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
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 – Tribology I – Salon C
1D – Surfaces & Interfaces I – 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 – Tribology 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 – Tribology 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

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September 21, November 13, 2023

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
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 Azadehjanbar, 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.
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 Groomey, 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.
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.
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.

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 NH3 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 NH3 molecules. The influence of structural changes of the iron nitride on the degradation process will be reported at the conference.

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.
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 microscope as well as SEM images, a better understanding of how to incorporate multi-scale friction into FEM models can be developed.

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.

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.

 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.
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 polyimide/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 Improving 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-Al₂O₃, activated carbon nano fillers etc.) composites 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 mm³/Nm < K < 1x10⁻⁶ mm³/Nm). To understand the evolution of wear, the tribosystem was analyzed using optical microscopy, profilometry, and surface energy measurements. Variance in transfer film morphology 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- Lubricating Polyimide for EV Wear and Friction Applications  

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

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 Al₂O₃ 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 Al₂O₃ 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 Al₂O₃ 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 Al₂O₃ 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 Al₂O₃ 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 shrunk 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 \( \sigma \) on the rates of tribochemical reactions is described using the Bell model, where the rate varies as \( \exp(\sigma \Delta V^\ddagger /k_B T) \), 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 triopolymerization, 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, Rengu 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.
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.

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 O₂ 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.

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, in spite 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 focuses 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.
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 multiphysical 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.

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 (2HDonald) in aqueous solution and its impact on friction and anti-wear properties were investigated. The findings reveal that 2HDonald 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 organophosphites 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.
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.

Machine elements such as gear teeth and cam-follower mechanisms often operate under elastohydrodynamic lubrication. 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%.

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.
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.
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\textsubscript{2} and ZnO nano-additives. The average size of MoS\textsubscript{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.\%o). The overall results of this experiment reveal that the addition of nano-MoS\textsubscript{2} reduced mass loss by 87\% due to the nano-MoS\textsubscript{2} lubricant effect. With 0.8wt.\% in nanoparticles content, the viscosity of MoS\textsubscript{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.

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.

Oxidation of metal surfaces during production processes acts predominantly as a limited factor. Even in high-vacuum environments, an oxygen partial pressure of 10\textsuperscript{-6} mbar is still present. A completely new approach is the production under an oxygen-free atmosphere with the aid of silane (SiH\textsubscript{4})-doped argon gas enabling oxygen partial pressures of less than 10\textsuperscript{-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.

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

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 CO₂ 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

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,
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 MoS$_2$ 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 MoS$_2$ powder or MoS$_2$ 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 MoS$_2$ have been created via electrodeposition from an aqueous solution of tetrathiomolybdate ions at room temperature. These films are amorphous, contain some MoO$_x$ 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 MoS$_2$ 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 ($\mu_{st} < 0.05$). 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 $\mu$, 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 (MoS$_2$) 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 MoS$_2$ to “age” into a high friction state. This poses a significant challenge in the reliable use of MoS$_2$. Despite the volume of the published literature, our understanding of the surface phenomena taking place during aging of MoS$_2$ 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-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  
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  
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 Al2O3/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 Al2O3 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 Al2O3, 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.

**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.
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 $1.6 \times 10^6 \degree/s^2$ 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
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.

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 electrochemical attributes. The versatility, speed, and simplicity of QCM for friction measurements renders it an ideal tool for the rapidly expanding research area of tribotronics.

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 elastohydrodynamic (EHD) contacts involving different contacting paired materials (glass, steel, Si₃N₄ 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.
Graduate Student Poster

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.

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 sp²/sp³ 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
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 pPential
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 ZrO₂ 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 ZrO₂. 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.
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.
2023 STLE Tribology Lubrication & E-Mobility Conference

November 14-15, 2023
Cleveland Marriott Downton at Key Tower
Cleveland, Ohio (USA)

Preliminary Technical Program
Updated as of Sept. 13, 2023

www.stle.org/EVconference
### Preliminary Program-at-a-Glance

As of 9-13-23 – Subject to Change

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<td>Joint Plenary Session – 8:00 am–9:00 am – Salon EFGH</td>
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<td><strong>Keynote Presentation:</strong> Troy Muransky, Lead Materials Engineer, American Axle &amp; Manufacturing</td>
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<td><strong>“Challenges of Selecting the Correct Electric Vehicle Driveline Fluid”</strong></td>
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<td>Networking Break (Exhibits &amp; Posters) – 9:00 am–9:20 am – Foyer</td>
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<td>Refreshment Break/Poster Session – 10:40 am–11:00 am – Foyer</td>
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[**FLUIDS CONTINUED**] – 11:00 am–12:00 pm

| Lunch on Your Own/Posters – 12:00 pm–1:15 pm |

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<td>Refreshment Break/Poster Session – 2:30 pm–3:00 pm – Foyer</td>
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| FOAMING – 3:00 pm–4:00 pm |
| Refreshment Break/Poster Session – 4:00 pm–4:20 pm – Foyer |

[**FOAMING CONTINUED**] – 4:20 pm–4:40 pm

| GREASE – 4:40 pm–5:20 pm |

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<td>General Attendee Breakfast – 7:00 am–7:45 am – Foyer</td>
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[**All EV Sessions are in Salon EFGH**]

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<tr>
<td>MODELLING – 8:00 am–9:20 am</td>
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<td>Refreshment Break/Poster Session – 9:20 am–9:40 am – Foyer</td>
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| PANEL SESSION: MATERIAL COMPATIBILITY – 9:40 am–11:40 am |
| Lunch on Your Own/Posters – 12:00 pm–1:00 pm |

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<td>TESTING – 1:00 pm–2:20 pm</td>
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[**TESTING CONTINUED**] – 3:00 pm–4:20 pm

| CLOSING REMARKS: 4:20 pm–4:30 pm |


**TOPIC: COMMERCIAL EV**

**Session Chair:** Hyeok Hahn, Chevron, Inc., Richmond, CA

9:20 - 9:40 am
*3961325: Hardware and Lubricant Considerations for Commercial Vehicle Electric Drive Fluids (EDFs)*

