STLE
Tribology
Frontiers
Conference

2023 STLE Tribology Frontiers Conference

November 12-15, 2023
Cleveland Marriott Downton at Key Tower
Cleveland, Ohio (USA)

Preliminary Technical Program

Updated as of Sept. 13, 2023

www.stle.org/tribologyfrontiers

2023 STLE Tribology Frontiers Conference
November 12-15, 2023
Cleveland Marriott at Key Center
Cleveland, Ohio (USA)
Preliminary Program-At-A-Glance
As of 9-13-23 – Subject to Change

Sunday, November 12, 2023

Meet & Greet Reception – 6:00 pm–7:00 pm – Foyer

Monday, November 13, 2023

Speaker Breakfast – 7:00 am–7:45 am – Erie/Superior

General Attendee Breakfast – 7:00 am–7:45 am – Foyer

Plenary Session: 8:00 am–9:00 am – Salon D
Keynote Presentation:
Juliette Cayer-Barrioz, CNRS Research Director, STMS/LTDS
"Surfaces in Lubrication: A Multiscale Analysis"

Networking Break (Exhibits & Posters) –
9:00 am – 9:20 am – Foyer

Technical Sessions – 9:20 am – 11:40 am
1A – Materials Tribology I – Salon A
1B – Lubricants I – Salon B
1C – Tribochemistry I – Salon C
1D – Surfaces & Interfaces – Salon E

Lunch on Your Own – 11:40 am–1:00 pm

Plenary Session: 1:00–2:00 pm – Salon D
Keynote Presentation:
Neil Canter, Chemical Solutions
"STLE Trends Report: Opportunities in the Future"

Technical Sessions – 2:00 pm–3:40 pm
2A – Materials Tribology II – Salon A
2B – Lubricants II – Salon B
2C – Tribochemistry II – Salon C
2D – Surfaces & Interfaces II – Salon E

Networking Break (Exhibits & Posters) – 3:40 pm–4:20 pm – Foyer

Technical Sessions Continued – 4:20 pm–5:40 pm
2A – Materials Tribology II – Salon A
2B – Lubricants II – Salon B
2C – Tribochemistry II – Salon C
2D – Surfaces & Interfaces II – Salon E

Poster Session – 6:00 pm–7:30 pm – Foyer

Networking Reception & Award Presentations –
6:00 pm–7:30 pm – Foyer

Tuesday, November 14, 2023

Speaker Breakfast – 7:00 am–7:45 am – Erie/Superior

General Attendee Breakfast – 7:00 am –7:45 am – Foyer

Joint Plenary Session – 8:00 am–9:00 am – Salon EFGH
Keynote Presentation:
Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing
"Challenges of Selecting the Correct Electric Vehicle Driveline Fluid"

Networking Break (Exhibits & Posters) – 9:00 am–9:30 am – Foyer

Technical Sessions – 9:20 am–11:40 am
3A – Biotribology I – Salon A
3B – Lubricants III – Salon B
3C – Fluid Lubrication I – Salon C
3D – Surfaces & Interfaces III – Salon D

Lunch on Your Own – 11:40 am–1:00 pm

Plenary Session: 1 - 2 pm – Salon D
Keynote Presentation:
Michael Kotzalas, Director of Global Customer Engineering, The Timken Company
"Presentation TBA"

Technical Sessions – 1:20 pm–3:40 pm
4A – Energy/Environment/Manufacturing I – Salon A
4B – Materials Tribology III – Salon B
4C – Fluid Lubrication II – Salon C
4D – Machine Elements & Systems I – Salon D

Networking Break (Exhibits & Posters) 3:40 pm–4:00 pm – Foyer

Technical Sessions Continued – 4:00 pm–5:40 pm
4A – Energy/Environment/Manufacturing I – Salon A
4B – Materials Tribology III – Salon B
4C – Fluid Lubrication II – Salon C
4D – Machine Elements & Systems I – Salon D

Wednesday, November 15, 2023

General Attendee Breakfast – 7:00 am–7:45 am – Foyer

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

1A Salon A

Materials Tribology I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 9:40 am

9:40 - 10:00 am
3930958: High Shear Stress and Highly Durable Electroadhesive Clutch for Soft Robotics and Haptics
Changhyun Choi, M. Cynthia Hipwell, Aditya Kuchibhotla, Texas A&M University, College Station, TX

In this work, we demonstrate an electroadhesive clutch that has high electroadhesive shear stress and high durability. Current research on electroadhesive clutch has been focused on only using a high dielectric constant to improve the electrostatic force in a parallel plate configuration. Since the change in the friction force is an electromechanical response, mechanical properties such as elastic modulus and yield strength should be taken into account as well as crack propagation at the interface. We also found that the current high dielectric constant materials have a durability issue. Using a high dielectric constant film that has a high dielectric constant and wear resistance and a structural design that minimizes the wear issue, we achieved high electroadhesive shear stress and high durability, which can be reliably used in soft robotics and haptic applications. This work will enable miniaturized robots and haptic devices as it can generate the same required force on a smaller area.

10:00 - 10:20 am
3953878: Developing Process-Structure-Property Relationships for Ultralow Wear Plasma-Enhanced ALD Ternary Nitride Films
Kylie Van Meter, Thomas Lockhart, Brandon Krick, Florida State University, Tallahassee, FL; Md. Chowdhury, Nicholas Strandwitz, Lehigh University, Bethlehem, PA; Mark Sowa, Veeco ALD, Waltham, MA; Alexander Kozen, University of Maryland, College Park, MD; Tomas Babuska, Sandia National Laboratories, Tallahassee, FL; Tomas Grejtak, Oak Ridge National Laboratory, Oak Ridge, TN

Metal nitride coatings are frequently used in tribological applications due to their high wear resistance and friction reducing properties. Compared to traditional TiN films, multi-metal nitrides such as TiVN are found to be lower wear and friction, and have higher oxidation resistance. Plasma-enhanced atomic layer deposition (PEALD) techniques enable atomic level thickness and composition control, allowing for the growth of thin (~100nm), conformal, conductive films at low deposition temperatures, where conventional CVD techniques are limited. These capabilities make PEALD nitride films candidates for microelectronics and MEMS/NEMS. Recently, PEALD ternary nitrides have achieved ultralow wear rates ($K < 10^{-7}$ mm^3/Nm). However, there lacks a fundamental understanding of the process-structure-property relationships in PEALD films. This work investigates the effects of deposition parameters, linking film structure, physical, mechanical, and chemical properties to tribological behavior.

10:20 - 10:40 am
3931666: Exploring Effectiveness of Vibro-Acoustic Damping in Elastic Structures with Frictional Contacts
Iyabo Lawal, Michael Haberman, Janghoon Kang, The University of Texas at Austin, Austin, TX

Reducing vibro-acoustic energy in structures can provide vibration isolation and mitigate noise in building spaces. Building materials with Constrained Layer Damping (CLD) have been used to dissipate vibro-acoustic energy in structures [1], improving vibration isolation and reducing noise transmission. The material assembly in CLD typically has a viscous “constrained layer” that allows for viscous dissipation. However, the use of friction within a material assembly has not been widely used to achieve the same effect. In this work, the effectiveness of using micro-friction events at the contact interface of material layers to provide friction driven dissipation is explored. Acoustic metrics: Transmission Loss (TL) and acoustic impedance that quantify the effectiveness of vibro-acoustic energy dissipation, will be generated for the traditional CLD assembly as well as for the friction driven dissipation material assembly. In addition to analytical solutions, a set of experiments have been conducted that quantify the acoustic absorption of different material assemblies within a range of frequencies as it responds to a plane pressure wave within an impedance tube.

10:40 - 11:00 am
3964052: How Surfaces Affect the Shape, Elastic Response, and Deformation Behavior of Small Metal Nanoparticles
Tevis Jacobs, Ruikang Ding, Soodabeh Azadehranjbar, University of Pittsburgh, Pittsburgh, PA; Ingrid Padilla Espinosa, Ashlie Martini, UC Merced, Merced, CA

In this talk, I will discuss three years of published and unpublished work using in situ TEM compression testing to understand how a nanoparticle's "bulk" behavior is controlled by its surface. First, I will discuss the size-dependent shape of single-digit-nm platinum nanoparticles, and how surface energy controls the distributions of shapes that are observed. Second, when those particles of various shapes are compressed, we show how to understand their size-dependent stiffness. We use atomistic simulations and in situ compression testing to show to disentangle geometric effects such as spatial variations in stress from surface effects, where the undercoordinated surface atoms have meaningfully different bond stiffnesses. Finally, in the permanent-deformation regime, we show how the surface weakens the nanoparticle. Moving beyond the traditional Coble-creep-like model, we reveal the how mechanical deformation of small particles is governed by a competition between surface nucleation of dislocations and surface-mediated shape change.

1B	Salon B

Lubricants I

Session Chair: TBD
Session Vice Chair: TBD

9:20 - 10:00 am
3950002: SPOTLIGHT: Self-Assembly and Chemistry of Molecules in Oil Environment
Hitoshi Washizu, Kyosuke Kawakita, Tomoya Hasegawa, Riku Araki, Tomohito Horio, Takehiro Kobayashi, Ryuichi Okamoto, Kosar Khajeh, University of Hyogo, Kobe, Japan; Yoshiki Ishii, Kitasato University, Sagamihara, Japan; Natsuko Sugimura, National Institute of Technology, Kagoshima College, Kirishima, Japan

Self-assembly of solute molecules in oil solvent is important since many of the lubricant are used in this condition. Molecular simulation is useful to treat these phenomena and recently we applied to self-assembled system such as liquid crystals and polymer solution. Here, we report our recent research on molecular simulations of additives and thickener in oil environment with and without metal surfaces. Although carbonate oiliness additives adsorb physically on the charged metal surface relatively quickly, extreme pressure additives such as organophosphate make aggregation structure in oil and do not easily adsorb on the surface. The dependence of the molecular structure to the stability is simulated. After adsorption to the surface, the pathway of charge transfer on the surface is different on the nascent surface and oxidized surface. In order to understand the grease, formation and breakage dynamics of self-organized structure of reverse-micelle under shear is analyzed using dissipative particle dynamics, and the dynamics is related to the experimentally found dynamics of grease thickener. The simulation method is further extended to treat wider time and space dynamics, such as multi-physics approach of coarse-grained molecules coupled with fluid dynamics, or molecular dynamics using AI based potential to treat huge chemical reactions. These new approaches are reveling the tribochemistry of lubricants on the surface from molecular level.

10:00 - 10:20 am
3729988: A Comprehensive Evaluation of Sustainable Raw Materials in Lubricant Production
Mark Miller, Ramapo College of NJ, Ramapo, NJ

The market demand for sustainable lubricants, bio-based base oil and green additives is growing, but what makes these products truly sustainable? The terminology in the sustainability landscape is confusing. In this session, the speaker will clarify key terms such as biobased, biodegradable, decarbonization, carbon footprint, bio-content etc. The speaker will also address the latest regulatory requirements and addresses the key issues of performance. From this session, attendees will learn about the key terms prevalent in the lubricant industry today, ad what key pitfalls to look out for in developing a sustainable grease offering. As many grease manufactures adopt strategies toward sustainable products and carbon negative footprint goals, the definitions become more important. In this session we will distinguish facts from fiction when it comes to sustainability and discuss the advantages and disadvantages of said strategies. In addition, we will cover the importance of a Life Cycle Assessment and all that assessment encompasses and how to effectively dissect the important elements of a Life Cycle Assessment.

10:20 - 10:40 am
3759364: Experimental Investigation of the Tribological Performance and Usability of Waste Tire Pyrolysis Oil in Engine Oils
Abdullah Alazemi, Kuwait University, Safat, Kuwait

More than one billion rubber tires are annually disposed of around the world as a major part of the solid waste stream, which presents an enormous environmental risk. Therefore, there is an urgent need to recycle and take advantage of waste rubber tire materials, more commonly referred to as end-of-life tires. In the current investigation, materials extracted from recycled used tires will be studied as potential additives to conventional engine oil. Pyrolysis oil or carbon black materials derived from waste tires will be mixed in different concentrations with engine oil to obtain a lubricant mixture. Structural and chemical analyses of those tire-recycled materials will be conducted via scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Furthermore, rheological studies will be conducted to explore the effect of recycled materials on the rheological properties of the engine oil at different temperatures and shear rates. Finally, a tribometer will be utilized to perform tribological studies of the lubricant mixture to assess the effect of tire-recycled materials on the tribological performance of engine oils.

10:40 - 11:00 am
3759260: Fuel Efficient Lubricants: Performance and Protection through Functionalized Polymers
Paul Kirkman, David Growney, Tim Smith, Lubrizol Ltd., Derbyshire, United Kingdom; Csilla Gyorgy, Steven Armes, University of Sheffield, Sheffield, United Kingdom

Historically, the use of polymeric additives in automotive lubricant formulations has been associated with viscosity control, ensuring optimal lubricant performance across a range of operating conditions through their temperature sensitive structures. Today, both the role and nature of polymers in lubricants is changing. Lower viscosity fluids impose challenges on traditional polymer content, whilst a growing emphasis on tribological friction control in the boundary regime generates interesting questions into the role that surface active polymers can play in lubricants. The work presented herein details the preparation, characterization, and evaluation of highly defined polymeric structures that yield friction reduction in the mixed to boundary lubrication regime. It is shown that such structures form via a self-assembly mechanism, which can be tightly tuned with polymer molecular structure. Surface activity can be refined through polymer functionalization, quantified through surface analysis, and ultimate performance benefits realized through frictional evaluation.

