribology II

Session Chair: Harman Khare, University of Pennsylvania, Philadelphia, PA

10:20 – 10:40 am | Enhancing Tribological Properties of Aluminum by Graphene as an Oil Additive and Reinforcements

Emad Omrani, UW-Milwaukee, Milwaukee, WI, Pradeep Menezes, University of Nevada Reno, Reno, NV, Pradeep Rohatgi, UW-Milwaukee, Milwaukee, WI

Embedding graphene into metal matrices and oil can improve the tribological properties. In the present investigation, The tribological behavior of the graphene as additive in oil were investigated with a pin-on-disk tribometer. Besides, aluminum matrix nanocomposites reinforced by graphene nanoplatelets were synthesized by powder metallurgy method and tested by pin-on-disk tribometer. The wear surfaces of the aluminum pins lubricated with the additive-containing oil were analyzed by scanning electron microscopy (SEM). The worn surface of self-lubricating aluminium nanocomposites were examined by SEM. The test parameters for both experiments were the same to compare the results and find which way is more effective to enhance the tribological properties. It was found that the graphene nanoplatelets reinforced nano-composites showed superior tribological properties and demonstrated the ability of the self-lubricating nature of the composite during tribological conditions. In addition, It has been found that the graphene as additive in oil show lower coefficient of friction and wear rate tribological properties than neat canola oil. Moreover, the worn surface of pins are more smother in presence of graphene rather than in absence of graphene as reinforcements or oil additive.

10:40 – 11 am | Investigation of the Compatibility Between Anti-wear Additives and Non-ferrous Bearing Alloys

Yan Zhou, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

The compatibility between oil-soluble ionic liquids (ILs) and non-ferrous bearing alloys has been investigated. We report here the results of lubricating bronze and aluminum bearing alloys by using a conventional secondary ZDDP and newly developed ILs additized SAE 0W-30 base oil. Linearly reciprocating ball-on-flat sliding tests using an AISI 52100 steel ball against the alloy flats were performed at various conditions. The addition of AW additives reduced the occurrence of scuffing and resulted in smoother worn surfaces. At room temperature and 800 ppm phosphorous content, the addition of IL and ZDDP reduced the wear rates on bronze by 75% and 85%, respectively. Comprehensive surface characterization from top and cross-section surfaces is being conducted to reveal nanostructures and compositions of the tribo-films formed on the steel balls and alloy flats to allow the development of a mechanistic understanding. This research was sponsored by the Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, US Department of Energy (DOE).

11 – 11:20 am | Tribological Effects of Alumina-Nanofluids on Heat-exchanger Materials: Assessment of Jet-speed and Test-time Factors

Gustavo Molina, Fnu Aktaruzzaman, Valentin Soloiu, Mosfequr Rahman, Georgia Southern University, Statesboro, GA

Nanofluids are alternative to traditional cooling fluids in heat-exchangers because of their enhanced thermal properties. The authors investigated nanofluid-led tribological effects on heat-exchanger materials with accelerated jet-impingement tests for jet-speeds in the range of 3.5 m/s to 15.5 m/s. Experimental research is discussed when typical nanofluids (2%-volume alumina-nanopowder in water, and in 50/50 ethylene glycol/water) are impinged on aluminum and copper, from which three factors seem to be relevant to the underlying surface-process modifications: jet speed, test time, and the surface material and fluid (i.e., nanofluid) system. This study provides a valuable insight for further systematic research and development in this new field of tribology.

11:20 – 11:40 am | Comparison of Sooty Oil Tribological Behaviours Under Different Lubrication Regimes

Lawal Abdulqadir, Roger Lewis, Tom Slatter, The University of Sheffield, Sheffield, South Yorkshire, United Kingdom

Diesel soot contaminant is an inevitable by-product of the combustion process and majorly responsible for wear of automotive tribological components by infiltrating into contacts between rubbing surfaces. The effects of different blends of fully formulated engine oil (HX5 SAE15W-40) with carbon black (0-10%) as a soot surrogate on viscosity, friction, and wear of materials under different lubrication regimes were investigated. HFRR (Plint TE77) and MTM Twin disc (Plint TE54) were used to generate ball-on-flat and disc-on-disc sliding frictions respectively. The viscosity of the sooty oils was initially determined along with the theoretical calculations of the film thickness and contact pressure. These assisted in predicting the lubrication regimes under which the proposed tests were to be carried out and the expected behaviour of each composition of the blends. A series of a posteriori wear measurements revealed that each carbon black composition presents its own peculiar wear profile and wear mechanism, based on the lubrication condition under which it operates.

Session 2B } Walton North

Surfaces & Interfaces II

Session Chair: Diana Berman, Argonne National Laboratory, Argonne, IL

10:20 – 10:40 am | Effect of Coupled Stresses on Nanoscale Interface

Gustavo Brunetto, Vishal Zade, Min Lee, Ashlie Martini, University of California Merced, Merced, CA

With the miniaturization of electronic and mechanic components, nanoscale contacts between materials have become a critical part of component function. It is therefore also important to understand how a nanoscale interface between materials responds due to external stimuli. In this work, we carried out atomistic simulations to understand how coupled stresses can affect nanoscale contacts. We modeled a gold atomic force microscope tip indenting a graphite substrate, where the simulation was designed to reproduce key features of a corresponding experiment. The experiments provided indirect measurements of contact properties from trends in electrical resistance. The simulations enable us to investigate the origins of those trends in terms of contact size, atomic structure in the interface, and the mechanical response of the near-contact materials. Understanding the way stresses couple to affect the nanoscale contacts can be important for enabling design of new multifunctional devices that will operate under a wide range of operating conditions.

10:40 – 11 am | Studying Wear at the Asperity Scale

Peter Jacobs, Fang Cao, Gary Hunter, Andrew Konicek, Alan Schilowitz, Martin Webster, ExxonMobil Corporate Strategic Research, Annandale, NJ

Tribological studies of lubricated machine contacts have long been limited to gathering information that is averaged over the length of the sliding contact and intermittently over the total time of the test. However, the fundamental processes that control friction and wear occur on asperity length scales and often vary in both degree and character over the time of a test. This has made it difficult to obtain a fundamental understanding of the chemical and mechanical processes that underlie friction and wear. Analytical techniques such as AFM, Auger spectroscopy, nanoindentation allow access to high spatial resolution information of surfaces about topography, chemical composition & mechanical properties, respectively. These techniques have been combined to investigate the initial phases of asperity scale tribofilm formation in tests with model lubricants. Findings point to the importance of local stresses & plasticity in the activation of some traditional anti-wear additives. For example, the sulfidation of iron metal in the presence of the anti-wear additive zinc dialkyldithiophosphate was observed over a range of local mechanical conditions, while the formation of a phosphate glass was only observed in locations where sufficient deformation had occurred to reduce the local stress. Phosphate-based films formation was observed under conditions of high local stress in the presence of tricresylphosphate, which contains no sulfur.

11 – 11:20 am | Micromechanical Origins of Adhesive Wear Mechanisms: From Asperity Smoothing to Debris Creation

Ramin Aghababaei, Jean-François Molinari, École polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland

The adhesive wear process consists of several physical phenomena including plasticity and fracture which occur at different length and time scales. Despite the critical importance of the adhesive wear process in engineering applications, it is still described via classical, yet fully empirical, models since the microscopic principles have not been yet understood. Using novel coarse-grained atomistic simulations, we capture for the first time sustained debris formation during the adhesive collision between surface asperities. A systematic set of atomistic simulations reveals a characteristic length scale that controls the adhesive wear mechanisms (i.e. asperity smoothing versus debris formation) at the asperity level. This length scale provides a critical adhesive junction size. Larger junctions produce wear debris by fracture while smaller ones smooth out plastically. This finding explains why wear debris has not been observed in previous atomistic simulations of adhesive wear, where the junction is too small and/or weak to form debris by fracture. Based on this observation, we formulate a simple analytical model that predicts the transition in the asperity-level adhesive wear mechanisms for simulation results and reported atomic force microscope (AFM) wear experiments. We discuss how the proposed framework opens up a new research path to explicitly model and explore wear processes and revisit classical models.

11:20 – 11:40 am | Computational Investigations into Macroscale Superlubricity Enabled by Ensembles of Low-dimensional Lubricants

Subramanian Sankaranarayanan, Sanket Deshmukh, Badri Narayanan, Diana Berman, Anirudha Sumant, Ali Erdemir, Argonne National Laboratory, Argonne, IL

The power of modern supercomputers together with the availability of highly scalable atomistic simulation codes have revolutionized modeling and computational analysis of materials. An enticing illustration comes from our recent work where large-scale molecular dynamics (MD) simulations performed on Argonne's supercomputer Mira closely coupled with experimentation led to a breakthrough in the field of tribology. An elusive phenomenon i.e. "Macroscale superlubricity" was shown to originate from an intriguing nanomechanical phenomenon: graphene patches wrap around nm sized diamond particles to form nanoscrolls that have significantly reduced contact area to an underlying surface. Atomistic simulations elucidated the overall mechanism and explained the mesoscopic link between the nanoscale mechanics and macroscale experimental observations. Given our recent success with nano-lubricants, we focus on accurately capturing ensemble effects across tribological interfaces using some representative lubricant materials (2-D materials, nanoparticles) and their combinations for different types of environments and operating conditions. This talk includes brief discussion on our efforts towards development of a new force fields to enable high-fidelity large scale dynamical simulations of tribo-interfaces, properties and functionalities of new lubricants, as well as pathways and mechanisms of their *in operando* synthesis and assembly.

2C } Georgian Room

Machine Elements & Systems I

Session Chair: Aaron Greco, Argonne National Laboratory, Argonne, IL

Session Vice Chair: Benjamin Gould, University of Delaware, Wilmington, DE

10:20 – 10:40 am | Performance of Small Bore 60NiTi Hybrid Ball Bearings: Preliminary Life Test Results

Christopher DellaCorte, Samuel Howard, NASA, Cleveland, OH

Small bore (R8 size) hybrid ball bearings made with 60NiTi races and silicon nitride balls are under development for highly corrosive aerospace applications that are also exposed to substantial static (shock) loads. The target application is the vacuum pump that is part of the wastewater recycling system on the International Space Station. To verify bearing longevity, life tests are run at 2000rpm for time periods up to 5000 hours. Throughout the tests, accelero - meters with data tracking monitors the operation of the bearings, which are removed, disassembled and inspected at intervals to assess ball, cage and race wear. Preliminary test results show that bearings made from 60NiTi are feasible for this aerospace application and potentially other industrial applications that must endure similar operating environments.

10:40 – 11 am | Influence of Manufacturing Processes and Related Residual Stresses on the Bearing Life Time

Gerhard Poll, Leibniz Universität Hannover, Hanover, Germany, Berend Denkena, Oliver Maiss, Leibniz Universität Hannover, Garbsen, Germany, Timo Neubauer, Florian Pape, Leibniz Universität Hannover, Hanover, Germany

Resource-efficient machine elements are in the focus of current research. One of the most widely used machine elements are rolling element bearings. Thus, the optimization of bearings and their tribological properties promises to result in significant resource savings. To do so, compressive residual stresses in the subsurface region of bearings raceways can be applied. The residual stresses in subsurface regions of a few hundred microns depth affect the fatigue life of bearings. On the one hand these stresses can be induced by initial overloading during a small number of revolutions. On the other hand these stresses can be achieved within the manufacturing process. In this work the maximum compressive stresses were extended to higher values and depths with a deep rolling process after hard turning. To investigate the benefit of the increased stresses bearing fatigue life tests were carried out applying a 4-bearing endurance test bench. This test rig allows testing four equal roller bearings of type NU206 at the same time. Before and after the tests the residual stresses were measured using X-ray diffraction technique. Additionally, a calculation model was developed]. For this, a 3D-FE model is used to calculate the three dimensional stress field by superimposition of residual and load stresses. The experimental bearing fatigue life tests as well as the calculation model show a significant increasing in bearing fatigue life.

11 – 11:20 am | Using Multiple Ultrasonic Echoes for Measurement of Surface Films and Coating

Rob Dwyer-Joyce, Robin Mills, University of Sheffield, Sheffield, United Kingdom

Ultrasonic NDT and its application to the measurement of oil films and contacts is usually carried out with short duration pulses of ultrasound. The individual pulses are reflected back from an oil film or contact region. The amplitude of the signal is processed to determine the contact stiffness and hence oil film thickness. A novel approach, described here, is to use a continuous wave of ultrasound and send this into the machine component. The wave reflects back and forth inside the component, reflecting at the tribological contact each time, and superimposing to form a kind of standing wave. In this way the effect of the interface is massively magnified. The nature of the superimposed standing wave (its resonances and amplitudes) is then highly dependent on what happens at the contact interface. This new approach has some important advantages; firstly the equipment to generate such waves is much cheaper and simpler. Secondly the response time is much faster, because it is not necessary to wait for individual pulses. And thirdly, the sensitivity to the surface is much greater. This means it is possible for the first time to measure free surface films (such as oil layers, coatings, or paints) as they grow or reduce. The method is demonstrated and evaluated on a number of such films under lab conditions.

11:20 – 11:40 am | Gaining Insight into Wind Turbine Gearbox Bearing Failures using Ultrasonic Measurements

Thomas Howard, R Dwyer-Joyce, M Marshall, The University of Sheffield, UK, Sheffield, United Kingdom

Poor reliability of wind turbine drivetrain bearings currently results in gearbox failures well in advance of the typical 20-year turbine design life. The loads and operational regimes that bearings must withstand are not currently well understood, therefore any insight into bearing operation could aid considerably in enhancing reliability and improving bearing specification in the design phase for future systems. The ultrasound technique is discussed as a means to provide such insight. This has been proven in recent years as a successful way to measure the oil film thickness in rolling element bearings, and is explored in this work as a potential on-line wind turbine bearing monitoring tool. Accelerated life tests have been performed on a bespoke wind turbine gearbox bearing test rig and ultrasonic trends have been identified that could be directly linked to oil film breakdown at the initial stages of a rolling surface failure. Further patterns were also observed within the ultrasonic measurements which offer additional insight into the tribological interactions occurring within the bearing. The ability to detect lubricant starvation at a local raceway point is illustrated, as well as features that could enable precise assessment of Hertzian contact width, thus allowing contact load to be inferred. Finally, more recent work is presented illustrating implementation of the technique to an operational wind turbine, thus demonstrating viability of such measurements in the field.

Session 2D } Venetian Room

Lubricants II

Session Chair: Philippe Vergne, LaMCoS, Villeurbanne, France, Fanny Briand, Total, Solaize, France

10:20 – 10:40 am | Overview of Fundamental Research Sponsored by the Department of Energy, Vehicle Technologies Fuels & Lubricants Programs

Michael Weismiller, Kevin Stork, U.S. Department of Energy, Washington, DC, Ewa Bardasz, Energetics, Inc, Columbia, MD

Over last decade the DOE Vehicle Technologies Program had created multiple research thrusts aimed at understanding improvements in light duty vehicle andheavy duty truck total fuel consumption efficiency, reductions in exhaust emissions and at developing sources of gaseous, liquid and electricity based alternate fuelsto reduce the consumption of petroleum derived fuels. Since lubricants' technologies can provide a vital role in reducing friction losses, increasing vehicle and engine life, and in preserving emissions performance, current DOE lubricants' technologies program supports multidisciplineresearch in new base fluids, additives,performance testing,modeling fundamental rheology/lubrication knowledge and creating correlation methods. Colaborative projects are conducted at national laboratories, universities, and private industry through direct funding and through competitive solicitations.KevThis presentation will describe the overall research portfolio and also discuss data collected inselected projects. Topics will include performance ofionic liquids, nano-additives, functionalized polymers for friction and wear reduction, impact of lubricant on ICE combustion, and correlations between the laboratory testing and real life performance.

10:40 – 11 am | Phenyl/Fluoro Siloxane Fluids with Enhanced Lubrication Properties

Manfred Jungk, Dow Corning GmbH, Wiesbaden, Germany

Silicone fluids are known to have high Viscosity Indices (VI), and high Oxidation Onset Temperatures (OOT). Silicone VI and OOT characteristics make these fluids appealing for use as lubricants in high temperature applications, and where lubricant longevity is desired. Despite thermal and oxidative benefits, silicone lubricants have a reputation as being poor lubricants in metal-to-metal applications, and are typically only selected for use in plastic applications. Most industrial knowledge about silicone lubricants is based on characteristics of PolyDiMethyl Siloxanes (PDMS), in which case, lubricity limitations do exists. However, there are other silicone based lubricating fluid technologies like Phenyl-Methyl Silicones (PMS) and Fluoro Silicones (FS) that have been commercially available for decades. As one outcome of a recent study a new copolymer of polyalkylphenyl siloxanes and alkylfluoroalkyl siloxanes with good lubrication properties has been developed. Other properties such as viscosity or temperature resistance of these new copolymers can be adjusted by varying the ratio of polyalkylphenyl siloxanes and alkylfluoralkyl siloxanes. The new copolymers [6] are also receptive to additives and can be used for preparing lubricating greases. This paper will discuss and compare different silicone-based fluids, as well as some comparison to polyalphaolefins, perfluoropolyethers, and other common synthetic lubricant technologies.

11 – 11:20 am | Permeation of Hydrogen Into Steel Under Rolling Contact in Various Gas with Additive Free Oils

Hiroyoshi Tanaka, Kyushu University, Fukuoka, Japan, Joichi Sugimura, Kyushu University, Fukuoka, Fukuoka, Japan

This study is on hydrogen permeation into bearing steel under rolling contact. Rolling contact tests were conducted under oil lubrication in air, nitrogen and hydrogen. Mineral oil, PAO(poly-alpha-olefin), POE(Polyol ester), PAG(Polyalkylene glycol) without additives are used as lubricants. Thermal Desorption Spectrometry, TDS, was performed to measure the amount of permeated hydrogen just after rolling contact tests. TDS analysis showed that hydrogen permeated into steel even under air. The amount of permeated hydrogen in steel increased with decrease in lubrication film thickness. The amount of hydrogen tested in nitrogen was greater than in air. These results suggested that basestock decomposed on the rolling contact surface and produced hydrogen. Longer duration of rolling test promoted surface oxidation in air and prevented the hydrogen permeation.

11:20 – 11:40 am | Prediction of the Frictional Properties of Halogen-free Ionic liquids in Elastohydrodynamic Contacts

Patricia Iglesias Victoria, Brandon Powell, Karthik Janardhanan, Edward Cigno, Rochester Institute of Technology, Rochester, NY

Ionic Liquids have emerged as effective lubricants and additives to lubricants. Halogen-free ionic liquids are now being looked at as they are far more environmentally stable than their halogenated counterparts. In order to understand the exact behavior of these lubricants, a suitable friction model has to be identified. In the present study, the behavior of two phosphonium-based, halogen-free ionic liquids are studied as additives to a Polyalphaolefin (PAO) base oil in steel-steel contacts. A blend of 0.5 and 2.5 wt. % of ionic liquid in the PAO is studied using a ball-on-flat reciprocating tribometer and the results are compared to an existing elastohydrodynamic friction model (Carreau's Model). The results show that the model tends to be accurate for lower concentrations of ionic liquids.

11:40 – Noon | Study of Potential of Waste Cooking Oils as Bio Based Lubricant

Dedison Gasni, Andalas University, Indonesia, Padang, West Sumatra, Indonesia, Ismet Hari Mulyadi, Jon Affi, M. Harry Rafsanjani, Andalas University, Padang, West Sumatra, Indonesia

Waste cooking oil is produced daily in immense volume by household, restaurant, and food industries. After it cannot be used anymore, most of them will be disposed and dumped on the ground. Although, it is not a hazardous material but it still has possibility to destruct the environment such as by affecting the health of the waterways. The recycle of this oil has been suggested to reduce the environmental burden. By recyling, the financial benefit would be extended. One of recyling method is by the use of waste cooking oil as biodiesel. it has been proofed to gain positive advantages. However, researchs utilizing waste cooking oil as lubricant are still limited. Therefore, in this study, the potential of waste cooking oil as lubricant would be investigated. The investigation focused on physical (i.e. viscosity and viscosity index) and tribological (i.e. wear and cooficient of friction) properties of waste cooking oil from palm and coconut oils produced in Indonesia. The coconut oils used were extracted from dry and wet processing (i.e. HCO and RCO). The results indicate that waste cooking oils from extracted coconut oils have positive figure in term of physical properties while tribological properties of palm oil posses benefit as bio-based lubricant source.

Session 2E } Astor Room

Fluid Lubrication I: Squeeze Film, Cavitation & Gaseous Lubrication

Session Chair: Wassim Habchi, Lebanese American University, Byblos, Lebanon

Session Vice Chair: Petr Sperka, Brno University of Technology, Brno, Czech Republic

10:20 am – 10:40 am | Conditions of Lift-off in Squeeze Film Levitation

Noel Brunetiere, Antoinette Blouin, Institut Pprime – CNRS, Futursocope Chasseneuil cedex, France

When an air film is squeezed between two solid surfaces with one of them vibrating, it is possible to generate a positive net pressure in this film. If the resulting net force is high enough, this process can be used to levitate a solid and move it without friction. The lift-off condition is controlled by the vibration amplitude and frequency but also depends on the mass of the solid and the contact area. If the oscillation magnitude and frequency are too small the solid will stay in contact with the vibrating plate. In this work an experimental test rig is used to analyse the lift-off condition. It is composed of vibrating flat linked to a piezo actuator, a cylindrical mass and two displacement sensors. The frequency and magnitude of oscillation are varied as well as the mass of the solid to identify the lift-off conditions. The experimental results are compared to numerical simulations. The model solves the transient compressible equation coupled with the Newton's law for the levitated mass. The model is then used to extend the experimental results to other operating conditions. An analytical solution is also proposed to have a simple description of the lift-off condition in squeeze film levitation.

