Lubrication Fundamentals I

Session Chair: Ashish Jha, Chevron, Richmond, CA
Session Vice Chair: Xin He, Syensqo, Levittown, PA

8:00 - 8:40 am
4201731: Unusual Lubricity and Lubrication Mechanism of CO2 Under Severe Tribological Conditions
Ali Erdemir, Seungjoo Lee, Cagatay Yelkarasi, Texas A&M University, College Station, TX; Hitoshi Washizu, Ryuichi Okamoto, University of Hyogo, Kobe, Hyogo, Japan

Carbon dioxide (CO2) is one of the largest contributors to climate change, accounting for over 75% of the global greenhouse gas emissions. In this work, combining comprehensive tribological tests with surface analytical studies, we confirmed that CO2 can reduce friction and wear by orders of magnitude below those observed in ambient air. Surface and structural studies confirmed the formation of carbon-rich tribolayers on rubbing surfaces when sliding occurs in a CO2 environment. Computational simulations revealed that CO2 can decompose under the influence of high pressure and shear of sliding test and thus turns into a carbon-rich tribofilm. Initial test results under lubricated contacts also look very promising. Overall, our work shows how an environmentally harmful gas like CO2 can be turned into an environmentally friendly lubricant for severe tribological applications.

8:40 - 9:00 am
4201472: Importance of Contamination Control Within Zinc-Containing Hydraulic Fluids
Rachel Drewitt, Afton Chemical Ltd, Bracknell, Berkshire, United Kingdom

Contamination of hydraulic fluids has been an end user concern for a number of years; with water identified as the greatest concern within the majority of applications. Understanding both the direct and indirect technical challenges contamination can cause in the field is key to developing a robust hydraulic fluid which provides reassurance and confidence to end users.
The ISO 13357 filtration tests are one of the key industry accredited methods in assessing hydraulic fluid performance in the presence of water. By further developing these filtration tests it is possible to better define potential failure modes which can then be related to the field. A key learning from this being able to link test data to in field failures and subsequently how formulation style can minimize these indirect challenges caused by water contamination.

9:00 - 9:20 am
4199759: Impact of Surface Roughness on the Lubrication Performance of Low-Speed, Heavy-Duty Water-Lubricated Polymer Bearings
Zhenjiang Zhou, Xincong Zhou, Shaopeng Xing, Lun Wang, Wuhan University of Technology, Wuhan, Hubei, China; Konstantinos Gryllias, KU Leuven, Leuven, Belgium

With the growing use of water-lubricated stern bearings, asperity contact has become a key challenge in designing low-speed, heavy-duty bearings. To explore how surface roughness affects lubrication performance and state transitions in water-lubricated polymer bearings, a mixed lubrication analysis model was developed. This model incorporates elastic deformation, thermal effects, surface topography, and asperity contact. Experimental validation confirmed its accuracy. The analysis revealed that increased liner roughness slows water film formation, requiring higher

speeds for hydrodynamic lubrication. In mixed lubrication, greater roughness slows friction reduction and temperature decrease, leading to higher contact pressure and flatter pressure distribution. In the hydrodynamic phase, surface roughness has less influence as speed increases.

9:20 - 9:40 am
4181729: Achieving Superlubricity in Water-based Lubricants Modified with Potent Corrosion Inhibitors
Xiaoman Wang, Alex Love, Zaid Al Hassan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL; Xiaoqian Wang, Ning Ren, Valvoline Global Operations, Lexington, KY; Jaylin Trice, Louisiana State University, Baton Rouge, LA

While water-based lubricants can achieve low-friction performance, even reaching the superlubricity regime (friction coefficient ≤ 0.01), they also introduce significant risk of corrosion in metallic systems. In this study, we addressed this issue by using aqueous glycerol solutions as the base fluid, supplemented with three corrosion inhibitors. Tribological tests on a mini-traction machine (MTM) revealed that these additives maintain the same ultralow friction performance under identical loads and rolling speeds as the aqueous glycerol solutions alone. Moreover, corrosion tests followed by modified ASTM D1384 showed that WB-4 with potent corrosion inhibitor provided excellent protection against corrosion in cast iron, steel, copper, and brass, compared to glycerol solutions without additives (WB-1). These results indicate that water-based lubricants, when combined with effective corrosion inhibitors, can provide both ultralow friction and enhanced corrosion protection.