11:00 - 11:20 am
3756294: Augmenting the Performance of Eco-Friendly Greases Using Synergistic Natural Resources
Ankit Saxena, Deepak Kumar, Naresh Tandon, Indian Institute of Technology Delhi (IITD), Delhi, India

Grease industry extensively uses non-renewable, non-biodegradable, and toxic entities as ingredients that satisfy the performance goals and jeopardize the environment simultaneously. Several environmentally benign ingredients have been tried to formulate eco-friendly greases; however, a potential alternative is not yet reached. The present study explores, for the very first time, an effort to enhance the performance of eco-friendly greases (based on vegetable oil and organoclay) using biopolymers as additives. Two different series of greases containing 0 - 10 %w/w of two biopolymers (B1 and B2) are developed and evaluated for anti-wear (AW), and extreme-pressure (EP) tests as per ASTM standards. B1-based greases displayed superior AW (upto ≈ 22% enhancement), frictional (upto ≈ 42% enhancement), and EP response (upto ≈ 60% enhancement). Whereas B2-based greases displayed superior EP characteristics (upto ≈ 60% enhancement), however, inferior AW response. The formation of an in-situ polymer-layered silicate nanocomposite film at the interface is attributed to the superior EP properties. The contradictory AW behavior of biopolymers is attributed to their distinct interfacial interaction tendencies (synergistic or antagonistic) with organoclay.

11:20 - 11:40 am
3756297: Investigation of Tribological and Vibration Performance of Vegetable Oil-Based Eco-Friendly Greases on Rolling Bearing
Ankit Saxena, Deepak Kumar, Naresh Tandon, Indian Institute of Technology Delhi (IITD), Delhi, India

Conventional greases are saturated with environmentally harmful (or unacceptable) ingredients for the sake of performance. Several eco-friendly alternatives to such harmful greases have been developed; however, a potential solution is not yet reached. The present study explores, for the very first time, eco-friendly greases with enhanced tribology and vibration performance. A series of greases is developed using vegetable oil as base oil, organoclay as a thickener, and several naturally-occurring additives. The greases are evaluated for anti-wear (AW), and extreme-pressure (EP) tests as per ASTM standards against a conventional commercial grease as a benchmark. Vibration and shock pulse measurements are also acquired to assess the actual dynamic performance of greases on a rolling bearing. Superior EP (upto ≈ 60% improvement) and frictional (upto ≈ 22% improvement) responses are observed for formulated greases compared to the commercial grease. Greases further display comparable AW and vibration performance to commercial grease.

1C	Salon C

Tribochemistry I

Session Chair: Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

9:20 - 10:00 am
3959444: SPOTLIGHT; Interplay of Mechanics and Chemistry Governs Wear of Diamond-Like Carbon Coatings Interacting with ZDDP-Additivated Lubricants
Michael Moseler, Fraunhofer IWM, Freiburg, Germany

Friction and wear reduction by diamond-like carbon (DLC) in automotive applications can be affected by zinc-dialkyldithiophosphate (ZDDP), which is widely used in engine oils. Our experiments show that DLC’s tribological behaviour in ZDDP-additivated oils can be optimized by tailoring its stiffness, surface nano-topography and hydrogen content. An optimal combination of ultralow friction and negligible wear is achieved using hydrogen-free tetrahedral amorphous carbon (ta-C) with moderate hardness. Softer coatings exhibit similarly low wear and thin ZDDP-derived patchy tribofilms but higher friction. Conversely, harder ta-Cs undergo severe wear and sub-surface sulphur contamination. Contact-mechanics and quantum-chemical simulations reveal that shear combined with the high local contact pressure caused by the contact stiffness and average surface slope of hard ta-Cs favour ZDDP fragmentation and sulphur release. In absence of hydrogen, this is followed by local surface cold welding and sub-surface mechanical mixing of sulphur resulting in a decrease of yield stress and wear.

10:00 - 10:20 am
3920625: Encapsulated Ionic Liquids as Lubricant Additives
Jieming Yan, Filippo Mangolini, Kenechukwu Moneke, University of Texas at Austin, Austin, TX

Ionic liquids (ILs) have been extensively studied for their potential use for lubrication due to their unique physiochemical properties and good tribological performance. However, the limited solubility of ILs in hydrocarbon fluids and the high corrosivity of halogenated ILs limits their adoption as lubricant additives. Here, we encapsulate ILs in polymer shells to overcome these challenges. Two classes of ILs were selected for the study, namely a commercially-available, halogenated IL and a halogen-free, boron-containing IL. The outcomes of macroscale steel-vs.-steel tribological testing together with the results of X-ray photoelectron spectroscopy measurements indicate that polymer-encapsulated IL additives in synthetic oils release the IL at the sliding interface following the mechanical rupture of the polymer shell at the contact inlet, reducing friction and wear with negligible surface corrosion. These novel additives will greatly facilitate the introduction of ILs into conventional lubricant formulations.

10:20 - 10:40 am
3962974: Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM
Kerry Cogen, Infineum USA L.P., Linden, NJ; Matthew Flynn-Hepford, Arya Ahmadi, Mahshid Ahmadi, Olga S. Ovchinnikova, University of Tennessee, Knoxville, Knoxville, TN

In electrified vehicle (EV) systems, the lubricating fluids deliver the chemistry needed to form the antiwear tribofilms in rolling / sliding contacting surfaces and serve to control friction and protect surfaces from wear and fatigue. Understanding the mechanism of antiwear film formation and how to tune surface chemistry to control functionality is essential for development of next generation of driveline fluids. In this work, we utilize a unique multimodal AFM methodology to understand initial film formation from different phosphorus-containing lubricants in-situ. We combine Friction Force Microscopy (FFM) to capture the spatial details of friction over the surface as the tribofilm forms and evolves and Nano Infrared Spectroscopy AFM (NanoIR-AFM) to understand the chemistry of the film. We investigate the different rates of film formation for different phosphorus-containing additives on steel surfaces under different load conditions and how other components typically found in EV fluids can impact that formation.

10:40 - 11:00 am
3908910: Wear and Degradation Behavior in Nitrided Steel Investigated by Reactive Molecular Dynamics Simulations
Mizuho Yokoi, Masayuki Kawaura, Yuta Asano, Yusuke Ootani, Nobuki Ozawa, Momoji Kubo, Tohoku University, Sendai, Miyagi, Japan

The development of wear-resistant materials is important because wear can cause serious accidents. Nitriding is a surface treatment that improves wear resistance by forming a hard iron nitride layer on the surface. However, it has been reported that N atoms in the iron nitride surface released by mechanical and chemical effect during sliding, which causes degradation. In this study, we analyzed tribochemical reactions to clarify the degradation process of iron nitride by using reactive molecular dynamics sliding simulations for the friction interface in water environment. The water reacted with the iron nitride, forming Fe-O-Fe structures. Then, N atoms in iron nitride surface formed NH_3 molecules. We concluded that the tribochemical reaction caused the degradation of iron nitride due to the formation of Fe oxide film on the surface and releasing NH_3 molecules. The influence of structural changes of the iron nitride on the degradation process will be reported at the conference.

11:00 - 11:20 am
3963120: Simulation study of DLC-Zirconia Sliding Under Alcohol Gas Environment
Ryuichi Okamoto, Hirotoshi Akiyama, Rio Nakae, Hitoshi Washizu, University of Hyogo, Kobe, Japan

Diamond-like carbon (DLC) has extensively been studied because of its tribological properties. Depending on the environment and the counter surface, the friction coefficient can drop down to less than 10^{-3}. In particular, using yttria-doped stabilized zirconia (YSZ) as a counter-surface, it was found that the friction coefficient goes down to order 10^{-4} under the environment of alcohol, hydrogen and water gases (friction fade-out, FFO). The experiments suggest that the ultra-low friction can be attributed to the hydrocarbon tribofilm of thickness 100-150nm formed on the YSZ surface in the running-in stage. To understand the early-stage chemical reactions, we perform molecular dynamics simulation using reactive force field (ReaxFF), which allows chemical reactions and varying atomic charges. In the simulation box, we place hydrogen-containing DLC film and zirconia film, between which the ethanol, water gases, and hydrogen gas (or radicals) are distributed. We then perform sliding simulation with speed 100m/s under a load pressure 1GPa. On the YSZ surface, we found that the sliding induces dehydrogenation reaction of the ethanol. Further, the sliding and the catalytic nature of the zirconia induce polymerization of ethanol molecules. These reactions may be a precursor of the tribofilm formation observed in the experiments. In this talk, we shall also discuss the energetics of these reactions using the potential of mean force between the chemical components.

Surfaces and Interfaces Including Nanotribology I

Session Chair: Deepak Kumar, Carnegie Mellon University, USA, Pittsburgh, PA
Session Vice Chair: Iakov Lyashenko, Berlin University of Technology, Berlin, Germany

9:20 - 9:40 am
3762022: Surface Characterization as Inputs for FEM Multi-Scale Model Development
Iyabo Lawal, The University of Texas at Austin, Austin, TX; Matthew Brake, Rice University, Houston, TX

In tribology experiments, the evolution of the wear track under fretting fatigue is a multi-physics problem involving friction, heat transfer, material phase change and local plastic deformation at different scales. It is a complex problem that is not well understood. As a first approach, an FEM model has been developed to model fretting fatigue using a non-smooth constitutive friction model that accounts for asperity level friction as well as meso-scale friction. By observing wear scar evolution from confocal micro-scope as well as SEM images, a better understanding of how to incorporate multi-scale friction into FEM models can be developed.

9:40 - 10:00 am
3736221: Residual Stress Behaviour in Contacting Rough Surfaces
Salem Elsheltat, Alastair Clarke, William Britton, HP Evans, Cardiff University, Cardiff, United Kingdom; Alexander Lunt, University of Bath, Bath, United Kingdom

The paper examines the way in which the running-in process modifies the as-manufactured surface roughness of hardened and ground steel disks, used to model gear tooth contact conditions in a disk machine experiment, and investigates the association between asperity shape changes due to plastic deformation and the asperity-scale residual stress generated in the material. Areas of high tensile residual stress at the surface are of interest as a potential precursor of surface micropitting damage in subsequent running. The shape changes of prominent asperities were measured using in-situ profilometry, and a novel depth-profiling residual stress measurement technique using FIB milling and digital image correlation enabled measurement of the near-surface residual stresses in the asperities, up to a depth of 4 microns. Comparisons were made with residual stresses predicted by ANSYS FEA elastic/plastic contact analyses, and residual stress fields could then be associated with the degree of asperity modification observed.

10:00 - 10:20 am
3964051: Surface Topography as a Material Parameter
Tevis Jacobs, Arushi Pradhan, Luke Thimons, University of Pittsburgh, Pittsburgh, PA; Antoine Sanner, Lars Pastewka, University of Freiburg, Freiburg, Germany

Surface topography controls the performance and reliability of surfaces in applications from automotive and aerospace to medical devices and consumer electronics. Yet too often our strategies to find the optimal surface finish rely on trial-and-error testing. While great strides have been made in the theory and simulation of roughness-dependent surface performance, it remains difficult to translate this into the design and control of real-world devices. First, I will discuss a recent special issue of MRS Bulletin entitled “The Materials Science and Mechanics of Rough Surfaces”, in which seventeen authors from around the world reviewed the cutting-edge science of surface engineering. Second, I will discuss recent efforts in my group to rationally control the adhesion of technology-relevant coatings. Specifically, I will discuss the use of polycrystalline diamond and other hard-carbon coatings, and also the use of nanoscale patterning to modify the adhesion of silicon computer chips.

10:20 - 10:40 am
3929643: Effects of Tip Geometry on Developing Young’s Modulus Maps in Atomic Force Microscopy
Logan Kirsch, Gregory Rodin, Filippo Mangolini, Nicolas Molina Vergara, University of Texas at Austin, Austin, TX

Atomic Force Microscopy (AFM) is commonly used to assess elastic properties at the nanoscale, but accurately calculating quantitative values for Young’s modulus from load-displacement data remains a significant challenge. One major source of error lies in assuming a constant spherical or conical geometry, which fails to accurately capture AFM tip geometry. Moreover, the tip can undergo drastic geometry changes during the tens of thousands of indentations required for a typical AFM Young's modulus map. We aim to address these issues by considering different indenter tip geometries and their evolution due to tip wear. We first develop analytical procedures to dynamically calculate Young's modulus and current tip geometry from load-indentation data for various indenter tip geometries. We then assess the accuracy of these different procedures by using them with experimental load-displacement data from samples with well characterized elastic properties over the lifetime of an indenter tip.

10:40 - 11:00 am
3930100: Understanding Small-Scale Topography Using Scanning Electron Microscopy
Vimanyu Chadha, Ruikang Ding, Kurt Beschorner, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA; Nate Miller, ASML, Wilton, CT

Roughness-dependent surface properties cannot be understood nor predicted without a comprehensive description of surface topography, which includes many different length scales, including down to nanometer sizes. Recent work has established comprehensive topography characterization using transmission electron microscopy (TEM), but this is time-consuming, labor-intensive, and not widely available. To address these limitations in TEM, we evaluated the potential of scanning electron microscopy (SEM) to characterize comprehensive topography. We describe a straightforward approach for sample preparation, measurement, and analysis, which goes from bulk sample to spectral characterization. We use this approach to measure the topography of ultrananocrystalline diamond and compare the accuracy of SEM-measured topography against prior TEM-based measurements. We use a statistical comparison of power spectral densities (PSDs) to show that, despite a loss of smallest-scale information, the results are similarly accurate across the range of 7.5 µm to 75 nm. This investigation demonstrates a simple and widely accessible path to advanced topography characterization and analysis. Finally, we apply this technique to characterize flooring surfaces in the context of research on slip-and-fall accidents.

11:00 - 11:20 am
3959395: The infamous Fuorinated Carbon Materials in Tribology: A Journey to the Atomic-Scale Origins of Their Unique Properties
Gianpietro Moras, Thomas Reichenbach, Leonhard Mayrhofer, Michael Moseler, Fraunhofer IWM, Freiburg, Germany; Takuya Kuwahara, Osaka City University, Osaka, Japan

The unique properties of per- and polyfluoroalkylic substances (PFASs) in terms of hydrophobicity, anti-adhesion, chemical stability and low friction make them popular materials also in tribology. However, their high chemical stability poses serious problems owing to their accumulation in the environment and in biological systems, and regulations in this area aim to their replacement. This step is not trivial but understanding the mechanisms behind their performance may help. Here, we summarize our atomistic modelling studies on the chemical and physical origin of some of the properties of PFAS that are relevant in a tribological context. We start by discussing how PFAS can be simultaneously polar and hydrophobic. Next, we investigate why and when fluorinated carbon interfaces exhibit lower friction than their hydrogenated analogs. Finally, we discuss the mechanism of film transfer and solid lubrication in PTFE-lubricated steel contacts.