10:40 am – 11 am | Dampening Performance of a Squeeze Film Damper in the Presence of Gaseous Cavitation

Carmen Cioc, Sorin Cioc, Christopher Deszell, University of Toledo, Toledo, OH

The performance of squeeze film dampers and liquid film bearings can be affected by the occurrence of cavitation. The compressibility of the liquid-gas mixture alters the pressure distribution and the velocity field inside the fluid film, which negatively impact the load capacity, stiffness, and damping characteristics of the fluid film. This paper presents the study of the impact of gaseous cavitation on the damping performance of a squeeze film damper. The quasi-periodic pressure change inside the fluid film is extracted when the squeeze film damper moves over a prescribed, measured trajectory. The pressure is measured as a function of time at two axial locations along the bearing. A theoretical model of the quasi-periodic pressure distribution inside the bearing is developed and uses these measurements to yield the force components acting on the bearing. Finally, combining the resulting force components with the imposed bearing motion, the damping performance is determined in terms of energy extracted from the bearing motion in time. The study is performed without cavitation and with various amounts of volumetric cavitation

levels for two different ratios of bearing length to diameter. The results are quantified as function of the volumetric gas ratio, whirl speed, and amplitude. In addition, the dynamics of the pressure developed inside the fluid film is correlated to the visually observed progress of the cavitation regions during the bearing whirl.

11 am – 11:20 am | Study on Air Bearing Characteristics of a New Type Inner Rotor Spindle Motor for HDD

Masayuki Ochiai, Hiromu Hashimoto, Tokai University, Hiratsuka-shi, Japan

Recently, amount of information is increasing every year all over the world. Therefore, the data centers which can manage information are increasing. Hard disk drives are used in the data centers because of their reasonability and high recording density. On the other hand, electric consumption has been increased with increasing data center amount. Therefore, the new structure of a spindle motor applied air bearing is proposed in this study. As new structure of the spindle motor, inner rotor is applied instead of outer rotor. The new spindle is expected to improve the characteristics of the air bearing. In this paper, the static and dynamic characteristics of the air bearing which is mounted new structural spindle motor was analyzed. As a result, the air bearing friction torque is lower than an conventional oil bearing one. In addition, angular stiffness of air bearing is larger than oil bearing.

11:20 am – 11:40 am | Spiral Groove Face Seals Behaviour in Liquid Lubricated Applications

Mathieu Rouillon, Institut Pprime, Chasseneuil Futuroscope Cedex, France, Noel Brunetiere, Institut Pprime – CNRS, Futursocope Chasseneuil cedex, France

Spiral groove face seals are usually used to seal gas in turbomachine applications. This type of sealing is suitable for generating a hydrodynamic lift allowing the formation of a gas film between the seal faces thanks to the grooves. This seal can thus operate with low friction. This study focuses on spiral groove gas face seals performance in water applications. The friction torque, the fluid pressure, temperatures through the gap, the flow rate (leakage), the axial displacement of the faces and the rotation speed of the rotor are measured. Fluid temperatures and pressure ranging from 40°C to 95°C and from 1 to 5 MPa have been tested. The rotation speed was varied from 2000rpm to 6000rpm. This wide operating range allows testing the seal in several lubrication regimes: mixed, hydrodynamic and turbulent lubrication as well as liquid and two-phase flow. Dimensionless friction torque, flow rate and temperature have been investigated and clearly highlight the transition between the different lubrication regimes. Results show dependencies between friction factor and G parameter. Hydro - dynamic regime is reached except for high pressure and low speed values. Moreover, a change of behaviour is noticed at high Reynolds number: friction torque increases while a decrease of the leakage is observed. This is typical of turbulent flow regime. Two-phase flow regime is also reached for particular configuration corresponding to high supplied fluid temperature (95°C).

11:40 am – Noon | Cavitation Algorithms for Tangential Slip/no-slip Boundary Conditions

Guy Bayada, Insa, Villeurbanne Cedex, France

The possibility of a slippage between the surface and the layer of a liquid next to it has been observed. Such Slip/no slip effects are often described by way of a non linear relation between the tangential shear stress and the velocity of the fluid near the solid surface. Advantages in terms of Load/friction of using heteregeneous surfaces including adjacent slip regions and no slip regions has been recognized., In this case, the overall effect is similar as the one produced by some surface texture in a no-slip contact. Consequently, cavitation may occured, even for devices made of parallel or even converging surfaces. As it is well known, it is then important to use a mass converging algorithm to correctly describe the cavitation effects. Other cavitation models as Half-Sommerfeld and and Reynolds models (based on Christopherson algorithms)can give false overall performances . Such algorithms are proposed here. The first one is dedicaced to for the solution of the 1-D Reynolds equation (infinite long devices). Based on a specific variational formulation, It allows a near analytical solution of the problem, incuding heterogeneous properties of both surfaces. The second one is available for both 1D/2D Reynolds equation, including both shear limiting models and a combination of shear limited/Navier models.This is illustrated by some 1D/2D numerical examples for slider and journal bearings.

Session 2F } Superior Room

Tribochemistry I

Session Chair: Yemi Oyeride, Chevron Phillips Chemical Co. Houston, TX

10:20 – 10:40 am | In-Situ Modeling of Tribochemical Reaction Pathways and Kinetics

Wilfred Tysoe, Heather Adams, UW-Milwaukee, Milwaukee, WI, Ashlie Martini, University of California Merced, Merced, CA

The most difficult surface-science challenge is to monitor reaction pathways and kinetics at sliding solid-solid interfaces, in particular for opaque materials. Optical techniques can be used to interrogate the interface when one of the contacting surfaces is transparent, but they are often not sensitive to the first monolayer. Strategies for measuring reaction pathways and their kinetics for well-defined surfaces in ultrahigh vacuum (UHV) are described using the example of sliding-induced decomposition of adsorbed methyl thiolate species, formed by exposure to dimethyl disulfide (DMDS), on copper. Methyl thiolates are stable up to ~425 K on copper, but decompose during rubbing; the effect of the external force is to lower the reaction activation barrier so that it proceeds at room temperature. The surface reaction products can be monitored immediately after sliding in UHV using surface spectroscopies (for example, Auger spectroscopy). However, the reaction kinetics can be monitored in situ first, by measuring the gas-phase species evolved as a function of the number of times the surface is rubbed, where methane and ethane are detected and second, by measuring the change in friction force due to the evolution of the nature of the species present on the surface. The elementary-step kinetics are then used to model the gas-phase lubrication of copper surfaces by DMDS to reveal how the nature of the interface evolves during a tribochemical reaction.

10:40 – 11 am | Tribological and Corrosion Studies of Al_2O_3 and Al_2O_3-TiO_2 Multilayer Thin Films Growth by Atomic Layer Deposition

Polyana Alves Radi, Giorgio Ernesto Testoni, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil, Angela Vieira, Rodrigo Sávio Pessoa, Homero Santiago Maciel, Lucia Vieira, Universidade do Vale do Paraiba-UNIVAP, Sao Jose dos Campos, Sao Paulo, Brazil

Metals and their alloys are very important for orthopedic applications, and the basic requirements for sucessful application of an implant are: chemical stability, mechanical behavior, and biocompatibility in body fluids and tissues [1,2]. For prosthesis application, the corrosion resistance of metals is one of the major prerequisites to avoid impairment of the material properties due to degradation [3]. Ti-6Al-4V has long been a main medical titanium alloy. However, for permanent implant applications the alloy has a possible toxic effect due to released vanadium and aluminum [3]. Multilayer coatings of alternatively ordered thin films of transition metal oxides with nanoscale thickness are known to have properties superior than that of a single film [4]. Atomic layer deposition (ALD) is an interesting method for the fabrication of thin sealing coatings for corrosion protection and TiO_2 and Al_2O_3 films have also been applied on PVD coatings to block pinholes and other defects left in the structure. In this work, aluminum oxide (Al_2O_3) and aluminum oxide and titanium dioxide (Al_2O_3-TiO_2) multilayer thin films were deposited on Ti-6Al-4V substrates by ALD and the tribological and corrosion behavior in Ringers solution have been investigated. The protective efficiency of the film was calculated. The coatings presented wear resistance and good adhesion. Raman analysis were performed before and after the tests. **Acknowledgments:** This work was supported by CNPq, CAPES, and FAPESP.

11 – 11:20 am | Study of Molybdenum Dialkyldithiocarbamate (Mo-DTC) Friction Reduction and Wear Resistance by Structure-Oriented Lumping (SOL) Method

Chao Zhang, Shanghai Universty, Shanghai, China

Mo-DTC is widely used as friction modifier and the effect of Mo-DTC on friction reduction and wear resistance in boundary lubrication regime is caused by the formation of MoS_2 film on the steel substrate. Any molecule can be described and represented by a set of certain of structural features or groups. The SOL method organizes this set as a vector, with the elements of the vector representing the number of specific structural features, and builds reaction network based on tribochemical reaction mechanisms and rules. Reaction rate constants are calculated with Dmol3 in Materials Studio software and kinetic differential equations of the molecular lumps are solved with fourth-and fifth-order Runge-Kutta method. SOL method is used to describe the process of tribochemical reaction on molecular level and predict film formation and removal, and friction behavior. Comparison between the simulation results and tribological experimental data are made, and a good agreement is observed.

11:40 – Noon | Ab Initio Investigation of Tribochemistry Mechanisms in Solid and Boundary Lubrication

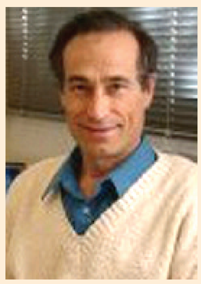
M. Clelia Righi, University of Modena and Reggio Emilia, Modena, Italy

We apply *ab initio* molecular dynamics to investigate the tribochemistry of some of the most common solid lubricants interacting with water molecules. We consider, in particular, molybdenum disulfide, graphene/graphite and carbon-based films. The lubricating performances of these materials are highly affected by humidity. We study both the physical- and chemical-interaction of water with (defected) layered materials and evaluate the effects of these interactions on interlayer slipperiness. We, then, consider diamond films and identify the effects of Si-dopants in enhancing the hydrophilic character of the surface and discuss its impact on the sliding properties. As second tribochemistry issue, we investigate the effects of surface chemical modifications on interfacial properties of iron. We consider the adsorption of sulfur-, phosphorus-based additives and graphene and elucidate the important role of metal passivation in reducing the adhesion and shear strength of the interface. We generalize the result by establishing a connection between the tribological and the electronic properties of interfaces. This adds a new piece of information for the ultimate understanding of the fundamental nature of frictional forces.

Keynote Session III } Grand Ballroom

1:20 – 2pm | AFM and TEM Studies of Friction and Wear in Pt-Graphene and Pt-SiO_2 Systems

Miquel Salmeron, Lawrence Berkeley National Laboratory, Berkeley, CA



AFM and TEM microscopes provide a wealth of atomic scale information on the nature of friction and wear. Here I will present results using these techniques that reveal some unique mechanical properties of graphene, including: a) Formation of friction domains on exfoliated monolayer graphene deposited on SiO_2-Si wafers, due to ripple distortions along preferential crystallographic directions. Within each domain the friction is anisotropic, b) Graphene reactivity when grown of substrates like Ru(0001) where water splits the graphene along grain boundaries and subsequently intercalates, c) Water intercalated between graphene and mica or SiO_2/Si increases friction. With the help of DFT phonon spectra calculations we can explain the role of water in increasing friction energy dissipation, and d) Finally I will present results on the wear of Pt tips when sliding over lubricated and unlubricated SiO_2 substrates where TEM reveals the atomic scale wear structures. Prospects for future applications of TEM to atomic scale tribology studies will be presented.

Session 3A } Walton North

Materials Tribology III

Session Chair: Ali Beheshti, Lamar University, Beaumont, TX

Session Vice Chair: Amir Rostami, Georgia Institute of Technology, Atlanta, GA

2pm – 2:20 pm | Highly Effective Wear Resistance Capability of Various Carbon Nanofillers in PTFE Not Transported to FEP Matrices

Thierry Blanchet, Mary Makowiec, Suvrat Bhargava, Rensselaer Polytechnic Institute, Troy, NY

Unlike microfillers, generally shown to provide PTFE polymer with reductions of its high wear rate ~$0.4*10^{-3}$ mm^3/Nm typically by a couple orders-of-magnitude over a broad range of filler materials, when further reduced to the nanoscale most such filler materials lose much of this wear reduction capability. One notable exception to this trend is that of carbon, which has been shown in several forms to not only maintain wear resistance but furthermore augment it to much higher levels of effectiveness. For example, at contents of 2%, Mesoporous Nanocarbon, Activated Nanocarbon and Carbon Nanotubes have been shown to provide PTFE with rates of approximately 6.9, 0.8 and $9.5*10^{-7}$ mm^3/Nm, respectively. In addition to being specific to these carbon nanofillers, it was additionally of interest whether this highly effective wear resistance was specific to the PTFE matrix material, thus the fillers were also tested within FEP matrix material which when unfilled shares a similar ~$0.4*10^{-3}$ mm^3/Nm wear rate. The highly effective wear resistances these carbon nanofillers provided to PTFE were found to not also be provided to FEP, with wear rates of 18, 0.94 and $2.6*10^{-5}$ mm^3/Nm for the Mesoporous Nanocarbon, Activated Nanocarbon and Carbon Nanotube fillers, respectively, typically two orders-of-magnitude higher than those measured in PTFE. Similar behavior was observed for graphene nanofillers, which were highly effective in reducing the wear of PTFE yet completely ineffective in FEP.

2:20 – 2:40 pm | Elastomer vs. Ceramic in Cyclically Loaded Contact: What Wears Less?

Michael Varenberg, Georgia Institute of Technology, Atlanta, GA, Yuri Kligerman, Peter Breitman, Haytam Kasem, Technion – Israel Institute of Technology, Haifa, Israel

Here we compare the wear performance of silica and polyurethane in a vacuum gripper. The problem is modeled numerically by evaluating the energy dissipated at the interface, and experimentally by examining surface damage in contact subjected to cyclic normal loading. In the numerical model, the energy dissipated during unloading is found to be negligible with respect to that of loading. Changing the contact geometry has a good effect in terms of wear reduction, but this is not as significant as the effect obtained by changing the material. Replacing silica with polyurethane reduces the frictional work by a factor of at least 20. The latter finding is validated in experiments and explained by prevention of sliding in a more compliant material.

2:40 – 3 pm | Humidity Dependence of Atomic-scale Friction Between Nanoasperities and Graphite

Zhijiang Ye, Miami University, Oxford, OH, Kathryn Hasz, Robert Carpick, University of Pennsylvania, Philadelphia, PA, Ashlie Martini, University of California Merced, Merced, CA

For certain materials, especially many solid lubricants, it is well-known that the friction force depends on the amount of humidity in the surrounding atmosphere. However, the nanoscale dependence of friction on humidity and its underlying mechanisms are still not well understood. Here, we probe the origins of humidity dependence of atomic friction on highly oriented pyrolytic graphite (HOPG) using atomic force microscope (AFM) measurements and Grand Canonical Monte Carlo (GCMC) simulations. A non-monotonic trend, where the friction first increased and then decreased with increasing humidity, was observed in both experiments and simulations. Further, a humidity-dependent friction hysteresis was observed during ramping up and ramping down the relative humidity. The underlying mechanisms were investigated using atomistic details obtained from simulations, where the non-monotonic friction trend and the hysteresis were correlated to water coverage of the samples at different humidities and intrinsic water sorption hysteresis, respectively.

3 – 3:40 pm – Break

3:40 pm – 4 pm | Strain Hardening: Can It Affect Abrasion Resistance?

Wilian Labiapari, Aperam South America, Timoteo, Minas Gerais, Brazil, Miguel Ardila, Henara Costa, Jose Daniel de Mello, Federal University of Uberlandia, Uberlandia, Minas Gerais, Brazil

It has been largely reported in the literature that previous strain hardening has none or negligible effect on abrasive wear resistance. Those results are mainly obtained using sand rubber wheel tests and pin-on-disk tests, and have been attributed to the large strain hardening promoted by the abrasion phenomena themselves. The stresses involved in those tests are very high and the stress distributions spread towards subsurface regions at large depths. This work investigates the effects of strain hardening on low severity (low stress at low depth) abrasive wear resistance. Microabrasion tests, normally regarded as lower stress tests were used in order to impose low severity. Two types of stainless steels were tested: an austenitic AISI 304 steel and a ferritic AISI 430 steel. Strain hardening was obtained via thickness reduction (20%) of stainless steel sheets in a laboratory cold rolling mill. The microabrasion wear tests were carried out in a fixed-ball micro-abrasion tester with a three-axis load cell to continuously and simultaneously monitor the forces involved in the tests. Contrarily to the findings so far in the literature, previous strain hardening increased abrasion wear resistance (55% and 63% respectively) for both materials. Hertz calculations, conventional mechanical tests, micro hardness profiles, microstructural analysis and x-ray diffraction analysis were used to explain this paradigm shift for the case of microabrasion tests.

4 pm – 4:20 pm | Identification of Strain-stress History Leading to Tribological Transformed Microstructure: Use of High Pressure Torsion Modeling

Aymen Ben Kaabar, Insa Lyon, Univ Lyon, Villeurbanne, France, Asdin Aoufi, Christophe Desrayaud, EMSE, Univ Lyon, Saint-Etienne, France, Sylvie Descartes, INSA Lyon, Univ Lyon, Villeurbanne, France

During contact's life, different deformation paths lead to the formation of high deformed microstructure, in the skin of the bodies in contact. The tribological conditions (high pressure and shear) are reproduced through High Pressure Torsion configuration (HPT). A 3D model finite element model (Abaqus/Explicit) of HPT test is developed to study the local deformation history leading to high deformed microstructure produced during HPT process. A numerical parametric study highlights the role of the imposed parameters (friction coefficient at the interfaces anvils/sample, P, law behavior …) on the stress/strain distribution in the sample bulk. Furthermore, a microstructural evolution model is enhanced by considering strain and strain gradient. Low coupling between this micro - structural model and the FE model of HPT test is introduced through an iterative process. The enriched FE model is expected to investigate in a sufficiently accurate way the strain paths, in relation with the developed microstructures and their localization. Mechanical criteria of extremely deformed microstructures formation is deduced from the coupling between experimental results (localization of high deformed microstructure) to local strain and stress fields estimated by the numerical modeling of tests.

4:20 – 4:40 pm | Compositions and Hardness Values

Meisam Nouri, University of Alberta, Edmonton, Alberta, Canada, H.L. Gui, Taiyuan University of Science & Technology, Taiyuan, China, Dongyang Li, University of Alberta, Edmonton, Alberta, Canada

The wear resistance of ductile metallic materials is largely dependent on their hardness as Archard's equation describes. However, discrepancy exists such as a case study reported in this article, in which two carbon steels having similar compositions and hardness values show very different wear resistances in both abrasion and erosion conditions. In order to understand the mechanism responsible for the observed phenomena, microstructures, hardness, Young's moduli, energy ratio of elastic deformation to plastic deformation, iron carbide distributions, and electron work functions of the steels were investigated. Results of the study demonstrate that the elastic behavior appears to play an important role in affecting the resistances of the steels to wear. Efforts are made to explain the observed phenomena using electron work function as an indicative parameter in combination with the microstructure feature, both of which affect intrinsic and overall mechanical properties of the steels.

Session 3B } Walton South

Surfaces & Interfaces III

Session Chair: Roland Bennewitz, INM Leibniz Institute for New Materials, Saabrucken, Germany

Session Vice Chair: James Ewen, Imperial College of London, London, UIC

2 – 2:20 pm | Molecular Mechanisms of Lubrication

Roland Bennewitz, INM Leibniz Institute for New Materials, Saabrucken, Germany

Sliding friction can be strongly affected by molecular layers covering the contacting surfaces. High-resolution atomic force microscopy helps to understand the mechanisms underlying this molecular lubrication. Examples from dry friction include the extraordinary nanometer-scale lubrication of a platinum surface covered with a single layer of graphene. In liquid lubrication, ordering of molecular layers occurs in the nanometer confinement between approaching asperities and surfaces. We have established dynamic shear force microscopy based on AFM for measurement of shear viscosity in nano-meter confined liquids. For hexadecane, we find a step-wise increase of viscosity with decreasing number of confined layers, rather than a distinct dependence on the normal pressure.

2:20 – 2:40 pm | Tribochemical Reactions of Adsorbed Organic Molecules and Formation of Highly-efficient Polymeric Lubricant Films at Sliding Solid Interfaces: Part 1 – Experiment Study

Xin He, Pennsylvania State University, State College, PA, Jejoon Yeon, University of California, Merced, Merced, CA, Seong Kim, Pennsylvania State University, University Park, PA, Ashlie Martini, University of California Merced, Merced, CA

The mechanochemical reactions of allyl alcohol adsorbed at a sliding interface were studied. Because of the allylic nature, allyl alcohol cannot be polymerized chemically. However, it was found that allyl alcohol can be readily polymerized by mechanical shear at the sliding interface forming poly-alcohols. Using the tribochemical reactions, highly-efficient poly-alcohol lubricant layers can be formed selectively at the sliding interface in vapor phase lubrication (VPL) conditions, without contaminating or covering the region where lubrication is not necessary. In order to understand the mechanism of this tribochemical process, we studied the adsorption isotherm of allyl alcohol as well as the tribochemical reaction yield as a function of the contact load applied to the sliding interface and the partial pressure of allyl alcohol vapor in the environment. By analyzing the load dependence using the modified Arrhenius equation, we determine the critical volume change to induce the tribochemical reaction of the adsorbed allyl alcohol molecule. This results is compared with molecular dynamics (MD) simulations obtained using a ReaxFF force field.

2:40 – 3 pm | Tribochemical Reactions of Adsorbed Organic Molecules and Formation of Highly-efficient Polymeric Lubricant Films at Sliding Solid Interfaces: Part 2 – Computational Study

Jejoon Yeon, University of California, Merced, Merced, CA, Xin He, Seong Kim, Penn State University, University Park, PA, Ashlie Martini, University of California, Merced, Merced, CA

Adsorbed organics are known to influence the tribological responses of sliding interfaces. During sliding, the adsorbed species can act as a molecular lubricant reducing friction in the interface. In addition, they may undergo chemical reactions due to mechanical activation originating from interfacial shear, called mechanochemical or tribochemical reactions. Although such reactions are well documented in the literature, reaction mechanisms and dynamics are not well understood. We have investigated the reactions of allyl alcohols at a sliding amorphous silica interface using molecular dynamics (MD) simulations with the ReaxFF reactive force field as well as vapor-controlled tribometer and surface characterization techniques. From the MD simulation, the mass amount of allyl alcohol and reaction products is calculated during sliding. The mass of the reaction products is found to decay exponential, and approximate reaction rate and activation volume are calculated. The results of simulations are compared to experimental measurements. In addition, the reactive force field provides information about the polymerization and dissociation of allyl alcohol molecules and how the allyl alcohol reacts with the silica surface during sliding.