9:40 - 10:00 am
4199290: Asphaltene Solvency of a Marine Trunk Piston Engine Oil – A Solution
Ramanathan Ramaswamy, Sathyam Reddy, Anil Bhardwaj, Indian Oil Corporation Ltd. R&D Center, Faridabad, Haryana, India

This abstract describes the studies conducted on a marine lubricant formulation with various polar additives and surfactants to assess their effectiveness in dissolving asphaltene contaminated to a marine lubricant in a marine engine. The screening method for assessing the asphlatene solvency is an in-house test method named ‘filterability test.’ The test was conducted by mixing measured quantity of Heavy Furnace Oil with marine oil formulation at room temperature and thermal ageing at 100 °C for 24 hrs followed by immediate filtration of weighed quantity of aged mixture. A test was conducted against industry reference oil. Candidate blends with special additives were subjected to thermo-oxidation evaluation to assess their effect on oil deterioration. The special additives are observed to be non-detrimental w.r.t thermal & oxidative degradation of the base line formulation. Additives which have aromaticity and polar functional group have yielded excellent results w.r.t asphaltene solvency.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4190006: Atomistic Insights into Friction and Wear Mechanisms of PTFE and its Synergy with PEEK
Thomas Reichenbach, Stefan Peeters, Gianpietro Moras, Michael Moseler, Fraunhofer IWM, Freiburg, Germany

PTFE is a widely used solid lubricant with high chemical stability and temperature resistance. However, its low wear resistance limits its applicability in highly loaded contacts. A possibility to extend the lifetime of PTFE lubrication is by mixing PTFE with other polymers that are more resistant to wear, such as PEEK.
In this contribution, I will first summarize our current understanding of the friction, wear and transfer mechanisms of PTFE as obtained by molecular dynamics simulations. Afterwards, I will

discuss how physically, and chemically mixed PTFE/PEEK composites can exhibit friction values as low as those obtained with PTFE alone, while strongly reducing the lubricant's wear. Our simulations indicate that the former property originates from shear localization within crystalline PTFE layers, while the latter is enabled by anchoring PTFE to PEEK via physical or chemical interactions.

11:00 - 11:20 am
4205713: Insights Into Synergistic Workings of Additives Improving Engine Cleanliness Performance of Lubricant Oils
Devin Wall, Ashish Jha, Felix Kha, Allan Isenberg, Matthieu Decuupere, Sandy Lemesle, Chevron Oronite, Gonfreville l'Orcher, France

As internal combustion engine designs continue to evolve, driven by the pursuit of improved fuel efficiency and enhanced power output, the demands placed on lubricating oils have reached unprecedented levels. These advancements in engine technology necessitate lubricating oils that can maintain engine cleanliness under more stringent operating conditions. This presentation will delve into the mechanistic insights of component synergies, exploring how various components within the formulations interact to meet these elevated performance standards. By understanding these synergies, we can develop lubricating oils that not only meet but exceed the challenges posed by modern internal combustion engines, ensuring optimal performance and longevity.

11:20 - 11:40 am
4201600: On the Effects of Reaction Order When Using the Arrhenius Equation to Estimate Lubricant Life.
Paul Shiller, FirstPower Group, LLC, Twinsburg, OH

Extrapolating lubrication life from one temperature to another using an Arrhenius relationship likely assumes first-order kinetics. The literature does not speak to the significance of this assumption. This paper presents the results of testing model and fully formulated lubricants by differential scanning calorimetry and thermogravimetric analyses. From these results, the reaction orders of hydrocarbon lubrication oxidation are calculated, along with activation energies. The assumption of first-order kinetics versus higher-order reaction kinetics is discussed.