2A Salon A

Materials Tribology II

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:40 pm
3952065: Spotlight: New Contact Temperature Model for Polymer Contacts, Considering Tribo-System Geometry: A Step Toward Generalization
Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Contact temperatures are clearly an important contact parameter in tribology design. However, we still lack a generally accepted and broadly used model allowing for easy and fast estimation of the contact temperature. This is true for steels and various other metals, and so much more for polymers. Namely, polymers are significantly more sensitive to contact temperatures due to their poorer mechanical and thermal properties. Therefore, the inaccuracy in predicting the contact temperatures in polymer contacts may result in notable variation of expected surface conditions and detrimental tribological behaviour. In this work we present a ready-to-use temperature model for poylmer/steel contact, preferentially designed for pin-on-disc studies, which also considers tribo-system geometry (volume, surface). Moreover, a further development of a more generalized model for various tribological systems and their geometries is presented and discussed, as well as the effect of different contact material properties.

2:40 - 3:00 pm
3750598: Laser Surface Texturing of Stainless Steel Substrate for iIproving the Wear Life of PDA/PTFE Coatings
Firuze Soltani-Kordshuli, Nathaniel Harris, Min Zou, University of Arkansas, Fayetteville, AR

Stainless steel substrates were laser textured according to two texture designs using four laser powers. Polydopamine/polytetrafluoroethylene (PTFE) thin coatings were then deposited on smooth and laser textured substrates. Tribological tests were performed using a reciprocating ball-on-flat configuration to study the effects of laser surface texturing the substrate on the durability of the coatings. It was found that laser texturing the stainless steel substrates significantly prolonged the coating life, slightly decreased the coefficient of friction, and effectively prevented large-scale delamination of the coating. Higher laser powers contributed to larger surface roughness and deeper texture grooves that led to better wear mechanisms. These texture grooves stored more PTFE and supplied the solid lubricant to the worn interface to restore the interface lubrication and thus delayed the coating failure.

3:00 - 3:40 pm
3963437: Spotlight: Effect of Counterbody Material on Tribofilm Formation of PTFE-Chromium Composites
Mark Sidebottom, Faysal Haque, Miami University, Oxford, OH; Sifat Ullah, Rensselaer Polytechnic Institute, Troy, NY

Different filler particles (e.g. α-Al_2O_3, activated carbon nano fillers etc.) composited with PTFE reduce wear by~10,000x when slid against 304 stainless steel. These composites are known as ultralow wear materials. Recently, three new composites (PTFE-Cr, PTFE-Ti, PTFE-Mn) achieved ultralow wear when slid against Brass 260. However, these composites showed mixed performance against 304 SS. In this study, four different counterbody materials (Cu 110, Zn-galvanized steel, 304 SS, and brass 260) were tested against PTFE-Cr to identify how counterbody material properties affected wear and friction performance. The tests revealed high variation in friction coefficient (μ~0.15-0.28) and wear rate ($8x10^{-9}$ $mm^3/Nm < K < 1x10^{-6}$ mm^3/Nm). To understand the evolution of wear, the tribosystem was analyzed using optical microscopy, profilometry, and surface energy measurements. Variance in transfer film morpohology was dependent on the counterbody material the PTFE-Cr composite slid against.

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

4:20 - 4:40 pm
3961476: Self-ILbricating Polyimide for EV Wear and Friction Applications
Hau-Nan Lee, Yasuaki Mashimo, Ruth Jackowiak, Yuichi Maruyama, Takuya Miyauchi, Lucas Amspacher, DuPont Vespel Technology, Wilmington, DE

DuPont Vespel® has developed new polyimide-based self-lubricating materials that perform in high pressure and velocity (PV) conditions. These materials also show low friction and excellent wear-resistance in dry or lubricated conditions, which makes them ideal tribological solutions for thrust washers, bushings, and seal rings in driveline applications for electric vehicles. In this study, we report tribological performance of three polyimide-based materials containing different solid lubricant packages. The tribological tests were performed using block-on-ring and pin-on-disk configurations under dry condition. The formation of transfer films on the steel counterpart was investigated by optical microscopy and elemental analysis. To understand the tribological performance of the materials under lubricated conditions, we developed a thrust washer test protocol to determine the PV limit, wear, and friction of the materials in an automotive transmission fluid. The new materials show more than 5 times higher PV limits in dry condition and 50% higher PV limit under lubricated condition, compared to current polyimide product offerings. The tribological testing results of other engineering polymer-based and metallic materials will also be presented as comparisons.

4:40 - 5:00 pm
3931243: Relative Scuffing Resistance of Aerospace Bearing Materials and Lubricants
Carl Hager Jr., The Timken Company, North Canton, OH; Robert Sadinski, Air Force Research Laboratory, Dayton, OH

Rotorcraft propulsion systems should continue to operate at drive system power for a minimum of 30 minutes after loss of lubricant or lubrication system, according to Aeronautical Design Standard ADS-50-PRF. Rolling element bearings within these systems are typically manufactured from steel alloys. The combination of alloy selection and heat treatment can significantly affect the propensity for adhesive wear to occur between rolling elements and raceways. This type of damage can be exacerbated by the loss of lubricant supply to the contacts. Modern hybrid bearings utilize steel alloy raceways with ceramic rolling elements, typically silicon nitride. Hybrid material contacts are often less susceptible to adhesive wear than all-steel contacts. For this work, bench level lubricated rolling/sliding wear tests were conducted to rank the relative adhesive wear resistance of six bearing steel alloys, as well as the pairing of each alloy with silicon nitride. Tests were conducted with an ISO VG 10 polyalphaolefin oil containing only rust and oxidation inhibitors, as well as five fully formulated aviation gear oils. The relative ranking of each material pair, and lubricant effects on test results, will be presented.

5:00 - 5:20 pm
3930929: Improving Tribological Properties of Low-Cost Carbon Steels via Chromizing
Tomas Grejtak, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Chromizing is a surface treatment method applied to ferrous alloys to improve their corrosion and mechanical properties. However, the influence of chromizing on the tribological properties of steel materials with different microstructure and composition is not well understood. In this work, we demonstrate that the low-cost carbon steels can achieve the mechanical properties of more expensive tool steels via an affordable and high throughput chromium diffusion process. The tribological and hardness properties of AISI 1095 carbon steel, 52100 bearing steel and A2, D2 and M2 tool steels were investigated via abrasion wear testing, nanoindentation, microindentation, and morphological characterization. The results showed that the chromizing significantly increases the hardness and wear resistance of 1095 and 52100 steels while the effect on the wear resistance in the D2 and M2 tool steels was insignificant.

2B	Salon B

Lubricants II

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:40 pm
3962263: SPOTLIGHT; CNTs to Enhance Heat Transfer of EV Fluids
Jun Qu, Chanaka Kumara, Wenbo Wang, Hsin Wang, James Haynes, Oak Ridge National Laboratory, Oak Ridge, TN; Ning Ren, Jacob Bonta, Edward Murphy, Roger England, Valvoline Global Operations, Lexington, KY

The e-motor in an EV rotates 15,000 rpm and potentially goes up to 30,000 rpm in the future. The copper winding on the e-motor gets very hot, which is cooled by the lubricant. Increasing heat transfer efficiency currently is a primary challenge for e-motor oils to allow higher currents for higher torque output. The remarkable thermal conductivity (2800–6000 W/mK, 10X higher than copper) of carbon nanotubes (CNTs) present another opportunity for being used as additives for the e-motor fluids to improve the heat transfer capacity. However, CNTs have poor suspendability in fluids and tend to aggregate and precipitate. This study innovated covalent functionalization for CNTs to enable stable suspension and uniform dispersion of CNTs in both polar and non-polar fluids. Initial research has added 0.1 wt.% of modified CNTs into an EV base oil, resulting in 10% higher thermal conductivity and 10% higher volumetric heat capacity with <4% viscosity increase, resulting in 8% improved heat transfer efficiency (Mouromtseff Number). The effects of CNT type, diameter, length, and concentration on the fluid’s

thermal and rheological properties are being investigated. Research sponsored by the Vehicle Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy (DOE).

2:40 - 3:00 pm
3963106: The Study of the Effect of Water on Engine Oil Rheology and Anti-Wear Performance in HEV (Hybrid Electric Vehicles) Application
Hongyu Li, Hua Hu, Jiandi Jiang, Junfang Nie, Weizi Li, Shell (Shanghai) Technology Limited, Shanghai, China; Jiping Zhang, Yan Wang, Chenhui Zhang, Tsinghua University, Beijing, China

Contamination of as much as 20% water was observed in field trial of hybrid electric vehicles in particular plug-in model. The presence of water can affect engine oil anti-wear performance in complex ways. To gain better understanding on the effect of water contamination on the anti-wear performance, experimental investigations including rheology properties, oil film thickness measurement and boundary anti-wear performance on several 0W-20 formulations with different water contents were conducted. Tribofilm were analyzed using X-ray photoelectron spectroscopy. It is found that water have a long-lasting detrimental effect on tribofilm formation, while formulation with different detergent-system showed different water resistance property regarding on oil film thickness in high speed elastohydrodynamic lubrication and SRV wear volume in boundary lubrication regime. Anti-wear performance was checked on simplified blend with ZDDP, water and different detergents, demonstrating detergent selection plays an important role in offsetting the detrimental effect of water on anti-wear performance.

3:00 - 3:20 pm - **Open Slot**

3:20 - 3:40 pm
3965747: Tribological Properties of Nano Al_2O_3 Gear Oil From Lube Oil Blending Plant Effluent Oil for Automotive Gearbox
Kaisan Usman, National Agency for Science and Engineering Infrastructure, Abuja, Nigeria; Shafiu Lawal, Yusuf Dambatta, Laminu Kuburi, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

The establishment of lube oil blending plants in Nigeria have led to a continuous discharge of industrial effluent in densely populated states like Lagos, Port Harcourt, Ibadan, Kano, Kaduna etc., that threatens well-being of humanity, plants, aquatic lives and even construction soils. This paper focused on the determination of tribological properties of Nano Al_2O_3 oil for extreme pressure application developed from lube oil blending plants effluent oil as an alternative means of mitigating negative effects associated with the effluent to the living environment. The Al_2O_3 nanoparticles were characterized with the use of Fourier transform infrared (FTIR), X-ray diffraction (XRD) and Scanning electron microscopy (SEM). The tribological properties of the four Nano lubricant samples were studied with varying weight percentages of Al_2O_3 in the pure effluent oil ranging from 0.1 wt.% to 0.4 wt.% in a step of one to understand the behaviour of the materials and comparison was made with pure effluent oil. The anti-wear property was observed to have considerably improved at 0.4 wt.% nanoparticles concentration with 26.14%, whereas, friction was observed to have slightly increased with the dispersion of Al_2O_3 nanoparticles with 6% at 0.3 wt.%. Based on the results obtained, the study indicated that the tribological properties of effluent oil can be enhanced with the dispersion of nanoparticles.

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

4:20 - 4:40 pm
3931086: The Effect of Rheological Feature of Graphene Oxide-Involved Emulsion on its Corresponding Lubricity Performance
Hsin-Hung Ou, China Steel Corporation, Kaohsiung, Taiwan

This study aims to investigate the effect of rheological property of graphene oxide (GO)-involved emulsion on its corresponding lubrication behavior. The friction of GO-involved emulsion could be reduced by a factor of 1.2 as compared to that of the base emulsion. The worn surface of steel specimen after lubrication demonstrated that the presence of GO shrank the wear size and depth by 7.6 % and 14 %, respectively. The welding loading of GO involved oil also gave rise to a 315 kg level, while that of base oil only allowed 250 kg. The improved lubricity performance of GO involved emulsion was attributed to the fact that GO enhanced either anchoring reaction between oil drops (increased oil viscosity) or chemical reaction toward steel substrate. Furthermore, the variations of d_{50} oil droplet sizes for base and GO emulsion were 16.9 and 11.2 %, respectively, suggesting a slight improvement on emulsion stability with the presence of GO during lubrication. This result was plausible since carboxyl groups within GO are

protonated at acidic condition such that the GO particles turned to less hydrophilic and form GO aggregates, resulting to a prevention of coalescence between oil drops. On the other hand , the I_D/I_G values of GO within emulsion before and after lubrication were 0.61 and 0.66, respectively, revealing a trivial increase in the disorderliness degrees after lubrication, which was corresponding to the change of d_{110} lattice, as determined in HR-TEM image.

2C — Salon C

Tribochemistry II

Session Chair: Filippo Mangolini, The University of Texas at Austin, Austin, TX

2:00 - 2:40 pm
3771581: SPOTLIGHT; A New Friction Modifier Mechanism Based on Pressure-Induced Hydrogen Bonding
Thomas Reddyhoff, James Ewen, Pushkar Deshpande, Imperial College London, South Kensington, London, United Kingdom; Mark Frogley, Diamond Light Sources, Didcot, United Kingdom; Mark Welch, Wren Montgomery, Natural History Museum, London, United Kingdom

We present new research into the use of n-alcohols as “traction-modifier” additives that can be blended with oils in order to reduce elstohydrodynamic friction (traction) without impacting film thickness. This is based on a recent discovery that neat n-alcohols can self-assemble under pressure to form layered structures that provide liquid superlubricity, (i.e., a friction coefficient below 0.01, inside lubricated contacts [1]). This occurs within the central, high-pressure region within a contact so that film thickness is unaffected. Furthermore, similar beneficial behaviour occurs even after n-alcohols have been diluted by a hydrocarbon base oil. These performance gains are supported by ball-on-disc tribometer friction and film thickness data, while insights into the mechanism are provided by FTIR measurements made on lubricants samples within a high-pressure diamond anvil cell. The link between molecular structure and friction reducing performance is discussed along with the practicalities of implementing such additives in practice.