3 – 3:40 pm – Break

3:40 – 4 pm | Molecular Dynamics Investigation of the Friction Reduction Mechanisms of Carbon Nanoparticles Confined Between Iron Surfaces

James Ewen, Chiara Gattinoni, Imperial College London, London, United Kingdom, Foram Thakkar, Shell Technology Centre, Bangalore, India, Neal Morgan, Shell Global Solutions UK Ltd, London, United Kingdom, Hugh Spikes, Daniele Dini, Imperial College London, London, United Kingdom

In this study we use non-equilibrium molecular dynamics (NEMD) simulations to examine the friction reducting mechanisms of carbon nanoparticles on experimentally relevant surfaces. The friction behaviour of carbon nano-diamond (CND) and carbon nano-onion (CNO) nanoparticles confined between α-iron slabs is probed at a range of coverages, pressures and sliding velocities. At high coverage and low pressure, the nanoparticles remain well-separated from the slabs, leading to a low friction coefficient which arises purely from Van der Waals interactions between the nanoparticles and the slabs. At low coverage and high pressure, as likely to be encountered in boundary lubrication, nanoparticles indent into, and plough through the slabs during sliding, leading to atomic-scale wear and a much higher friction coefficient. This contribution to the friction coefficient is well predicted through purely geometric considerations by an expression developed for macroscopic indentation by Bowden and Tabor. Even at the highest pressures and lowest coverages simulated, both nanoparticles are able to maintain separation of the slabs and reduce friction by approximately 75% compared to when no nanoparticle is present; similar to what has been observed experimentally.

4 – 4:20 pm | Effect of Core-shell Chemistry of Metal Nanoparticles on Achieving the Superlubricity at Macroscale in Graphene-Nanoparticle System

Diana Berman, Badri Narayanan, Subramanian Sankaranarayanan, Argonne National Laboratory, Argonne, IL, Ali Erdemir, Energy Systens Division, Argonne National Laboratory, Argonne, IL, Anirudha Sumant, Argonne National Laboratory, Argonne, IL

In our previous study, we demonstrated achieving superlubricity at macroscale when graphene patches wrap around tiny nanodiamond particles forming nanoscroll structures that slide against amorphous diamond-like carbon (DLC) surface providing near zero friction [1]. In the present studies, we have investigated replacing nano - diamonds with range of metal nanoparticles to observe the influence of other nanoparticle materials on achieving the superlubricity. Interestingly, we indeed achieved superlubricity, however, unlike in graphene-nanodiamond system where nanodiamond particles remain intact acting as a nanoscale ball-bearings, in the present case, we have observed that metal nanoparticles (such as iron and cobalt) in presence of graphene under high contact pressure act as catalysts leading to the formation of onion-like-carbon (OLC) structures with high stiffness values, enabling superlubricity. However, such catalytic behavior is observed only for pure metal nanoparticles and sensitively depends on the core-shell chemistry of the nanoparticle. In case of iron and cobalt nanoparticles with oxidized shell, the catalytic reaction was hampered due to the presence of oxide shell iron core preventing the formation of OLCs and therefore loss of superlubricity. To support our findings, we performed molecular dynamic simulations for comparative investigation of tribology behavior of graphene-iron and graphene-iron oxide ensembles.

4:20 – 4:40 pm | Understanding the Behavior of Ionic Liquids at Carbonaceous Surfaces

Rosa Espinosa-Marzal, Luis Jurado, University of Illinois at Urbana-Champaign, Urbana, IL

Ionic liquids (ILs) are non-flammable and known to have remarkable properties including wide thermal stability windows, vanishingly low vapor pressures, and their physical and chemical properties are tunable, making them ideal for many applications including lubrication. Carbon based materials such as graphite and graphene are considered to be good solid lubricants. Several studies have looked at the interfacial properties of ILs on various substrates, which have shown ILs to have solid-like behavior upon confinement, preventing contact between the confining surfaces. However, there are a limited number of experimental studies that explore the IL-carbon interface, and in particular, the graphene-IL interface. This work lends to the fundamental understanding of graphite-IL and graphene-IL systems as lubricants. We have investigated the behavior of IL nanostructures on graphene and graphite using atomic force microscopy. Normal force measurements reveal significant differences in solvation layers between graphene and graphite. Layering statistics were evaluated over numerous force measurements to gain insight into the behavior of ILs on these surfaces. We have further evaluated the friction response of ILs on carbon substrates using lateral force microscopy. Our results suggest that ILs can behave differently on chemically similar carbon materials, and we explain these mechanisms.

4:40 – 5:00 pm | Stress-promoted Thermal Activation in Tribology

Hugh Spikes, Imperial College London, London, United Kingdom

The temperature dependence of the rates of many processes, such as diffusion and chemical reaction, is governed by the Arrhenius equation in which the rate is determined by the proportion of species having sufficient thermal energy to overcome an activation energy barrier. The stress-promoted thermal activation model, first developed by Prandtl in the early 20thcentury, proposes that when shear stress is present, the work done by applied mechanical force on a molecular system can reduce the activation energy barrier and thus increase the rate of the process. The concept has particular relevance to tribology since large shear stresses in sliding contacts and it has been variously applied to explain the viscosity of liquids, EHD friction, rubber friction, boundary friction and tribochemical reactions. This paper will review the application on the stress-promoted thermal activation concept in rubbing contacts and show three recent examples of where it appears to control lubrication behaviour.

5 – 5:20 pm | Measurements of Liquid-Mediated Adhesion between Contacting Rough Surfaces

Amir Rostami, Jeffery Streator, Georgia Institute of Technology, Atlanta, GA

Liquid-mediated adhesion, which can negatively affect the fabrication and operation of small-scale devices, is investigated. A liquid film that wets both surfaces is introduced at the interface of two contacting rough surfaces. The free surface of the liquid develops a concave configuration and gives rise to negative capillary pressures within the film. These tensile stresses intensify the compressive stresses at the solid-solid contact regions and make it harder for the surfaces to be separated vertically or displaced laterally. Several types of measurements are performed to assess the strength of the adhesive forces, including pull-off force, friction force, and friction torque. Experiments are conducted for varying external load, composite elastic modulus and surface roughness. Results are compared with the predictions of a recently developed numerical model.

5:20 – 5:40 pm | Contrast Mechanisms on Nanoscale Subsurface Imaging in Ultrasonic-AFM

Philip Egberts, Hossein Jiryaei, University of Calgary, Calgary, Alberta, Canada, Gajendra Shekhawat, Vinayak Dravid, Northwestern University, Evanston, IL, Simon Park, Seonghwan Kim, University of Calgary, Calgary, Alberta, Canada

Mechanical, electrical, and thermal properties of nano-composite materials depend on the dispersion and connectivity of embedded nanoparticulates. Imaging techniques that can be used to visualize and characterize local aggregations of the embedded and buried nanoparticulates with sufficient resolution have attracted a great deal of interest today. Ultrasonic atomic force microscopy (AFM) and its derivatives are nondestructive techniques that can be used to elucidate subsurface nanoscale structures and mechanical properties. Although many different ultrasonic methods have been used for subsurface imaging, the mechanisms and crucial parameters associated with the contrast formation in subsurface imaging are unclear. Here, the impact of mechanical properties of the particulates/matrix, size of the nanoparticulates used to reinforce the composite, buried depth of the nanoparticulates, and the ultrasonic excitation frequency on the developed ultrasonic AFM images are been investigated. In investigating the contrast mechanisms, we have considered two factors: scattering of ultrasonic waves and tip-sample contact stiffness. To verify our theoretical model, experimental measurements of scanning near-field ultrasound holography (SNFUH) have been recreated in our theoretical analysis to reveal comparable variations in amplitude and phase contrast measured in SNFUH while scanning over the particulates embedded in a polymer matrix.

5:40 – 6 pm | In-situ Generation of W-S Tribofilms Using Functionalized Surfaces and Green Additives

Manel Rodriguez Ripoll, Vladimir Totolin, AC2T research GmbH, Wiener Neustadt, Austria

Transition metal dichalcogenides (TMDs) – such as MoS2 and WS2 – have a lamellar structure with a strong bonding between the metal and chalcogenide ligands which contrasts with the weak chalcogenide-chalcogenide bonding between the layers, allowing them to easily slide over each other. This makes them suitable as solid lubricants. TMDs can be applied to mechanical components by various techniques. Sputtering is one of the most commonly used methods due to the excellent coating quality. Recently, W-S-C coatings doped with metals have been proposed for enhancing the mechanical properties of TMDs coatings, while maintaining their low friction properties. The major drawback of TMDs coatings is their poor performance in humid air, which limits their use only to vacuum and space applications. The present work shows a novel method for generating in-situ TMD tribofilms in lubricated contacts. The method relies on the surface functionalization with mechanically embedded tungsten carbide particles. The functionalized surfaces are able to react with Sulphur containing additives and form low friction W-S tribofilms, as demonstrated by x-ray photoelectron spectroscopy. The in-situ formed tribofilms enable low friction under conventional lab conditions, even at humidity levels of up to 60%. Tribofilm formation is not limited to a particular Sulphur-based additive. The presented results show that very low friction levels can be achieved using environmentally friendly additives.

Session 3C } Georgian Room

Machine Elements & Systems II

Session Chair: Harpal Singh, Sentient Science Corp, Idaho Falls, ID

Session Vice Chair: Aaron Greco, Argonne National Laboratory, Argonne, IL

2 – 2:20 pm | Experiments and Simulations of Polymer-Basestock Solutions for Hydraulic Applications

Paul Michael, Milwaukee School of Engineering, Milwaukee, WI, Ashlie Martini, University of California Merced, Merced, CA

Polymer-basestock solutions were investigated using molecular dynamics simulations, benchtop rheological tests, and hydraulic dynamometer evaluations. Molecular simulations examined the nanoscale effects of polymer structure on solution viscosity and compressibility. Dynamometer testing assessed the effects of fluid properties on flow and torque losses in an open-loop hydraulic system. Rheological testing provided a validation of the simulations and a bridge between the simulations and dynamometer measurements. Polymer-containing hydraulic fluids were found to reduce pump flow losses and increase low-speed motor torque losses. Flow and torque losses were unaffected by shear-induced permanent viscosity change. Characterizing polymer solutions at multiple length scales and using several complementary techniques makes possible a better understanding of the relationship between molecular structure and the behavior of fluids in hydraulic machines.

2:20 – 2:40 pm | Formulation and Validation of a Mixed-TEHD Model for the Lateral Lubricating Interfaces in External Gear Machines

Divya Thiagarajan, Andrea Vacca, Purdue University, Lafayette, IN

Lateral lubricating interfaces exist between the floating lateral bushes and the rotating gears in high pressure (up to 250 bar) hydraulic external gear machines (EGM) and perform functions of sealing and bearing loads. High pressure loads in the lubricating gap create a fluid structural and thermal interaction problem where the elastic and thermal deformation of the solid components needs to be coupled with the fluid flow. A thermo-elastic hydrodynamic (TEHD) gap model with a full film assumption at all times, which accounts for the fluid and structural coupled effects in the gap was previously developed in the authors' research team. However, at certain severe operating conditions and for fluids with low viscosity, there are possibilities of a mixed lubrication regime occurring in the gap which warrants the inclusion of load support by surface asperities along with the surface topography of the components in the modelling of the interface. In the present work, a mixed-TEHD model has been developed to include the coupled surface-thermal-elastic deformations and asperity contact along with the fluid flow in the lubricating gap through rough surfaces. Furthermore, the numerical results predicted by the simulation model have been shown to have a good agreement with the experimental measurements of torque losses and leakages on a reference EGM unit at extreme operating conditions which are expected to be in a mixed lubrication regime.

2:40 – 3 pm | Improvement of Scuffing Load Capacity of Gears by Running-in – Top or Flop?

Thomas Lohner, Klaus Michaelis, Karsten Stahl, Technical University of Munich, Garching b. München, Germany

Running-in is known as proven means to avoid early scuffing failure of gear drives. This is most often explained by smoothing of the surface roughness during running-in and thus increasing the mean lubricant film thickness in the gear contact. Running-in is usually conducted in mixed to boundary lubrication regime, where besides changes to the surface roughness also changes to the gear material close to the mating surfaces by tribofilm formation are induced. This study investigates the influence of running-in on the scuffing load capacity of cylindrical gears in a FZG back-to-back test rig. For running-in, different lubricants based on an ISO VG 100 mineral oil are considered: (i) base oil without additive, (ii) base oil with Extreme Pressure (EP) additive and (iii) base oil with Plastic Deformation (PD) additive. The lubricant used for the scuffing load carrying experiments is base oil with EP additive and kept constant. Results show an increase of scuffing load by up to 300% for gears after running-in with base oil with EP- or PD-additive compared to gears without running-in. However, the load carrying capacity of gears after running-in with base oil without additive tends to be even lower compared to gears without running-in. As the surface roughness after running-in in comparison of the different lubricants does not show significant differences, explanations can be found in the different nature of tribofilms after running-in. This is supported by surface analyses.

3 – 3:40 pm – Break

3:40 – 4 pm | Self-lubricating Ni-based Laser Hardfacings For High Temperature Sliding Contacts

Hector Torres, Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria, Braham Prakash, Lulea University of Technology, Lulea, Sweden

Laser cladding has proven to be an effective way for reducing wear in industrial applications like ore processing or steel making. However, under severe operating conditions at high temperatures (HT) they are not able to control and reduce friction. In order to develop multifunctional hardfacings for HT applications, a nickel-based powder alloy was mixed with varying concentrations of self-lubricating constituents such as silver, molybdenum disulfide and pure molybdenum in order to provide low and stable friction in a broad temperature range up to 800°C without adversely affecting wear resistance. The resulting powder was deposited by means of direct diode laser. The microstructures of the resulting coatings were characterized in order to reveal the phases formed as a consequence of solidification at fast cooling rates during the deposition process. Subsequently, HT reciprocating sliding tests were performed on the coatings. It was found that the addition of silver and molybdenum compounds resulted in HT self-lubrication, as the measured coefficient of friction significantly decreased at 600°C and 800°C. At temperatures equal or below 400°C no decrease in friction compared to the unmodified nickel-based alloy was observed. The results obtained are regarded as a first step towards the implementation of similar laser claddings in HT sliding contacts for metal forming applications.

4 – 4:20 pm | Reciprocating Seal Friction: Transition From Dry Regime to Full Film Lubrication

Matthias Wangenheim, Martin Zimmermann, Leibniz University of Hannover, Hannover, Germany, Ravindrakumar Bactavatchalou, Freudenberg New Technologies SE, Weinheim, Germany

Typically, hydraulic and pneumatic elastomer seals face a reciprocating sliding motion with regular inversion of sliding direction. Particularly in these reversal points, the seals have time to creep into the asperities of the counter surface. At the same time, the lubricant is squeezed out of the contact. Depending on the resting time, boundary lubrication or even dry friction states can arise. For the latter case we have developed a dry friction model for elastomers in recent years. It consists of a hysteresis friction module which describes the energy dissipation within the elastomer material due to dynamic excitation while sliding on the microscopically rough counter surface. An adhesion friction module covers the sliding friction share required to destroy direct chemical and physical bonds between the surfaces in contact. If we compare dry friction simulations with experiments starting at very low sliding speed, we find our expectations confirmed: With increasing speed, we over-estimate the friction with our modelling approach, as the transition towards hydrodynamic friction is not covered. In this presentation we will discuss an approach on using our dry friction model to indirectly calculate the fluid film thickness in mixed friction regime. These results will be compared with those obtained from EHL simulations. The final goal is to exactly define the range of validity for our friction models (dry friction, EHL) and the transition between them.

Session 3D } Venetian Room

Lubricants III

Session Chair: Manfred Jungk, Dow Corning, Wiesbaden, Germany

Session Vice Chair: Michael Weismiller, US Department of Energy, Washington, DC

2 – 2:20 pm | Catalytic Antioxidants – Novel Substituted N,N'-Diarylphenylenediamine Derivatives as Potential Lubricant Additives

Abhimanyu Patil, ExxonMobil, Annandale, NJ

We have synthesized several new substituted phenylenediamine derivatives, that show good antioxidancy in various synthetic base stocks. The concept of the Catalytic Additives is to identify additives for lubricants that are catalytic and last longer or can be used at lower concentrations than current additives. Antioxidants (AOs) slow oxidative degradation by retarding or inhibiting a variety of degradation chemistries, thereby protecting and extending the life of formulated oils. Conventional AOs are stoichiometrically consumed in the degradation process. On the other hand, additives that are regenerated in a catalytic cycle offer the potential for better performance and/or lower cost. The potential for an AO to be catalytic is dictated by its structure. The ashless antioxidant, diphenyl amine (DPA), has the right structure to be catalytic, but it is not. The key to making DPA catalytic is to modify the structure to prevent the side reactions that destroy its catalytic activity. This presentation deals with the synthesis, characterization and evaluation of a series of substituted phenylenediamine (PDA) derivatives. The structures of the compounds were systematically varied to understand the effect of various substituents on the performance of the molecules. All nine compounds synthesized showed good antioxidant activity based on PDSC studies. This molecular based approach enables the development of structure performance activity for these types of antioxidant molecules.

2:20 – 2:40 pm | On the Flow of Lubricating Greases: A Computational Fluid Dynamics Approach

Lars Westerberg, Erik Höglund, Chiranjit Sarkar, Luleå University of Technology, Luleå, Sweden

Being able to model the flow dynamics of grease is highly valuable in the design of lubricated machine elements such as rolling element bearings. An understanding of the grease flow dynamics enables prediction of grease distribution for optimum lubrication and for the migration of wear- and contaminant particles. In this paper the potential of combined analytical modelling, flow visualizations, and numerical modelling in grease flow dynamics is presented. Specifically, the relation between the rheology of the grease and its impact on the flow motion is of interest in combination with validation of the numerical models in simplified geometries. The numerical models then enable simulations in more complex geometries of particular interest for the grease and bearing industry. It is shown that grease flow is heavily influenced by its non-Newtonian properties and the shear rates in the contact, resulting in distinct regions of yielded and un-yielded grease. Further, the numerical models are shown to match well with experiments and analytical models, enabling numerical models on more intricate geometries in the bearing industry.

2:40 – 3 pm | Phosphonium-Based Ionic Liquids as Additives of Mineral Oils in Steel-Steel Contacts

Patricia Iglesias Victoria, Brandon Powell, Edward Cigno, Karthik Janardhanan, Rochester Institute of Technology, Rochester, NY

A need has emerged to develop more effective automotive lubricants, as the number of automobiles has steadily risen since the turn of the 20th century, and experts agree the number will continue to grow exponentially into the future. Overcoming automotive powertrains friction accounts for approximately 17% of the total potential energy stored in gasoline [1], so improvements in lubrication technology is of increased importance. Ionic Liquids (ILs) are salts that, by definition, have a melting point lower than the vaporization temperature of water (100°C). ILs have proven to be effective additives to base oils to reduce friction and wear coefficients. In this study, the lubricating ability of Trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl)-phosphinate is investigated on steel-steel contact as an additive to mineral oils, with and without current market additives. Base mineral oil, as well as mineral oil with proprietary Repsol additives (HLP VG46), are mixed with 1 wt. % IL, and the friction and wear characteristics are studied using a ball-on-flat reciprocating tribometer. Results show the addition of the IL reduces wear volume on the Steel disks, while friction values remain relatively constant for all tests. [1] K. Holmberg, P. Andersson, and A. Erdemir, “Global energy consumption due to friction in passenger cars,” Tribol. Int., vol. 47, pp. 221–234, 2012.

3 – 3:40 pm – Break

3:40 pm – 4 pm | Novel Borate Ester Additives with Superior Tribological Performance

Giovanni Ramirez, Argonne National Laboratory, Argonne, IL, MIchelle McCray, Brendan Yonke, David Schubert, U.S. Borax Inc., Greenwood Village, CO, Ali Erdemir, Argonne National Laboratory, Argonne, IL

Boron based compounds have been studied for decades due to their unusual anti-friction and –wear characteristics. In particular, hexagonal boron nitride (h-BN), boric acid, and boron oxide are good solid lubricants and used in a variety of tribological applications. Nanoparticulate h-BN and boric acid as well as borate esters and boron-based ionic liquids have also been tried in the past for their anti-friction and –wear characteristics around the world even though some problems have been encountered with their thermal stability, moisture sensitivity, chemical compatibility, and solubility with carrier oils and additive package. Here we report on the development of a new breed of borate esters that when mixed with the lubricating oils (base oil and/or fully formulated oil) bring out interesting tribological properties in terms of friction reduction and wear protection of the sliding steel surfaces. Tribological tests conducted using a variety of bench top machines showed more than 50% reduction in friction coefficients without affecting the wear protection offered by the fully formulated oils. The chemistry of the tested surfaces was studied by Raman microscopy to elucidate the events that are responsible of this tribological behavior.

4 – 4:20 pm | Tribological Performance of Functionalized Nanoparticles in Oils and Mechanism of Tribofilm Formation Under Boundary Lubrication

Vinay Sharma, The University Of Texas At Arlington, Arlington, TX, Richard Timmons, University Of Texas At Arlington, Arlington, TX, Ali Erdemir, Argonne National Laboratory, Lemont, IL, Braham Prakash, Jens Johansson, Luleå University Of Technology, Lulea, Sweden, Pranesh Aswath, The University Of Texas At Arlington, Arlington, TX

Zinc dialkyl dithiophosphate (ZDDP) is the main workhorse antiwear additive, that also doubles as an antioxidant in engine oils for light and heavy duty vehicles. However, a significant demerit in the use of ZDDP is the creation of sludge in the oil and the deposition of volatile phosphate glass on catalytic convertors that reduce their efficiency and increase the quantity of undesirable emissions. There have been many studies tailored around development of alternatives to ZDDP. In our approach, we have developed molecularly tailored functionalized nanoparticles for use as additives to help reduce wear and friction in oils under tribological conditions. Surface analytical tools such as XPS and XANES were used to evaluate the mechanism of tribofilm formation using this approach. The local coordination chemistry of the elements in the tribofilm were determined and helped provide insight into the chemical makeup of the films responsible for providing the significantly improved wear and friction observed when the functionalized nanoparticles are present.