Ian Stewart, Chris Cleveland, Michael Glasgow, Dan Horvath, Tracy McCombs, Stephen Walker, Afton Chemical Corporation, Richmond, VA; Amy Zyski, Darren Ziskovsky, Bill Waltz, Dana Incorporated, Maumee, OH

The global shift from combustion engines to electric vehicles requires ingenuity in driveline hardware. Transmission and axle designs are being wholly reimagined to enable electrification, requiring the introduction of new gear and bearing configurations to accommodate the higher rotational speeds, loads, and stresses associated with electric motors, along with new coating and sealing materials to protect power electrics and other componentry. As eMobility expands beyond passenger vehicles (PV) and other light duty (LD) applications to commercial vehicles (CVs; Class 6-8), drivetrain designs are further increasing the performance and compatibility demands placed upon lubricants used in these applications. Existing electric drive fluids (EDFs) must adapt to meet these needs. Here, hardware design considerations for CV electrification are expounded. The effect of different variables driving the balance between individual lubricant performance requirements for CV battery, eMotor, inverter, and gearbox systems is presented. The relevance, or potential lack thereof, of standard ASTM guidance or contemporary PV/LD EDF criteria, such as durability, oxidation, and materials compatibility, for gauging EDF and CV affinity is discussed. Likewise, conventional driveline fluid formulation styles and componentry need to be reconsidered (i.e. ATF vs MTF vs Axle et.). This presentation will explore those challenges and the merits of parallel hardware and EDF formulation during development.

**TOPIC: FLUIDS**

**Session Chair:** Hyeok Hahn, Chevron, Inc., Richmond, CA

9:40 - 10:00 am
*3935796: Novel EV Fluid Formulation Developments to Enhance Performance and Meet OEM EV Fluid Requirements*

Babak Lotfi, Gordon Lee, ExxonMobil, Annandale, NJ

Early fluid solution approaches for lubricating electric vehicle gearboxes mostly involved utilizing existing, off-the-shelf ATF’s. These fluids were lower in viscosity than their traditional gear oil counterparts, and readily available to manufacturers through existing fluid inventory. As gearbox designs have matured, the first-generation fluid designs are proving to be no longer appropriate, leading to the need for bespoke fluids with targeted performance properties. Over recent years, integrated electric drive units (eDU) where a single fluid is being used to lubricant gears, bearings, clutches and also used for thermal management of e-motor and electronic components has become popular in electric vehicle powertrain designs. These integrated systems provide additional challenges and opportunities driving lower viscosity formulations, and highlighting the need for dielectric properties, thermal management and material compatibility. In this presentation we will review our current work in developing optimized fluids specifically engineered to enhance fluids properties in 3 key areas – Energy efficiency (leading to reduced battery stress and potentially extending driving range), Low Speed Wear (protecting the gearbox), and Aeration (tie back into efficiency, new & aged oil). We will compare the results of different formulations and discuss how we can improve key performance areas using advanced formulations to deliver superior properties and ultimately meet OEMs requirements.
10:00 - 10:20 am

3940690: Latest Developments in Driveline e-Fluid Types for Electric Vehicle (EV) Transmissions and Axles.
Michael Gahagan, The Lubrizol Corporation, Derby, United Kingdom

Entirely new driveline e-fluid classes are being developed as a now integral part of the electric vehicle (EV) powertrain engineering technology revolution. This has been driven by the need for new dedicated fluids to directly cool electrical components whilst fulfilling the requirements of lubricant thermal and fluid electrical insulating properties and corrosion protection under new, severe operating conditions. Notwithstanding the familiar challenges of transmission, gear, and bearing lubrication; recent research and development has led to such a new e-fluid type by optimizing the additive components present in the e-fluid. Additionally, eliminating the need for sulfur-containing additive chemistry (coined “sulfur-free” technology) has seen state-of-the-art fluid technology types just entering the market, which will be described. Fluid electrical properties will be discussed plus results observed from advanced electrical circuit corrosion methods. The fluid's enhanced ability to effectively protect component hardware in a range of fluid viscosity types will also be highlighted.

10:20 - 10:40 am

3975098: The Next Generation Ultra Low Viscosity Electric Drive Fluids (EDFs) Enabled by the Synergy Between the Additive and Base Oil Technologies
Chris Cleveland, Christopher Gowdy, Ian Stewart, Michael Meffert, Afton Chemical Corporation, Richmond, VA; Jason Rosalli, Jason Wells, William Downey, Novvi, Alameda, CA

As the industry continues its transition to electrified vehicles, there is an ever-increasing emphasis on the role of the electric drive fluid (EDF). One specific area of focus in the design and development of the fluid is energy efficiency, which has to do with Axle operation and battery range. In order to achieve these efficiency gains, the implementation of ultra-low viscosities (KV(100°C) < 4 cSt) and novel additive and base oil technologies to mitigate churning and frictional losses. Such EDFs are only viable when the additive and finished fluid formulations are robust and balanced to provide the appropriate level of wear, scuffing and pitting protection, oxidation prevention and compatibility with and protection of the key materials components. In this presentation, we will review some recent work in the development of such EDFs.

10:40 - 11:00 am - POSTER BREAK

11:00 - 11:20 am

3962846: Improving Heat Transfer Properties of EV Transmission Fluids Using Oil Soluble PAGs
Steffen Glänzer, Clariant, Frankfurt, Germany

Several key parameters, such as anti-wear properties, energy efficiency, electric properties, foam, and material compatibility, must be considered when developing formulations of transmission fluids for electric vehicles. It is especially desirable to maximize the heat transfer properties of these fluids in wet motor applications to improve the efficiency of the electric motor. PAG Group V base fluids are well known in industrial applications, such as industrial gear oil, compressor fluids and hydraulic fluids. However, the immiscibility with hydrocarbons limited their application in automotive oils so far. Here, we will discuss new ultra-low viscosity PAG Group V base oils that demonstrate exceptionally high heat transfer properties, are hydrolytically stable and are compatible with Group I-III mineral oils, Group IV PAO and Group V ester base oils. These mixtures show enhanced properties and can improve vehicle efficiency in wet transmission fluids.