11:40 am - 12:00 pm
4202292: High-Pressure Viscometry of ISO Viscosity Grade Mineral Oils
David Casey, William Hannon, Rachel Wasik, The Timken Company, Munroe Falls, OH

Lubricant properties are required for elastohydrodynamic modeling. These properties are seldom available due to paucity of high-pressure laboratories, and the labor it takes to generate sufficient data. Prior works addressed Aerospace, Industrial, Automotive lubricants. This work focuses on mineral oils and the transition of properties across seven viscosity grades. High-pressure density and viscosity modeling parameters are tabulated for ISO VG 22, 32, 46, 68, 100, 150 and 220. These single sourced lubricants only include basic rust and oxidation inhibitors. The standard deviation residuals, of density and low-shear viscosity models, are less than 0.25 and 6.65%, respectively. Integration of the low-shear viscosity models yields temperature dependent reciprocal asymptotic iso-viscous pressure-viscosity coefficient models. Conclusionary observations note that although the viscosity grades are ordered by reference viscosities, interpolation of high-pressure parameters can be misleading.

5B Hanover C

Commercial Marketing Forum V

Session Chair: TBD

8:00 - 8:20 am - **Available**
8:20 - 8:40 am - **Available**
8:40 - 9:00 am - **Available**
9:00 - 9:20 am - **Afton Chemical Company**

9:20 - 9:40 am
4205415: Advanced Chemical Concepts: Soluble Bases and Water-Based Rust Preventative Technologies for the Metalworking Industry
Christopher S. Monday, J. Eldick, Advanced Chemical Concepts, Kentwood, Michigan

Advanced Chemical Concepts has been designing and developing new products for presentation to the metalworking community. In this presentation we focus on two important types of additives: New types of soluble bases: The new soluble bases deliver very-high performance. They provide excellent emulsification and stability in soft and hard water, multi-metal lubricity, corrosion protection for ferrous metals, stain resistance for non-ferrous metals and generate very-low foam, even in high pressure operations. The above soluble bases are based on readily available raw material. They are free from sulfonates, PIBSA and TOFA. Water Based Rust Preventives: The timely introduction of water-based rust preventives will fill a growing need in the market. ACC has developed water extendable rust preventatives that protect ferrous metals in harsh environments as supported by our salt fog and humidity cabinet testing.

9:40 - 10:00 am - **Available**

10:00 - 10:40 am – **Break**

10:40 - 11:00 am - **Available**
11:00 - 11:20 am - **Available**
11:20 - 11:40 am - **Available**
11:40 am - 12:00 pm - **Available**

5C Hanover D

Contact Mechanics I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:40 am
4190500: The Prediction of the Coefficient of Restitution Between Impacting Spheres and Finite Thickness Plates Undergoing Elastoplastic Deformations and Wave Propagation
Itzhak Green, Retired, Atlanta, GA

This work fuses two distinct models that predict the coefficient of restitution. That involves the interplay between elastic waves generation and elastoplastic deformations. This resultant model is

then compared to recent experimental and FEA results reported by Higgs, et al. The comparison is performed for a wide variation of material property combinations, plate thickness to sphere diameter ratios, and impact speeds. It is shown that a straightforward use of the model herein predicts very accurately the apparent coefficient of restitution.

8:40 - 9:00 am
4183718: Asperity Pressures and Deformations in Elastic-plastic Rough Surface Contacts
Keita Inose, Amir Kadiric, Imperial College London, London, United Kingdom

Asperity pressures and deformations in a rough surface contact are of fundamental concern in understanding most tribological phenomena. Since the 1980s, several numerical models have been developed to predict them. Such models rely on crude assumptions as to the maximum plastic pressure that can be carried by an asperity. These assumptions are known to be questionable but are necessary given our lack of understanding of asperity plastic behavior. To help address this, this study uses a combination of experimental and numerical approaches to observe and investigate the plasticity at asperity level in a rough contact of several metallic materials and over a range of roughness. The results show that asperity plastic behavior is strongly influenced by the initial asperity slope, and that contrary to common modelling assumptions, asperities can carry pressures in excess of bulk material hardness, a behavior termed ‘asperity persistence’.