4:20 – 4:40 pm | Influence of Contact Conditions on the Interaction Between MoS_2 Nanotubes and Oil Additive

Manel Rodriguez Ripoll, Agnieszka Tomala, AC2T research GmbH, Wiener Neustadt, Austria, Maja Remskar, Jozef Stefan Institute, Ljubljana, Slovenia

The use of transition metal dichalcogenides (TMD) nanoparticles – such as MoS_2, WS2 – as boundary lubrication additives has steadily gained attention in the last few years. There is currently a large amount of research reporting that MoS_2 nanoparticles can act effectively as friction modifiers. However, in fully-formulated lubricants other properties such as oxidation and corrosion protection or sludge control are essential to provide a comprehensive protection of sliding components against degradation. As a consequence, the use of conventional additives in fully-formulated products that are able fulfill these additional roles is unavoidable. The number of investigations addressing the interaction of TMD nanoparticles with conventional additives is very recent and limited. The present work focuses on the compatibility between MoS_2 nanotubes and conventional oil additives. The results under reciprocating sliding conditions show synergetic interactions between MoS_2 nanotubes with selected detergents and anti-wear additives and antagonistic interactions with selected extreme-pressure additives and dispersants. However, the synergistic and antagonistic effects are significantly different when changing the contact conditions. These drastic change in behavior is discussed in terms of tribofilm formation. For this, the tribofilms formed using the different mixtures are analysed in order to reveal their main differences in morphology and chemical composition.

4:40 – 5:00 pm | Tribological Properties of Metal-working Fluids with Halloysite Clay Nanotube Additives

Laura Peña Parás, Carlos Martínez, José Ontiveros, Karla Saldivar, Luis Urbina, Moisés Arias, Patricio García, Demofilo Maldonado Cortés, UNIVERSIDAD DE MONTERREY, San Pedro Garza Garc, Mexico

The study of nanoparticles as additives for metalworking fluids have received increasing attention due to their enhancement of tribological properties. In this study, low-cost and environmentally friendly nanoparticle additives of halloysite clay nanotubes (HNTs) were dispersed in metalworking fluids. Concentrations of 0.01, 0.05, 0.10 wt.% were incorporated into a mineral oil and a semi-synthetic fluid by ultrasonication. The tribological properties of metalworking nanofluids were characterized with a T-05 block-on-ring tribotester. Surface roughness of worn materials were obtained with an optical 3D surface measurement system. Results showed that at a concentration of only 0.01 wt.% HNTs block mass loss was lowered by 20% and 40% for the mineral oil and a semi-synthetic fluid, respectively. Coefficient of friction (COF) was also lowered up to ~70%. Furthermore, surface roughness studies of worn blocks showed a smoother surface with lower groove density. The results in this study demonstrate that HNTs can improve lubricity of metal-working fluids, which may increase tool life and provide better surface finish.

5:00 – 5:20 pm | The Tribological Characteristics of Brass Lubricated with Oil-Based ZnO Nanofluid

Chuanlin Tao, Bingxu Wang, Gary C. Barber, Dave Schall, Qian Zou, Oakland University, Rochester Hill, MI

In recent years, the evaluation of the tribological characteristics of nanofluids has become a much studied topic because previous research showed these fluids could potentially reduce friction and wear damage compared with base oil. However, most of the previous tribological research has been conducted on hard materials. Few studies were done with soft materials such as brass, bronze and aluminum. In this research, friction and wear characteristics of oil-based ZnO nanofluids were studied on brass. Oleic acid was used as surfactant to improve the stability and dispersibility of the nanofluid. Nanoparticles were dispersed by using an ultrasonic homogenizer. A ball-on-disk wear testing fixture was used to collect the coefficient of friction data and the wear tracks were analyzed by using an optical surface profiler. The worn surfaces were also examined by scanning electron microscopy to determine the wear mechanisms. The effects of concentrations of nanoparticles, load, surface roughness and sliding speed on friction and wear reduction were investigated. It was concluded that oil-based ZnO nanofluids were able to reduce the friction by up to 42.5% and wear by up to 54.1% under certain experimental conditions.

Session 3E } Astor Room

Fluid Lubrication II: Rheology & EHL

Session Chair: Philippe Vergne, LaMCoS, Villeurbanne, France, Fanny Briand, Total, Solaize, France

2 – 2:20 pm | Dynamics and Thermodynamics of Lubricants in Flow: A Molecular and Tribological Approach

Yingying Guo, Imperial College London, London, United Kingdom, Department of Mechanical Engineering

While lubricants have been used for a long time to reducing friction and wear of rubbing surfaces, little is known about the local properties of lubricants in tribological contacts. The high pressure, high shear occur in tribological contacts mean fluids in tribological contacts very often exhibit different properties as compared to its bulk properties. This is supported by recent experimental observations that the local flow and local viscosity of lubricants in tribological contact is heterogeneous [1,2]. Yet it remains unclear the underline physics of these observations. This work investigates the origins of these peculiar observations with molecular dynamic (MD) simulations. The structure of a model lubricant in the contact both at equilibrium with stationary walls and at steady state with shearing walls are examined. The thermodynamics properties of the lubricant will be tabulated. How local viscosity of the lubricant and friction of the system will be explored. The results with local viscosity measurements, friction measurements and MD simulations will be compared.

2:20 – 2:40 pm | Refrigerants as ILubricants: From Molecular Dynamics Characterization to the Applicability at the Contact Scale

Stéphane Tromp, LaMCoS – INSA Lyon, Villleurbanne, France, Laurent Joly, ILM – Univ. Lyon1, Lyon, France, Manuel Cobian, LTDS – ECL, Lyon, France, Nicolas Fillot, INSA Lyon, Villeurbanne, France

One of the major current technological challenges consists in reducing the size, weight and environmental impact of tribological systems. The reduction of the quantity of lubricant is nowadays coupled with the use of low-viscosity fluids (e.g. refrigerant), so that the width of lubricant films can reach the nanometric scale locally. Because experimental in-situ analysis inside the contact area is very difficult according to high confinement, high pressure and high shear, we aim at providing constitutive equations from molecular modeling that can be used in continuum modeling of the contact. Some experiments and simulations have been made in order to characterize the performance of one of these refrigerants within an elastohydrodynamic (EHD) contact. The present work focuses on the development of a methodology to analyze the rheological behavior of these refrigerants. To that aim, we used molecular dynamics (MD) simulations in order to account for the molecular detail of the fluid and confining surfaces. We also explored the use of reactive force fields and ab initio MD to account for chemical reactivity within the fluid or at the surfaces. These simulations allowed us to extend the previous experimental rheological results.

We could then implement improved parameters of classical laws (e.g. Tait model) into continuum models at the EHD contact scale.

2:40 – 3 pm | Disjoining Pressure and Diffusion Equation for Submonolayer Liquid Film

Kyosuke Ono, Tokyo Institute of Technology, Tokyo, Japan

In the field of head–disk interface technology in hard disk storages, evaluating the lubrication effect of a submonolayer lubricant film is becoming increasingly important as the thickness of the mobile lubricant film is reduced to less than 0.3 nm, i.e., submonolayer thickness in average. Although the spreading and replenishment speed of a submonolayer lubricant can be evaluated by conventional diffusion theory if a large effective viscosity value is selected, it is considered inappropriate to use the conventional diffusion equation based on continuum mechanics for a submonolayer liquid film. For this reason, author has already presented a new diffusion equation that formulates the averaged flow of a submonolayer liquid film with a reduced density from the bulk density, where the Hamaker constant for disjoining pressure in the submonolayer liquid film is also modified to be proportional to the film thickness. Because this treatment is somewhat intuitive, this paper presents a derivation of disjoining pressure for a submonolayer film from integration of the Lennard-Jones potential. Then a new concept of Poiseuille flow model for submonolayer film and derived diffusion equation are explained. In addition to the good comparison between the theory and experiment described in the first paper, some successful examples of this diffusion equation are introduced by referring to the experimental data presented by other researchers thereafter.

3 – 3:40 pm – Break

3:40 pm – 4 pm | Experimental Observation of Lubricant Flow in EHL Contacts Under High Sliding Conditions

Milan Omasta, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

Elastohydrodynamic lubrication (EHL) includes various phenomena that are not fully understood yet. One of them is a dimple phenomenon that is characterized by local increase in film thickness instead of classical flat plateau in the central part of the contact and occurs under high sliding conditions. During last decades, a number of models have been proposed to explain the dimple phenomena. Nowadays a thermally induced viscosity wedge effect is the most commonly accepted; nevertheless other models becoming increasingly debated. Current research in EHL uses a variety of experimental methods mainly for film thickness measurement. However, only a little has been reported about experimental observation of fluid flow through EHL contact. As the fluid flow is strongly connected with a lubricant rheology, it may help to clarify many effects occurring in EHL. The aim of this work is to provide an experimental evidence of lubricant flow under high sliding conditions, when a dimple phenomenon occurs. For the fluid-flow visualization an approach based on particle tracking velocimetry is implemented in an optical ball-on-disc tribometer. In the approach, the flow velocity is calculated by the displacement of tracer particles during a time interval.

4 – 4:20 pm | Surface Roughness Effects on a Border of Mixed Rolling-sliding EHL Contact

Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

Numerous machine elements operate under conditions of mixed lubrication where load is carried by contact between asperities and elastohydrodynamic lubricating film. Generated mean film thickness is often lower than initial average surface roughness. However, roughness is deformed elastically or plastically inside the contact which tends to mitigate severity of the situation. Previous results showed that surface roughness is more heavily deformed under rolling-sliding conditions. In this case entrained lubricant has generally different speed to roughness features. As a result of lubricant flow continuity, a lubricant flows across roughness features while deforms them and contributes to separation of surfaces. Still there is a lack of knowledge about bordering state when lubricant changes flow behaviour and direct contact between asperities occurs. The aim of the study is to reveal lubricant behaviour at the border between full film and mixed lubrication under rolling-sliding conditions. Improved thin film interferometric technique and ball-on-disc apparatus is used to measure ultrathin two-dimensional film distribution with low uncertainties. Film thickness evolution during decreasing speed is presented for one and two-dimensional roughness features.

4:20 – 4:40 pm | Lubricant Film Thickness in Compliant Contacts Using Optical Interferometry

Hugh Spikes, Nigel Marx, Johan Guegan, Carmine Putignano, Daniele Dini, Imperial College London, London, United Kingdom

A new method of measuring and mapping lubricant film thickness in soft EHL contacts has been developed based on the application of semi-reflective coatings to polymer surfaces. The technique yields accurate film thickness data, of comparable quality to that currently available from optical interferometry of hard EHL contacts. Experimental film thickness data over a range of test conditions are described and compared to numerical solutions obtained from a boundary element method. Several applications of this new method are outlined.

4:40 – 5:00 pm | A Fully-Coupled Finite Element Model for the Solution of Thermal Elastohydrodynamic Lubrication Problems

Wassim Habchi, Lebanese American University, Byblos, Lebanon

This work investigates coupling strategies for finite element modelling of thermal elastohydrodynamic lubrication (TEHL) problems. The TEHL problem involves a strong coupling between several physics: solid mechanics, fluid mechanics and heat transfer. Customarily, this problem is split into two parts (elastohydrodynamic (EHD) and thermal) and the two problems are solved separately while an iterative procedure is established between their respective solutions. This weak coupling strategy involves a loss of information, as each problem is not made intimately aware of the evolution of the other problem's solution during the resolution procedure. This typically leads to slow convergence rates. The current work presents a full coupling strategy for the TEHL problem i.e. both the EHD and thermal parts are solved simultaneously in a monolithic system. The system of equations is generated from a finite element discretization of the governing field variables: hydrodynamic pressure, elastic deformation and temperature. This full coupling strategy prevents any loss of information during the resolution procedure leading to very fast convergence rates (solution is attained within a few iterations only).

5:00 – 5:20 pm | Heavily Loaded Point EHL Contacts for Functionally Graded Elastic Materials. Part 1: Dry Contacts

Ilya Kudish, Kettering University, Flint, MI, Sergey Volkov, Andrey Vasiliev, Sergey Aizikovich, Don State Technical University, Rostov-on-Don, Russian Federation

Using the method of matched asymptotic expansions the EHL problem for heavily loaded contacts of functionally graded materials is reduced to solution of: a) the problem for a non-lubricated (dry) contacts and b) the problem for lubricated contacts. The solution of the problem for dry contacts is obtained using asymptotic and semi-analytical methods. A specific case of nominally axially symmetric contacts is considered in more detail. The distributions of pressure for coatings made of homogeneous materials with different elastic properties and of different thickness are obtained and analyzed. The asymptotic behavior of contact pressure in a dry contact near its boundary is determined. This pressure asymptotic behavior is used in the analysis of the pressure behavior in the inlet and exit zones of lubricated contacts. The proposed research has been partially financially supported by the Russian Science Foundation grant no. 15-19-10056.

5:20 – 5:40 pm | Heavily Loaded Point EHL Contacts for Functionally Graded Elastic Materials. Part 2: Lubricated Contacts

Ilya Kudish, Kettering University, Flint, MI, Sergey Volkov, Andrey Vasiliev, Sergey Aizikovich, Don State Technical University, Rostov-on-Don, Russian Federation

Using the method of matched asymptotic expansions the EHL problem for heavily loaded contacts of functionally graded materials is reduced to solution of: (a) the problem for a non-lubricated (dry) contacts and (b) the problem for lubricated contacts. The asymptotic solution of the problem for lubricated heavily loaded contacts is obtained based on the asymptotic behavior of the pressure near the boundary of dry contacts. It is shown that in the inlet and exit zones of a heavily loaded contact the lubrication problem for functionally graded materials is reduced to the asymptotic equations in these zones valid for homogeneous materials. That allows to easily compare the lubrication film thickness and sliding friction force in lubricated contacts with and without coatings. The conclusions regarding the benefits and drawbacks of coatings with different elastic properties and thickness are obtained. The proposed research has been partially financially supported by the Russian Science Foundation grant no. 15-19-10056.

5:40 – 6 pm | Transient Elastohydrodynamic Analysis of Line Contact Under Load and Speed Impulse

Shriniwas Chippa, Hiren Vador, Nitin Borse, Vishwakarma Institute of Technology, Pune, Pune, India

Elastohydrodynamic lubrication (EHL) regime is prevailed in machine elements like gears, cam-follower, rolling contact bearings. Due to nonconformal nature of contact in such elements, the pressure of about 0.5-3Gpa exist which results into elastic deformation of contact surfaces. In reality, these machine elements are subjected to dynamic condition due to variation in load, speed or surface geometry. In the present, work transient analysis of smooth elastohydrodynamic line contact has been carried out with an objective of investigating the effect on pressure distribution, film thickness and subsurface stresses. Lubricant is considered to be Newtonian in behavior and moreover, isothermal condition is assumed. Barus relationship is used to incorporate the pressure-viscosity effect. The Reynolds equation and film thickness equation which contains elastic deformation equation are solved simultaneously by satisfying force balance equation and fulfilling the boundary conditions. Due to load impulse, a significant increase in the central film thickness is observed. In fact, under heavy load, the effect on central film thickness occurs after the execution of load impulse. However, with low load, the variation in film thickness is observed during the period of impulse. Variation in subsurface stresses follows exactly the load impulse. In addition, transient analysis due to speed impulse is also studied.

Session 3F } Superior Room

Tribochemistry II

Session Chair: Yemi Oyeride, Chevron Phillips Chemical Co. Houston, TX

2 – 2:20 pm | Challenges in Advancing Slideway Lubrication Technology

David Racke, Heinrich Braun, Angela Bruneau, Kathy Cooper, ExxonMobil, Paulsboro, NJ

Slideways, also known as linear bearings, are used to control the movement of machine tools of varying sizes and designs. When paired with a high-performing slideway lubricant, modern slideway movement can achieve sub-micron precision. Industry trends toward increased machine tool precision must be matched by advanced slideway lubricant technology. Effective slideway lubrication requires exceptional friction control between multiple friction pairings in the boundary lubrication regime. At the same time, the surface activity of the lubricant components must be carefully balanced to maintain other key performance features such as metalworking fluid compatibility, corrosion prevention, and water separability. It is therefore important to understand the fundamental mechanisms of friction control and other interfacial interactions in complex slideway systems. For this reason, a study was conducted to examine the relationship of lubricant chemistry selection on friction test performance. This paper will discuss the general classes of chemistries available for slideway friction control, focusing on the challenges inherent in balancing molecular interactions to achieve excellent friction control and retain other key properties.

2:20 – 2:40 pm | Influence of Organic Sulfate and Phosphate Additives on Tribochemical Decomposition of Hydrocarbon Oil on Nascent Steel Surfaces

Yoshinori Fukushima, DENSO, KARIYA, Japan, Ikumi Tada, RICOH Industrial solution, Iwate-ken,hanamaki-shi, Japan, Shigeyuki Mori, Iwate university, Iwate-ken,morioka-shi, Japan

Multialkylated cyclopentane(MAC) is a type of synthetic hydrocarbon oil which has an excellent viscosity property, high thermal and chemical stabilities and especially super low vapor pressure, so MAC can ensure adequate lubrication for the entire lifetime. Although the chemical stability of MAC is very high, MAC partially decomposes under friction conditions and forms low molecular weight products such as hydrogen, methane and ethane in contact with metals. The decomposition of the lubricant results in problems such as hydrogen embrittlement, contamination, and lubricant loss. The influence of sulfate were investigated on the decomposition of MAC. The decomposition processes of the lubricants on the nascent surface of bearing steel AISI52100 were investigated using a ball on disk friction tester in a vacuum chamber with a quadrupole mass spectrometer. Although the decomposition reaction can be deactivated by the effect of lubricant additives such as organic phosphates, organic sulfide was not effective for the deactivation. The order of efficiency in decreasing the decomposition rate was obtained as follows :organic sulfide organic sulfate   organic phosphate. XPS analysis revealed that metal sulfides as a boundary film were formed from the sulfate additive. It is clear that sulfate was reduced by nascent steel surface. It can be concluded from the result that decomposition of MAC was not suppressed significantly by sulfate.

2:40 – 3 pm | Effect of Hydrogen and Oxygen Partial Pressure on the Tribochemistry of Silicon Oxide-containing Hydrogenated Amorphous Carbon

Filippo Mangolini, University of Leeds, Leeds, United Kingdom, Medard Komlavi Dzidula Koshigan, Ecole Centrale de Lyon, Ecully cedex, France, Mark H. Van Benthem, James A. Ohlhausen, Sandia National Laboratories, Albuquerque, NM, John Brandon McClimon, James Hilbert, University of Pennsylvania, Philadelphia, PA, Julien Fontaine, Ecole Centrale de Lyon, Ecully cedex, France, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Among the variants of diamond-like carbon films developed for the ever-increasing performance and durability requirements of advanced tribo-mechanical applications, silicon oxide-containing hydrogenated amorphous carbon (a-C:H:Si:O) is of interest as it exhibits good tribological performance across a broader range of environments compared to hydrogenated amorphous carbon, and higher thermo-oxidative stability. However, the scientific basis for this improved behavior is not established. In this work, we develop fundamental understanding of structural transformations occurring in a-C:H:Si:O when sliding against steel in different environments (from high vacuum to controlled hydrogen and oxygen pressures). The results of tribological experiments revealed a transition from high friction to low friction upon leaking hydrogen and oxygen in the experimental chamber at a pressure of at least 50 mbar or 10 mbar, respectively. Imaging near edge X-ray absorption fine structure (NEXAFS) spectroscopic measurements of a-C:H:Si:O after tribological testing indicated that, independent of the gas, a conversion from sp3- to sp2-bonded (disordered) C-C bonds occurred. On the basis of NEXAFS results, we propose that when sliding in oxygen (hydrogen), the dissociative reaction of oxygen (hydrogen) molecules with strained sp2 C-C bonds resulted in the formation of carbonyl groups (hydrogenated carbon) at the sliding interface, which could explain the evolution of friction with gas pressure.

3 – 3:40 pm – Break

3:40 – 4 pm | Investigation of Adsorption Kinetics and Nanoscale Tribological Properties of Fatty Amines as Organic Friction Modifiers in Engine Lubrication

Prathima Nalam, University of Illinois Urbana Champaign, Champaign, IL, Veronica Castillo, Benoit Thiebaut, Total, Solaize Research Center, Solaize, France., France, Rosa Espinosa-Marzal, University of Illinois, Ubrana-Champaign, Urbana, IL

The performance of the final lubricant formulation as lubricants is in direct relationship with the performance of additives in petroleum products. Even if these additives can be evaluated by dedicated engine tests, these tests in fully formulated lubricants, engine tests are expensive, time-consuming and do not allow physical or chemical process to be assessed in relation with molecules properties. The developments of rapid but efficient screening methods are necessary for the formulation of high-quality lubricants and efficient additive selection. In this study we investigate the adsorption mechanisms for friction modifiers on steel surface using quartz crystal microbalance. The nature of the interaction, i.e. chemi- or physisorption, and the adsorbed mass on the steel surface is measured as a function of surfactant concentration in base oil. The additives showed formation of multiple layers in presence of excess surfactant in the base oil along with one strongly bound chemi-adsorbed layer at the steel interface. Friction behavior of the layers was explored in the absence of wear using lateral force microscopy and the friction coefficients were investigated. The relationship between concentration of additives in the solution and friction will be discussed. Further, the structure of the loosely-bound surfactant layers at the interface are investigated by compressing the layers using a sharp AFM tip.

4 pm – 4:20 pm | Growth Observation of ZnDTP Tribofilms on Different Nitrided Surface Layers and Evaluation of Their Antiwear Performances

Saiko Aoki, Takashi Yokoyama, Tokyo Institute of Technology, Tokyo, Japan, Yoshimi Konno, Hiroshi Yamamoto, KOMATSU Ltd., Kanagawa, Japan

Zinc dialkyldithiophosphate (ZnDTP) has been widely used as an antiwear and antioxidant additive ever since it was introduced more than seventy years ago. A lot of studies regarding the tribofilms derived from ZnDTP have been conducted and then many researchers have reported various structures of the tribofilms and mechanisms by which the tribofilm was formed on the steel substrate. On the other hand, steel materials for hydraulic motor and pomp are also subjected to some kinds of nitriding treatments to harden the steel surface and improve antiwear performance and seizure resistance of the materials. In nitriding treatments, nitrogen is introduced and diffused into the surface of steels, resulting in a marked improvement of fatigue and wear resistance. Although much attention has been directed to the effect of the nitriding treatment on hardness and antiwear performance of the steels, neither the friction and wear characteristics of the nitrided steels under lubrication with lubricant oil nor the interaction between lubricating additives such as ZnDTP and nitrided layer formed on steel surfaces are yet fully understood. In this study, the friction and wear characteristics of the nitrided steels having different nitrided layer under lubrication with ZnDTP-formulated oil were investigated and then the formation of ZnDTP tribofilm were evaluated using several kinds of surfaces analyses for clarifying the effect of the nitrided layer on the formation of the ZnDTP tribofilms.