11:20 - 11:40 am

3962676: Effect of Polymers on the Electrical Properties of Lubricants for EVs
Jacob Scherger, Functional Products Inc., Macedonia, OH

One of the key areas specified in the SAE J3200 ‘Fluid for Automotive Electrified Drivetrains’ standard is the electric properties of the fluid. It will become important for formulators to know how different types of additives might affect a fluid’s conductivity, dissipation factor, and/or dielectric breakdown voltage. Optimal performance in terms of electrical properties will likely not involve maximizing or minimizing any of these properties, but operating in a moderate range to both prevent static build-up (where sudden releases lead to pitting in bearings, or where fires might occur in extreme cases) and current shorting to
In this study, the effect of polymer additives on a lubricant’s electrical properties are examined in terms of polymer chemistry, polymer concentration, and base fluid. Polymers have unique physics due to their macromolecular structure, which can affect surface chemistry and mass or charge transport through bulk fluids. The strength of these effects are compared to those of non-polymer additives.

11:40 am - 12:00 pm
3960387: Dedicated E-Fluids for Energy Efficiency
Hitesh Thaker, Changlin Zhao, Infineum USA L.P., Linden, NJ

The automotive industry trends toward improved fuel efficiency and CO₂ emission reduction have resulted in automotive manufacturers incorporating greater levels of electrification, and developing more compact, higher voltage designs. The new generation e-fluids for these applications need to offer reduced energy consumption at lower viscosities while providing necessary hardware protection. Careful optimization of e-fluid parameters like viscometrics and additives is required to achieve high energy efficiency in controlled testing environments and real world conditions.

Electric Vehicles II

PANEL SESSION: ESTERS
Session Chair: Neil Canter, Chemical Solutions, Willow Grove, PA

1:15 - 1:30 pm
3957569: Using Synthetic Esters as Performance Components For E-Fluids
Siegfried Lucazeau, NYCO, PARIS Cedex 08, France

It is now generally recognized by the industry that direct cooling in e-mobility applications delivers extended hardware lifetime as well as improved energy efficiency. Synthetic esters, when carefully designed, do possess high performance features for such applications: excellent heat transfer properties, a high level of fire safety, low traction coefficients, and superior resistance to oxidation. It has also been shown such esters did not affect the performance of additive packages on copper protection or mechanical properties. This work has been extended to blends of esters with group III base fluids, considering two different approaches: introduce a hydrocarbon in an ester base fluid, to improve cost-effectiveness and reduce its impact on elastomers- boost the performance of a group III based formulation using esters to reduce traction and improve fire safety. Making blends allows formulators to find ways around some of the drawbacks of both group III and synthetic ester base fluids.

1:30 - 1:45 pm
Hoon Kim, Zschimmer-Schwarz US, Gordon, GA

EV runs on high voltage electrical power, and battery pack, inverter & electric motor are three essential components of the EV powertrain system. Compact battery packs with high energy density and high-speed electric motor generate excessive heat. Accordingly, proper electrical properties and better thermal control are critical requirements of EV lubricants that are new concepts in lubricant industry. With that, synthetic esters (Gr V) and PAO (Gr IV) are by far the most promising base oil candidates to date to accommodate those key requirements. Especially, the unique polar nature of synthetic esters is more beneficial to accomplish subtle/optimal balance between dielectricity and conductivity under the electromagnetic stress circumstances during the EV operation. In addition, synthetic esters have high thermal conductivity and heat capacity to enhance cooling capacity. Along this line, in this presentation we report our latest investigation on useful structure-property-performance relationships of synthetic esters for EVL application in terms of their various electrical properties including dielectric constant, power factor/loss factor & resistivity/conductivity and thermal properties such as thermal conductivity and specific heat capacity.
1:45 - 2:00 pm  
**3959714: Sustainability Effects of Esters in Electric Vehicle Lubricants – Efficiency and Biobased Content.**  
Alexei Kurchan, Gareth Moody, Cargill Inc., Wilmington, DE

The increase in electrification of vehicles can have a dramatic impact on lowering CO$_2$ emissions. Lubricant can further improve sustainability benefits via improving intrinsic and extrinsic aspects of EV operation and maintenance. The intrinsic benefits are provided by using biobased raw materials. Here, the CO$_2$ created in production and transportation of lubricants can be partially or entirely offset by carbon sequestration during growing of crops. The second, extrinsic benefits are gained from increased efficiency and extension of vehicle range. This talk will combine both these effects and discuss how the holistic approach to lubricant formulation can have the maximum impact on sustainability.

2:00 - 2:15 pm  
**3962962: Optimizing EV Fluids by Balancing Performance and Sustainability with Ester Technology**  
Jared Nelson, Emery Oleochemicals, Cincinnati, OH

Thermal management fluids will be a vital part of the new generation of electric vehicles. While most battery systems currently use indirect cooling systems, it is assumed that in the future either direct or immersion cooling techniques will be implemented. For these high-efficiency systems, a new generation of fluids will need to be developed moving away from traditional water-glycol blends. Esters can play an important role in the formulation and development in of new EV fluids. This Gp V base stock chemistry has shown to have higher breakdown voltages as well as more favorable combinations of low viscosity and high flashpoint. Due to higher costs for more advanced ester technology, blends with petrochemical base stocks can provide a good balance of material sustainability, system sustainability, high performance, and economics. In our latest research, we have evaluated the dielectric and cooling properties of ester blends with petrochemical base stocks.