9:00 - 9:20 am
4205467: An Investigation of Axisymmetric Elliptical Indentation
Robert Jackson, Auburn University, Auburn, AL; Shuangbiao Liu, Northwestern University, Evanston, IL

Surface features, asperities, and indenters can vary greatly in shape. This variation in shape can influence the mechanical behavior of these features when they come into contact with other surfaces. This work investigates the deformation of an axisymmetric elliptical geometry using a fully plastic slip line theory technique. The predicted behavior differs significantly from other commonly assumed feature geometries such as spheres or cones. The ratio between the average pressure (i.e., hardness) to yield strength ratio varies in an interesting way. The results are also compared to finite element predictions.

9:20 - 9:40 am
4204711: Phase-Field Simulations of Capillary Interactions Between Rough Surfaces
Yizhen Wang, Martin Ladecky, Lars Pastewka, University of Freiburg, Freiburg, Germany

At a small enough length scale, surfaces are always rough, regardless of whether they are generated by nature or via artificial process. When two such surfaces are placed close enough, the water molecules in the humid air are absorbed and hence form capillary bridges. Theories for adhesive interactions typically use simple cohesive laws, which are good models for Van-der-Waals interactions but may not be appropriate for capillary adhesion. We here present a phase-field model that explicitly represents water present between two contacting rough interfaces. We show results obtained with this model on synthetic, computer-generated, self-affine rough interfaces. In quasi-static simulation, we observe the merging and splitting of droplets under the normal and shear movement of the interfaces. The overall force is dominated by the perimeter of the droplet, indicating the importance of a detailed understanding of droplet morphology.

9:40 - 10:00 am
4204254: A Study on Numerical Algorithms and Decoupling Property for Sliding Frictional Contact Problems
Kai Zhu, Zhen Chen, Guangdong Ocean University, Yangjiang, Guangzhou, China; Zhizhen Jiang, Xiaoqing Jin, Chongqing University, Chongqing, China

The integrity of "layer-substrate" structures, such as protective coatings, is entirely dependent on the stress state of the surface and subsurface. Development of numerical algorithms for stress calculation, and further investigation of potential physical characteristics, are therefore with significant implications for structural optimization design. In this work, an CF algorithm for frictional contact problem is proposed, and the mathematical basis of the direct method for singular integral equation is peeled from the theory of Riemann boundary value problems. Investigation on the coupled action of layer thickness, Poisson's ratio, and friction coefficient, is then conducted. It is found that at a given layer thickness, when matched with corresponding Poisson's ratio values, the normal and tangential contact stresses are decoupled, and a symmetric distribution of contact pressure is unaffected by the coefficient of friction.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4200886: Experimental Setup for Nano-Scale Surface Topography and Contact Mapping
Gage Olson, Hamid Ghaednia, Cedars-Sinai Medical Center, West Hollywood, CA

We have developed a new experimental setup for 3D scanning of contact regions using FTIR (Frustrated Total Internal Reflection). The setup uses acrylic as the contact surface and LEDs of 11 different wavelengths trap photons inside the acrylic as objects are pressed against it. Force and displacement are measured using an impedance-based force sensor and Digital Image Correlation. A camera records contact areas at various force levels and LED wavelengths, while a black box covers the setup, preventing external interference. Macro-scale tests involve pressing rubber balls of various properties, while nano-scale tests use 3D-printed samples with known roughness. This low-cost and easily integrable method creates 3D maps of contact regions for comparison with existing contact models. The setup enables more accurate measurement of real contact area, which can significantly enhance our understanding and optimization of friction, wear, and lubrication in the field of tribology.

11:00 - 11:20 am
4200687: Predicting Load Variation in an Elliptical Contact Overrolling Surface Cavities
Marco Van Zoelen, SKF, Houten, Netherlands

A model is developed to predict load variation in an elliptical contact as it overrolls small surface cavities. Starting from the classic solution for a circular flat punch on an elastic half-space with a central hole, an analytical solution for a spherical cavity in an elliptical contact is derived, showing load independence from cavity position. This solution is validated using a multi-grid dry contact solver.
Contact simulations were done to extend the model to multiple cavities, including clustering scenarios, predicting the load relative to the nominal load. Results indicate a non-linear increase in this load due to cavity clustering. Derived engineering formulas predict the load as a function of the Hertzian contact parameters, the number of cavities, and the cavity radius and depth.
Finally, the model’s application to obtain contact load variation is demonstrated, providing input for dynamic simulations in systems like rolling bearings.