4:20 – 4:40 pm | Tribo and Tribocorrosion Studies on Low Hydrogenated DLC Films Deposited on Ti6Al4V Using PECVD-DC Pulsed with Additional Cathode System

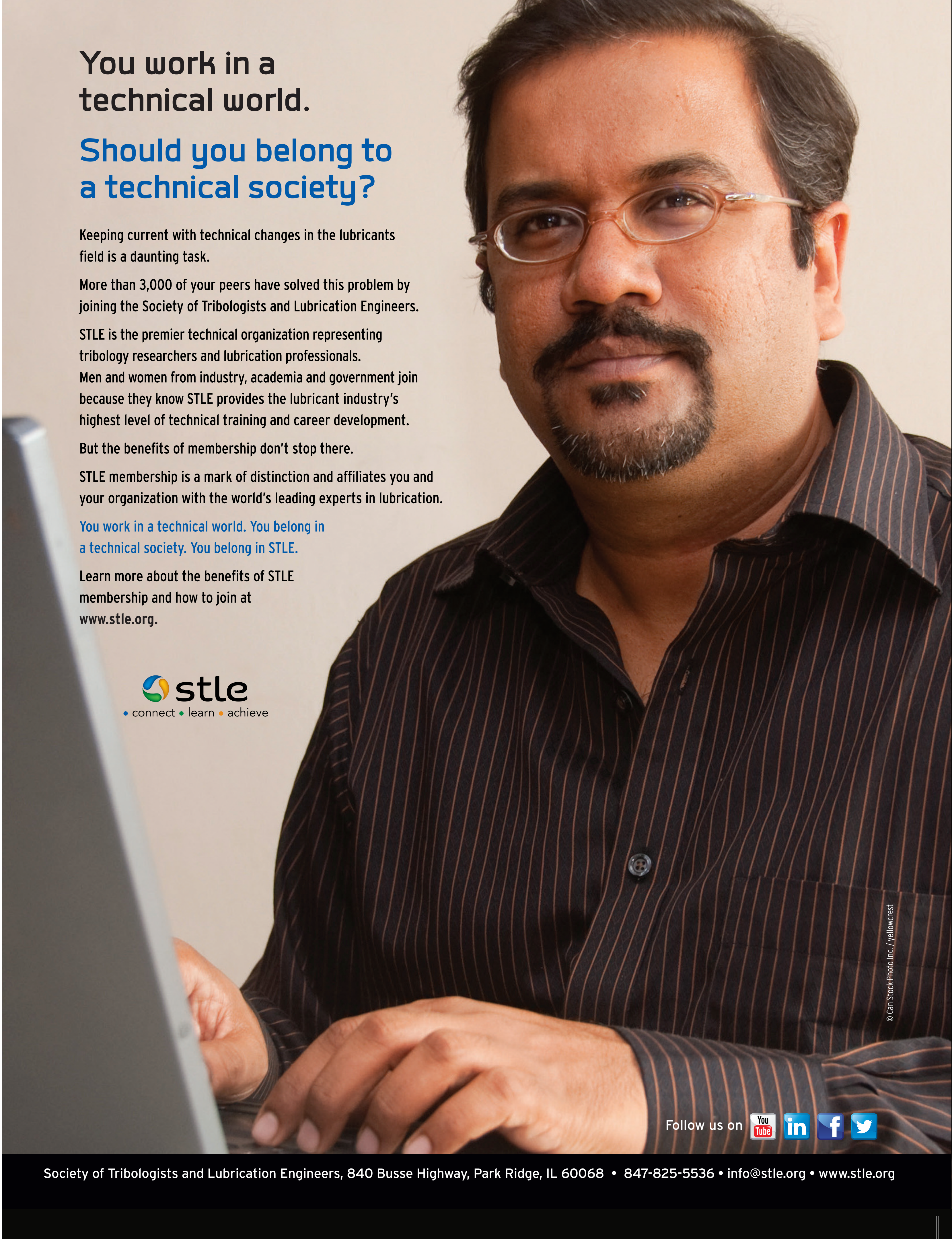
Polyana Alves Radi, Instituto Tecnológico de Aeronáutica-ITA, São José dos Campos, Brazil, Marco Ramirez Ramos, Instituto Nacional de Pesquisas Espaciais-INPE, Sao Jose dos Campos, Sao Paulo, Brazil, Angela Vieira, Universidade do Vale do Paraíba-UNIVAP, Sao Jose dos Campos, Sao Paulo, Brazil, Vladimir Jesus Trava-Airoldi, Instituto Nacional de Pesquisas Espaciais-INPE, Sao Jose dos Campos, Sao Paulo, Brazil, Homero Santiago Maciel, Lucia Vieira, Universidade do Vale do Paraíba-UNIVAP, Sao Jose dos Campos, Sao Paulo, Brazil

Ti-6Al-4V alloy is among the most corrosion-resistant materials used for implants, but the release of titanium, aluminum, and vanadium can cause poisoning and certain diseases, which can be aggravated with implant fretting and subsequent fracture [1,2]. DLC (Diamond-Like Carbon) films have been extensively studied due to their properties that can increase biocompatibility and protect the prosthesis from corrosion. Additionally, DLC coating can be used on Ti6Al4V prosthesis to prevent the substrate from eluting Al and V by plastic deformation and corrosion. In this paper low hydrogenated DLC films were growth under Ti6Al4V sample using the PECVD-DC pulsed with Additional Cathode system. The tribocorrosion behavior of the films was investigated in reciprocating mode in Ringers solution. The protective efficiency of the films were calculated and the results show that DLC films improved corrosion resistance the films. The coatings presented hardness around 20 GPa, also wear resistance and good adhesion. Raman analysis were performed before and after the tests. **Acknowledgments:** This work was supported by CNPq, CAPES, and FAPESP.

4:40 – 5:00 pm | Studying the Tribocorrosion Behavior of Duplex Stainless Steels in Chloride Media Using Spatially Resolved Friction and Electrochemical Measurement

J. Michael Shockley, Derek Horton, Kathryn Wahl, Naval Research Lab, Washington, DC

Stainless steels achieve good corrosion resistance through the formation of a passivated oxide layer, but sliding wear can remove this layer and greatly enhance material loss rates through corrosion and wear. Duplex stainless steels, containing both ferrite and austenite grains, are often used in moving parts exposed to seawater, yet a detailed understanding of their tribocorrosion behavior and the operating mechanisms is lacking. In the present study, a common duplex stainless steel was subjected to sliding wear while submerged in a chloride-containing salt solution. By performing friction and electrochemical measurements at a high sampling rate, evidence for depassivation and wear were resolved in time and space during testing. Complementary analysis, performed ex situ, correlated microstructural features to the resolved events to construct a mechanistic model of the tribocorrosion behavior.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9 – 9:40 am

Keynote Session IV – Grand Ballroom

Advanced Vehicle Technology Research, p. 42

Donald Hillebrand, PhD, Argonne National Laboratory

9:40 – 10:20 am

NETWORKING BREAK (Exhibits & Posters) – Grand Ballroom

	Session 4A Materials Tribology IV	Session 4B Surfaces & Interfaces IV	Session 4C Machine Elements & Systems III
Location	**Walton South**	**Walton North**	**Georgian Room**
TIME			
10:20 am	The Role of Microstructure and Chemical Composition in High Temperature Hardness of Iron-based Alloys, Hector Torres, p. 42	Towards a Unified Classification of Wear, Michael Varenberg, p. 43	Friction and Surface Damages of Rubbers Under Reciprocal Tangential Loading in Hydrogen, Joichi Sugimura, p. 44
10:40 am	Maximizing the Benefit of Aluminizing to Mg-3Al Alloy for Elevated Resistance to Wear and Corrosive Wear by Surface Nanocrystallization, Meisam Nouri, p. 42	Experimental Study of the Effect of Coating Thickness and Substrate Roughness on Turning Tool's Wear, Izhak Etsion, p. 43	Assessing Wear of Nuclear Fuel Claddings Using a Unique Autoclave Fretting Rig, Jun Qu, p. 44
11 am	Improve the Wear Resistance of Low-C Steel Via Tailoring Its Electron Work Function (EWF) Through Alloying with High-EWF Solute, Hao Lu, p. 42	Extending the Statistical Models at Nearly Completely Contact to Cover the Light and Medium Load Ranges, Yang Xu, p. 43	
11:20 am		Impulsive Pressures and Residual Stresses Induced By Cavitation Peenin, Daniel Nelias, p. 43	
11:40 am		Finite Element Modeling and Analysis of the Traction Behavior at the Interface of the Fraction Sheave and the Wire Rope, Xi Shi, p. 43	

	Session 4D Energy/Environment/Manufacturing I	Session 4E Fluid Lubrication III	
Location	**Venetian Room**	**Astor Room**	
TIME			
10:20 am	A Study of the Drivers that Lead to the Formation of White Etching Cracks in Bearing Steel, Benjamin Gould, p. 44	The Effect of Helical Groove Geometry on the Selected Journal Bearings Static Characteristics, Jaroslaw Sep, p. 45	
10:40 am	The Effect of Impact on Bearing Wear and White Etch Cracking, Brandon Strahin, p. 44	A Detailed Study of the Frictional Response of Textured Piston Ring-Cylinder Liner Contacts, Daniele Dini, p. 45	
11 am	Investigation of Premature Bearing Failures in Wind Turbine Gearboxes, Harpal Singh, p. 45	Systematic Steady-State Hydrodynamic Analysis of a High Performance Textured and Profiled Journal Bearing, Thomas Gu, p. 45	
Noon	Lunch On Your Own	Lunch On Your Own	Lunch On Your Own

Time	Session 5A Materials Tribology V	Session 5B Surfaces & Interfaces V	Session 5D Energy/Environment/Manufacturing II
Location	Walton South	Walton North	Venetian Room
1:20 pm	Electron Work Function: A Promising Parameter For Tribological Studies, Dongyang Li, p. 46	Surface Characterization Using Atomistic Models of Amplitude Modulation Atomic Force Microscopy, Xiaoli Hu, p. 47	Quo Vadis Engine Oil: The Development From Internal Combustion Engines to Electromobility, Wilfried Bartz, p. 50
1:40 pm	Surface Characterization of Laser Engineering NetShaping Processed 316 Stainless Steel, John Shelton, p. 46	Achieving Macroscale Superlubricity with 2D Materials Through Nanoscale Catalytic Reaction at the Tribological Contact, Anirudha Sumant, p. 47	Surface Modification with Quasicrystals (QC) and Friction Stir Processing (FSP), Oyelayo Ajayi, p. 50
2 pm	The importance of Spectrum or Actual Loading in Milled MoS2 Powder Greases Using Four Ball Wear Test, Gabi Nehme, p. 46	Structural Evolution of Nanoscale Silicon Asperities Under Load, Sai Bharadwaj vishnubhotla, p. 47	Effect of Minimum Quantity Lubrication Aerosol Temperature on Surface Roughness in Machining AISI P20 and D2 Steels Using Coated Tungsten Carbide Tool Inserts, Amal Senevirathne, p. 50
2:20 pm	Influence of Nanoadditive on the Wear and Friction Characteristics of Aluminium Alloy 7075 Under Boundary Lubricated Conditions, Ankush Anand, p. 46	The Effect of Surface Texture on Lubricated Fretting, Pawel Pawlus, p. 48	Optimization of Laser Surface Texturing With Nanolubricants, Demofilo Maldonado Cortés, p. 50
2:40 pm	Innovative Development of Coatings for Polymer Injection, Nicoleta Crisan, p. 47	Tuning Wetting Properties of Aluminum Surface, A.V. Aravind, p. 48	The Tribology of Zirconium Oxide: Dry Sliding Under Severe Service Conditions, Catalin Pruncu, p. 51
3 pm	Break	Break	Break
3:40 pm		Measurement of Nanoscale Topography Using the Transmission Electron Microscope, Subarna Khanal, p. 48	Formulation Challenges and Performance Testing for Environmentally Acceptable Lubricants, Don Satchell, p. 51
4 pm		Wear of Carbon Overcoat Subjected to Laser Heating in an Inert Gas Environment During Heat-assisted Magnetic Recording, Norio Tagawa, p. 48	
4:20 pm		Rolling Contact Fatigue Resistance of Austempered Ductile Iron Processed at Various Austempering Holding Times, Minsheng He, p. 49	
4:40 pm		Experimental and Numerical Analyses of Localized Wear and Friction of Tool Steels During Micro-scale Reciprocating Tests, Newton Fukumasu, p. 49	
5 pm		In-situ Observation of Grain Structures During Scuffing of Steel by Synchrotron X-ray Diffraction, Kazuyuki Yagi, p. 49	
5:20 pm		Control of Frictional Damping by Geometry and Load Fluctuations, Lejie Liu, p. 49	

Keynote Session IV } Grand Ballroom

9 – 9:40 am | Advanced Vehicle Technology Research

Donald Hillebrand, PhD, Argonne National Laboratory

This talk will address the topic of advanced vehicle technologies with an assessment of the state of the research. It will explore promising new technology paths including the electrification of the automobile, the smart grid, advanced combustion, and the impact of autonomous technologies on energy consumption. The talk will be a critical look at the new technologies and will address the shortcomings and strengths of advanced vehicle technology currently being researched.

9:40 – 10:20 am • Break • Grand Ballroom

Session 4A } Walton South

Materials Tribology IV

Session Chair: Amir Rostami, Georgia Institute of Technology, Atlanta, GA

10:20 – 10:40 am | The Role of Microstructure and Chemical Composition in High Temperature Hardness of Iron-based Alloys

Hector Torres, Markus Varga, Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria

High temperature hardness is one key parameter for determining the wear resistance of components operating at elevated temperatures. This study is centred on the high temperature hardness behaviour of iron-based alloys with various microstructures and chemical compositions by relying on measurements performed at the Austrian Competence Center for Tribology (AC2T research GmbH) during several years. The results show the existence of several softening regimes with increasing temperature. In particular, a significant hardness drop starting close to 0.4 times the melting temperature was found for most of the selected alloys. An additional softening regime at lower temperatures has been observed for austenitic alloys. This is similar to what has been reported in deformation mechanism maps for fcc materials, attributed to the low lattice resistance to dislocation glide. The temperature dependence shown by hardness is discussed in this context and the two most widely cited hardness models are critically reviewed. Additionally, from an engineering point of view, chemical elements such as molybdenum or boron have been linked to the slow softening behaviour shown by several iron-based alloys. Carbide-forming elements such as vanadium and tungsten were found to be beneficial for room temperature hardness.

10:40 – 11 am | Maximizing the Benefit of Aluminizing to Mg-3Al Alloy for Elevated Resistance to Wear and Corrosive Wear by Surface Nanocrystallization

Meisam Nouri, Dongyang Li, University of Alberta, Edmonton, Alberta, Canada

Low resistances of Mg to corrosion and wear are parts of the barrier to extended applications of Mg alloys in industry. Surface modification is an effective approach for improving surface properties of the materials. Among various surface modification techniques, aluminizing is an economical and effective one, which has been applied to various metallic materials for increased resistances to oxidation, erosion, wear, and corrosive wear. The effectiveness of aluminizing can be further enhanced by surface nanocrystallization. In this work, effects of surface nanocrystallization on the effectiveness of aluminizing in enhancing the resistance of Mg-3Al alloy to corrosion, wear and corrosive wear were investigated. Results of the investigation demonstrate that aluminizing is effective to increase the resistance of the Mg alloy to wear, corrosion and corrosive wear. Surface nanocrystallization maximizes the benefits, largely attributed to improved passivation capability and associated passive film.

11 – 11:20 am | Improve the Wear Resistance of Low-C Steel Via Tailoring Its Electron Work Function (EWF) Through Alloying with High-EWF Solute

Hao Lu, Xiaochen Huang, Dongyang Li, University of Alberta, Edmonton, Alberta, Canada

Recent studies have demonstrated that electron work function (EWF) is directly related to intrinsic properties of metallic materials and could be used as an alternative parameter to guide designing materials. A higher EWF corresponds to a more stable electronic state, leading to higher resistance to any attempt to change the material structure and corresponding properties caused by mechanical and electrochemical actions. In this study, effects of Ni as a solute component, which has a high EWF, on resistance of low-C steel to dry sliding wear and corrosive wear in a dilute sodium chloride solution were investigated. It was demonstrated that adding Ni brought more valence electrons to the steel, resulting in enhanced electrons-nuclei interactions and consequently elevated atomic bond strength and higher corrosion resistance. As a result, the resistance of the steel to wear and corrosive wear was markedly improved. The mechanism for the improvement elucidated through analyzing EWF-related variations in Young's modulus, hardness, corrosion potential, friction and adhesive behavior as well as wear track observations. This work demonstrates a new approach or methodology for development of metallic tribo-materials on a feasible electronic base.

Session 4B } Walton North

Surfaces & Interfaces IV

Session Chair: Michael Varenberg, Georgia Institute of Technology, Atlanta, GA

Session Vice Chair: Daniel Nelias, University of Lyon, Villeurbanne, France

10:20 – 10:40 am | Towards a Unified Classification of Wear

Michael Varenberg, Georgia Institute of Technology, Atlanta, GA

Since the beginning of the systematic study of wear, many classification schemes have been devised. However, though covering the whole field in sum, they stay only loosely connected to each other and do not build a complete general picture. To this end, here we try to combine and integrate existing approaches into a general simple scheme unifying known wear types into a consistent system. The suggested scheme is based on three classifying criterions answering the questions "why," "how" and "where" and defining a 3-D space filled with the known wear types. The system can be used in teaching to introduce students to such complex phenomena as wear and also in engineering practice to guide wear mitigation initiatives.

10:40 – 11 am | Experimental Study of the Effect of Coating Thickness and Substrate Roughness on Turning Tool's Wear

Izhak Etsion, Technion, Haifa, Israel, Meir Bar-hen, Iscar, Tefen, Israel

The effect of coatingS thickness and substrate roughness on the tool wear in turning is studied experimentally. TiAIN coating of various thicknesses is applied on tungsten carbide (WC) insert substrate having various surface roughnesses. The tool wear is measured following a fixed cutting distance and speed tests. In general, when plotting the wear vs. coating thickness alone or vs. substrate roughness alone a trend of decreasing wear with either increasing coating thickness or reducing substrate roughness is observed. However, the scatter of the results is very large. On the other hand, excellent fit is obtained when the wear results are plotted vs. the dimensionless ratio t/Rsu where t is the coating thickness and Rsu is the average radius of curvature of the rough substrate asperities. Hence, this ratio can provide good prediction for tool wear.

1 – 11:20 am | Extending the Statistical Models at Nearly Completely Contact to Cover the Light and Medium Load Ranges

Yang Xu, Robert Jackson, Auburn University, Auburn, AL

In a recent paper *(Xu et al., 2014, Int. J. Solids. Struct., 51, pp. 1075-1088),* Xu et al. developed a statistical approach under the framework of the Greenwood and Williamson(GW) model to determine the real area of contact and the average interfacial gap at nearly complete contact (where the real area of contact is nearly the same as the nominal contact area). In the current study, this statistical model is extended to predict the real area of contact at the light and medium load ranges as well. A weighting function is used to adjust the statistical model at nearly complete contact to approximate the solution at the lower load ranges. The numerical model developed by Polonsky and Keer (1999) as well as the other analytical models (e.g., the Persson model) are used to confirm the aforementioned approximation. The groups of self-affine rough surfaces(each contains many different realizations) associated with various cut-off frequencies and the Hurst dimensions are generated. The comparisons between the real area of contact from the current approximated model and the numerical model are shown. The difference is also discussed to guide the future improvement of the current model.

11:20 am – 11:40 am | Impulsive Pressures and Residual Stresses Induced By Cavitation Peenin

Daniel Nelias, Emmanuel Sonde, Thibaut Chaise, University of Lyon, Villeurbanne, France, Vincent Robin, AREVA, Lyon, France, Nicolas Boisson, University of Lyon, Villeurbanne, France, Cyril Mauger, CNRS, INSA Lyon, LMFA, University of Lyon, Villeurbanne, France

Cavitation peening is a surface treatment method which is used to introduce superficial compressive residual stresses in metallic materials, in order to delay the initiation and propagation of cracks. During this process, a high-speed submerged water jet creates cavitation bubbles whose collapse and impacts on the surface induce high loading pressure and thereby plastic deformation in the material. This method is known to provide a better surface finish than that of the conventional shot peening with less roughness. To study the cavitation peening, CFD simulations are run to localize the cavitation zone, then the two possible types of loading pressure are compared. Firstly, the pressure wave emitted during the collapse of a spherical cavitation bubble is determined by simple cavitation model and in a second time, fluid mechanics calculations are performed to simulate the micro-jet impact resulting from the collapse of cavitation bubble near the surface. Finally, these impulsive pressures are used as loading conditions for a mechanical calculation to obtain the residual stresses.

11:40 – 12 pm | Finite Element Modeling and Analysis of the Traction Behavior at the Interface of the Fraction Sheave and the Wire Rope

Xi Shi, Yalu Pan, School of Mechanical Engineering Shanghai JiaoTong University, Shanghai, China

Due to the geometrical complexity of the contact between traction sheave and the wire ropes, the traction behavior at the interface is hard to observe and analyze in practice, thus it is not well understood and need further study. In this paper, a 3D FE model of a seven-wire strand in contact with a traction sheave are developed to investigate the dynamic traction and slip mechanism. Two appropriate diameters of traction sheave(D) and wire ropes(d), which are smaller than the full size, are considered to make sure that the diameters ratio(D/d) remains unchanged. FEM analysis results indicate that an ascending discrete normal pressure distribution is attained along the sheave contact arc( ), which is from the entrance of contact interface(θ=0) to the exit($\theta=\pi$).

Similarly, the slip spots are seldom found at the contact entrance and mostly occur at the exit. Meanwhile, the different effects of D/d ratio, the rope groove angle, coefficient of friction of the traction area, the preloaded forces of ropes and the load moment are explored and discussed.