2:15 - 2:30 pm - Panel Session Questions

2:30 - 3:00 pm - POSTER BREAK

**TOPIC: FOAMING**

Session Chair: William B. Anderson, Afton Chemical Corporation, Richmond, VA

3:00 - 3:20 pm  
**3960517: Low Foaming/Aeration and Low Traction Coefficient Synthetic Lubricant Solutions for High-Speed Electric Drivetrain Fluids**  
Philip Ma, Donna Mosher, Chad Steele, BASF, Tarrytown, NY

Internal combustion engines (ICE) are being replaced by electric motors as power sources for both passenger cars and heavy-duty trucks. OEMs are using off-the-shelf lubricant fluids, such as industrial gear oils (IGO), automatic transmission fluids (ATF), manual transmission fluids (MTF), dual clutch transmission fluids (DCT), etc. as electric drivetrain fluids (EDF). EDFs are driving toward lower viscosity for better heat transfer capacity and better energy efficiency, and in the meantime satisfying all the other challenging requirements, such as gear/bearing scuffing/wear protection, coating/seal material compatibility, electric properties, etc. In this paper, we will highlight the importance of low foaming and low aeration, low traction coefficient which are critical for the performance of low viscosity EDF during the high rotation-per-minute (rpm) speed applications. EDFs with ultra-low foaming/aeration can potentially reduce electric induced bearing damage (EIBD), bearing creep (BC), thus provide better bearing protection and life, and in the meantime provide better heat transfer capacity. Low traction coefficient fluids will also contribute to better lubricant energy efficiency in comparison to other fluids with the same viscosity.

3:20 - 3:40 pm  
**3969218: A Study of the Effects of Foam and Antifoam Performance in Electric Vehicle Base Fluids**  
Safia Peerzada, Münzing North America, LP, Bloomfield, NJ
As electric vehicles (EVs) enter the automotive market, one vital area involves the development of fluids specifically for EVs. Compared to fluids for traditional Internal Combustion Engine (ICE) vehicles, fluids for EVs are required to provide lubrication and cooling under much higher shear conditions and are also required to stabilize the vehicle’s electronics and battery’s temperature. These different requirements often lead to EV base fluids exhibiting different foaming tendency compared to traditional fluids due to the different fluid chemistry and viscosity. While the fluid is in use, the antifoam functions to minimize foam buildup, which is undesirable for reasons such as reduction of lubrication and poor heat removal. A study of foam tendency in several EV base fluids using new foam test methods to simulate real world application will be reviewed. Furthermore, the performance of various antifoam chemistries will be studied to understand the most optimal antifoam for EV fluids.

3:40 - 4:00 pm
3964246: Electric Vehicle Drive System Specialty Fluids
Anant Kolekar, Valvoline LLC, Lexington, KY

The recent growth in the electric vehicle (EV) market has significantly affected the automotive industry along with the lubricant industry. For the lubricant industry, EV requirements are unique compared to Internal Combustion Engine Vehicles (ICEVs) where electrical, thermal, extreme pressure and foam performances are becoming more critical. The driving range or efficiency and the durability boost are becoming significant goals for EVs that pave the way towards a greener future. In EVs, Gears and bearings rotate at very high speeds (8,000-30,000 RPM) and experience significant fluctuations in power, torque and speed which demand for more precise testing work to improve standard ICEV transmission fluid tests. EV DSFs target vital EV requirements to improve friction reduction, overall efficiency, electrical compatibility and insulation, and electric motor and drive system heat transfer. There is an imperative need to design the best of all worlds EV fluid that maintains excellent mechanical, electrical and tribological properties to give optimal driving range and fuel economy performance. The unique benchtop test is developed to study further on the high-speed foam impact. Different ingredients were compared by designing and developing benchtop tests, transmission rigs and full vehicle tests. There were significant improvements in the overall vehicle efficiency (up to 3%) and reductions in operating temperatures (up to 9 °C).

4:00 - 4:20 pm - POSTER BREAK

4:20 - 4:40 pm
Ricardo Hein, CONEXO, Inc., Acworth, GA

Previous STLE meetings addressed oil aeration as a key stressor for E-fluids operating in EV transmissions. This talk will present the comparative testing results of EV transmission fluids, the apparatus, and the testing method. It includes information on how this efficient and cost-effective tester simulates the complexity of EV transmission operation in order to correlate the aeration characteristics in E-fluids. Under the newly developed testing method, the fluid volumes are reduced, the speed is increased to ultra-high, the air dispersion gear is fully immersed, and the temperatures are raised. We compared several market-available fluids that ranged in quality and specifications. This benchtop aeration tester offers a concrete solution to rethink the fluid design and hardware architecture for low aeration. Manufacturers of EV transmissions, E-fluids, antifoam agents and other additives will benefit from the implementation of this testing method.

TOPIC: GREASE

Session Chair: William B. Anderson, Afton Chemical Corporation, Richmond, VA

4:40 - 5:00 pm
3959450: Greases Based on Perfluoropolyether (PFPE) Oils for E-mobility High Speed Bearing
Greg Poterala, Solvay Specialty Polymers, Commerce Township, MI

The shift towards electric vehicles plays an important role in the transition to a more sustainable mobility. Electrical powertrains are pushed to higher rotational speed in order to efficiently improve the power density. This brings new challenging requirements for the roller bearings, in which advanced EV grease formulations are needed to reduce friction, wear, and NVH on long run while preventing electrical erosion. To address these challenges, we have tested different grease compositions based on PFPE. These fluids
are synthetic lubricants largely used for highly demanding applications thanks to their outstanding thermal and oxidative stability, chemical inertness, and hydrolytic stability. In this presentation, we will report the influence of the characteristics of the grease components on the bearing performance at high speed: the viscosity of the PFPE base oil, the type of thickener as well as the additives. We will also discuss the optimization of the electrical properties of the PFPE-based lubricating grease for EV bearing application.

Wednesday, November 15, 2023

Electric Vehicles III

TOPIC: MODELLING

Session Chair: Babak Lotfi, ExxonMobil Technology & Engineering, Annandale, NJ

8:00 - 8:20 am
3959913: Modelling of the Triboelectric Contact of a Roller Bearing
Stefan Paulus, Simon Graf, Oliver Koch, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

In modern inverter-fed electric drive systems, rotor bearings are loaded by parasitic voltage. When this voltage exceeds the breakdown voltage of the lubricant, it discharges across the lubrication gap. This can lead to damages and premature failure of the used roller bearings. To understand and predict the electrical phenomena inside a rolling contact, roller bearings have to be described as electrical circuit system. In this work, the transfer from the mechanical component roller bearing to an electrical equivalent system is shown. Furthermore, the electrical properties of roller bearings are modeled regarding the capacitive and resistive behaviors of the lubricant and the bearing components. In addition to that, the resistance of occurring discharge channels is taken into consideration. The investigated parameters include the running speed, the ambient lubricant temperature and the mechanical and electrical load. With help of this model, the influence of the operating conditions on the electrical behavior of a roller bearing can be described.