2:40 - 3:20 pm
3757795: SPOTLIGHT: Understanding the Effect of Forces on Tribochemical Reaction Rates
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

The effect of applied stress σ on the rates of tribochemical reactions is described using the Bell model, where the rate varies as $\exp(\sigma\Delta V^{\ddagger}/k_BT)$, where $\Delta V^{\ddagger}$ is the activation volume. Strategies for measuring reaction pathways are illustrated using the gas-phase lubrication of copper by dimethyl disulfide (DMDS) where the rate of reaction of on a Cu(100) single crystal substrate is measured by exerting the force using an atomic force microscopy tip. The measured angular dependence of the methyl thiolate decomposition rate suggests that the kinetics can be analyzed using quantum mechanical methods that are used to analyze thermal reaction rates and is confirmed by measuring the effect of a normal stress on the reaction rate which is excellent agreement with values calculated using quantum theory. This approach is extended to studying shear-induced methyl thiolate decomposition which occur more rapidly and on investigating the tribochemical decomposition of carboxylates on Cu(100).

3:20 pm - 3:40 pm
3755889: Description of High Throughput Elemental Analysis in Oil Samples Utilizing ICP-OES and Automation to Overcome Common Issues in Measurement
Christopher Conklin, Paul Krampitz, Agilent Technologies, Wood Dale, IL

The determination of elements in used and unused lubricating oils and base oils and rapid screening of used oils for wear-metals such as Fe, Cu, and Al is a common approach to monitoring wear in engine, gearbox, and other components. The trace metals that enter these lubricating oils as mechanical wear from moving parts are likely to be present in the oil as metallic particles rather than dissolved in the oil; thus, it can be essential to homogenize each sample before analysis to ensure representative data. This talk will discuss high throughput analysis of used lubricating oils using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and an Autosampler that homogenizes samples immediately before analysis, resulting in improved throughput and results.

3:40 - 4:20 pm - Break

4:20 - 4:40 pm
3959765: Exploring the Role of Metalworking Fluids in Tribochemistry : Enhancing Performance and Efficiency on the Surface Level
Jesse Ziobro, Univar Solutions, Houston, TX

The field of metalworking fluids (MWFs) has seen significant advancements in recent years, with a particular focus on the effects of tribochemistry. Tribochemistry refers to the study of chemical reactions that occur at the interface between a metal surface in relative motion. The interplay between the MWF and metal can have significant impact on the performance and longevity of the tool used in the metalworking process. This abstract will explore the effects of tribochemistry on MWFs, including the formation of tribofilms, the impact on surface finish, and the potential for corrosion and wear. Additionally, the role of additives in MWFs will be discussed, as well as emerging technologies that may further enhance the understanding and utilization of tribochemistry in metalworking fluids.

4:40 - 5:00 pm
3966149: Surface-Protective Tribofilms via Tribocatalysis and Surface-Active Precursors
Q. Jane Wang, Jannat Ahmed, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

This study investigates the mechanisms involved in the in-situ formation of lubricious and wear-protective tribofilms in systems utilizing chromium oxide surfaces and dodecane as the lubricant. Through the use of reactive molecular dynamics simulations, we explored the process of dodecane fragmentation and tribopolymerization, while also examining the impact of environmental oxygen on the fragmentation rate. Our visualization of the simulation outputs revealed that chromium oxide acts as a catalyst, facilitating the fragmentation of dodecane molecules through the synergistic effects of Cr^{3+} sites and oxygen vacancies. Subsequently, the fragmented molecules polymerize, leading to the formation of tribopolymers. We further extended our simulation by introducing five mole percent of cyclopropanecarboxylic acid (CPCa) into dodecane. Notably, CPCa was found to accelerate the fragmentation of dodecane, resulting in tribopolymers that directly attach to the surface, thereby enhancing its lubrication efficacy.

5:00 - 5:20 pm
3931288: Minimizing Engine Wear in the Sequence IVA Through Tribofilm Formation
Darryl Williams, Grant Pollard, Afton Chemical, Richmond, VA

Engine wear protection is the key metric in the Sequence IVA test. While obsolete, this test remains a good platform for evaluating camshaft wear with engine lubricants. We have found that tribofilm formation is a key element in providing good performance in this test. Surface analysis results will be presented from test specimens and related to the measured wear in the test. Surface analysis by SEM allows definition of portions of the lifter pad where tribofilms are formed. .

2D Salon E

Surfaces and Interfaces including Nanotribology II

Session Chair: Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA and Gianpietro Moras, Fraunhofer IWM, Freiburg, Germany
Session Vice Chair: Vimanyu Chadha, University of Pittsburgh, Pittsburgh, PA and Loren Baugh, Mechanical Engineering , Auburn University, Auburn, AL

2:00 - 2:20 pm
3746490: Effect of Humidity on Head Smear Generation in Magnetic Disk Surfaces under Heat-Assisted Magnetic Recording
Norio Tagawa, Hiroshi Tani, Hiroshi Kurafuji, Kenji Yakata, Renguo Lu, Kansai University, Suita-shi, Osaka, Japan

In heat-assisted magnetic recording (HAMR) technology, diamond-like carbon (DLC) protective films and lubricant films on the magnetic disk surface are heated to high temperatures. This process results in the decomposition of materials by heat and their deposition as "smear" on the magnetic head surface. The smear generation is suggested to be dependent on the environmental conditions in helium (He)-enclosed hard disk drives (HDDs). This study experimentally investigated the possibility that humidity may influence the generation of head smear. Two-kinds of magnetic disks are used in the experiment. The results show the amount of smear increases as the humidity increases in actual magnetic disks with lubricant films, whereas it decreases in magnetic disks with only DLC thin films as the humidity increases. Therefore, the humidity should be low to mitigate smear in terms of practical HDDs design. The mechanisms behind these experimental results are also discussed herein.

2:20 - 2:40 pm
3964058: Hydrogenated Diamond-Like Carbon Coatings in the Protection of Differential Cross-Shafts
Timea Stelzig, Christian Scholz, Constantino Costa, Oliver Hunold, Oerlikon, Bingen, Germany

The rapid movement of the automotive industry to develop and commercialize electric vehicles is placing growing demands not only on the lubricants enabling optimum operation but also on identifying alternative, synergistic solutions to keep cost flexibility and durability of the components. The general trend to move to low viscosity fluids presents challenges when it comes to wear and friction management. In general three methods can be carried out to reduce friction loss and limit wear: 1) changing the design of the component; 2) optimizing lubrication in terms of the lubricant composition and/or component materials and 3) implement advanced novel coatings. Coatings play the role of protective layers to reduce friction coefficient and increase wear resistance of the components. In this work we present the beneficial effect of hydrogenated diamond-like carbon coatings on the performance of differential cross-shafts wear and friction behaviour.

2:40 - 3:00 pm
3958274: Friction in Adhesive Contacts Between Hard Indenters and Soft Elastomers: Experiments and Simulations
Iakov Lyashenko, Valentin Popov, Berlin University of Technology, Berlin, Germany

The effects of roughness, hard particles in contact zone, and chemical inhomogeneities on contact properties (normal and tangential contacts) in adhesive contacts between hard indenters and soft elastomers were experimentally investigated. Influence of indentation depth, radius of indenter, elastomer thickness, elastic modulus of an elastomer, velocity of indenter motion was analyzed. The case was investigated, in which elastomer's surface was coated with a thin layer of a chalk dust to exclude adhesion between contacted bodies. Based on experiments, an adhesive strength and mechanical energy dissipation in a full cycle indentation/detachment was analyzed. It is shown, that if the amplitude of the indenter oscillations is less than this critical value, there is no dissipation in a contact due to adhesion. We also performed theoretical modelling in the frameworks of the boundary element method (BEM), method of dimensionality reduction (MDR), also proposed different phenomenological models were proposed. This work was supported by Deutsche Forschungsgemeinschaft (Project DFG PO 810-55-3).

3:00 - 3:20 pm
3931532: Analytical Friction Models for Molecular Adsorbates
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

Atomic-scale nanoscale friction models, based on ideas from Tomlinson and Prandtl, conventionally use simple periodic sliding potentials to model the velocity and temperature dependences but this approach is not well suited to describing the friction of adsorbed molecular overlayers. To address this, we use the ideas of Evans and Polanyi to develop a thermodynamic theory to analyze stress-dependent reaction rates. We also use a simple model interaction potential between the tip and the outer surface of the organic substrate to develop analytical models for molecular friction of self-assembled monolayers (SAMs) on surfaces, so-call friction modifiers. In particular, this potential can be coupled to the molecular tilt to provide an analytical model for the chain-length dependence of SAM friction that is in good agreement with experiment. Interestingly, this model does not invoke intermolecular van der Waals' interaction to explain the effect. Finally, this strategy is used to model the chain-length and velocity-dependence of shear-induced tribochemical reaction rates.

3:20 - 3:40 pm
3768861: Transient Analysis of the Rolling/Sliding Contact with a Multi-Layered Visco-Elastic Material
Daniel Nélias, Efoé R. Wallace, Thibaut Chaise, Univ Lyon, Villeurbanne, France

The purpose of this work is to analyze the contact of a rolling or sliding body on a viscoelastic multilayered half-space, from the early stage of the movement up to the steady-state regime. The numerical technique, known as the semi-analytical method (SAM), is based on the use of Fast Fourier Transforms (FFT) and Conjugate Gradient Method (CGM) algorithms. An Elastic/Viscoelastic correspondence is employed to account for the visco-elastic behavior of the material. This correspondence imposes to recalculate the influence coefficients at every time step. The influence coefficients are found for an elastic multi-layered half-space using the Papkovich-Neuber potentials, for a coating with one or several layers. This way the influence coefficients have been found in the Fourier frequency domain. A numerical inversion using FFT algorithms has allowed to find the influence coefficients in the space domain. A parametric study is performed to highlight the effect of a gradient of properties in the half-space. The effects of the variation of the instantaneous shear modulus and of the variation of the relaxation time through several layers are highlighted. It is also shown that the contact solution in terms of contact pressure distribution and subsurface stress field greatly changes from t=0 to the steady-state regime.

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

4:20 - 4:40 pm
3959548: Effects of Hot Switching on Contact Reliability of Pt-Coated Microswitches at Low Contact Voltages
Deepak Kumar, Carnegie Mellon University, Pittsburgh, PA

The reliability issues, particularly with the MEMS switch contacts, have hampered the commercialization of these switches. Under cold switching conditions, the platinum (Pt)-coated MEMS switches, demonstrated a long lifetime (300 million cycles). However, hot switching at high contact voltages (Vc) (>1V) exacerbates contact erosion and surface degradation, which shortens the lifetime of MEMS switches. Little attention has been paid to the switching behavior of Pt-coated MEMS switches at low Vc (<1V). We hypothesize that below 0.5 V, well below the work function of Pt, hot switching damage will be greatly diminished. In the present work, using a designed MEMS test setup, we investigated the hot switching behavior of O_2 plasma-treated Pt-coated MEMS switches at lower Vc, down to 0.1 V. To gain the fundamental understanding of various phenomena, including field evaporation, field emission, electromigration, arcing, and bridge formation/ohmic heating, that can contribute to contact surface degradation, the hot switching behavior at leading (switch closure) and trailing edge (switch opening) of the switching cycle is also investigated. Scanning electron microscope (SEM) is used to inspect the degradation mechanisms, post experiments. Results indicated that hot switching damage decreased significantly, improving reliability at low contact voltages. The outcomes of the research are valuable in hot switching applications of nanoswitches, where contact voltages are very low.

4:40 - 5:00 pm
3972299: UHMWPE Polymer Composite and Hybrid Composite Coatings for Tribological Applications
Abdul Samad Mohammed, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Ultra-high molecular weight polyethylene, commonly known by its abbreviated form UHMWPE, falls under a class of polymers referred to as thermoplastics and finds its use in a variety of applications requiring a high degree of impact and wear resistance in both medical and industrial applications. It has found its way either in the bulk form or as a coating, into various tribological applications ranging from biomedical to bearing applications due to its excellent abrasion resistance coupled with low friction coefficients. However, inspite of its excellent inherent properties, UHMWPE does suffer from few limitations such as, low load bearing capacity and low thermal stability. Hence, various researchers developed different techniques to enhance these properties by fabricating UHMWPE composite/hybrid composite coatings to make it suitable for demanding tribological applications. The present talk focusses on two such successful attempts made recently by our group in developing UHMWPE composite and hybrid nanocomposite coatings for bearing and bio-medical applications, respectively. An overview of the selection of proper reinforcements keeping in mind the targeted applications, efficient filler dispersion techniques, developed coating procedures, substrate pre-treatment procedures and various characterization techniques useful for effectively interpreting the results will be presented.

3A Salon A

Biotribology I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 9:40 am

9:40 - 10:20 am
3972425: Spotlight: Slippery pHysics
Angela Pitenis, Allison Chau, Conor Pugsley, Madeleine Miyamoto, Yongkui Tang, Claus Eisenbach, Thomas Mates, Craig Hawker, Megan Valentine, University of California Santa Barbara, Santa Barbara, CA

Hydrogels are three-dimensional, crosslinked networks of hydrophilic polymers swollen in water. This class of soft materials is used in many industries (e.g., biomedicine, agriculture, wastewater management) due to their high water content, capacity for water retention, and tunable mechanical properties. Polyacrylamide hydrogels have also attracted scientific interest in the tribology community due to their fascinating energy-dissipation properties. In this study, we observe that increasing solution pH reduces the friction coefficient of polyacrylamide hydrogels in sliding contact with hemispherical probes of either borosilicate glass or polytetrafluoroethylene (PTFE). We propose that the mechanisms of pH-dependent polyacrylamide friction may be a combination of electrostatics and hydrolysis.

10:20 - 10:40 am
3931172: A Coupled BEM-FEM Contact Mechanics Model of the Finger-Device Interface in Electroadhesive Haptic Devices
Sitangshu Chatterjee, M. Cynthia Hipwell, Texas A&M University, College Station, TX

Electroadhesive haptic devices apply electrostatic forces to modulate the friction force (by changing the true interfacial contact area) and render tactile sensations. Almost all existing studies predict the frictional performance using either Finite Element or Boundary Element models. However, each method has its own limitations and is individually inadequate to capture the multiscale roughness of the finger, comprised of multilayered tissues with different material properties. Thus, a good contact mechanics model is essential to predict the friction force and strain energy density at mechanoreceptors to design better devices. In this study, we develop a coupled BEM-FEM model. First, a BEM model is used to solve the microscale contact mechanics model and accurately predict the air gap distribution and true contact area, which are used to compute the normal electroadhesive and tangential friction force respectively. The forces from the BEM model are then used in an FEM model to study how the stresses and strains propagate through the multi-layered structure of the human finger. Thus, this model allows us to accurately predict the friction performance in electroadhesive devices. Additionally, the strain energy densities at the mechanoreceptor locations also help us understand how the friction affects haptic perception. The learnings from this study can also be extended to optimize electroadhesive braking performance between any rough surfaces with complex underlying structures.