11:20 - 11:40 am
4199495: Numerical Simulation of Fast Contact Interface Dynamics
Francesco Massi, Sapienza University, Rome, Italy; Laurent Baillet, Institut des Sciences de la Terre, Grenoble, France; Killian Hollebeke, Anissa Meziane, Université Bordeaux 1, Bordeaux, France; Mathieu Renouf, Universite De Montpelllier, Montpellier, France

Whenever dry contact occurs, the interactions between surface asperities are favored sites for local ruptures and impacts, acting as sources of acoustic waves propagating along the interface and within the volume. Simulating such phenomena can provide meaningful information on the

origin of friction-induced vibrations and the dynamic vibrational response of solids under frictional contact. On another side, waves propagating at the interface can lead to fast transient local evolutions of velocity and stress fields, which need to be further investigated. Simulating such phenomena needs to overcome several difficulties, due to the characteristic space (dimensions of the wavelengths) and time (wave propagation velocities) resolutions, together with the nonlinear contact interaction. This work focuses on recent advancements in simulating fast transient contact dynamics and its role in the evolution of dry contacts.

11:40 am - 12:00 pm - **Contact Mechanics Business Meeting**

5D — Hanover E

Tribochemistry I

Session Chair: Cinta Lorenzo Martin, Argonne National Laboratory, Argonne, IL
Session Vice Chair: Santiago Lazarte, Florida State University, Tallahassee, FL

8:00 - 8:40 am
4205884: How Does Friction Govern Chemistry - "Catalysis" by Shear?
Seong Kim, Pennsylvania State University, University Park, PA

Tribochemistry deals with chemical reactions facilitated by interfacial friction (or shear). At sliding interfaces, unconventional chemical reactions that do not occur in typical thermal conditions are often observed. When reaction yield or rate is measured as a function of shear stress (calculated from the applied load and friction coefficient) and plotted onto a semi-log graph, the slope is related to so-called 'activation volume.' Although the activation volume can be readily determined experimentally, its physical meaning is still debated. We have investigated the shear-induced polymerization reaction of various types of organic molecules under vapor-phase lubrication (VPL) conditions. In this talk, experimental and computational evidence supports the hypothesis that the deformation of reactant molecules from their equilibrium geometry is the main driving force for shear-induced mechanochemical chemical reactions.

8:40 - 9:00 am
4175007: Advancing Gear Oil Insights - Tribofilm and Subsurface Correlation
Ashutosh Gupta, Allan Matthews, David Matthews, University of Manchester, Manchester, United Kingdom; Ieuan Adams, BP Technology Centre, Pangbourne, United Kingdom

As bearing failures are becoming common inside the wind turbine gear box, this paper focused predominantly on the hardened AISI 52100 steels used as bearing material. Gear oils are particularly designed to provide lubrication and can lower the generation of heat and friction while improving gear performance, which makes them the most significant element determining the lifespan of wind turbine bearings. The present study investigated the effects of molybdenum and ashless based anti-wear additives in the gear oils on the tribological performance of the contact surfaces and the subsurface changes occurred under reciprocating-sliding conditions. The results demonstrate that low-friction molybdenum tribofilms generated during chemical activation at appropriate bulk oil temperature are primarily responsible for improving surface-additive interaction when compared with ashless based gear oil where the formed polar molecules of phosphorus and sulphur act as a friction modifier.