8:20 - 8:40 am
3962867: Simulation of Electrical Properties of Drive Trains Including Bearings and Gears
Hannes Grillenberger, Andreas Meinel, Bernhard Jakob, Martin Correns, Schaeffler Technologies AG & Co KG, Herzogenaurach, Germany

Electric potentials in generators and electric motors may cause damaging parasitic currents in drive train components like bearings or gears. These currents can lead to subsequent damages like re-melting, re-hardening, grey staining, or aging of the lubricant. An effective and efficient design of the gearbox or motor can only be achieved by simulation that includes mechanical, thermal, and electrical properties for every operating condition. The presentation shows a method to calculate these properties for gears and bearings within a mechanical system. It considers the exact geometry, load distribution, friction, surface roughness, and lubrication conditions. This detailed knowledge enables high quality results, and the system can be optimized for a variety of load cycles. This presentation shows physical background, implementation in a software tool, method workflow and validation. Finally, some corrective measures to avoid parasitic currents will be introduced.

8:40 - 9:00 am
3950663: Modeling Electrical Contact During a Rolling Vibratory Motion Considering Mixed Lubrication
Robert Jackson, Auburn University, Auburn, AL; Santosh Angadi, Gannon University, Erie, PA

In many devices and applications, electrical contacts are exposed to vibrations, sliding, or rolling conditions and are prone to the fretting-based degradation. This could also have applications to electrified rolling element bearings, such as in electric vehicles. Thus, lubricants are often employed in such contacts to reduce wear and fretting corrosion. However, due to the non-conductive behavior of the lubricants with fluorocarbons and hydrocarbons, lubricants lead to a few adverse problems. Also, the fluid dynamics upon excitation, motion causes extended breaks or gaps in between the conducting surfaces. Factors such as surface roughness and fluid viscosity will determine the time taken for the two surfaces of
the connectors to separate from a solid conductive contact. In this work, a coupled structural-fluid theoretical model is developed for evaluating such intermittent contact breaks/gaps when two metallic rough surfaces in contact are under vibrations. The model is capable of predicting the increase in the fluid film as well as the contact resistance change with time due to the possible connector vibration.

9:00 - 9:20 am
Tim Newcomb, The Lubrizol Corporation, Wickliffe, OH

The importance of cooling electric motors is driving the construction of e-lubricants that are optimized for heat transfer. The lubricant properties that influence heat transfer are viscosity, thermal conductivity, specific heat capacity and density. The importance of each depends on the flow regime. There are many electric drive unit configurations and, without design details or access to actual hardware, flow regimes can only be approximated or guessed. The lubricant’s heat transfer ability can be assessed using a “figure-of-merit”, which incorporates the flow regime impact on the thermal properties. In this presentation we will review the figure-of-merit models as they relate to lubricant thermal properties and compare them to models derived for general e-motor systems where some of the design information is known. We will share our work on the thermal characterization of actual electric drive unit hardware and contrast the thermal models constructed from this work to the prior estimates.

9:20 - 9:40 am - POSTER BREAK

PANEL SESSION: MATERIAL COMPATABILITY

Session Chair: Matthias Hof, Emery Oleochemicals GmbH, Duesseldorf, Germany

9:40 - 9:50 am - Problem Description

9:50 - 10:05 am
3894802: Conductive Layer Deposits and the Development of Bench Test Technology for Electric Vehicle Drivetrains
Greg Miller, William VanBergen, Savant Inc., Midland, MI; Alexei Kurchan, David Gillespie, Cargill, Newark, NJ; Gunther Mueller, APL, Landau, Germany; Timothy Newcomb, Gregory Hunt, The Lubrizol Corporation, Wickliffe, OH

As the enhancement of EV technology continues, so do the improvements with fluids and additives utilized within them. Varying conditions, depending on the EV system and usage, can cause the formation of conductive deposits and corrosion within drivetrain. Corrosion is a well-known entity and tools to evaluate under these conditions are imperative. However, the formation of conducting layer deposits, a corrosion product, has also been identified as a failure mechanism for current electric motor designs. Different drivetrain base stocks along with additive formulations may have inherently different corrosion rates producing conducting layer deposits in both solution and vapor phases. To help resolve these issues, a group of industry experts involving both OEM’s and lubricant experts from across the globe, have developed bench tests to better predict these conductive and corrosion deposits. The apparatus' developed are the conductive deposit test and the wire corrosion test. This paper covers several different aspects of the EV drivetrains and fluids performing in the CDT and WCT that show correlation to field data along with reactions due to the dilution of esters, base stocks and traction reducers.

10:05 - 10:20 am
3939138: Impact of Thermal Transient Effects on the Corrosivity of Lubricants: Part 1 Results of Cyclic Temperature Profiles
Gregory Hunt, Lindsey Choo, Tim Newcomb, The Lubrizol Corporation, Belper, United Kingdom

Lubricant corrosion performance is generally assessed isothermally. The selection of the test temperature has a large influence on the extent of corrosion, typically higher temperatures are more severe. However, vehicles operate over a variety of temperatures, with fluctuations from the nominal temperature being common. There is a question as to whether a short excursion to high temperature would negatively influence the corrosion once the fluid has returned to the nominal condition. This transient temperature relationship with corrosion performance has not previously been investigated. Corrosion is typically assessed using the ASTM D130 copper corrosion strip test which provides a visual rating. However, as
the ASTM D130 is a qualitative test, it is not an optimal tool for this type of investigation. A more appropriate method is the Wire Corrosion Test (WCT) because this test follows corrosion processes by monitoring changes in resistance. The WCT therefore is both quantitative and highly sensitive. In this first study, a set of sulfur containing oils was exposed to a cyclic thermal profile, where the temperatures were transitioned between high and low values. The corrosion during the cycling test was found to be more significant than expected. This implies that brief excursions at high temperatures could have greater impact on the corrosion performance over the life of the lubricant than previously expected this is of particular interest in Electric Drive Units (EDUs).