10:40 - 11:00 am
3748381: Multiphysics and Variability of the Finger-Material Interface for Consumer Product Design
Xinyi Li, M. Cynthia Hipwell, Texas A&M University, College Station, TX; Yinzhong Guo, Dow Chemical Company, Lake Jackson, TX

The sense of touch has been found to affect people’s preference of consumer products through touch of its surface or packaging. Studies have shown that people generally perceive low friction surfaces as more pleasant. Texturing is often the approach to reduce the friction, yet the interface is complex due to multi-physical phenomena such as capillary bridges formed by sweat, deformation and contact as well as the textures ranging from macroscale to nanoscale on both surfaces. In addition, the existence of lipids and sebum makes the friction force and the tactile feeling of the textured surface more difficult to predict by affecting the interface in different ways. In this work, we propose a multi-physics model to elucidate the

underlying physics and mechanisms of the finger-material interface at the single asperity level, which predicts well the measured friction force and tactile perception of two plastic films used for food packaging.

11:00 - 11:20 am
3939738: Numerical Investigation of Rate-dependent Adhesion in Viscoelastic Contacts with Application to Articular Cartilage
Uraching Chowdhury, Melih Eriten, University of Wisconsin-Madison, Madison, WI

Viscoelastic contacts are known to exhibit rate-dependent adhesion. Previously, the authors tested porcine articular cartilage and observed similar rate-dependence in adhesion. The aim of this study is to model those experiments and investigate the influence of bulk viscoelasticity and interfacial properties on the rate-dependent adhesion observed. A finite element model of a rigid sphere contacting a linear viscoelastic half-space is constructed. Constitutive parameters for the half-space are tuned to the measured relaxations. Interfacial interactions are modeled via traction-separation laws. The quasistatic interfacial models delivers rate-dependent adhesion response in close agreement with the experiments. This finding suggests that adhesive process zone at the contact edge expands at high unloading rates due to limited bulk relaxation over the contact. This expansion leads to increase in pull-off forces and apparent work of adhesion. Simulated crack-shapes, tractions and viscoelastic energy dissipation at the contact edges closely follow the predictions of the Greenwood-Johnson 1981 model.

3B Salon B

Lubricants III

Session Chair: TBD
Session Vice Chair: TBD

9:20 - 9:40 am
3930612: Active Control of Friction Coefficient under Lubricated with Ionic Liquids
Shouhei Kawada, Kazuki Akamatsu, Kansai University, Osaka, Suita-shi, Japan; Shunsuke Tanji, Masaaki Miyatake, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

To realize a sustainable society, energy loss due to friction must be reduced to the minimum in mechanical systems. On the other hand, high friction force is required for efficient power transmission. Maintaining oil film thickness is a very important factor in terms of maintenance tribology. This investigation aims to develop novel lubrication system that achieve all of these requirements. Ionic liquids are expected to active control the structure and thickness of the tribo-layer by imparting an electrical potential to the friction surface due to the electrically charged lubricant. This investigation researched the correlation between the chemical structure and physical properties of ionic liquids with friction coefficient and responsiveness.

9:40 - 10:00 am
3923096: Surfactant Aggregation and Tribological Properties in Water: A Study of Sodium 2-Hexyldecanoate
Haiyang Gu, Tomoko Hirayama, Naoki Yamashita, Nobuhiro Sato, Kyoto University, Sennan-gun, Osaka, Japan; Tomoaki Okano, Idemitsu Kosan Co.,Ltd., Chiba, Japan; Masako Yamada, KEK, Ibaraki, Japan

Surfactants have emerged as promising additives for enhancing the lubrication performance of water-based lubricant surfaces, owing to their ability to adsorb on metal surfaces and reduce friction under boundary lubrication conditions. Their unique molecular structure, featuring a hydrophobic end and a hydrophilic end, enables them to form various aggregates in aqueous solutions, including micelles, vesicles or lamellar. In this study, as an example, the aggregation behavior of sodium 2-hydroxydecanoate (2HDNa) in aqueous solution and its impact on friction and anti-wear properties were investigated.
The findings reveal that 2HDNa exhibits large vesicles at low concentrations, which transition into micelles as the concentration increases. The presence of vesicles significantly reduces the friction coefficient and improves the anti-wear properties by forming a bilayer film on the metal surface, as evidenced by neutron reflectometry. These findings emphasize the lubrication performance of vesicles

and highlight the importance of controlling surfactant concentration in water-based lubrication.

10:00 - 10:20 am
3771597: Electrical Impedance Spectroscopy to Analyse Lubricant Composition and Performance
Thomas Reddyhoff, Yu Min, Thomas Kirkby, Jie Zhang, Imperial College London, South Kensington, London, United Kingdom; Arndt Joedicke, Shell, Hamburg, Germany

It is becoming increasingly important to be able to monitor the condition of lubricated contacts, and electrical methods provide a promising solution, given their robust sensing at relatively low cost without needing an optical window. Traditionally, either contact resistance or capacitance have been measured in order to partially reflect lubrication conditions. However more recently, Electrical Impedance Spectroscopy (EIS) is being explored since it can provide richer information in the form of magnitude/phase spectra. EIS monitoring involves a setting up a circuit around the contact and applying an alternating voltage with varying frequency while measuring the flow of current. The measured relationship between voltage and current (i.e., the impedance) varies as a function of frequency and can also be modelled as a network of electrical components. The parameters of these components (e.g., resistances and capacitances) can be found by fitting theory to experiments data and the resulting values used to characterise lubrication conditions. In this work, we demonstrate the use of EIS as a means of concurrently monitoring lubrication regime, hydrodynamic film thickness, boundary film formation, and lubricant degradation. Results, for a range of lubricants, are obtained from both an ex-situ probe and from within a rolling/sliding contact. The practical implementation of this monitoring approach is also discussed.

10:20 - 10:40 am
3931396: Tribological Properties When MoDTC, ZDDP and OFM are Used Together
Sohei Nambo, Weiqi Shen, Tomoko Hirayama, Naoki Yamashita, Naoya Hatano, Kyoto University, Kyoto, Japan; Yasuhiro Niwa, KEK, Tsukuba, Japan

To reduce friction under boundary lubrication, molybdenum compounds and organic friction modifiers (OFMs), such as fatty acids and amines, are added to lubricating oils. However, the combination use of these friction modifiers is not fully understood. Though N-oleoylsarcosine, one of OFMs, was found to exhibit excellent friction properties when used with molybdenum dialkyl dithio carbamate (MoDTC) and zinc dialkyl dithio phosphate (ZDDP), the cause of low friction has not been elucidated, partly due to the complexity of the polar group. In this study, friction tests and chemical analyses were conducted using MoDTC, ZDDP, and OFMs which have similar structures to Noleoylsarcosine and simple polar groups. By clarifying how the friction properties and surface conditions change depending on the structures of OFMs used in combination with MoDTC, a knowledge on the combination use of friction modifiers was obtained

10:40 - 11:00 am
3761911: Molecular Simulation Approach for Dynamics of Extreme Pressure Agents
Hitoshi Washizu, Kyosuke Kawakita, Mutsuki Homma, Riku Araki, Yoshiki Ishii, University of Hyogo, Kobe, Hyogo, Japan; Hiroaki Koshima, Idemitsu Kosan, Co., Ltd., Sodegaura, Chiba, Japan

Carbonic acids and organophosphates are representative compounds of oiliness additives and extreme pressure additives, respectively. It is quite interesting that these two molecules are quite similar in physicochemical nature, but the Tribological effect is quite different. In this study we used molecular dynamics simulation to understand the behaviour of organophosphates in oil. We first found that organophosphtes make strong aggregates in oil, whereas carbonic acids do not. This is the reason why carbonic acids adsorb on the metal or metal oxides surface as oiliness additives, and the organophosphates do not work on the surface in mild condition, i.e. in low temperature and in mild boundary lubrication. We then extend our simulation to the several types of organophosphates, including mono-phosphates and di-phosphates, and including double bond in hydrocarbon chain. The size of aggregates and the diffusion coefficients are due to the molecular structure. We also simulate the adsorption process on the solid surface using reactive molecular dynamics. The nature of charge transfer are different in the molecular structure. We then extend our reactive method to organosulfates additives. The adsorption dynamics are almost same that of organophosphates, but shows difference due to the functional groups.

Fluid Lubrication I

Session Chair: TBD
Session Vice Chair: TBD

9:20 - 10:00 am
3957120: SPOTLIGHT; Soft Lubrication: Beyond Classical EHL Theory
Carmine Putignano, Polytechnic University of Bari, Bari, Italy

Assessing the main peculiarities of lubrication between soft solids is a crucial issue that has only recently raised the attention of the lubrication science community. Indeed, in the last decades, massive research efforts have been dedicated to understanding the role of non-Newtonian lubricants, but very little has been done to determine what occurs when the lubricated solids are not linearly elastic, and are instead characterized by a different rheology, including viscoelasticity and porosity. In this work, an innovative numerical methodology is presented to analyze the lubrication regimes between linear viscoelastic and porous layers. In detail, an explicit finite difference scheme is coupled to a Boundary Element solver: this enables the study of the viscoelastic lubrication without any limitation in terms of material properties, geometry and viscosity. All this is validated by means of experiments specifically developed to deal with soft matter. To measure the film thickness, an innovative technique based on interferometry for soft solids has been employed.
The following step deals with the analysis of squeeze conditions, where the fluid is interposed between the rigid punch and a viscoelastic substrate. Results show the presence of pressure peaks the contact edges and very peculiar trends for the central and the minimum thickness values. This confirms the necessity of ad hoc developed numerical methods for soft lubrication.

10:00 - 10:20 am
3764569: Dual Experimental-Numerical Investigation of Elastohydrodynami Contact: From Pure Rolling to Opposite Sliding
Georges Amine, Nicolas Fillot, David Philippon, Nicolas Devaux, Univ Lyon, INSA-Lyon, LaMCoS, France; Johnny Dufils, IREIS - Institut de Recherche En Ingénierie des Surfaces, Andrézieux-Bouthéon, France

Machine elements such as gear teeth and cam-follower mechanisms often operate under elastohydrodynamic lubrification. In addition, opposite sliding with a slide-to-roll ratio (SRR) reaching 800% is not uncommon. We present a dual experimental-numerical study, using a tribometer with a steel barrel and sapphire disk and a Finite Element Analysis software. Lubricant film thickness is measured by Differential Colorimetric Interferometry (DCI). Simultaneously, frictional and normal forces were recorded through a multiaxis gauge sensor. Together, both forces translate to friction coefficient. SRR is varied from 0 to 400%. Combined experimental and numerical results shed light on the appearance of the viscosity wedge effect at high sliding. Moreover, having friction and thickness results enables a deeper discussion of the underlying phenomena behind friction variation with the sliding, especially at SRR>200%.

10:20 - 10:40 am
3766169: Elasto-Hydro Dynamic Lubrication With Water Droplets in Oil Emulsion
Fan Zhang, Nicolas Fillot, Guillermo E. Morales-Espejel, INSA-LaMCoS, Villeurbanne, France

The current work investigates water-in-oil flow at the inlet of EHD contacts using both experimental and numerical methods. A high-speed camera was used to observe a micro-sized water-in-oil emulsion flow at the inlet of an EHL point contact for the first time. Based on the experimental findings, a numerical model was developed. The Navier-Stokes equation and Newton's second law were solved sequentially to trace the movements of water droplets in oil. The effects of several operational factors on the flow of a water-in-oil emulsion, such as rolling velocity, water droplet size, applied load, and lubricant viscosity, have been investigated. The findings of this work demonstrate the critical conditions under which water-in-oil emulsion affects EHL contacts and give a possible explanation for the disparities in the literature.

10:40 - 11:00 am
3938517: Lubrication Subjected to the Effect of Electromagnetic Fields: Recent Research Progress and A Generalized All-Field Reynolds Equation
Xiaoman Wang, Q. Jane Wang, Northwestern University, Evanston, IL; Ning Ren, Roger England, Valvoline Inc, Lexington, KY

Electrical and magnetic fields have been shown to both positively and negatively affect lubrication system performance, as the presence of electrical and magnetic fields can significantly change the properties of the lubricants. Electric vehicles (EVs) have exhibited lubrication based failures due to the effects of magnetic fields and electrical current, adding to the demand for an in-depth study of lubrication systems subjected to these conditions. This presentation highlights recent research on lubrication related to electrical or magnetic fields, which are: 1) electric double layer in lubrication, 2) electrorheological fluids, 3) magnetorheological fluids, 4) ferrofluids, and 5) typical fluids used in the current EVs. Commonly used lubricants in each area are reviewed; lubrication mechanisms are analyzed, and successful related mathematical models are summarized. Methods for and results from numerical analyses and experimental exploration are discussed, and typical failures seen in EV applications caused by electric or magnetic field are evaluated. Based on the progress of the research in related fields, a generalized all-field Reynolds equation is proposed to describe the relevant scenarios mentioned above.

3D	Salon D

Surfaces and Interfaces including Nanotribology III

Session Chair: Philip Egberts, University of Calgary, Calgary, Alberta, Canada
Session Vice Chair: Jamal Choudhry, Luleå University of Technology, Luleå, Norrbottens Län, Sweden

9:20 - 9:40 am
3762152: Environmentally-Sustainable Thickeners for Greases: Engineering a Replacement for Lithium Salts
Philip Egberts, Babak Soltannia, Leonardo Martin-Alarcon, Jackson Uhryn, Milana Trifkovic, University of Calgary, Calgary, Alberta, Canada

Sustainable nanoparticle materials can be used to thicken base oils into greases without the use of lithium soaps. In this study, we approach grease development from the base oil up and link mechanical (rheological) and tribological (friction) properties with the microstructure of the lubricants using laser scanning confocal microscopy. More specifically, greases thickened with two different nanoparticles will be examined: nanoclay (Cloisite 20A) thickened grease; and a combination of nanoclay and tempo-oxidized cellulose nanofibers (TOCN). The impact of oleic acid, a common dispersing agent, on the rheological and tribological properties will also be examined. We show that particle-particle interactions impact hydrodynamic sliding, which can be linked with rheological properties, while particle-steel interactions impact boundary lubrication properties.