9:00 - 9:20 am
4188416: The Effect of Lubricity of Calcium Sulfonate on ZnDTP and MoDTC
Yumi Hayashi, Sumitomo Heavy Industries, Ltd., Kanagawa, Japan; Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

This study investigates the effects of calcium sulfonate on the lubricity of zinc dialkyldithiophosphate (ZnDTP) and molybdenum dithiocarbamate (MoDTC). ZnDTP and MoDTC are known for their low-friction properties and may exhibit unexpected synergistic or competitive effects when combined with other additives. In this study, we investigated the effect of calcium sulfonate on the combined use of ZnDTP and MoDTC, focusing particularly on their wear behavior. Friction tests revealed that calcium sulfonate improved antiwear performance. XPS and AFM analyses showed that the tribofilm formed with calcium sulfonate contained CaCO3, which increased film density and enhanced antiwear properties. The aim of this study is to clarify and understand the mechanism of action of these additives through tribofilm formation, wear processes, and surface analysis. These findings provide valuable insights into optimizing lubricant formulations for improved antiwear performance.

9:20 - 9:40 am
4194171: Analysis of the Effect of Phosphorus/sulfur Additives' Concentration on Wear Phenomena using AE Measurements and Study of Additive Reaction Mechanisms
Miho Morita, Takuma Tsuchiya, Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika, Tokyo, Japan; Takehisa Sato, Technical Committee on Additive Technology for JAST, Funabashi, Chiba, Japan

Recently, the viscosity of oil has been reduced, resulting in thinner oil films and an increased risk of damage to sliding surfaces. It has been reported that the combined use of phosphorus-based (P-based) additives, which are expected to provide anti-wear performance, and sulfur-based (S-based) additives, which are expected to provide anti-seizure performance, improves anti-wear performance compared to when using individual additives. In this study, we propose a comprehensive verification method for additive concentrations by friction tests using a variable additive concentration system as an evaluation method for efficiently determining the optimal combination of P-based and S-based additives. In addition, we perform in-situ evaluation of the damage state of the friction interface by measuring acoustic emission. Together with the results of surface condition observations, we consider the effect of additive concentration changes on friction and wear properties and their mechanisms.

9:40 - 10:00 am
4200800: Interfacial Ice-like Layers Formed on the Two Contacting Silica Surfaces under Water
Yuguang Cai, Joshua Melendez-Rivera, James Batteas, Texas A&M University, College Station, TX; Brandon McClimon, Robert Carpick, University of Pennsylvania, Philadelphia, PA

The tribological properties between two contacting silica surfaces in water is investigated by employing an Atomic force microscope (AFM) tip to contact and slide on a silica surface. We find that the adhesion decreases with increasing loading stress, reaching a minimum at 2 MPa, after which adhesion slightly increases due to the expansion of the contact area by higher loading force. At 2 MPa, the coefficient of friction (COF) changes from 0.15 to 0.03. Control experiments confirm that these transition behaviors are specific to aqueous environment and hydrophilic silica as the contact surfaces. Our findings suggest that an interfacial ice-like water layer forms on the hydrophilic silica surface in water. Only at pressures above 2 MPa do the measured values represent the true adhesion and friction between the hydrophilic silica surfaces.

10:00 - 10:40 am – Break

10:40 - 11:00 am
4204362: Analyzing the Charge Transfer Mechanisms in Multiple Electrode Droplet Triboelectric Nanogenerators
Oliver Prendergast, Imperial College London, London, United Kingdom

Droplet-based triboelectric nanogenerators (TENGs) offer a sustainable solution for harvesting energy from moving water, generating alternating current through triboelectrification and charge transfer. By introducing an additional electrode to the traditional single-electrode configuration, we achieved a 7000% increase in voltage output. Building on this, we are now investigating the effects of electrode geometry, quantity, and placement in multi-electrode configurations and their impact on charge transfer mechanisms. These insights are key to scaling droplet TENGs for real-world applications and advancing the understanding of fundamental charge transfer processes in triboelectric nanogenerators.