10:20 - 10:35 am
3962166: Effects of Test Conditions on an Oil Emersed Energized Copper Circuit Board
Scott Campbell, Infineum, Linden, NJ

An energized copper corrosion test (ECT) has been developed to study the effects on copper surfaces as may relate to the performance of e-Fluids used in areas such as motor, battery, and electronics. Performance of fluids in these areas is critical to the effective implementation of current and next generation Electric Vehicle drivelines. Energized corrosion testing is still evolving with much variation in competing test designs. This presentation is intended to highlight learnings centered around the variations of certain physical test parameters and their effects on test outcomes.

10:35 - 10:50 am
3964730: Electrification Effects on Oxidation Performance and Corresponding Changes in Dielectric Properties of Drivetrain Lubricants
Joshua Conner, Southwest Research Institute, San Antonio, TX

As electric drive unit design continues to incorporate a common fluid for lubrication of the rotating components and cooling of the electric motor, the electrification of lubricant testing equipment enables test methods that are more representative of electric vehicle applications. This study evaluates: 1) how oxidation affects the dielectric properties (relative permittivity, dissipation factor, electrical conductivity, and dielectric breakdown voltage) of various drivetrain lubricants and 2) how oxidation performance may be impacted by different types of electric and magnetic fields. A common drivetrain lubricant oxidation test was used to study these effects, under both electrified and non-electrified conditions.

10:50 - 11:05 am
3955654: Electric Motor Winding Durability: A simple Ex Situ Test for Determining the Integrity of Insulating Coatings on Conductive Metal Wires
Richard Brenda, Tyler Petek, Lubrizol Ltd., Derby, Derbyshire, United Kingdom

Electric motors in automotive applications have led to new material challenges for the working fluids which enable their operation, including lubricants. One such challenge is the new introduction of polymeric materials used as thin film insulators on copper windings in a motor. Thin motor windings must be electrically insulated from each other to enable high power density motor function. Insulator degradation leading to electrical shorts may result in catastrophic motor failure. Specific application testing is needed to ensure that the insulation properties are not harmed during the motor lifetime. For this purpose, this presentation will discuss a simple test developed to measure the effects of long-term exposure of insulated wires to the lubricating fluid. The test uses industry standard wires with a polyimide type coating and measures their post-exposure insulating properties. The wires undergo accelerated aging in different fluids at high temperature. Once the aging is complete, the wires are installed into the test cell where a conductive fluid fills any void which may have formed in the coating. This creates an ionically conductive path to the wire. A standard potentiostat measures the conductivity through the voids to quantify the coating void fraction. The test can differentiate between fluids that will harm the coating and those that will not whilst also measuring the functionally important properties.

11:05 - 11:20 am
3955641: Investigation of Magnet Wire Compatibility with Electric Transmission Fluids for Enhanced eMotor Performance
Yungwan Kwak, Afton Chemical Corporation, Richmond, VA

The implementation of new global regulations aimed at reducing pollutants, greenhouse emissions, and improving fuel economy has prompted OEMs to accelerate vehicle electrification efforts. In this regard, the electric motor (eMotor) plays a crucial role as one of the key components in the electric drive unit. The eMotor utilizes a significant amount of magnet wire (MW), which is a copper wire coated with a polymeric
insulation material that comes into contact with an electric transmission fluid (ETF). Therefore, the compatibility of MW with ETFs emerges as the primary performance requirement, as poor compatibility can result in decreased performance, electrical shorts, or even catastrophic eMotor failure. This talk presents new insights into MW compatibility with various ETFs. Key performance criteria investigated include adhesion, breakdown voltage, and partial discharge behavior of the insulation coating. The study investigates MWs with different shapes (round and rectangular) and various types of coating materials, such as polyester, polyamide, and polyimide. Furthermore, the impact of water concentration in ETF on MW performance during aging is examined. It is demonstrated that the additive package or formulation chemistry of the lubricant plays a pivotal role in generating significant differences in MW performance. The authors elucidate the mechanisms behind MW deterioration and propose strategies for optimizing lubricant formulations to enhance MW compatibility.

11:20 - 11:40 am - Panel Session Questions

6E Salon EFGH

Electric Vehicles IV

TOPIC: TESTING

Session Chair: Leonardo Farfan-Cabrera, Instituto Tecnológico Y De Estudios Superiores De Monterrey, Monterrey, Mexico

1:00 - 1:20 pm
3963994: “E-Mobility an Ever-Changing Landscape for India – Latest Update on Customized Fluids Development”
Sarita Seth, Indian Oil Corporation Ltd., Faridabad, Haryana, India

Out of variety of emerging new transmission designs for electric vehicles, Indian market is dominated by e-axle configuration with single, double or multiple speed gear box for most of the battery powered electric vehicles (BEVs). Wide variety of transmission fluids are being used for lubrication of gears, bearings and other hardware parts. These fluids include, API GL4, GL5, dedicated manual transmission fluids (MTFs), Automatic Transmission Fluid (ATFs) and some dedicated products for specific OEM applications in various viscosity grades. Lab scale evaluation through bench level tests is the key in finding the perfect lubrication strategy to get the best performance from the potential electrified solution as these fluids represent a new challenge for lubrication such as electrical breakdown, heat/thermal management in addition to conventional performance challenges like cooling & anti-wear, bearing protection, NVH and efficiency. Role of base oils and additives in finished lubricants is still to be evaluated in wider perspective. This paper focuses on lab studies of compositions based on varying additive chemistries and base oils in line with SAE J3200 specification meeting the requirements of the various segments of the Indian Market.

1:20 - 1:40 pm
3959446: Application of the Four-Ball EP Test as an FZG (A10/16.6R/90) Scuffing Screening Test with Reference Fluid Assessment
Kerry Cogen, Yanzhao Wang, Infineum USA L.P., Linden, NJ

Scuffing performance is a key metric in assessing electrified vehicle fluid performance. The FZG (A10/16.6R/90) gear scuffing test is typically used, but it is resource intensive. A bench screener test, based on the 4 Ball EP Test (ASTM 2783), has been developed to facilitate prioritizing oils to be run in the more resource-intensive gear test. The screener test also makes it possible to study the formation of tribofilm as a function of load. This systematic approach to analyzing film formation with load offers the opportunity to better understand tribofilm formation and the impact on scuffing performance.