9:40 - 10:00 am
3764102: Developing Acoustic Emission Techniques to Monitor Rubbing Contacts
Robert Gutierrez, Imperial College London, Bristol, United Kingdom

The machine condition monitoring market is expanding as there is an increasing interest in reducing economic losses to friction and wear related problems. Acoustic emission (AE) offers in use monitoring of rubbing contacts with no need for direct contact with the rubbing surfaces or an optical window. A test setup has been developed which can simultaneously measure the AE and friction force produced from a ball on disc reciprocating contact. Signal processing methods involving histogram counts, short-time fourier transform (STFT), and machine learning for correlating AE to friction force have been explored. It was found that the log of an STFT and histogram count rate for small bin voltages both show high correlations with friction. Based on this, models were formed to predict the friction coefficient from on AE data. This paves the way for AE to be used to remotely monitor rubbing contacts.

10:00 - 10:20 am
3747077: A Review of Friction Performance of Diesel Fuel with Nano Additives.
Andrew Sakyi, University Of Pretoria, Pretoria, Gauteng, South Africa

A lubricant is derived from mineral oils or synthetic hydrocarbon blends. However, on their own these oils lack quality in order to meet the specifications specified by Original Equipment Manufacturers. Nanotechnology offers the possibility of using nano-additives to increase the performance of lubricating oils. This study examines the tribological and thermophysical properties of lubricating oil using MoS_2 and ZnO nano-additives. The average size of MoS_2 and ZnO nanoparticles were 80nm and 40nm, respectively. The nanoparticles were suspended in a commercial diesel fuel at three different concentrations (0.2, 0.5, and 0.8 wt.%). The overall results of this experiment reveal that the addition of nano-MoS_2 reduced mass loss by 87% due to the nano-MoS_2 lubricant effect. With 0.8wt.% in nanoparticles content, the viscosity of MoS_2 and ZnO nano lubricants at 100°C increased by about 8.12% and 9.11%, respectively. Moreover, the flash point of the fuel increased with the addition of the nano-additives.

10:20 - 10:40 am
3932829: Tribological Performance of Polymeric Coatings for HFO-1234yf-based EV Air Conditioning Compressors
Ajinkya Raut, Ahmad Amiri, Andreas Polycarpou, Texas A&M University, College Station, TX

The use of HFO-1234yf as a climate-friendly refrigerant for air conditioning and refrigerator compressors is becoming increasingly popular. However, there is a need to investigate its effectiveness in electric vehicle air conditioning systems. With the growing demand for lightweight materials in electric vehicles, it is crucial to develop parts made of light aluminum and magnesium alloys to improve vehicle efficiency, however, they mostly suffer from low tribological properties. To get around this issue, coating with high-performance polymers was suggested as a common solution. This study evaluates the tribological performance of advanced polymeric coatings (ATSP, PTFE, and PEEK) on lightweight aluminum alloy surfaces with HFO-1234yf and polyalkylene glycol (PAG) lubricant under starved lubrication conditions. Scuffing and wear experiments were conducted on a specially designed tribometer. Results indicate that all three coatings significantly outperformed the bare substrate. Further surface analysis was conducted to study the wear mechanisms of the polymer coatings. These findings provide valuable insight into the effectiveness of polymeric coatings for HFO-1234yf-based electric vehicle air conditioning compressors.

10:40 - 11:00 am
3956817: Silane the Novel Game Changer in Production Technology
Selina Raumel, Marc Wurz, Institute of Micro Production Technology, Hannover, Niedersachsen, Germany

Oxidation of metal surfaces during production processes acts predominantly as a limited factor. Even in high-vacuum environments, an oxygen partial pressure of 10^{-6} mbar is still present. A completely new approach is the production under an oxygen-free atmosphere with the aid of silane (SiH_4)-doped argon gas enabling oxygen partial pressures of less than 10^{-23} bar. In this work, the changes in wear mechanisms, mechanical properties and local film formations for oxygen-affine materials (copper and titanium bulk material and SiC and TiN thin film layers) as a function of the atmosphere were studied. The investigations have shown that the complete lack of oxygen has a significant influence on the tribological properties and thus on the friction/wear behaviour. By suppressing oxidation a significant reduction of tribochemical wear (factor 4.5) could be shown, which is accompanied by changes in the adhesion tendency. Only limited edge layer particles were removed during the adhesive processes and a significant reduction in cracks in the fusion zone was visible. The chemical investigations showed local Si-containing layers on Cu with advantageous passivating and mechanical properties. The investigations have demonstrated the potential of an oxygen-free atmosphere on the wear behavior. Silane could be the game changer for further resource-relevant advantages as well as completely new production approaches and material applications that were previously not possible.

11:00 - 11:20 am
3963312: A Friction Determination in Sheet Metal Forming
Abdurasul Pirnazarov, Anvar Makhkamov, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan

This investigation focuses on the impact of friction in the deep drawing process. Tribological tests were carried out using a pin-on-disc machine and modified strip drawing tests, which were aimed at simulating

behavior and determining the coefficient of friction between sheet metal and tools during forming. Experiments were carried out using a pin-on-disc machine for the determination of the coefficient of friction and behavior between sheet metal and tools during forming. Reciprocating sliding tests were examined for frictional characteristics as well as the impact of lubricant and other factors on the coefficient of friction of cold-rolled HSLA (High Strength Low Alloy) with a set of two types of oils.

4A	Salon A

Energy/Environment/Manufacturing I

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:20 pm
3756326: Machining Evaluation of Novel Phosphate Ester for Hard Metal Machining.
Ron Lemke, Italmatch Chemicals, Wilmington, IL

Environmental pressure to reduce CO_2 emissions globally continues to pressure manufacturers to improve efficiency of vehicles and aircraft by reducing weight and increasing power density. Harder, lightweight and more heat resistant materials enable designers to do more with less material. Italmatch Chemicals, Lubricant Performance Additives, embarked on a partnership with The Advanced Manufacturing Research Centre, UK (AMRC) to develop scientific, real-world representative test methodology and ultimately a performance additive to enable efficient manufacturing when using these materials. Utilizing single point milling tests and Taylor curve analysis in titanium and high nickel alloys, significant tool life increases were observed in collaboration with AMRC and Italmatch LPA successfully developed a novel Polymer Phosphate technology that improves productivity when machining modern hard metal alloys utilized in today’s aerospace industry.

2:20 - 3:00 pm
3964054: SPOTLIGHT: In Situ Investigations into the Adhesion and Compression of Catalyst-relevant Metal Nanoparticles
Tevis Jacobs, Ruikang Ding, Andrew Baker, Soodabeh Azadehranjbar, University of Pittsburgh, Pittsburgh, PA; Ingrid Padilla Espinosa, Ashlie Martini, UC Merced, Merced, CA

We have used in situ manipulation of metal nanoparticles, coupled with atomistic simulations of the same materials, to investigate the performance of catalyst-relevant metal nanoparticles. First, we used in situ adhesion testing, and matched simulations, on nanoparticles composed of various metals in contact with a variety of oxide substrates to understand the physics of adhesion. The results showed that, instead of being governed by traditional fracture mechanics, particle adhesion is more closely described by the adhesive strength of an interface failing in tension. We could then relate this adhesive strength to material properties of the system. Second, we used matched experiments and simulations of nanoparticle compression to show how the elastic stiffness and compression strength of small-metal nanoparticles varies with shape and size. Taken together, these investigations reveal the fundamental science that will guide the creation of stronger and more stable nanoparticle catalysts.

4B	Salon B

Materials Tribology III

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:20 pm
3761702: Oil-Free Superlubricity on Rough Steel Surfaces under Sustained Sliding-Rolling Contact
Anirudha Sumant, Aditya Ayyagari, Benjamin Gould, Aaron Greco, Argonne National Laboratory, Lemont,

IL

Although great progress has been made demonstrating superlubricity utilizing various two-dimensional (2D) materials as a solid lubricant, in various environments and at moderate to high contact pressures, the sustained, long-term reliability of these solid lubricants in more complex tribological conditions is yet to be established to consider them as a potential candidate for replacing oil-based lubricants. In this study, we show the demonstration of a fully dry solid lubricant showing superlubricity in rough steel against steel sliding-rolling contacts at high contact pressures (1GPa). We utilize MoS_2+Graphene Oxide as a solid lubricant to produce ultra-low friction of 0.005 under rolling-sliding conditions for up to 200 hours (70 km) of uninterrupted rolling-sliding. This was observed to result from complex physico-chemical and physico-mechanical phenomena occurring in situ in the tribolayer. I'll discuss the mechanism of formation of tribolayer and will try to explain how shearing and reorientation of MoS_2 along with the formation of amorphous carbon are playing a key role in friction reduction. This demonstration paves the way for further development and realization of oil-free superlubricity in various real-world applications and helps toward the decarbonization goal in the lubrication industry

2:20 - 2:40 pm
3959713: Deposition and Properties of Electroplated MoS2 Solid Lubricant Coatings
Michael Dugger, Christopher Reed, Tomas Babuska, Dhego Banga, Josh Sugar, Ping Lu, John Curry, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide thin films are excellent solid lubricants for aerospace applications due to their steady-state friction coefficient of 0.05 or lower in inert atmospheres, wide operating temperature range and high contact pressure capability. These films are commonly deposited by sputtering from targets of pressed MoS2 powder or MoS2 plus oxide or metallic dopants. Uniform coatings on complex shapes by sputtering requires fixturing and moving the parts during deposition. In this work conformal coatings of MoS2 have been created via electrodeposition from an aqueous solution of tetrathiomolybdate ions at room temperature. These films are amorphous, contain some MoOx and exhibit friction performance in limited duration tests that is comparable to sputtered coatings. These films can also be doped by including the desired ions in the bath. The structure, composition, performance and aging behavior of electrodeposited MoS2 solid lubricant films will be discussed.

2:40 - 3:00 pm
3950741: Performance Driven Metrics to Assess Microstructural Characteristics of Molybdenum Disulfide Coatings
Tomas Babuska, Michael Dugger, Steven Larson, Mark Rodriguez, John Curry, Sandia National Laboratories, Tallahassee, FL

Sputter-deposited molybdenum disulfide (MoS_2) solid lubricant coatings have been used for decades in aerospace applications due to their ultra-low steady-state coefficients of friction (μ_{ss} < 0.05). Developing MoS_2 coatings for demanding applications with predictable and reliable performance over time (i.e., high-quality) requires tuning the coating microstructure through process variations (process-structure). Achieving desirable coating properties (structure-property) such as wear resistance, low μ_i, high density, and resistance to oxidation can be accomplished through microstructural control. In this work, we investigate the role of processing parameters such as argon sputtering pressure, bias voltage, adhesion layer, and power density on the resulting coating microstructural characteristics, tribological properties and oxidation resistance. Additionally, we investigate the batch-to-batch repeatability and impact of indirect processing variables on the coating microstructure and properties for multiple deposition runs using screening parameters such as wear rate and nanoindentation to quantify batch quality. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

3:00 - 3:20 pm
3931324: Quantifying Water Diffusion in Molybdenum Disulfide Coatings Using ToF-SIMS Depth Profiling
Nicolas Molina Vergara, Robert Chrostowski, Filippo Mangolini, University of Texas at Austin, Austin, TX; John Curry, Michael Dugger, Tomas Babuska, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS2) has been used as solid lubricant in aerospace applications because of its low friction response in inert environments. However, exposure to atmospheric conditions and periods of inactivity can cause MoS2 to “age” into a high friction state. This poses a significant challenge in the reliable use of MoS2. Despite the volume of the published literature, our understanding of the surface phenomena taking place during aging of MoS2 is still limited. To address this knowledge gap, we performed ToF-SIMS depth profiling analysis using an isotopic tracer (D2O) to quantify and characterize the diffusion of water in MoS2 by means of an isotopic tracer. This work was funded by the Laboratory Directed Research and Development program at Sandia National Lab., a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the US DOE's National Nuclear Security Administration under contract DE-NA0003525.

3:20 - 3:40 pm
3964090: Self-Lubricating Novel 2D High Entropy Alloy on Steel Surfaces
Sai Varun Sunkara, Shuxi Wang, Sukriti Manna, Subramanian K. R. S. Sankaranarayanan, Amin Salehi-Khojin, University of Illinois at Chicago, Chicago, IL; Yuzi Liu, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Traditional thin film high entropy alloys (HEAs) in tribology have shown good wear resistance and ability to work under extreme conditions but with moderate friction coefficient. This work introduces a novel two dimensional (2D) HEA synthesized by chemical vapor transport (CVT) process and subsequently coated onto a stainless steel substrate via simple spray coating technique. We demonstrate excellent lubricious behavior of 2D-HEA using ball-on-disk experiments with steel tribo-pair in ambient air with coefficients of friction as low as 0.068, wear rates in the magnitude of 10^{-9} $mm^3/(N\text{-}m)$, and functions at high contact pressures (0.94 GPa). Detailed analysis from various characterization modalities coupled with AIMD simulations show that its superior performance is attributed not only to its structure and composition but also its exceptional tribocatalytic activity that leads to operando self-lubricating tribolayer formation during sliding. We'll discuss possible mechanisms responsible for such exceptional performance towards developing more reliable and long-lasting lubricants.