11:00 - 11:20 am
4205138: Effect of Electric Fields on the Decomposition of Nanoconfined Lubricant Additives
Zhaoran Zhu, James Ewen, Daniele Dini, Imperial College London, London, United Kingdom

The increasing demands in electric vehicles (EV) has propelled advancements in lubricant technology for new operational environments under electric fields (EFs). However, the triboelectrochemistry mechanism at molecular scale during tribofilm formation are not well understood. Therefore, in this study, we perform nonequilibrium molecular dynamics (NEMD) simulations with a reactive force field (ReaxFF) [2] to study the effect of EFs on tributyl phosphate (TNBP) lubricant additives, in between two iron oxide surfaces, under nanoconfined [3] and sliding conditions. Meanwhile, two charge equilibration methods implemented in NEMD are also investigated and compared, known as QEq [4] and QTPIE [5]. These findings provide an atomistic understanding of the effect of EFs on lubricant additives' behaviours during the redox reactions. Results also suggest the potential discussions on influence on adsorption process before chemical reactions.

11:20 - 11:40 am
4204817: Molecular Assembly of Organic Fluorine Compounds on Water Using Molecular Dynamics Simulations
Hitoshi Washizu, Ryuji Hanano, Takehiro Kobayashi, Ryuichi Okamoto, University of Hyogo, Kobe, Japan; Takeshi Hasegawa, Kyoto University, Uji, Kyoto, Japan

Organofluorine compounds have been used as useful materials that exhibit a variety of excellent properties such as water-and-oil repellence, lubricity, and heat resistance, whereas the physicochemical basis for these properties have long been unclear. Recently the Stratified Dipole-Arrays (SDA) theory has been developed to explain the fundamental physical properties of organofluorides. According to this theory, by separating the physicochemical properties of organofluorides into single molecules and molecular assemblies, we can explain contradictory features such as water repellence and oil repellence. In this talk, we used molecular dynamics simulations to clarify the molecular assembly structure of organofluorides on water. Molecular structures for our study are molecules in which a part of the alkyl groups of myristic acid is replaced by perfluoroalkyl group. The equilibrium structure of 2D crystal and broken one are readily explained by the SDA theory.

11:40 am – 12:00 pm - Available

Environmentally Friendly Fluids-Synthetics I

Session Chair: John Fang, Chevron Products Company, Richmond, CA
Session Vice Chair: Selim Erhan, Process Oils, Inc., Trout Valley, IL

8:00 - 8:40 am
4180141: Sustainability and Circular Economy in Lubrication
Michael Holloway, 5th Order Industry, Highland Village, TX

This paper explores the role of the lubrication industry in promoting sustainability and reducing environmental impact. The lubrication industry plays a critical role in supporting economic growth, but they also have a significant environmental footprint. As the world transitions towards a more sustainable future, this industry must adopt practices that minimize their environmental impact. This paper will explore the role of the lubrication industry's impact in promoting sustainability and circular economy principles. By adopting sustainable practices and embracing circular economy principles, the lubrication industry can contribute to a more sustainable future. This paper will provide valuable insights and recommendations for industry stakeholders to drive positive change.

8:40 - 9:00 am
4187411: Novel Antiwear and Antioxidant Additives with a Safe Toxicological Profile Designed for Lubricant Applications
Gregoire Herve, NYCO, Paris, France

Evolving regulations are shedding light on the true toxicity of various chemicals, particularly affecting performance additives. The search for effective, non-toxic additive chemistries remains a big challenge for the industry. Our work directly addresses this issue through a holistic approach that combines both modeling and biotesting of anti-wear and antioxidant additives. The outcome? High-performance, label-free lubricants, including greases, with superior safety profiles. The performance of our both safe polyaminic antioxidant and organophosphorus antiwear additives is demonstrated across several stringent applications, including gear oils, turbine oils, and greases. These additives exhibit enhanced thermal and tribological properties compared to existing market lubricants. This research offers new solutions to the formulators that meet both industry and environmental needs.

9:00 - 9:20 am
4183754: Using Polyalkylene Glycols to Meet Today's Sustainability Needs in Industrial Lubrication.
Lauren Huffman, Cindy Liu, Qian Gou, Dow Chemical Company, Midland, MI

Polyalkylene glycols (PAGs) are well-known synthetic fluids for use in a wide variety of applications like hydraulic fluid, gear oil, compressor fluid, refrigeration lubricant and metalworking fluids. Today, PAGs are finding favor with those who need to meet sustainability goals without sacrificing performance. This talk will cover the use of polyaklylene glycols in sustainable applications for industry including food processing, marine, and mining operations. We will also address ways we are tracking important factors for sustainability, and approaches for using PAGs to address sustainability needs.