1:40 - 2:00 pm
3964021: Investigation of the Discharge Voltage in EV Motor Bearings
Liang Guo, Henk Mol, Lieuwe de Vries, Thijs Nijdam, SKF Research and Technology Development, Houten, Netherlands
As the automotive industry shifts towards electric vehicles (EV), the issue of electric discharge in motor bearings is increasingly gaining attention due to its potential to cause damage on bearing surfaces and even lead to premature failures. The level of discharge damage is directly influenced by the discharge energy, which, in turn, is dependent on the bearing capacitance and discharge voltages. To gain insights into the discharge voltage within EV motor bearings, electric discharge tests were conducted using in-house developed Tractor equipment, which enables the accurate reproduction of real-world application conditions. The test findings confirm that the discharge voltage follows a probabilistic distribution and is contingent upon the working conditions. The presentation will comprehensively cover essential aspects, including the design of the test rig, the precise acquisition and extraction of the discharge signal, the analysis of damaged surfaces and a comprehensive model explaining the distribution of discharge voltage.

2:00 - 2:20 pm

3953867: Validation of EV Fluids: An In-Depth Exploration of System Efficiency, Durability, and Thermal Performance
Flavio Sarti, TotalEnergies, Solaize, France

The electric vehicle industry has advanced rapidly. As new electric powertrain technologies continue to evolve, new and promising prospects for electric vehicle fluids are emerging. Multi-purpose fluids (lubrication, thermal control, component protection) are starting to be used, which raises the question of how to develop and validate them. The classic approach to transmission fluid development consists of multi-level testing (from contact (tribometers) to components (gears, bearings, pumps, seals) to final application in the vehicle). To enhance this approach, TotalEnergies is incorporating novel in-house tests derived from previous EV fleet campaigns. The use of vehicle data and fluid samples is essential to shorten the testing cycle while maintaining the representativeness of a real road test.

2:20 - 3:00 pm - POSTER BREAK

Session Chair: Carlos Sanchez, Southwest Research Institute, San Antonio, TX

3:00 - 3:20 pm

3952381: E-Fluid Effects Made Visible Through Full-Scale EDU Testing
Suzanne Patterson, Auke Faber, David Whitticar, The Lubrizol Corporation, Wickliffe, OH

The global transition to electrified powertrains necessitates new lubricants which provide e-device durability, minimize power loss, and participate in thermal management. The correlation of mechanical efficiency in traditional gear boxes to fluid viscosity, traction, and friction has been extensively studied, and we are now studying those correlations to power loss in e-axes, with and without embedded motors. We are also studying the relationship between thermal management of an e-device and a fluid’s viscosity, heat capacity, and thermal conductivity. For full scale electric drive unit testing, Lubrizol has upgraded our three-motor transmission test stands with the addition of a 400 kW battery simulator and can precisely control embedded electric machines with a pair of universal inverters. This upgrade allows testing of myriad lubricants in almost any e-device, generating fundamental knowledge for how to formulate the highest performing e-fluids.

3:20 - 3:40 pm

3962033: Development of High-Speed/High-Load Three-Roller Type Pitting Wear Tester for Tribo-Elements Sliding Parts of Electric Vehicle
Takuto Kunii, Vishal Khosla, Jun Xiao, Michael Vinogradov, Rtec-Instruments, Chiba, Kashiwa, Japan; Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

The E-Axle as a transmission/motor system in electric vehicles is becoming an alternative to traditional engines. In the development of the E-axle, increasing the rotation speed of the motor and improving the efficiency of the transmission are urgent issues in order to make the system more compact. The high-speed rotation of the transmission and the resulting low viscosity of the lubricating oil affect the poor lubrication of the gear and bearing surfaces and the increase of pitting wear. Pitching wear causes transmission vibration and noise and reduces powertrain efficiency and life. In this research, we have developed a three-roller pitting wear tester that enables higher speed (>4.0m/s) and higher load (>2000N) testing. Using this device, we investigated the effect of the slip ratio on the occurrence and progression of micro-pitting on the rolling friction surface of gear steel using an acoustic emission method.
3:40 - 4:00 pm
3923522: The Investigation of Lubricant Viscosity on Fatigue Wear of Gear/Bearing Steel under Rolling Contact Conditions
Ryotaro Ohashi, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

In recent times, the popularity of electric vehicles (EVs) has grown significantly, necessitating the enhancement of fatigue wear resistance in reducers due to the higher rotational speeds of motors. Lubricant viscosity has been found to affect gear failures like pitting, but the mechanism is not fully understood. In this study, in addition to the rolling-sliding condition, we used a pure rolling condition. Ball-on-disc traction tests with different viscosity poly-alpha-olefin (PAO) were conducted, and the damaged area on the discs was evaluated using a laser microscope and MATLAB. Results showed that increasing lubricant viscosity increased the damaged area on the discs. Higher viscosity in a base oil like PAO increases the pressure-viscosity coefficient, leading to higher contact pressure. This yielded a correlation between the pitting and viscosities of PAO. To optimize the fatigue wear resistance of EV reducers, it is necessary to design lubricant from the fundamental perspective of its viscosity.

4:00 - 4:20 pm
3962105: Effect of Phosphorus and Sulfur Based Additives on Wear and Micro-Pitting Under Rolling and Sliding Conditions.
Yunah Jeung, Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Ryotaro Ohashi, Kenya Nakayama, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan

As the E-axle is being made smaller, the speed of motor rotation is increasing, and low-viscosity transmission lubricating oil is required in order to reduce stirring resistance and improve cooling performance. As a result, the gears and bearings of transmissions are forced to move under poor lubrication conditions, so lubricating oils are required to have further improved wear resistance. Phosphorus- and sulfur-based additives are commonly used to improve wear resistance, but their anti-wear mechanisms are not well understood. As a result of an investigation using a mini-traction machine (MTM), it was confirmed that the S-type additive exhibited a greater anti-wear effect than the P-type additive. The anti-wear and anti-pitting fatigue mechanisms were discussed based on the surface analysis results of the tribo-reaction films on sliding surfaces derived from P-based and S-based additives.