Session 4C } Georgian Room

Machine Elements & Systems III

Session Chair: Harpal Singh, Sentient Science Corp, Idaho Falls, ID

Session Vice Chair: Aaron Greco, Argonne National Laboratory, Argonne, IL

10:20 – 10:40 am | Friction and Surface Damages of Rubbers Under Reciprocal Tangential Loading in Hydrogen

Joichi Sugimura, Hiroyoshi Tanaka, Kazumi Okada, Tetsuo Yamaguchi, Kyushu University, Fukuoka, Japan

This paper describes an experimental study on surface damages of rubber for seals under repeated tangential loading in hydrogen gas. Reciprocating sliding tests are conducted with some rubbers and stainless steel in hydrogen, air and in vacuum by using a pin-on-disk type friction test rig. The rubbers do not virtually slip and do not suffer from surface damage under smaller amplitude. At larger amplitude, cracks at trailing edge of the contact area develop and lead to removal of materials from the surface. It is found that the number of reciprocating cycles for this cracking to occur depends on material, surrounding gas, and the tangential stress at the critical points for onset of sliding.

10:40 – 11 am | Assessing Wear of Nuclear Fuel Claddings Using a Unique Autoclave Fretting Rig

Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, George Plint, Phoenix Tribology Ltd, Hampshire, United Kingdom, Roger Lu, Westinghouse Electric Company, Hopkins, SC, Peter Blau, Blau Tribology Consulting, Enka, NC

In pressurized water nuclear reactors, grid-to-rod-fretting (GTRF) may lead to wear-through of the fuel cladding wall and leakage of radioactive species. In order to investigate the important GTRF wear concern, an autoclave-enclosed fretting bench tribometer (AFBT) has been designed and fabricated to allow tests in a pressurized water environment with testing temperature up to 220˚C under up to 24 bars of pressure. The fretting test uses actual cladding-grid pairs under simulated contact stress and motion frequency and amplitude. Here, initial fretting wear results using the AFBT are presented for the wear of Zr alloy cladding material, both self-mated and against stainless steel specimens, and with several contact geometries. The influences of the water temperature, contact force, and oscillation frequency on the wear behavior have also been explored. The experimentally-determined wear coefficients have been used to train a stage-wise GTRF engineering model to allow correlations with in-reactor experience for predicting the trend of cladding lives.

Session 4D } Venetian Room

Energy/Environment/Manufacturing I

Session Chair: Aaron Greco, Argonne National Laboratory, Argonne, IL

Session Vice Chair: Benjamin Gould, University of Delaware, Wilmington, DE

10:20 – 10:40 am | A Study of the Drivers that Lead to the Formation of White Etching Cracks in Bearing Steel

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

White etching cracks (WECs) have been identified as the dominant mode of premature failure for bearings within wind turbine gearboxes. Though WECs have been observed in the field for over a decade, the exact mechanisms which lead to this failure are still debated. Sliding at the contact, load, lubricant chemestry, and electrical discharge across the contact have all been identified as potetial drivers of WEC formation. In this paper, WECs have been replicated on a three rings on roller, benchtop test rig, which allowed for a direct investigation into the influence that some of the above listed postulated drivers have on surface failures and WEC generation. It was determined that the formation of WECs within test samples can be turned on and off by varying the afformentoned drivers.

10:40 – 11 am | The Effect of Impact on Bearing Wear and White Etch Cracking

Brandon Strahin, Haifeng Qin, Gary Doll, The University of Akron, Akron, OH

Smearing wear, radial cracking, and subsurface cracking that gives rise to white etching areas are life-limiting issues encountered by cylindrical roller bearings that support the high speed output shafts in wind turbine gearbox bearings. Evidence has been offered that these effects can be attributed to large and rapid shaft displacements caused by torque reversals in the gearbox. This study reports the results of two experiments designed to probe the relationships between impact forces and stress cycles on the initiation of smearing wear and subsurface fracture that can give rise to white etching areas. In the first experiment, a custom impact tribometer was designed that produces high stress, high cycle impacts on flat steel specimens. This experiment produces smearing, radial cracking, and white etching areas in AISI 52100 steel specimens as a function of contact stress and the number of impacts. Results of these experiments were then used as testing parameters for the second experiment, a bearing tribometer utilizing commercially available NU306 cylindrical roller bearings operating at 1800 rpm that are exposed to a series of load reversals that rapidly change the load zone of the bearing by 180 degrees. Collectively, data gleaned from these experiments may be used to predict wear modes encountered by wind turbine gearbox bearings.

11 – 11:20 am | Investigation of Premature Bearing Failures in Wind Turbine Gearboxes

Harpal Singh, Raja Pulikollu, Sentient Science, Buffalo, NY, Wayne Hawkins, Tennessee Tech University, Cookeville, TN, Gregory Smith, NextEra Energy, Port Saint Lucie, FL

Wind turbine drive system failures have been the major source of down time and costly repairs. It is well known that the gearboxes are prone to premature failure although they are designed to meet 20 years of operational life. The lifespan of gearboxes depends on the turbine design, supplier quality, maintenance practices, and site operating conditions. Bearings and gears are the most critical components associated with gearbox durability. According to gearbox reliability collaborative, the majority of the gearbox issues result from premature bearing failures from axial cracks, wear and pitting/spalling. The major cause of failure in bearings is related to white etching matter. In this work, we have examined the failed bearings collected from various sites to study the cause of white etched areas. This analysis will help in better understanding of white etching matter formation to develop promising solutions for wind turbine gearboxes.

Session 4E } Astor Room

Fluid Lubrication III: Textured Lubricated Contacts

Session Chair: Noel Brunetiere, University Poitiers, Chasseneuil, France

Session Vice Chair: Jonathan Raisin, Total Marketing & Services, Province France

10:20 – 10:40 am | The Effect of Helical Groove Geometry on the Selected Journal Bearings Static Characteristics

Jaroslaw Sep, Lidia Galda, Leszek Tomczewski, Rzeszow University of Technology, Rzeszow, Poland

The hydrodynamic bearings could suffer serious damage operating in contaminated environments or under starved lubrication conditions. In such situations the hydrodynamic bearings with journal having helical groove are less sensitive to damage than plain bearings. Contaminants are moved out from the contact zone by the grooves created on the journal surface. The shape, geometry and dimensions of the groove strongly influenced the bearings performance. However, only a few publications considered the static characteristics of grooved journal bearings lubricated by the clean oil. The aim of this paper is to present the selected static characteristics of hydrodynamic bearing consisting of the journal with the helical groove on its surface. The static characteristics were determined based on the flow simulation in an oil clearance. Three-dimensional, adiabatic model of the oil flow was assumed. The oil flow was described with the Navier-Stokes, continuity and energy equations. The equation system was solved by the finite volume method. The numerical model of the flow was verified experimentally on the test stand. It has been stated that the groove existence resulted in a 20% reduction in load carrying capacity, but also provided over two-times decrease in bearing wear in the case of the abrasive particles presence in the oil. The results of investigations also showed that the groove cross section area and the helical groove lead affected the bearings static characteristics.

10:40 am – 11 am | A Detailed Study of the Frictional Response of Textured Piston Ring-Cylinder Liner Contacts

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

Recent experiments carried out by the authors have shown that automotive piston-liner friction may be reduced by up to 50% if the surface of the liner is laser textured with certain configurations of micro-pockets. It is important to model this behaviour to understand and optimise the friction reduction mechanisms that are occurring. However, until now, very few models that predict the lubrication performance of textured surfaces have been successfully validated against experimental data. This is due to the requirement for them to (i) reproduce experimental configurations with a certain degree of fidelity, (ii) conserve mass properly, and (iii) account for transient effects and different lubrication regimes. To address this, the current paper presents a comparison between the results from a newly developed numerical model, which fulfils these criteria, and an experimental test rig operating under the same conditions. The focus of this conribution is on the mechanisms responsible for the behaviour of individual pockets as they are swept through the contact.

11 – 11:20 am | Systematic Steady-State Hydrodynamic Analysis of a High Performance Textured and Profiled Journal Bearing

Thomas Gu, Northwestern University, Chicago, IL, Arup Gangopadhyay, Zak Liu, Ford Motor Company, Dearborn, MI, Qian Wang, Northwestern University, Chicago, IL

Textured journal bearings have long confounded researchers and designers due to their inconsistent performance. In literature, experimental and simulation work have been reported on both fully textured and partially textured journal bearings; however, the overall design is still not clear. This uncertainty is largely due to the fact that there are numerous conflicting results in literature by which adding textures yields beneficial results in some studies but negative results in others. Therefore, a systematic numerical study is needed. The current research focused on achieving an in-depth understanding of texture placement and parameters via solving the steady-state hydrodynamic Reynolds equation. Specifically, the load capacities and friction coefficients of the textured bearings of different dimensions and operating conditions are analyzed and compared with those of smooth bearings to indicate performance enhancements. Fundamental trends have been identified, which should shed light on the optimal texture placement and the best parameters to maximize bearing performance. In addition to this, various journal profiles have been combined with these optimal texture configurations to further enhance journal bearing lubrication performance.

Session 5A } Walton South

Materials Tribology V

Session Chair: Ali Beheshti, Lamar University, Beaumont, TX
Session Vice Chair: Philip Egberts, University of Calgary, Calgary, AB

1:20 – 1:40 pm | Electron Work Function: A Promising Parameter For Tribological Studies

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

Electron work function (EWF) is the minimum energy required to move electrons at Fermi level from inside a metal to its surface without kinetic energy. This parameter reflects the stability of electrons in solids and thus related to the atomic bonding strength and consequently the mechanical and electrochemical properties of materials. Such relationships make it promising to get insight into tribological phenomena and elucidate mechanisms behind using electron work function as an indicator or probing parameter. In this talk, a brief overview of the correlations between EWF and material properties will be provided, mainly on mechanical and electro - chemical properties. Based on the correlations, applications of EWF in research on tribological phenomena and material performance will be demonstrated. The following aspects will be discussed: EWF of materials and corresponding adhesive behavior and friction. EWF and the resistance to wear, corrosion and corrosive wear. EWF of nanocomposites and corresponding properties and wear behavior. EWF of some ceramic materials and their wear behavior.

1:40 – 2 pm | Surface Characterization of Laser Engineering NetShaping Processed 316 Stainless Steel

John Shelton, Iman Salehinia, Federico Sciammarella, Northern Illinois University, DeKalb, IL

As progress continues to be made in the development of material property benchmarks for the additive manufacturing (AM) process, there is still a need for development of more robust process-property-structure relationships. One of the properties that has received little attention in this regard is surface topography. A better understanding of the overall surface roughness and areal surface texture characteristics of polished AM materials will help better determine how these materials could potentially wear under various loading conditions. In this investigation, a coherent light interferometer is used to perform surface roughness measurements and determine areal surface texture characteristics of a polished AM 316 stainless steel manufactured at the Advanced Research of Materials and Manufacturing Laboratory located at Northern Illinois University. The 316 stainless steel was built using the Laser Engineered NetShaping (LENS) process according to a distribution of process parameters that include: a) laser power, b) powder feed rate, and c) travel speed.

2 – 2:20 pm | The importance of Spectrum or Actual Loading in Milled MoS_2 Powder Greases Using Four Ball Wear Test

Gabi Nehme, University of Balamand, Koura, Lebanon North, Lebanon

The relationship between the milled and unmilled MoS_2 (molybdenum disulfide) greases to its tribological properties such as coefficient of friction, wear and chemical-mechanical properties of tribofilms is examined for constant extreme pressure loading and spectrum loading using four ball test with chromium steel ball bearing quality and aircraft grade E52100. In this study, A series of tests were conducted for all loading conditions after heating the grease to 75°C and applying the desired load and speed via Plint four-ball wear tester (Model number TE92) software where a program is written for each condition to adjust for the speed and loading. Design of Experiments (DOE) approach was used to analyze the different loadings and speeds at a specific duration of 36000 revolutions to examine the lithium base grease wear behavior with milled and unmilled molybdenum disulfide (MoS_2) powder. Results indicated that ball milled MoS_2 grease tests showed significant improvement in the wear behavior and friction coefficient under all conditions especially spectrum or actual loading. Unmilled MoS_2 powder exhibited worse wear outcomes than the milled one. SEM (scanning electron microscopy) with EDS (energy dispersive spectroscopy) analysis of the actual loading tribofilms indicate that a protective tribofilm is formed on the wear surface of the milled powder grease initially at lower loads in the ramp-up tests that protects the wear surface from wear and abrasion at higher loads.

2:20 – 2:40 pm | Influence of Nanoadditive on the Wear and Friction Characteristics of Aluminium Alloy 7075 Under Boundary Lubricated Conditions

Ankush Anand, MIR IRFAN UL HAQ, Ankush Raina, SMVD UNIVERSITY, JAMMU, Jammu and Kashmir, India, Mohammad Wani, National Institute of Technology, Srinagar, Jammu and Kashmir, India

Aluminium alloy AA 7075 due to its high strength to weight ratio finds tremendous applications in automotive and aerospace industry. The sliding wear characteristic of this alloy needs to be thoroughly investigated so as to enhance its performance under different operating conditions. In this work, friction and wear characteristics of aluminium alloy AA 7075-T6 were investigated by using nano-Al2O3 as an additive in SAE 20W40 lubricant. The experiments were performed on pin-on-disc tribometer with EN 31 steel as the counterface material. The results were obtained for nano additive concentrations of 1 wt%, 2 wt% and 3 wt% corresponding to the different loads and speeds within the boundary lubrication regime. The coefficient of friction and wear volume reduced significantly with the use of nano lubricant additives in comparison to the base oil. To interpret the possible mechanisms of anti-friction and anti-wear with nanoparticles SEM and EDS analysis was performed.

2:40 – 3 pm | Innovative Development of Coatings for Polymer Injection

Nicoleta Crisan, Sylvie Descartes, Philippe Sainsot, Yves Berthier, INSA Lyon, Univ Lyon, Villeurbanne, France, David Baud, Centre Technique de la Plasturgie et des Composites, Bellignat, France, Caroline Chouquet, DMX, Cluses, France

Injected plastic parts with high level of surface quality are more and more desired in areas such as luxury, packaging, automotive, medical and optics. The key in developing optimal surface molds that can overcome the present disadvantages lies in the comprehension of the interactions that occur at the mold/injected piece interface. Our study established a critical characterization of the non-coated surfaces and surfaces coated with the developed protective coatings suitable for the polymer injection process. The first step [2] allowed to study the corrosion-mechanical and the mechanical-physico-chemical phenomena and to identify the contact conditions at the non-coated mold/injected piece interface. The effects of the polishing, of the mold geometry and of the injected material was taken into account [2]. The second step developed specific coatings, while the contact conditions have been identified in the step 1, to overcome the problems generated by tangential (injection) and normal (ejection) effects. The beneficial effect of the considered coatings in preserving a high quality of the mold surfaces has been highlighted. This study was performed as part of the collaborative research project POLIREV (FUI). Thanks are due to competitiveness clusters Arve Industries and Plastipolis, “Conseil régional de l’Ain”, “Conseil régional Franche-comté”, “Région Rhone-Alpes”, for their financial support.

3 – 3:40 pm – Break

Session 5B } Walton North

Surfaces & Interfaces V

Session Chair: Aburydha Sumant, Artonne National Laboratory, Argonne, IL

Session Vice Chair: Melih Eriten, University of Wisconsin-Madison, Madison, WI, Ahmet Usta, University of Wisconsin-Madison, Madison, WI

1:20 – 1:40 pm | Surface Characterization Using Atomistic Models of Amplitude Modulation Atomic Force Microscopy

Xiaoli Hu, University of California Merced, Merced, CA, Nicholas Chan, Philip Egberts, University of Calgary, Calgary, Alberta, Canada, Ashlie Martini, University of California Merced, Merced, CA

Amplitude modulation atomic force microscopy (AM-AFM) is an important and powerful tool for high resolution imaging of a wide variety of surfaces. It has been suggested that wear is one of the main factors that can hinder the reliable performance of probes in atomic force microscopy, including the widely used AM-AFM mode. In this work, molecular dynamics simulations are employed to model the process of using AM-AFM to characterize surface features. The effect of tip shape and size on topography measurement is analyzed using the model complemented by experimental AM-AFM results. In addition, surfaces with different features are studied to explore how and what properties can manifest themselves in terms of AM-AFM amplitude and phase shift. These results may enable better understanding of the data obtained from AM-AFM measurements.

1:40 – 2pm | Achieving Macroscale Superlubricity with 2D Materials Through Nanoscale Catalytic Reaction at the Tribological Contact

Anirudha Sumant, Diana Berman, Badri Narayanan, Subramanian Sankaranarayanan, Ali Erdemir, Argonne National Laboratory, Argonne, IL

In our previous studies, we have demonstrated that the new superlubricity mechanism at macroscale by combined uses of graphene mixed with nanodiamonds sliding against diamond-like carbon (DLC) [1]. In the present study, we show that other two dimensional (2D) layered materials such as molybdenum disulfide (MoS2) and boron nitride (BN) are also capable of demonstrating superlubricity through unique catalytic reaction with carbon leading to formation of onion-like carbon (OLC) at the tribological contact. We have observed that beyond some initial run-in period, the friction comes down to some un-measurable levels and maintains in that state for a very long period of time. Our initial experimental and theoretical investigations suggest that formation of OLCs is possible through catalytic reaction with these 2D materials that could occur at the tribological contact due to high contact pressure. We will discuss the detailed mechanism and highlight the similarities and differences with the previously demonstrated superlubricity mechanism involving graphene-nanodamond ensembles. This new discovery broadens the fundamental understanding of frictional behavior of 2D materials beyond graphene and opens a wide range of possibilities for implementing them in mechanical and tribological applications involving static, sliding, and rotating contacts.

References: 1. Berman, Deshmukh, Sankaranarayanan, Erdemir, and Sumant, Science, 348, 6239, 1118 (2015)

2 – 2:20 pm | Structural Evolution of Nanoscale Silicon Asperities Under Load

Sai Bharadwaj vishnubhotla, University of Pittsburgh, Pittsburgh, PA, Subarna Khanal, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, Xiaoli Hu, University of California-Merced, Merced, CA, Ashlie Martini, University of California Merced, Merced, CA

Understanding the behavior of contacts between nanoscale bodies is critical for probe-based microscopy, nanomanufacturing, and nanodevices. However, many of the assumptions of continuum contact models are violated at these length scales. Therefore, contact properties such as the adhesion force between the surfaces, deformation of the near-surface material, and “true” size of the contact region are difficult to predict and control. Here we use matched experiments and simulations to quantitatively investigate single, nanoscale asperities of silicon and diamond during formation, loading, and separation of contact. Experimentally, we use transmission electron microscopy to pre-characterize the shape and structure of the contacts, and then to perform the loading tests. We perform molecular dynamics simulations on identical nanocontacts that are precisely matched in terms of materials, geometry, and loading conditions. The deformation and apparent area of contact under load are analyzed and compared to continuum contact mechanics models. Also, the evolution of the shape and structure of the nanoasperity during the loading and unloading processes is characterized.

2:20 – 2:40 pm | The Effect of Surface Texture on Lubricated Fretting

Pawel Pawlus, Rzeszow University of Technology, Rzeszow, Poland, Agnieszka Lenart, Heli-One, Jasionka, Poland, Andrzej Dzierwa, Slawomir Wos, Rzeszow University of Technology, Rzeszow, Poland, Rafal Reizer, University of Rzeszow, Rzeszow, Poland

The term fretting denotes a small oscillatory movement between contacting surfaces. Fretting is a dynamic process therefore the initial surface topography is an important factor influencing sliding condition. However only a few works were concerned with study of the effect of surface roughness on lubricated fretting. Experiments were made using Optimol SRV5 ball-on-disc tribotester. 100Cr6 sphere co-acted with a disc made of 42CrMo4 steel under lubricated conditions. The lubricant used was SAE 40 oil SUPEROL. During tests, the coefficient of friction was monitored as a function of time. Wear of disks and balls was measured after the test using white light interferometer. Disc surfaces were prepared by various techniques, including milling, vapour blasting, polishing and grinding. Temperature inside the chamber was 30oC. Normal loads, amplitudes and frequencies varied. We found that disc surface texture affected coefficient of friction. For 45 N normal load, 0.05 mm displacement amplitude and 80 Hz frequency due to roughness height, defined by the Sq parameter, increase from 0.01 µm to 1.9 and 2.9 µm the coefficient of friction decreased from 0.17 to 0.14.

2:40 – 3 pm | Tuning Wetting Properties of Aluminum Surface

A.V. Aravind, Ahalapitiya Jayatissa, Sorin Cioc, University of Toledo, Toledo, OH

Aluminum is a widely used metal for numerous applications because of its mechanical properties and sometimes for its surface properties. However it is important to investigate suitable surface modification methods for tuning the surface wetting properties of aluminum. Numerous investigations have been carried out, such as electrochemical treatment, laser treatment and coating of low surface energy materials. However, the application of these processes in large area devices is very challenging. Thus, a simple and low cost technique is important from the view point of practical applications. In this investigation we have treated Aluminum surfaces with an acid solution to change the surface wetting properties. The untreated aluminum has contact angle of ~30o; after a treatment with oxalic acid solutions it can be converted to a hydrophobic surface (contact angle 90˚). In this presentation, we will detail our experimental investigations. For example the results show that the temperature as well as treatment time are important parameters of this process.

3 – 3:40 pm – Break

3:40 – 4 pm | Measurement of Nanoscale Topography Using the Transmission Electron Microscope

Subarna Khanal, Abhijeet Gujrati, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Nanometer- and Angstrom-scale topography can be challenging or impossible to determine using conventional surface analysis techniques. While scanning probe microscopy can achieve atomic-lattice resolution for very flat surfaces, it is fundamentally limited in its measurement of rough surfaces by the geometry of the tip. For many experimental surfaces, this precludes accurate measurement of topography at the single-nanometer-scale or below. Yet analytical models predict a significant effect of roughness at these scales on adhesion and other contact properties. Here we demonstrate a technique for the characterization of quantitative surface topography down to the Angstrom-scale using transmission electron microscopy (TEM). Two-dimensional surface profiles can be obtained from direct side-view imaging of a thin specimen with quantitative image analysis routines. Then, the statistics of the three-dimensional surface can be reconstructed through mathematical analysis of two-dimensional profiles. Sample preparation, material limitations, and detection/elimination of artifacts will be presented. Overall, this technique significantly expands the range over which rough-surface topography can be determined.