3:40 - 4:00 pm - **Break**

4:00 - 4:20 pm
3930260: The Influence of Solid Lubricant Reservoir's Morpho-Dimensional Evolution on the Sliding Wear of Sintered Iron-Based Self-Lubricant Composites.
Jose Daniel De Mello, Nicolás Araya, Rafael Arenhart, Guilherme Neves, Cristiano Binder, Aloisio Klein, Universidade Federal de Santa Catarina, Florianopolis, Santa Catarina, Brazil

This study investigates the influence of the morpho-dimensional (porosity, solidity, circularity, eccentricity and Feret diameter) evolution of pores, e.g. solid lubricant reservoirs, on the tribological behaviour of impregnated materials. In addition, a new parameter, the mean carbon intensity inside each individualised pore, was proposed to further understand the solid lubrication phenomenon in sintered composites. PM techniques produced low alloy sinter-hardened steel specimens vacuum-impregnated with graphite particles. Interrupted incremental load tests (7 N increments every 10 minutes) were used to study the evolution of open pores (solid lubricants reservoirs) in the wear scars. During tribological testing, the impregnated pores get sealed. The narrow sections connecting pores deform and close, reducing porosity and the Feret diameter of individual pores. Then pores get smaller and sealed up to the point where the lubricity regime ends. Small and narrow pores retain better the impregnated graphite, slowly releasing it, helping to maintain the lubricity regime.

4:20 - 4:40 pm
3969621: Al_2O_3/SiC Composite with Graphite as Self-lubricant: A Material-by-Design Development Approach for Cutting Tools
Syed Sohail Akhtar, Abba Abdulhamid Abubakar, Abbas Saeed Hakeem, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

The current research focuses on using a material-by-design approach to develop Al_2O_3/SiC composites with graphite for cutting tool inserts that have a balanced combination of structural and thermal properties as well as improved tribological response. During the material design stage, several combinations of Al_2O_3 and SiC together with Graphite as self-lubricant are selected based on in-house designed codes that predict mechanical and thermal for tailored cutting tools. The constitutive behavior of the composites is predicted using a mean-field homogenization scheme while the theoretical optimum thermal characteristics are predicted using an effective medium approximation. The Spark Plasma Sintering process was used to synthesize the samples for validation of the designs. Tribological tests are carried out under dry conditions to see the self-lubrication behavior of the samples in terms of their coefficient of friction and wear rates. These experimental data are then compared against the predicted data obtained through mathematical models developed to estimate the wear performance. FESEM and XRD techniques

are used to support the experimental trends by comparing the microstructure and wear track images of the samples. The optimum combinations of Al_2O_3, SiC, and the addition of graphite have led to the expected effect of lowering the coefficient of friction and compressive strength while increasing the material's hardness.

4C	Salon C

Fluid Lubrication II

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:40 pm
3930900: SPOTLIGHT; The Slippery Slope: Temperature, Pressure and Speed Dependent Friction Modifier Performance in a Wet Clutch
Darryl Williams, Afton Chemical, Richmond, VA

Friction modifiers play a significant role in controlling NVH in wet clutch applications. The complexity of a wet clutch – consisting of a friction material, a steel surface, and a fully formulated transmission fluid – can obscure the well-known effects of friction modifiers in wet clutch test data. The Briscoe and Evans model is applied to show the predicted linear relationships between Langmuir-Blodgett film shear strength and Ln(v), pressure, or temperature. There is a limited sliding speed range over which the model may be applied in these tests. We show the importance of using an estimated actual contact area rather than the clutch surface area for this purpose. This approach can be a useful way to study friction modifier performance in clutches

2:40 - 3:00 pm
3761419: The Role of Performance Polymers in Friction Reduction in Engine Oil Formulations
Eugene Pashkovski, Farrukh Qureshi, Reid Patterson, The Lubrizol Corporation, Wickliffe, OH; Alexander Michlberger, Southwest Research Institute, San Antonio, TX; Tim Murdoch, Loughborough University, Loughborough, United Kingdom; Ilya Kudish, ILRIMA Consulting, Millersburg, MI

Engine oils with polymeric additives are known to reduce friction and improve fuel economy in engine tests. In hydrodynamic lubrication, these polymers can modify the stress and strain rate field within the contact zone leading to increasing gap and reduced viscous energy loss. When the polymers are functionalized in a way that they adsorb to moving surfaces, the soft layers reduce friction under a heavy loaded regime. In this presentation, we report experimental data for lubricants containing functionalized and non-functionalized polymers that demonstrate their function under different regimes of lubrication. Theoretical modeling of the friction reduction mechanism for various lubrication regimes is presented.

3:00 - 3:20 pm
3931524: Experimental Investigation into Minimum Flowrate Conditions for Ultra-Smooth Surfaces
Michael Handschuh, Anthony Ngo, Ahmet Kahraman, The Ohio State University, Columbus, OH

Maximizing efficiency of power transmission systems continues to be the driving mechanism behind innovation and overall advancements in transmission design. Whether due to environmental or expenditure concerns, any additional efficiency improvement is important. In a power transmission system, two types of power losses are present: load-dependent frictional losses due to load carrying components and load-independent drag losses of rotating components. This experimental study investigates the quantity of lubrication required for ultra-smooth surfaces operating at elevated speeds targeting aerospace and electric vehicle applications. A high-speed twin-disc tribometer was operated over various velocities, contact pressures, and lubricant temperature and flowrate conditions applicable to gear contacts while simultaneously measuring contact torque and surface temperature. Measurements reveal the minimum amount of lubrication to prevent scuffing and increase efficiency for ultra-smooth surfaces. Results show that load-dependent losses are married to the temperature of the disc surfaces and are directly impacted by lubricant flowrate. Power transmission designers can implement these findings and modify delivery requirements to gear meshes throughout a transmission to help optimize overall efficiency.

3:20 - 3:40 pm - **Open Slot**

3:40 - 4:00 pm - **Break**

4D	Salon D

Machine Elements and Systems I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 2:20 pm

2:20 - 2:40 pm
3756412: An Abnormal Rolling Contact Fatigue Failure with Fluorine Grease
Hiroyoshi Tanaka, Kyushu University, Fukuoka, Japan

This study introduces an abnormal rolling contact fatigue failure with fluorine grease which consists of Perfluoropolyether, PFPE, oil. Some PFPE oil decompose to acid by moisture in ambient air. In this study, rolling contact fatigue, RCF, test was conducted to know the effect of fluorine grease on fatigue life of rolling element bearing. In order to know effects of environmental gas, RCF test was conducted in air and argon. After the RCF test, hydrogen content in bearing steel was measured by thermal desorption spectrometry. Also, structural changes were discussed by sectioning observation just below the rolling surface.

2:40 - 3:20 pm
3905089: Extreme Condition Tribology: High Temperature Vacuum Bearing Operation
Christopher DellaCorte, University of Akron, Akron, OH

Friction and wear behavior of rolling element bearings is highly dependent upon operating environment. In many cases, the environment dictates the lubricants and lubrication methods used to ensure proper bearing operation. Bearings that operate in vacuum must employ specialty lubricants and lubrication methods that can range from vacuum compatible oils and greases to dry film lubricants. Bearings that operate at high temperature must employ specialty construction materials as well as specialty lubricants. In this presentation, bearing materials and lubricants suitable for high temperature bearing operation are presented. Their performance is demonstrated in a unique high vacuum, high speed, high load bearing test rig. Future research plans to evaluate the effects of test conditions (load, speed, lubricant choice) on bearing life will be discussed.

3:20 - 3:40 pm
3930194: Rolling Element Bearing Damage in the Presence of Applied Electric Current
Lizeth Sanchez-Camacho, Ryan Evans, Carl Hager Jr., The Timken Company, North Canton, OH

Equipment designers prevented the passage of electric current through rolling element bearings as a standard design principle for decades to prevent arc pitting and other known types of bearing damage. However, the proximity of bearings to electrical generators, motors, and inverters in modern wind energy and battery electric vehicle designs has reinvigorated research about the effects of low-level or stray electric current passage in operating bearings. The emergence of white etch cracking (WEC) and other previously uncommon damage mechanisms created questions about the role electric current has in promoting high-cycle damage modes. This work presents a study of the influence of applied electric current and lubricant selection on bearing surface damage over millions of operating cycles. Micro-pitting, WEC, and the creation of a surface white layer were investigated by optical microscopy in conjunction with scanning electron microscopy after bearing tests with various levels of applied current and two lubricant oil types (additized and non-additized). A black oxide coating was also applied to evaluate its effect on WEC formation. It was found that these damage modes could be turned on and off in bearings, depending on the type of oil used and the applied electric current. Higher applied electric currents directionally increased bearing surface damage in these tests.

3:40 - 4:00 pm - **Break**

4:00 - 4:20 pm
3931643: Productivity Improvement of The Loom Shed by Optimizing Friction
Abdurasul Pirnazarov, Namangan Institute of Engineering and Technology, Kosonsoy, Namangan, Uzbekistan

The productivity of the loom is governed by the speed, efficiency, and quality of the fabric produced. During the weaving process, loom stoppages not only reduce productivity but also affect the fabric's quality. In woven fabric manufacturing, weft ends are generally sized so that they can withstand various stresses encountered in the weaving process. The breakage rate of weft yarn is highly sensitive to stretch and shows a large difference with a change in friction on solid materials. In a weaving machine, it is a challenging task to find the optimum level of friction to get a minimum weft breakage rate. The present study was done to analyze the effect of friction on weft insertion and optimize friction with a minimum weft breakage rate.

4:20 - 4:40 pm
3964459: White Etch Cracks in Wind Bearings
Mandyam Sridhar, GE Research, Bengaluru, Karnataka, India

White Etch Crack (WEC) failures can reduce bearing life by >90 %. WEC is an industry wide issue which includes wind turbine bearings. For this issue, there is no consensus about the root causes in the industry. This work critically reviews literature work (mainly coupon level tests) to identify factors affecting WEC. The four main factors affecting bearing life are material & manufacture, bearing design and type, operating conditions and lubricant (base oil and additive). Results from four test configurations i) 4-ball test, ii) Thrust test, iii) MPR tests and iv) FE8 rig have been reviewed here. Even though the above factors contribute to reduction of Weibull life, a clear correlation between low Weibull life and WEC formation cannot be established. Lube additive has most significant influence in life reduction and slip has lowest influence. Other factors which contributes to life reduction between lube additive and slip are current, material quality, surface hardening, Lube# and base oil in that order. Based on this critical literature review lubricant additive, current and material quality emerge as major factors influencing the reduction of wind turbine bearing life.

5D Salon D

Cutting Edge Symposium I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
3771598: More on Mouthfeel: Imbibing Bubbly Beverages
Thomas Reddyhoff, Sorin Vladescu, Connor Myant, Imperial College London, South Kensington, London, United Kingdom; Sophie Bozorgi, Guy Carpenter, Kings College London, London, United Kingdom; Stefan Baier, Motif FoodWorks, Boston, MA

The perception of carbonation is an important factor in beverage consumption which must be understood in order to develop healthier products. This presentation describes the effects of carbonated water on oral lubrication mechanisms involved in beverage mouthfeel and hence taste perception. Friction was measured in a compliant PDMS-glass contact simulating the tongue-palate interface (under representative speeds and loads), while fluorescence microscopy was used to visualise both the flow of liquid and oral mucosal pellicle coverage. Results from tests, in which carbonated water is entrained into this contact, reveal two distinct tribological mechanisms - namely bubble-induced starvation and salivary pellicle removal. Both of these will modulate the flow of tastants to taste buds and are suggested to be important in the experience of taste and refreshment. For example, this may be one reason why flat colas taste sweeter.

8:30 - 9:00 am
3935552: Linking Strength, Friction, and Ordering in Metallic Glasses
Nicolas Argibay, Ames National Laboratory, Ames, IA; Michael Chandross, Sandia National Laboratories, Albuquerque, NM

The friction and strength of shearing metal interfaces was previously linked to grain size in a predictable way for pure metals and dilute alloys, although the accuracy of these correlations was shown to be limited to inert conditions where oxidation and adsorbates have a negligible effect on interface properties. Recent work shows that macroscale friction experiments can also be used to probe the fundamental strength of structurally and chemically disordered alloys, including metallic glasses, with predictable results again limited to inert environments. We show how tribological experiments are being used to inform development of a theoretical framework for the strength of alloys as a function of their structural and chemical ordering and discuss opportunities for alloy composition and structure optimization to promote desirable mechanical behavior.

9:00 - 9:30 am
3756396: The Ultrafast Finger Snap is Mediated by a Frictional Skin Latch
Elio Challita, Raghav Acharya, Saad Bhamla, Georgia Tech, Atlanta, GA; Mark Ilton, Harvey Mudd College, Claremont, CA

The snap of a finger is a ubiquitous human motion that has been used as a form of communication across human cultures throughout millennia. Using high-speed imaging, we present the first study of the dynamics of finger snapping. We show that the finger snap can achieve angular accelerations of 1.6×10^{6} °/s^{-2} in 7 ms making it one of the fastest movements the human body can produce. Our analysis shows that friction between finger pads acts as a latch in controlling this ultrafast movement. Using an experimental and mathematical approach, we show how skin friction lies in an optimally tuned regime enabling it to play a dual role in both loading potential energy and mediating the release of that energy during the finger snapping motion. Our work provides design insight towards the frictional complexity in many robotic and ultra-fast energy-release structures.

9:30 - 10:00 am – **Break**

10:00 - 10:30 am
3933692: Linking Molecular Structure and Lubrication Mechanisms in Tetraalkylammonium Orthoborate Ionic Liquids
Filippo Mangolini, Jieming Yan, Hsu-Ming Lien, University of Texas at Austin, Austin, TX

While ionic liquids (ILs) have attracted wide interest as potential lubricants owing to their unique properties (e.g., high thermal stability) and good tribological properties, our understanding of the mechanisms by which ILs reduce friction and/or wear is still elusive. Here, we synthesize a homologous series of halogen-free ILs, namely tetraalkylammonium orthoborate ILs, and combine macroscale tribological experiments with surface-analytical measurements to gain insights into the relationship between the IL molecular structure and their lubrication mechanisms/performance. The results of steel-vs.-steel tribological tests indicate an improvement of the friction-reducing properties of these ILs as the length of the alkyl chains attached to ammonium cations increases. Based on ex situ X-ray photoelectron spectroscopy (XPS) analyses of the surface chemistry of steel after sliding tests, a phenomenological model is proposed for the observed tribological behavior.