4:20 - 4:30 pm - Closing Remarks, Peter Lee, Southwest Research Institute, San Antonio, TX

3975429: Toward a Single Fluid: Balancing Lubrication and Thermal Management Through Ti3C2Tx MXene Nanoparticles
Hong Liang, Texas A&M University, College Station, TX

Mexene particles, Ti3C2Tx nanosheets exhibit high thermal conductivity, electrical conductivity, and mechanical strength, making them promising candidates as lubricant additives to design an single fluid for electric vehicles. Using a single fluid in vehicles for balanced lubrication and thermal management can improve fuel economy, reduce emissions, and improve performance. These fluids can be used as transmission, differential, and power steering fluids where lubrication and thermal management are essential factors to avoid the wear of vehicle component. In this research, we evaluate the performance of Ti3C2Tx as an additive to enhance the heat transfer, rheological properties, and tribological performance of silicone and polyalphaolefin (PAO) base oils. Experimental results showed that adding Ti3C2Tx improved thermal conductivity by 16 % and 23 % in silicone and PAO oils, respectively. The rheological data revealed that adding Ti3C2Tx nanosheets reduced the viscosity by 12.3 % (at 0.09 wt%)
and 18.1 % (0.04 wt%) in silicone and PAO oil, respectively. The addition of Ti$_3$C$_2$T$_x$ reduced the friction by 23 % (0.09 wt%) and 65 % (0.04 wt%) in silicone and PAO oils, respectively. The improved properties and reduced fluidic drag in viscosity and friction can offer the utilization of Ti$_3$C$_2$T$_x$ MXene-based fluid in EVs applications which will help to achieve improved fuel economy by meeting the stringent requirements of EV compared to ICE vehicles.

**3965022: Effect of a Bio-Derived Lubricant on the Tribological Properties of Electrified Contacts**  
Leonardo Farfan-Cabrera, Carlos Rubio-Hernández, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Ali Erdemir, Texas A&M University, College Station, TX; Peter Lee, Southwest Research Institute, San Antonio, TX

Interest in highly functional EV Lubricants has increased tremendously. They need to fulfill a wide range of functionality including excellent electrical, thermal, tribological and chemical properties, material compatibility and eco-friendliness. Considering state-of-the-art progress being made in bio-based lubricants, novel fluid formulations using these oils as additives in mineral or synthetic-base oils hold great promise in meeting the multifunctional requirements of EV drivetrains. This work presents the results of a systematic study involving the use of Jatropha crude oil as an additive in a group II Mineral oil on dielectric strength and tribological properties in a four-ball tester instrumented with DC power.

**3964760: eTribology – Electrified Mini Traction Machine Test Results**  
Peter Lee, Carlos Sanchez, Andrew Velasquez, Michael Moneer, Southwest Research Institute, San Antonio, TX

SwRI in partnership with PCS Instruments have electrified a Mini Traction Machine to allow AC and DC voltage with various currents, voltages, and frequencies to be applied across the ball and the disk test specimens. Different behaviors have been observed with the presence of AC and DC voltage versus the non-electrified tests. Traction coefficient across the Striebeck curve increases, as does wear volume and the wear type changes. Lubricants used were an Ultra-Low Viscosity and Dexron VI automatic transmission oil, and an automatic gear oil. Tests were performed at different temperatures and electrified conditions. These results will be presented and discussed.

**3964759: eRheology – Test Methods and Analysis of E Lubricants**  
Carlos Sanchez, Peter Lee, Southwest Research Institute, San Antonio, TX

Lubricants in electric vehicles tend to behave differently in the presence of an electric field. There are many rheological test methods used for engine and drivetrain applications that are relevant to EV systems. Rheology can be used to evaluate lubricants for visco-elastic behavior, churning losses, and viscosity, to name a few. Several lubricant properties were investigated using different rheological test systems while subjected to an electric field. This work will discuss current test methods used for evaluating driveline fluids and greases, and new methodologies being developed to meet the demands of electrification.

**3964146: Fluid Durability Study in Electrified Drivetrains**  
Cole Frazier, Southwest Research Institute, San Antonio, TX

Three complementary programs have been undertaken to determine the real-world conditions that stress a fluid in an electric or hybrid-electric vehicle (EV/HEV) drive unit and determine what a “failed” fluid looks like at the end of its life. By utilizing in-vehicle testing on chassis dynamometers, road conditions have been closely replicated to simulate the stressors that a fluid undergoes during its life cycle. This report provides an update on testing results for the Toyota RAV4 Prime Hybrid and Hyundai Ioniq5 which were disassembled, documented, extensively instrumented, tested for efficiency and range, and set on a 100,000-mile fluid durability test cycle. Incidental findings, used fluid analysis and operational data will be presented from each vehicle.

**3963911: Effect of a Protic ionic Liquid on Friction and Wear Performance of an-Ultra-Low Viscosity Synthetic Oil under Electrified Sliding Conditions**  
Seungjoo Lee, Ali Erdemir, Texas A&M University, College Station, TX; Leonardo Farfan-Cabrera, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Patricia Iglesias, Rochester Institute of Technology, Rochester, NY

Market penetration of electric vehicles (EVs) has been growing rapidly in recent years to meet the future transportation needs of world community. As opposed to the tribological issues in traditional internal
combustion vehicles, not much is known about the tribological issues in EVs especially under electrified contact conditions. In this study, we used a pin-on-disk machine under ASTM G99 conditions to explore the friction and wear behavior of an ultra-low viscosity oil (PAO 2) under electrified sliding conditions with and without the use of a protic ionic liquid. Combining excellent thermal stability with high electrical conductivity, the protic ionic liquid had a significant positive effect on the friction and wear behavior on steel test pairs. Post-test structural and surface analytical studies revealed the formation of very different kinds of tribofilms when electrified and the ionic liquid was used. Specifically, tribofilms contained higher levels of carbon nanostructures under electrification and in the presence of ionic liquid which together resulted in superior wear performance.
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