4 – 4:20 pm | Wear of Carbon Overcoat Subjected to Laser Heating in an Inert Gas Environment During Heat-assisted Magnetic Recording

Norio Tagawa, Hiroshi Tani, Yusuke H, Shinji Koganezawa, Renguo Lu, Kansai University, Suita, Osaka, Japan

Because the diamond-like carbon (DLC) thin film overcoat on either a hard disk surface or an air bearing surface plays an important role in maintaining the reliability of the head-disk interface, DLC wear and degradation is a critical issue in heat-assisted magnetic recording (HAMR). The use of helium in hard disk drives (HDDs) has been developed to decrease air-induced structural vibrations, windage loss, and temperature rise. HAMR technology is suggested to be achieved in a helium environment. In this study, fundamental experiments were conducted to understand the wear and related degradation characteristics of DLC overcoat subjected to laser heating in both air and inert gas environments, using a pin-on-disk tester. The experiments were conducted using DLC-coated glass pins and actual magnetic disks without a lubricant film. The differences in the wear and degradation characteristics of a DLC overcoat on the pin and disk surfaces between inert gas and air environments were investigated after wear test were performed, primary through Raman spectroscopy. We found that the wear and graphitization of DLC films became greater in the case with laser heating, whereas the friction coefficients between the pin and magnetic disk became remarkably smaller. Moreover, the wear and graphitization of the DLC film were significantly less in an inert gas environment than in an air environment because the wear mechanism was suggested to be based on oxidation wear in this experiment.

4:20 – 4:40 pm | Rolling Contact Fatigue Resistance of Austempered Ductile Iron Processed at Various Austempering Holding Times

Minsheng He, Bingxu Wang, Gary C. Barber, Dave Schall, Oakland University, Auburn Hills, MI, Ben Slattery, XIcheng Sun, FCA, Auburn Hills, MI

Austempered ductile iron (ADI) has been widely used in industrial machinery due to its excellent mechanical properties. Compared with conventional ductile iron, ADI has higher tensile strength, ductility and toughness due to its unique ausferritic microstructure. The rolling contact fatigue (RCF) resistance of austempered ductile iron is important for applications in engineering components such as cam shafts, gears and valves. However, rolling contact fatigue resistance of ADI has not been thoroughly investigated for various heat treatments. Therefore in this research a ball-on-disk rotational rig was used to determine the rolling contact fatigue resistance of austempered ductile iron which was austempered at 276 °C for various austempering holding times. The ADI microstructure for short holding times consisted of more martensite and less ausferrite, and longer holding times resulted in more ausferrite and less martensite. The onset of fatigue failure was detected with an acoustic emission sensor. It was found that the ADI samples with more martensite were harder and resulted in higher RCF resistance. Contact fatigue mechanisms of the ADI samples were analyzed using optical and scanning electron microscopy.

4:40 – 5:00 pm | Experimental and Numerical Analyses of Localized Wear and Friction of Tool Steels During Micro-scale Reciprocating Tests

Newton Fukumasu, Vanessa Seriacopi, University of São Paulo, Sao Paulo, Sao Paulo, Brazil, Esteban Broitman, Linköping University, Linköping, Sweden, Izabel Machado, Roberto Souza, University of São Paulo, Sao Paulo, Sao Paulo, Brazil

In this work, the influence of hard second-phase particles (HSPP) on localized wear and friction behaviors was analyzed using micro-scale reciprocating tests. Exprimental tests were carried out on a Ti950 tribometer from Hysitron Inc., in which a conical diamond indenter with spherical tip was used to scratch the matrix and the HSPP. Particles with volume fraction of 5% and size distribution centered on 10 m in diameter were homogeneously distributed in a steel matrix. Surface depth profile was measured using the same tip in between reciprocating cycles, while friction was measured during the cycles. Numerical simulations using a 3D Finite Element Model allowed the evaluation of the behavior of both phases in the material at the contact region between the diamond tip and the tool steel. Mechanical properties (Young's modulus and yield stress) for both phases were measured using nano-indentation technique. Experimental results indicated higher wear and friction coefficients for pure steel matrix while a reduction of both coefficients was obtained when HSPP was present in the wear track. Stress distribution on the numerical simulations suggests significant plastic deformation for the steel matrix. Also, the improved hardness and toughness of the analyzed HSPP absorbed the mechanical energy during the reciprocating test, avoiding significant damage to the particles for the analyzed load.

5:00 – 5:20 pm | In-situ Observation of Grain Structures During Scuffing of Steel by Synchrotron X-ray Diffraction

Kazuyuki Yagi, Kyushu University, Fukuoka, Japan, Takashi Izumi, Toyota Central R&D Labs., Inc., Aichi, Japan, Tomoya Adachi, Kyushu University, Fukuoka, Japan, Shuzo Sanda, Satoshi Yamaguchi, Toyota Central R&D Labs., Inc., Aichi, Japan, Koji Saito, Toyota Motor Corporation, Aichi, Japan, Joichi Sugimura, Kyushu University, Fukuoka, Japan

In the current study, in-situ observation of grain structures of friction surfaces was conducted during scuffing. A contact area was created between a rotating sapphire ring and a fixed martensitic steel pin. The grain structures such as dislocation density and grain size were obtained by Williamson-Hall analysis of synchrotron XRD spectra that were captured by a two-dimensional detector during the test. Visible and near-infrared images of the contact area were also simultaneously captured by digital cameras. The relationship between the grain structures of the steel surface and catastrophic scuffing process is discussed.

5:20 – 5:40 pm | Control of Frictional Damping by Geometry and Load Fluctuations

Lejie Liu, University of Wisconsin-Madison, Madison, WI, Melih Eriten, University of Wisconsin-Madison, Madison, WI, Ahmet Usta, University of Wisconsin-Madison, Madison, WI

Accurate estimation and tuning of frictional damping is critical for proper design, safety and reliability of assembled structures. In this study, we investigate how surface geometry and load fluctuations affect frictional energy dissipation under microslip contact conditions. In particular, we investigate the frictional losses in sinusoidal and spherical contacts under varying normal and shear loading. Controlling geometry and load fluctuations enable tuning of energy dissipation within orders of magnitude, and thus provide a sustainable mean of damping control. Using surface wrinkling mechanisms proposed by recent studies, we show that contact geometry can be altered for desired frictional dissipation. We also demonstrate an example of damping control by adjusting loading fluctuations through wave depolarization.

Session 5D } Venetian Room

Energy/Environment/Manufacturing II

Session Chair: Benjamin Gould, University of Delaware, Wilmington, DE

Session Vice Chair: Aaron Greco, Argonne National Laboratory, Argonne, IL

1:20 – 1:40 pm | Quo Vadis Engine Oil: The Development From Internal Combustion Engines to Electromobility

Wilfried Bartz, Technische Akademie Esslingen, Ostfildern, BW, Germany

Environmental as well as availability reasons are the main forces to look for other energy carriers to operate cars. Engine oils today are the largest group of lubricating oils (about 50 % of the lubricant market, and about 50 % of this group for passenger cars). Combustion engines need engine oils – electromotors do not need engine oils. For this development the following steps might be discussed: Using hydrogen as fuel with no influence on the demand on lubricants. Battery, charged outside the car. Fuel cell , operated by hydrogen in the car to produce electricity to operate an electromotor to move the car. The final step is the only use of a battery on the car to operate an electromotor. The steps b to d are characterized by a reduced demand of engines oils. For the battery operated car based on an electromotor no engine oil at all is needed. These different steps are characterized by the steps micro-hybrid, mild-hybrid, full-hybrid, plug-in-hybrid and electro motor.

1:40 – 2pm | Surface Modification with Quasicrystals (QC) and Friction Stir Processing (FSP)

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

Quasicrystal materials have been shown to exhibit very good tribological properties, hence are candidate material to enhance the friction and wear behavior of relatively soft materials. This will require creating a surface layer of quasicrystals on the surface of interest. Friction stir processing is an excellent candidate for the creation of such layer, because it essentially involves mechanical mixing and grain refinement. In the present study, Al65Cu23Fe13 quasicrystals were incorporated into the near-surface layer of Al-alloy 6061 and bronze alloys using FSP process. The quasicrystals powders were fabricated by mixing appropriate compositions following by milling and annealing process. FSP to incorporate the powders into the alloy surface was conducted with densimet W alloy tool. XRD analysis showed effective incorporation of Al65Cu23Fe13 quasicrystals into the aluminum and bronze surface layer. Work is in progress to determine the impact of this particle incorporation on mechanical properties and tribological performance of the two alloys. Microstructural analysis were also conducted with different levels of microscopy.

2 – 2:20 pm | Effect of Minimum Quantity Lubrication Aerosol Temperature on Surface Roughness in Machining AISI P20 and D2 Steels Using Coated Tungsten Carbide Tool Inserts

Amal Senevirathne, Himan Punchihewa, University of Moratuwa, Moratuwa, Sri Lanka

This experimental investigation is focused on turning AISI P20 and D2 steels using coated carbide cutting tools. The temperature of an emulsion cutting fluid aerosol applied with minimum quantity lubrication (MQL) method was varied and evaluated its effect on surface roughness of the work piece being machined. Trials were carried out with cutting fluid aerosol temperatures from 5 oC to 20 oC in steps of 5 oC. In addition, another set of trials were carried out for dry cutting and conventional flood cooling method at 25 oC, with all other parameters kept same as in MQL method to obtain a benchmark. Chilled MQL aerosol method given a better surface smoothness in machining both AISI P20 and AISI D2 steels, compared to dry cutting and regular flood cooling methods. Minimum surface roughness in machining AISI P20, was observed at 5 oC aerosol temperature with MQL method, and it has shown a trend of decreasing surface roughness when temperature was lowered to 5 oC from 20 oC. A surface roughness reduction of 35% from dry cutting, and 29% of flood cooling, is observed with MQL at 5 oC aerosol temperature. Similarly, in machining AISI D2, minimum surface roughness was observed at 5 oC temperature with MQL aerosol, and it has shown a trend of decreasing surface roughness when temperature was lowered to 5 oC from 20 oC. In conclusion, with AISI P20 and D2 tool steels, the surface roughness can be improved by reducing the temperature of the MQL aerosol.

2:20 – 2:40 pm | Optimization of Laser Surface Texturing With Nanolubricants

Demofilo Maldonado Cortés, Laura Peña Parás, Gerardo Tadeo Garza, Universidad De Monterrey, San Pedro Garza Garc, Mexico

Laser surface texturing (LST) has been used in deep-drawing tools steels under lubrication conditions achieving reductions in coefficient of friction and wear; conformal contact samples have studied with a series of combinations of diameter and depth of the micro holes, and density of the applied textured area. This work studies two aspects in order to further improve the tribological characteristics (coefficient of friction and wear) obtained previously: a) Optimization of the parameters mentioned above: diameter, depth, and density of the applied textured area in order to use as little as possible of laser surface texturing, minimizing energy consumption of the laser; and b) The use of nanoparticles to enhance and improve lubricating tribological properties. The results show that it is possible to improve the tribological characteristics with less energy resources and cost in order to increase the life time of the tools for metal mechanical applications.

2:40 – 3 pm | The Tribology of Zirconium Oxide: Dry Sliding Under Severe Service Conditions

Catalin Pruncu, University of Birmingham, Birmingham, United Kingdom, Tony Hill, Robert Watson, IMI Truflo Marine Ltd, Birmingham, United Kingdom, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

The ball/seat interaction is critical to ball valve performance providing a sufficient seal and appropriate durability over many years of (potentially intermittent) use, whilst minimising frictional losses to reduce actuation torque. These requirements are more challenging where corrosion and high temperatures and sealing pressures, as can be found in Civil Nuclear valves. SAE 316 stainless steel is usually deployed with some surface treatments and limited success. In this paper, Zirconia Ceramics was assessed as an alternative seat material. Severe conditions were simulated using a Plint TE77 tribometer. Tests were conducted at loads between 5 and 20N, 50mm/s for a fixed 15000 cycles, at 23, 100 and 300°C. Frictional force, bulk temperature and wear were recorded. A high-speed data acquisition system was used to record stroke specific frictional data at key test stages. After the tests the friction coefficient (COF) was calculated and the wear scar and surface topography were measured. An Alicona InfiniteFocus G5 was used to assess surfaces, and a JOEL 6060 SEM was used to map wear. Analysis of the wear tracks revealed the main wear mechanisms; predominantly of adhesion (with significant material transfer from the 316 pin to the ZrO_2 plates), formation of a significant debris layer, and pitting damage. Wear rates were very low compared with more common valve materials. The COFs were constant regardless of temperatures. ZrO_2 ceramics are very promising seal materials.

3 – 3:40 pm – Break

3:40 – 4 pm | Formulation Challenges and Performance Testing for Environmentally Acceptable Lubricants

Don Satchell, Situ Biosciences, LLC, Wheeling, IL

Those that experience operational discharge, stern tube leakage, or accidental spills know the costly time consuming processes that follow such an incident with traditional lubricants. Consequences can be reduced with Environmentally Acceptable Lubricants (EALs), which are continuing the development for alternative blends away from traditional petroleum lubricants. For EALs, formulating the base oil, thickening agents and performance additives for certain performance characteristics, such as biodegradability, must be demonstrated through testing regulated by agencies including the Environmental Protection Agency, European Union, and other third party branding agencies. Common methods that test for aquatic biodegradation include OECD 301, OECD 306, and ASTM D5864. Properly formulated and soluble EALs may have no issues meeting the stringent requirements in standardized methods. However, physical and chemical properties like solubility can effect biodegradation testing and lubricants may require pre-test modifications, like a water accommodated fraction (WAF) analysis, to take into consideration low solubility. Other testing options include OECD 302B for inherent biodegradability. Challenges exist for choosing the correct biodegradation method and formulary development for a successful EAL; however, utilizing EALs can save time and costs associated with accidents, reduce environmental impact, and gain a competitive edge in the market.

Fluid Lubrication

The Bearing Performance of Journal Bearing Having Two Oil Filler Holes Under Starved Lubrication

F. Sakai, Science and Technology, Tokai University, Hiratuka-shi, Kanagawa-ken, Japan, M. Ochiai, H. Hashimoto, Department of Mechanical Enginieering, Tokai University, Hiratuka-shi, Kanagawa-ken, Japan

Oil whip is excited vibration that is caused by the action of oil film force of journal bearing. In this study, a stabilization method which can control an oil whipping utilizing the starved lubrication on small bore journal bearing is described. The effects of two oil filler holes and these oil supply angles on journal bearing characteristics are tested, because it is considered that the critical flow rate under starved lubrication of bearing having two oil filler holes increases compared to that of bearing having one oil filler hole. Moreover, the distribution of oil supplied two sites is visualized by oil of two color, the blended color quantitatively analyzed by RGB representation. Moreover, the difference in pressure distribution are confirmed by CFD analysis. As a result, in comparison of bearings having one filler hole and two filler holes, the critical flow rates for stabilization of the two oil filler holes are larger than that of one oil filler hole bearing. The temperature rise and the film thickness under starved lubrication have been changed by changing the conditions of the oil filler hole. Moreover, it was found that the route of flow of oil supplied two sites indicate a similar tendency. Consequently, the problems of the oil temperature and the oil film thickness on stabilization method using the starved lubrication is considered to be solved by the proposed two oil filler holes method.

Tribochemistry

Friction and Wear Reducing Behavior of Graphene-based Nanomaterials in Polyethyleneglycol (PEG) base oil as Energy Efficient low SAPS Antiwear

V. Jaiswal, K. Kalkhanday, R. Rastogi, Department of Chemistry, Indian Institute of Technology (Banaras Hindu University) Varanasi, Varanasi, Uttar Pradesh, India; R. Kumar, Department of Mechanical Engineering, Indian Institute of Technology (Banaras Hindu University) Varanasi, Varanasi, Uttar Pradesh, India

The reduced graphene oxide (rGO), boron-doped-reduced graphene oxide (B-rGO), nitrogen-doped-reduced graphene oxide (N-rGO), boron, nitrogen-co-doped-reduced graphene oxide (B-N-rGO) and TiO2-reinforced-B-N-rGO (TiO2-B-N-rGO) nanomaterials have been synthesized and characterized by various state-of-the-art techniques. The friction and wear reducing properties of these nanomaterials in polyethylene glycol as base oil have been investigated on four ball lubricant tester at optimized additive concentration (0.15% w/v). The tribological results indicated that the incorporation of a small amount of these nanoadditives into the base oil could reduce friction and wear drastically under various test conditions. Friction and wear reducing behavior of rGO has increased upon successive doping of nitrogen, boron; nitrogen and boron both. Among these additives, B-N-codoped-rGO shows superior tribological behavior in PEG base oil. Besides this, load carrying properties of B-N-co-doped-rGO have significantly improved after its reinforcement with TiO2 nanoparticles by following the nanobearing and/or tribosinterization mechanism. A comparative study of the surface morphology of lubricated track in presence of various additives has been assessed by SEM and AFM. The XPS studies have proved excellent lubrication properties of TiO2-B-N-rGO due to the formation of in situ tribofilm composed of boron nitride, adsorbed graphene layers and tribosintered TiO2 nanoparticles during the tribocontact.

Surfaces and Interfaces

Friction and Adhesion Study of Deformation-Resistant Nanostructure-Textured Surfaces

R.A. Fleming, M. Zou, University of Arkansas, Fayetteville, Arkansas

Nanoscale friction and adhesion measurements have been performed on nanostructure-textured surfaces (NSTSs) composed of deformation-resistant Al/a-Si core-shell nanostructures. The results show that NSTSs have a coefficient of friction (COF) as low as 0.015, with no surface deformation observed for normal loads up to 8,000 µN (estimated contact pressure of 1 GPa). In comparison, Al nanodot-textured surfaces (ANTSs) and polished Si have much higher COFs of 0.044 and 0.061, respectively, and the ANTSs are deformed at a normal load of 250 N. Both the NSTSs and ANTSs have low pull-off adhesion forces on the order of less than 1 µN, which is substantially smaller than previously reported values 10-15 N on polished Si. Analysis of the COF data shows that for applied normal loads of 250 N and less, adhesion is the primary friction mechanism, while deformation-based friction dominates at higher loads. Due to their unique tribological properties, NSTSs have potential uses in a variety of applications, such as MEMS/NEMS, magnetic recording, and nanoimprinting.

Lubricants

Effect of Nanoparticle Size and Surface Roughness on the Tribological Properties of PAO_2 Nanolubricants

D. Maldonado Cortés, Engineering, Universidad de Monterrey, San Pedro Garza Garcia, Nuevo Leon, Mexico, K.L. Nava-Montemayor, O.E. Montemayor-Sanmiguel, L. Peña Parás, Engineering, Universidad de Monterrey, San Pedro Garza Garcia, Nuevo Leon, Mexico, P. García, Engineering, Universidad de Monterrey, San Pedro Garza Garcia, Nuevo Leon, Mexico

Nanoparticle size and surface roughness play an important role on the performance of nanolubricants. This study investigates the effect of the size of TiO2 nanoparticle additives in a poly-alpha olefin 2 (PAO2) base lubricant. Nanoparticles with sizes of 100, 165, 300, and 500 nm were dispersed in PAO2 with a concentration of 0.05 wt% by ultrasonication. Anti-wear tests were performed in a T-05 block-on-ring tribotester using a tribo-pair consisting of a D2 ring and AISI 1018 block with roughnesses of 300, 700, and 1400 nm. Wear mass loss and friction force (N) were determined for each combination of nanoparticle size and block surface roughness. Results showed that there is an optimal size of nanoparticle where the highest reduction on friction force and wear is obtained. The tribological mechanisms of nanoparticles were characterized by Energy Dispersive Spectrometry (EDS) and Scanning Electron Microscopy (SEM). Nanoparticles were deposited onto surface grooves; smaller sized nanoparticles were more efficient at filling surface valleys showing higher tribological improvements.

Surfaces and Interfaces

Improvements on Laser Surface Texturing (Multivariable Study) to Improve Tribocharacteristics

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In previous work using laser surface texturing (LST), we achieved reductions in coefficient of friction and wear in laboratory tests with conformal contact probes through a series of combinations of diameter and depth of the micro holes and the density of the applied textured area intended for deep drawing tool steels under lubrication conditions. This poster presents three aspects to further improve the tribological characteristics (coefficient of friction and wear) obtained previously: a) Optimization of the parameters mentioned above: diameter, depth and density of the applied textured area in order to use as little as possible of laser surface texturing and minimizing energy use of the laser, b) Use of variable laser texturing dimensions in order to reduce statical COF, c) The use of nanoparticles to enhance and improve lubricating tribological properties. The results show that it is possible to improve the tribological characteristics whit less energy resources and cost in order to increase the life time of the tools for metal mechanical applications.

Fluid Lubrication

Systematic Steady-State Hydrodynamic Analysis of a High Performance Textured and Profiled Journal Bearing

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Textured journal bearings have long confounded researchers and designers due to their inconsistent performance. In literature, experimental and simulation work have been reported on both fully textured and partially textured journal bearings; however, the overall design is still not clear. This uncertainty is largely due to the fact that there are numerous conflicting results in literature by which adding textures yields beneficial results in some studies but negative results in others. Therefore, a systematic numerical study is needed. The current research focused on achieving an in-depth understanding of texture placement and parameters via solving the steady-state hydrodynamic Reynolds equation. Specifically, the load capacities and friction coefficients of the textured bearings of different dimensions and operating conditions are analyzed and compared with those of smooth bearings to indicate performance enhancements. Fundamental trends have been identified, which should shed light on the optimal texture placement and the best parameters to maximize bearing performance. In addition to this, various journal profiles have been combined with these optimal texture configurations to further enhance journal bearing lubrication performance.

Energy/Environment/Manufacturing

Studying the Formation Mechanisms of White Etching Cracks Through High Energy X-Ray Tomography

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Crack surrounded by local areas of microstructural alteration deemed "White etching cracks" (WECs) lead to unpredictable and premature failures within a multitude of applications including wind turbine gearbox bearings. While the exact cause of these failures remains unknown, a large number of hypotheses exist as to how and why these cracks form. The aim of the current work is to elucidate some of these hypotheses by mapping WEC networks within failed wind turbine bearings using high energy X-ray tomography, in an attempt to determine the location of WEC initiation, and the role of defects within the steel, such as inclusions or carbide clusters. Four completely subsurface WECs were found throughout the presented analysis, thereby confirming subsurface initiation as method of WEC formation. Additionally, a multitude of small butterfly like cracks were found around inclusions in the steel, however further analysis is needed to verify if these inclusions are initiation sites for WECs.