10:30 - 11:00 am
3761773: Tribotronic Control and Electrochemcial Properties of Nanofluid Interfaces.
Jacqueline Krim, Caitlin Seed, Biplav Acharya, Alex Smirnov, North Carolina State University, Raleigh, NC

We have employed Quartz Crystal Microbalance (QCM) and cyclic voltammetry (CV) methods to explore nanotribological and electrochemical attributes of platinum or gold electrodes immersed in nanosuspensions of charged species (nanoparticles, ionic liquids, nanodiamonds). The setup consists of a QCM immersed in a nanosuspension whose sensing electrode faces a nearby counter electrode. An electric field perpendicular to the QCM surface is created when a potential is applied between the two electrodes, which allows the charged constituents in the suspension to be repositioned. QCM measurements are able to detect differences in friction under various field conditions, and thus detectably tune the friction in both nanoparticle and ionic liquid systems. CV simultaneously monitors the system's electrochecmical attributes. The versatility, speed, and simplicity of QCM for friction measurements renders it an ideal tool for the rapidly expanding research area of tribotronics.

11:00 - 11:30 am
3764635: Nanosensors for In Situ Measurement of Pressure and Temperature in EHD Contacts
David Philippon, Tarek Seoudi, Lionel Lafarge, Nicolas Devaux, Philippe Vergne, INSA Lyon - LaMCoS, Villeurbanne, France; Nicolas Fillot, INSA-LaMCoS, Villeurbanne, France; Alexandre Mondelin, SKF Aerospace France, Châteauneuf-sur-Isère, France

A new methodology based on the photoluminescence properties of non-intrusive nanosensors is presented for in situ measurement of pressure and temperature in lubricating confined films. Pressure and temperature calibrations of these sensors dispersed in a selected fluid were established through experiments in diamond anvil cells (DAC). Afterwards, measurements were carried out in elastohydrodynalic (EHD) contacts involving different contacting paired materials (glass, steel, Si_3N_4 and sapphire) and submitted to various operating conditions. The experimental results were compared with numerical simulations. Experimental pressure profiles obtained in isothermal experiments show a very good agreement with the values predicted by the numerical model. Non-isothermal cases were also carried out. Temperature rises in the central zone of EHD contacts involving various material pairs were measured and compared to predictions, leading to a very satisfying agreement.

3962816: In Situ AFM Observation of ZDDP-Derived Tribochemical Reaction Film Formation Under Controlled Atmosphere Environment

Chinari Shimura, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

Zinc dialkyldithiophosphate (ZDDP) is widely used in lubricating oils as an anti-wear additive. ZDDP is known to form a reaction film consisting of metal phosphate and polyphosphate on the sliding surface through a tribochemical reaction. The formation of these films exerts the effect of improving wear resistance and seizure resistance. Oxygen in the atmosphere is thought to be necessary for the formation of these reaction films, but there are many unclear points about the detailed reaction processes. In this study, we set up an AFM in an atmosphere-controlled environment using nitrogen, and performed in-situ observation of the formation process of ZDDP-derived tribo-films by performing nano-friction between the tip of the AFM tip and a steel substrate. As a result, it was confirmed that the presence or absence of oxygen in the atmosphere did not affect the growth rate of ZDDP-derived tribo-films. Based on these experimental results, we report the results of consideration of the phosphate formation process by tribochemical reactions.

3954098: Predicting Traction Fluid Performance Using Materials Informatics

Tsuyoshi Fukaya, Yohei Shimizu, Hitoshi Washizu, University of Hyogo, Kobe, Japan; Eiji Tomiyama, University of Hyogo and RIST, Kobe, Japan

Materials Informatics (MI), which applies information science methods to improve the efficiency of materials development, can search for optimal materials from many materials, and the use of MI is expected to accelerate materials development. This study focuses on the physical properties of traction fluid.
First, machine learning is conducted using 37 compounds used as base oils for lubricants as supervised data. Since regression prediction is difficult due to low accuracy, the explanatory variables are changed, and machine learning was conducted again. The results suggest that changing the explanatory variables may improve accuracy and allow regression predictions to be made. From the MI perspective, the explanatory variables should be the physical property values obtained from the simulation. Currently, simulations are being performed and machine learning is being conducted based on the physical property values obtained.

3931382: Study on Potential of Mean Force of Carbon-Addition Bonds on the Surface of Diamond-Like Carbon Under Different Preparation Conditions.

Koshiro Torimoto, Hirotoshi Akiyama, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Motoyuki Murashima, Tohoku University, Sendai, Japan

The adsorption properties of DLC surfaces and additives in oil have been found to have a decisive influence on the nano-interface tribofilm formed in the early stages of friction, the final tribofilm, and friction properties. The characteristics of tribofilm formation depend on the atomic structures of DLC films such as sp^2/sp^3 ratio and the amount of hydrogens. Using molecular dynamics simulation, we investigate the bond strength between multiple DLCs, which are prepared in different conditions, and additive molecules. We use LAMMPS as the simulator and Reaxff for the force field that can handle chemical reactions as well as charge transfer. To measure the bond strength, we computed the potential of mean force (PMF) between the DLC surface and the additive molecule using Jarzynski equation. Our calculation shows that the more sp2 structures, the smaller the PMF value (bond strength becomes stronger).In this talk we discuss how the PMFs differ depending on the structure of DLCs.

3931399: Simulation of Solid Friction of Metal in Micron Scale using SPH Method

Keito Nitta, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Le Sang, Ho Chi Minh City University of Information Technology, Ho Chi Minh, Viet Nam; Natsuko Sugimura, National Institute of Technology, Kagoshima College, Kirishima, Japan

Friction between two sliding objects depends on various factors such as surface roughness, load, sliding speed, temperature, and time. Here, we perform simulations to observe the friction occurring at the sliding interface under controlled conditions. This study focuses on simulating sliding of metals in micron scale using the Smoothed Particle Hydrodynamics (SPH) method, which approximates a continuum as a large number of particles and calculates their dynamics. Coarse (CG) particles are used to simulate large systems, and the PT (Prandtl-Tomlinson) model is applied to calculate friction forces. The simulation results confirm the Stick-Slip phenomenon, in which the friction force curve oscillates periodically due to atomic-level friction against the PT oscillator. Dependence of surface roughness is found by changing the number of particles in contact area and a significant effect is found to the frictional force.

3931586: Make your Own Hydrogel

Nusrat Chowdhury, University of Illinois Urbana-Champaign, Urbana, IL

Hydrogels are a type of polymeric material characterized by their three-dimensional structure that contains remarkable water absorption capacity. Polyvinyl(alcohol) hydrogel has long chains that form physical crosslinking through a freeze-thawing process where the hydroxide group forms crosslink by crystallization. The physically crosslinked PVA hydrogel has a structure that can be modified by adding different molecular weight polymers and it would change the mechanical and surface properties accordingly. These hydrogels have a lower limit of molecular weight to form physically with their polymer chain length. In our current work, we investigate the mechanical and surface properties of high and low molecular-weight hydrogels and find a way to tune them within the range by changing their molecular composition by mixing high and low molecular-weight PVA. As a result, combining the lower and higher molecular weight of PVA hydrogel, it is possible to get tougher but softer hydrogels with varying elastic modulus, permeability, friction coefficient, and hydrodynamic lubrication. These hydrogel surfaces would give rise to unique contact mechanics including improved hydrodynamic lubrication, and friction coefficient, and they can be used for various biomedical applications.

3938574: The Effect of Surface Properties on Friction in the Solid Friction Simulation Using the Smoothed Particle Hydrodynamics Method

Mizuki Era, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Natsuko Sugimura, NIT, Kagoshima College, Kagoshima, Japan

Lubricants and coatings that reduce friction have been widely discussed, however, there are still many unresolved issues regarding solid friction, such as seizure. Therefore, in this study, we created two models with different surface roughness to investigate the effect of the surface roughness on the heat of friction. In this study, the metal was aluminum. The sliding and vertical initial velocities were fixed in the both models. The results showed that the trend of increase was more intense for the model with the larger protuberance, and the frictional heat was higher. This is because the interfacial interaction is determined by the neighboring particles, and the larger the contact surface, the more neighboring particles are in contact, and thus the interfacial interaction is also larger. We will prepare several models with different surface roughness and sliding speeds to further analyze the effects of surface roughness and sliding speed on the heat of friction.

3931667: Development of an In-Situ Scanning Probe Microscopy Equipped with Raman Spectrometer

Ryosuke Kitamura, Kaisei Sato, Tomoki Kawasaki, Tokyo University of Science, Kohoku Ward, Yokohama, City, Kanagawa, Japan; Seiya Watanabe, Osaka University, Toyonaka-shi, Osaka, Japan; Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

Tribochemical reaction films derived from lubricant additives have a significant impact on friction and wear properties in the boundary lubrication regime. However, because the phenomena at the friction interface are complex, such as large changes in temperature and stress, and the interaction of various molecules, the film formation process and lubrication mechanism are not yet fully understood. In-situ observation of the sliding interface is an important and effective method to understand the mechanism. In this study, we have developed a scanning probe tribometer incorporating an in-situ Raman spectrometer that can simultaneously measure the friction coefficient, surface profile, and chemical composition in a minute area on the sliding surface while applying high stress (approximately 1.0 GPa). In this presentation, we report the observation results of Raman spectra on sliding surface applying high compression/shear stress using this device.

3960741: Analysis of the Chain Matching Using Molecular Dynamics Simulation

Takehiro Kobayashi, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Japan

Organic friction modifier molecules are composed of alkyl chains and polar groups on the end. The polar group adsorbs on the metal surface and the molecules form a self-assembled monolayer (SAM). There is the concept of "chain matching" in a boundary lubrication firm. When the chain length of the fatty acid additives and base oil are equal, the load-carrying capacity or thickness of the OFM film exhibits a higher value than in case of other base oils. Although this idea is supported by experiments, the precise mechanism on a molecular level has yet to be understood. In this study, the all-atom MD simulation is used to solve the precise mechanism of chain matching. Interestingly, the molecules are most regularly oriented in the combination of the same chain length of the organic additive and the base oil. This result shows that MD simulation also support the idea of chain matching.

3938589: Analysis of Reaction Dynamics of ZnDTP and MoDTC Lubricant Additives on Iron Nascent and Oxide Surfaces Using a Novel Universal Neural Network pPtential
Tomohito Horio, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Akihiro Nagoya, Preferred Computational Chemistry, Inc., Tokyo, Japan; Tasuku Onodera, ENEOS Corporation, Tokyo, Japan

ZnDTP and MoDTC are known as extreme pressure additives. On metal surface, their adsorption, subsequent chemical reaction and synergy are not well understood. This is an obstacle to further improve tribological performance. We analyzed adsorption and chemical reaction of two additives on nascent and oxidized iron surfaces by molecular dynamics (MD) simulation. In the simulations, an universal neural network potential (NNP) implemented in Matlantis™ was used. The model was consisted of several molecules of ZnDTP, MoDTC and n-Octane sandwiched between substrates. To simulate friction, sliding velocity and contact pressure were applied. We observed multiple adsorption of some ZnDTP molecules and they formed phosphate structure in the form of bridged two zinc atoms. This result corresponds to an experimental fact that tribofilm with gradient structure in zinc concentrations is formed . Details of simulation and results will be discussed in our presentation.

3945101: Detailed Analysis of Chemical Reactions Near the Surface of Hydrogen-Free DLC Film During Sliding
Yudai Tanaka, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Hirotoshi Akiyama, University of Hyogo and NIPPON GREASE Co.,Ltd., Kobe, Japan

Friction Fade-out(FFO) is the phenomenon that the friction coefficient drops to 0.0001 order when a ZrO_2 pin slides on a hydrogenated diamond-like carbon (DLC) film under specific environments such as alcohol and hydrogen gases. It has been considered that the characteristics of the ZrO2, such as the catalysis of hydrogenation, play significant roles in FFO. In a previous study, when hydrogen-free DLC was used, it was found that the polymerization reaction occurred on the DLC surface, not on ZrO_2. In this study, molecular dynamics simulations are performed using ReaxFF, a reactive force field that can also handle chemical reactions and charge transfer, to investigate the strength of the bonds between ethanol and other molecules involved in the polymerization of carbon and FFO on the hydrogen-free DLC film surface. In addition, physicochemical analysis is performed for different surface conditions such as hydrogen-termination of the DLC surface.

3950839: Evaluation of Surface Topography Measurement Techniques for As-Built Additively Manufactured Metal-Specimens
Loren Baugh, Samsul Mahmood, Kyle Schulze, Nima Shamsaei, Robert Jackson, Auburn University, Auburn, AL

The proliferation of metal additive manufacturing has brought into focus the crucial role of surface characterization in determining the properties and performance of printed parts across diverse applications. This study aims to establish an optimal methodology for acquiring critical surface parameters of additively manufactured as-built specimens that pertains to the part's surface properties. The discussion focuses on critical parameters, measurement techniques, data analysis, and practicality of usage. Moreover, the study examines the surface characterization of fatigue samples in their as-built state. The investigation reveals that the surface roughness of these samples can vary based on their placement on the build plate. Additionally, the directional dependence of surface roughness has been evaluated for various printing parameters. The proposed approach enables a comprehensive assessment of surface parameters acquired from a variety of instruments, facilitating comparative analysis. It also provides an opportunity to gain a deeper insight into the factors that influence roughness beyond traditional linear measurements, allowing for a more comprehensive understanding.

3952249: Analysis of Friction Behavior of Crystalline Polymers With and Without Fillers by Coarse-Grained Molecular Dynamics Method

Kazuki Ito, Masaki Hayama, Hitoshi Washizu, University of Hyogo, Kobe, Japan; Yuji Higuchi, Kyushu University, Fukuoka, Japan

In recent years, metallic materials have been shifted to polymer materials to achieve lighter weight and higher functionality in products. To improve the mechanical properties, polymer materials are reinforced with fillers. For the further improvement of the mechanical properties in composite polymer materials, understanding the relation between the structure and mechanical properties at the molecular scale is essential. We think that the clarification of the general properties of polymers and fillers leads to material design. In this study, we use polyethylene as the model of crystalline polymer and carbon nanotubes (CNTs) as the filler model. We perform friction simulations on crystalline and amorphous layers by the coarse-grained molecular dynamics method. The friction and wear behaviors with and without fillers are compared. We aim to reveal a universal understanding of the effects of adding fillers to polymer materials.