Fluid Lubrication

Superlubricity Achieved by Polyalkylene Glycol (PAG) Aqueous Solutions

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Superlubricity has attracted overwhelming attention due to the ability to provide negligible friction between sliding solid surfaces. In our work, ultralow friction coefficient (COF, μ) of a polyalkylene glycol (PAG) aqueous solution has been obtained in both droplet state (40 μL) and full immersion state after a short running-in period. Here, two key factors in achieving the superlubricity state (μ< 0.01) have been demonstrated: the low shearing strength of the hydrated layer and the presence of a suitable amount of free water molecules. In the initial running-in period, a decrease in contact pressure contributes to the formation of elastohydro - dynamic behavior of fluid.The hydrogen-bonded PAG chains produce a hydrated layer between two sliding solid surfaces so as to lower the shear strength.The presence of free water molecules effectively weakens interactions between polymer chains. Therefore, the superlubricity state can be realized over a wide range of concentration (30-60 wt%). Present work shows the mechanism of a stable lubricating system with superior tribological properties, and has a significant potential in industrial applications.

Biotribology

Tribological Rehydration: A New Lubrication Mechanism for Biphasic Materials

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Cartilage achieves its unusual tribological functionalities through a unique mechanism known as interstitial lubrication. Interstitial fluid pressure develops in response to tribological contacts to lower matrix stresses, friction, and wear by at least an order of magnitude. It has been shown that if the contact moves faster than the exudation rate of the interstitial fluid the loss of fluid from the contact can be prevented, unfortunately there are invariably periods of static loading and rest that occur throughout a person's daily routine. The question of how fluid is transported back into the cartilage remains unanswered. The goal of this study is to demonstrate that under physiological speeds cartilage can pump fluid back into the interface and rehydrate the contact. The mechanism, which we term tribological rehydration, is able to rapidly decrease friction and re-pressurize interstitial fluid. These findings suggest that conditions of high friction and wear in cartilage are short lived transient events.

Fluid Lubrication

Elastohydrodynamic Lubrication Analysis of Herringbone Groove and Profile Designs in Roller Contacts

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Finite length roller contacts are found in many mechanical systems, such as those found at the interfaces of gear teeth, cam followers, bearing rollers and apex seal-housing in rotary engines. rollers are usually designed with crowns and modified ends to cancel potential misalignment, thermal deformation and non-uniform load distribution. However, with these features, side leakage is not improved. This paper proposes several methods to improve the tribological performance of roller contact, in terms of increasing minimum film thickness and reducing side leakage and friction. Three approaches are investigated: herringbone groove design to reduce side leakage; profile design to increase minimum film thickness and smooth the distributed film; and combination of the herringbone groove and profile designs to integrate the improvement effects. Film thickness distributions, pressure distributions and flow maps are analyzed to reveal the insight of \ the tribological behavior of the novel designs.

Surfaces and Interfaces

The Area of Contact Between Nanoscale Bodies in Molecular Dynamics Simulation

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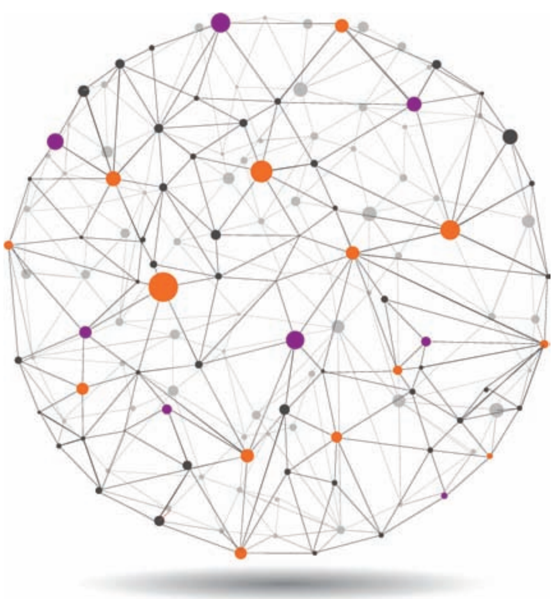
The area of a contact between materials affects friction, adhesion, heat transfer, and other transport properties. However, the definition and determination of the area of a contact is ambiguous at the atomic scale. Here, we use molecular dynamics (MD) simulation, which provides atomic-scale information about the contact interfaces, to simulate a realistic nanocontact experiment and estimate its contact area. In this work, we evaluate two criteria to identify contact: distance and force. In the distance criterion, two atoms are considered to be in contact when their distance is closer than the distance at which their potential energy reaches a minimum. In the force criterion, atoms are identified as being in contact when they experience a repulsive force from the atoms in the counter surface. We then employ different approaches to convert the number of contact atoms to contact area. Lastly, we compare the contact areas estimated by these methods and evaluate them in the context of continuum adhesive contact model predictions.



Materials Tribology

Texture Extraction of Wear Particles Based on Improved Random Hough Transform and Visual Saliency

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This paper proposes a texture extraction method based on improved random Hough transform and visual saliency of wear particles. In this method, in order to extract texture primitives, such as lines or circles which represents the visual saliency of the texture on wear particles, firstly, Canny detector is used to obtain the initial texture image. Secondly, the improved Random Hough Transform based on the connectivity of pixels is applied on texture images to extract texture primitives such as lines and circles. Lastly, the extracted texture primitives such as lines or circles are used to analyze the periodicity and randomness of texture pattern so as to determine the type of wear particles. The proposed method mimic what human eyes see when they analyze wear particle images, it is an intuitive and fast method. Experimental results show that the method has good practical application.

Materials Tribology

A Biomimetic Lubricating System Based on the Synergy Between Polymer Brush and Ionic Liquid

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Imitating natural synovial joints, swollen polymer chains anchored on tribopairs have shown potential as lubricating systems. The fluid-like cushioning layer of solvated polymers effectively reduces friction. To fully leverage the lubricating feature of polymer brushes, a good solvent is needed to stretch the anchored polymer chains. Ionic liquids (ILs) are considered outstanding solvents, and thus, they could potentially serve as the swelling agent for polymer brushes.Starting from a reference system of poly (l-lysine)-g-poly (ethylene glycol) (PLL-g-PEG) coupled with 1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIM-NTf2), we characterize structural properties of IL-swollen polymer brushes and correlate these parameters to the lubrication performance. The height of the polymer brush is determined from the repulsion force measured by an extended surface forces apparatus. It has been reported that the conformation of polymer brushes results from two counterbalancing free energy terms, the interaction energy and the entropy elasticity; this study experimentally investigates this interplay in the case of ILs. The second step is measuring friction forces as function of sliding velocity and load. Efforts are made to associate the friction behavior with important parameters of the polymer brush-IL system, such as solvent viscosity, and the brush height. Friction force measurements are conducted on an atomic force microscope.

Biotribology

Determining Supported Membrane Leaflets Friction from Correlated Diffusion Measurements

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We propose a theoretical prediction for the dependence of the diffusion coefficient of lipids in a supported membrane and the intermonolayer friction. We use the regularized stokeslets method to extend this prediction for differed shape membrane proteins. By comparing the diffusion coefficient of the two lipid populations (upper and lower leaflets) and comparing them to the unsupported can, we can accurately extract the frictional drag coefficient between the membrane leaflets. A prediction for the correlated diffusion coefficient between two lipids is also calculated and can be used to verify the results obtained by the self-diffusion measurements.

Materials Tribology

Study on Bending Fretting Fatigue Damage in 17CrNiMo6 Steel

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Bending fretting fatigue behavior of 17CrNiMo6 alloy structural steel at room temperature was researched, the tests were carried out under different bending and contact loads, and the S~N also was built up. The surface wear scars of the samples were examined by optical microscope, scanning electronic microscope (SEM), energy dispersive X-ray spectrum (EDS) and transmission electron microscope (TEM). The results showed that the S~N curve presented a shape of "C", and the bending fretting fatigue life of 17CrNiMo6 steel sharply decreased owing to fretting damage. Under same normal contact stress and the number of cycles, with the increase of the bending fatigue loads, the contact surfaces were sequentially running in the partial slip regime (PSR), mixed fretting regime (MFR), and slip regime (SR), respectively. The fretting fatigue crack sources were usually located in the subsurface of the contact zone, and the behavior of crack propagation was discussed in detail.

Fluid Lubrication

Computational Modeling of the Boundary Friction Regime in Tribological Systems

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Boundary friction is the condition in which surface asperities dominate the contact between opposing surfaces prior to full film lubrication development. This phenomenon occurs during contact start / stop cycles or throughout the mechanical breaking-in period of new equipment. Friction is generally the greatest during the boundary friction regime and its trend follows a Stribeck Curve where the friction is reduced once full film lubrication is achieved. Rarely is this trend in friction provided as a function of time for the boundary friction regime and it is left for the designer to choose from either a static or kinetic coefficient value. In this poster, a transient coefficient of friction is presented for the pin-on-disk and oscillating piston-cylinder tribological systems. These coefficient of friction curves are calculated using Solidworks Simulation software during the run-in period for these tribological systems.

Machine Elements and Systems

Green Energy's Hard Truth

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As efforts are made to bring green technologies to the energy mix, one hard truth is clear: wind energy faces technical roadblocks inhibiting its ability to make a bigger contribution. One such roadblock is main guide bearing failure, accounting for about 57% of mechanical failures in wind turbines, This paper addresses metallurgy, lubricants and bearing configurations which are struggling to handle increasing loads as turbines grow in size. Lignum Vitae (LV) has a long history of handling forces similar to wind turbines. Current rolling element bearings large enough to handle the loads introduce challenges that call for new lubricants and new metallurgy. Without a new approach to the main bearing, new technologies wont remove white etch cracking, rolling elements scoring the race at rest from constant vibration, or inordinate thrust axially into the gearbox. LV's self-lubricating properties create a glaze that acts as a hydrodynamic running surface, thereby solving these issues.

Surfaces and Interfaces

Study of the Frictional Properties of MoS_2 Nanosheets Modulated by Surface Chemistry and Nanoscopic Roughness

Z. Liu, J. Batteas, Chemistry, Texas A&M University, College Station, TX

Reducing friction and wear in devices is important because of the immense cost savings from minimizing energy loss. Solid 2D materials such as MoS2 have gained significant interest because their tribological properties lend to their use as solid lubricants. Adding a single layer of MoS2 (SLM) restores a crystal lattice to amorphous interfaces, leading to incommensurate contact and increased ease of sliding. However, the nanoscopic roughness present at sliding interfaces poses a challenge to the implementation of SLM because its tribological properties depend on the interactions with the supporting substrate. To understand and control the mechanical behavior of SLM in sliding contacts, it is crucial to learn how the frictional response of SLM is influenced by both the SLM-substrate interaction strength and its conformity on rough surfaces. To study this behavior, atomic force microscopy (AFM) was used to evaluate the structure of MoS_2 nanosheets deposited on SiO2 surfaces that have controlled chemistry and nanoscopic roughness. Friction force microscopy (FFM) was used to investigate the tribological properties. It was found that MoS_2 partially conforms to nanoscopically rough surfaces, and that the conformity depends on the layer thickness and applied load. In addition, the frictional response changes with layer thickness and surface chemistry. These studies provide preliminary work towards the investigation of MoS_2 as a solid lubricant for nanoscopically rough surfaces.

Biotribology

Tribological Behavior of Hydrogel-supported Lipid Bilayers

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Phospholipids play vital biological functions in living beings, and as component of the joint- lubricating synovial fluid, their role in biolubrication can be also essential. We have developed a novel biomimetic system that can be used to understand the mechanisms underlying lubrication by phospholipids. The model system consists of a hydrogel-supported lipid bilayer, in which the mechanical characteristics of the underlying polymer cushion can be modulated. This enables in- depth physiologically relevant studies of phospholipid lubrication, when supported by a soft support. Atomic Force Microscopy has been used primarily to study the unique friction behavior of the developed biomimetic system. Friction measurements show a dependence on applied normal load with a transition from lipid-mediated to hydrogel-mediated friction by increasing the load. Additionally, measurements on hydrogel-supports of varying stiffness show the limit in the lubricating capability of the lipid bilayer when reducing the stiffness of the hydrogel support. Furthermore, the friction force was found to be independent of the sliding speed in the range studied, supporting boundary lubrication regime. Our findings also contribute to understand better the mechanisms underlying cartilage and ocular lubrication. These results might inspire new strategies in development of devices or implants such as catheters or ocular lenses where biocompatibility and effective lubrication are essential.

Machine Elements and Systems

Method for Detection of the Lean Meat Ratio in Pork Carcass Based on Fiber Optic Sensor

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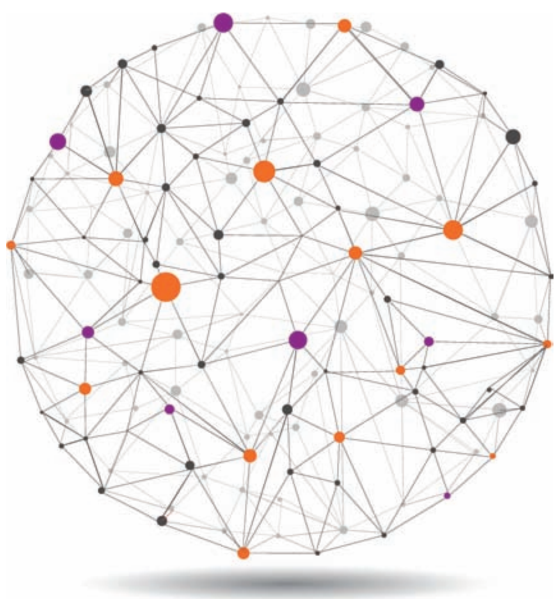
How much lean or how much fat is there inside the meat will affect its quality and the taste. As a main evaluating indicator, lean meat ratio is one of the assessments for pork carcass grading. A method based on Fiber optic sensor and NIR (Near Infrared) to acquire the ratio was proposed in this paper. This method acquired the reflected light intensity of the meat inside the pork carcass, by using double optical paths to reduce the errors caused by the stability of light. The fiber was lead inside a probe which can be stabbed into the pork carcass, and then the reflected light was detected by a circuit named LIA (lock in amplifiers) to recognize the weak reflected light intensity effectively. A filtering method of Medium filter was taken to deal with the data to remove the influence of unevenness of the meat surface. The results suggested that the reflected light of the fat part of the pork was much higher than that of lean part, and through medium filter, the conditions of fluctuation was improved. The system was proved to be quick and accuracy for the detection of lean meat ration in pork carcass.

Materials Tribology

Abrasive Wear Resistance of Polymers

H. Ronkainen, M. Karttunen, J. Pelto, VTT Technical Research Centre of Finland, Espoo, Finland

The role of polymers is expanding in material technology and engineering since structural lightness is favoured due to ecological aspects and energy savings. In many cases the abrasive wear resistance is not good enough for demanding applications and new material solutions are required. In this study the abrasive wear resistance of selected polymers and polyether-ether ketone (PEEK) composites is evaluated with sand abrasion tests using two load levels. The polymer samples were fabricated by injection moulding. The PEEK matrix was modified with different micro and nanoscale fillers, such as Al2O3, SiC, TiC and TiN. The micro-indentation was used to determine the indentation modulus and hardness, and microscopy was used to analyse the filler-matrix structures. The wear surfaces were also analysed by optical microscopy and SEM. The results showed that the abrasive wear resistance of polymers differed and the elasticity of the basic polymers influenced the wear resistance. The use of fillers in polymers improved the wear resistance, e.g. nanoscale TiN fillers improved the abrasive wear resistance of PEEK. The experimental compounds showed that development for abrasive wear resistance of polymers and the link between abrasive wear resistance and basic material properties is complicated. The surface modification of fillers is also necessary to reach the desired material properties and further development is needed to fulfil the requirement of demanding applications.



Lubricants

Tribological Study of Halloysite Nanotubes Reinforced Polyethylene Glycol Lubricants for UHMWPE-CoCrMo Knee Implants

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Wear resistance of biomaterials used in artificial knee joints contributes to the success of the implant. Alloys of CoCrMo and ultra-high molecular weight polyethylene (UHMWPE) are commonly used in knee joint prostheses. In this study, nanolubricants of halloysite clay nanotubes (HNTs) were prepared by dispersing 0.05 wt.% nanoparticles in polyethylene glycol (PEG) and proposed as artificial lubricants, as HNTs and PEG have both shown to be biocompatible materials. The tribological properties of HNT/PEG lubricants, un-reinforced PEG, and Hartmann solution were characterized with a T-05 block-on-ring tribotester using a tribo-pair consisting of a CoCrMo ring and UHMWPE block. Wear mass loss, displacement, and coefficient of friction (COF) were measured at 12, 24, and 36h. Surface roughness measurements were obtained with an optical 3D surface measurement system. Results showed that the mass loss of block and ring were lowered by 260% and 75% for HNT/PEG lubricants, respectively, compared to Hartmann solution. Coefficient of friction was also lowered by 60%. These improvements were attributed to PEG forming a tribofilm with the UHMWPE blocks due to their chemical compatibility, and HNTs filling surface roughness valleys decreasing COF. The results obtained in this study demonstrate that nanolubricants HNT/PEG can effectively reduce wear of UHMWPE and CoCrMo biomaterials and increase life span of artificial knee joints.

Surfaces and Interfaces

Yield Inception of Hard Coating/Substrate System: Single Layer, Multilayer and Functionally Graded Coating

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In case of a hard coated surface, it is important to control the crack initiation at the coating/substrate interface to prevent delamination or spalling. Therefore, it is essential to know the location of yield and the critical condition for yielding onset at the surface, the coating, interface or the substrate. The local yielding is defined by von Mises yield criterion and the stress distribution is generated by finite element analysis. A comparison is made between the single layer, multilayer and functionally graded coating/substrate systems. The effect of different parameters such as coating thickness, coating and substrate elastic moduli and yield strength on yielding behavior is studied for all systems.

Surfaces and Interfaces

Simulation of Running-in Process of Line Contacts in Mixed Lubrication Conditions for a Reciprocating Motion

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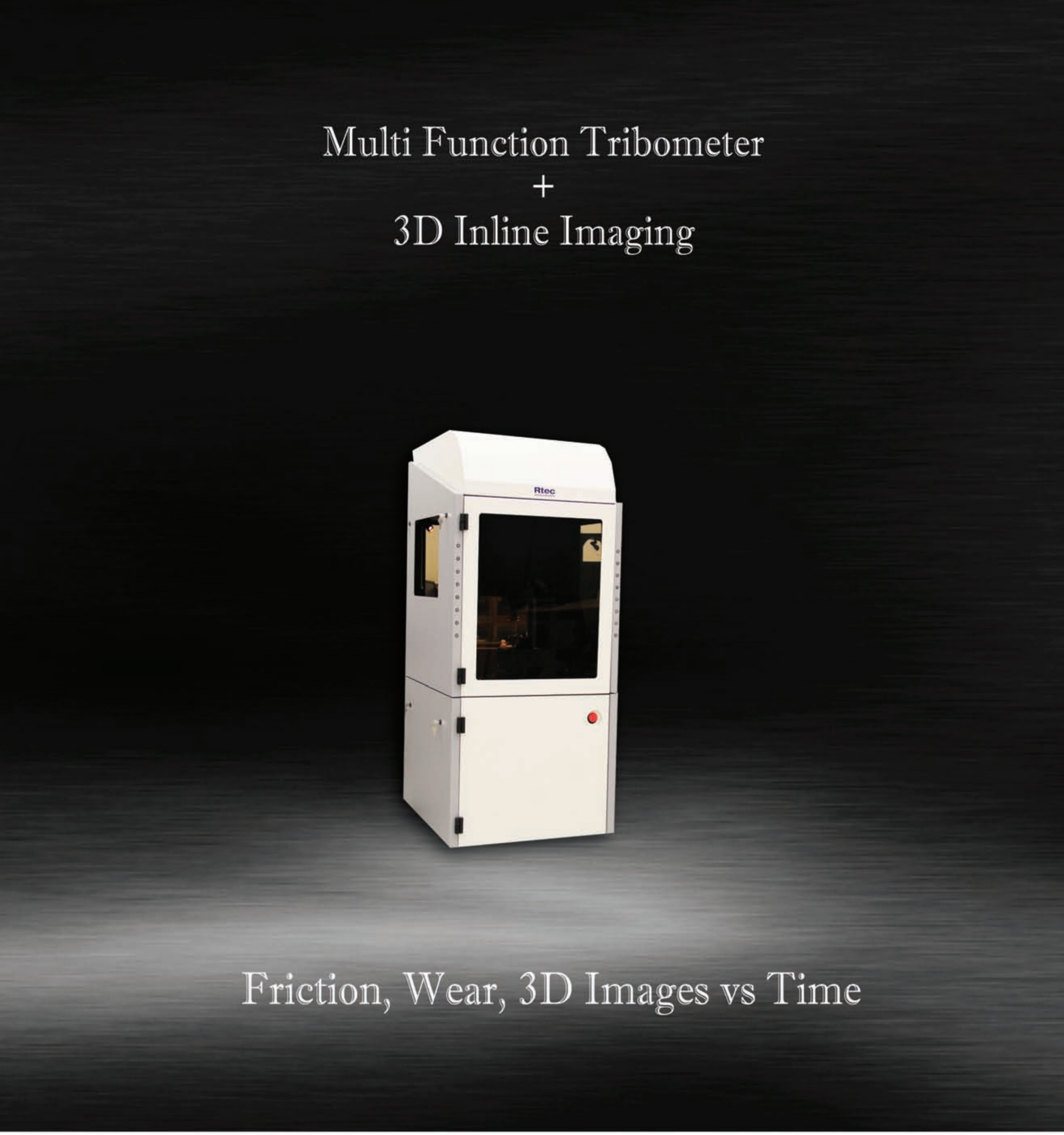
A 2-D model that predicts the sliding friction and wear process between surfaces with roughness in line contacts is presented. The numerical approach is established on the basis of the statistical solution of mixed lubrications, which can calculate the asperity contact pressure and fluid hydrodynamic pressure by using the elastic-plastic contact model and the average flow model respectively. Wear occurs in the locations where the asperities come into direct contact with relative motion and the mixed lubrication condition is transformed into a new transient balance due to the extension of the contact region. The surface shape and roughness computed with the Archard's wear law are changing with the wear process, which influences the hydrodynamic and asperity contact pressure and then changes the friction coefficient of the contacting tribopairs. The 2-D model has higher calculation efficiency than 3-D model and so it can deal with the reciprocating motion in mixed lubrication.

Notes


Multi Function Tribometer
+
3D Inline Imaging
Friction, Wear, 3D Images vs Time