9:20 - 9:40 am
4187366: Making the Most of Neopoly Esters in Non-Toxic, High Temperature Chain Oils
Siegfried Lucazeau, NYCO, Paris, France

High temperature chain oils may be exposed to temperatures exceeding 570°F. In such conditions, the best type of ester to respond to this challenge is neopolyol esters, as they show outstanding resistance to thermo-oxidation, less volatility than other base fluids, improved cleanliness, and fire safety. When designing a neopolyol ester, linear acids differ from branched acids from a performance standpoint. Designing esters for this application therefore consists in smartly combining linear and branched acids to balance volatility, resistance to degradation, cleanliness, and lubricity. In this process, it is important to understand the main tradeoffs. Additionally, formulating with selected antioxidants and metal passivators is essential to maximize the performance of neopolyol esters. Recent advances in formulation and molecular design now allow formulators to develop high performance, non-toxic high temperature chain oils, using carefully designed neopolyol esters and additives.

9:40 - 10:00 am
4202676: Performance Aspects of Novel and Sustainable Secondary Polyol Ester™ Technology
Martin Greaves, Jeff Dimaio, Zach Hunt, Michelle DiMaio, Ben Bergmann, VBASE Oil Company, Pendleton, SC
Synthetic esters are the most versatile of all common base oils used in our industry today. The inclusion of high levels of oxygen built into their molecular architecture has led to the creation of a novel family of Secondary Polyol Ester™ base oils. These oxygen-rich products offer some unique functionalities that enhance modern lubricant formulations. Their thermo-physical properties, in-built detergency and their excellent environmental performance will be presented. Concepts for using them as base oils or performance additives in industrial, marine and metalworking fluid formulations will also be highlighted. Their unique chemistry offers innovative solutions to developing new generations of sustainable lubricants.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4203653: Shear Stable Biobased Thickeners as Alternatives to High Viscosity PAOs in Synthetic Gear and Transmission Fluids
Kevin Duncan, Cargill, Snaith, United Kingdom

The demand for efficient lubricants that tolerate more duty cycles and reduce oil sump capacity is rising in both industrial and automotive sectors. This has increased interest in high-performing synthetic base oils and additives. Simultaneously, there's a push to increase the bio-based content of lubricants, which conflicts with the use of petroleum-based polyalphaolefins (PAOs). Ester-based shear stable thickeners offer a solution, providing excellent friction reduction and formulation efficiency while enhancing bio-based content across a wide viscosity range. This paper presents a 'design of experiments' approach to identify optimal product properties, enabling the development of high viscosity thickeners for ISO 68 industrial gear oil and EV transmission fluid formulations. Performance will be demonstrated through benchtop tribological tests and validated using industry-standard test rigs.

11:00 - 11:20 am
4205253: Chemical and Biological Upcycling of Plastic Waste into Mixed Ester Lubricant Base Oils
Jake Lilly, Battelle Memorial Institute, Columbus, OH

Global annual plastic production is approximately 400 million tons, and demand is projected to continue to increase production to an annual 1.1 billion tons by 2050. (Geyer et al. 2020) Chemical

recycling technologies are emerging that offer promise to valorize plastic waste that would otherwise be landfilled, which we view as a rich and underutilized source of organic precursors for high value products, like lubricant base oils. Here, we present hybrid chemical and biological approaches for converting common consumer plastics like polyethylene (PE) and polyethylene terephthalate (PET) into aliphatic bis-esters and fatty acid esters, respectively. We report product composition, viscosity, and pour point data for various plastic conversion conditions. These conversion processes are being developed as mobile and low power valorization technologies in remote settings, but could also adapted for large scale manufacturing of lubricant oils from waste plastics.

11:20 - 11:40 am
4229195: Studies on the Thermal Stability and Kinetics of Bio-lubricants Derived from Various Vegetable Oils
Majher Sarker, Kalidas Mainali, Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA

The non-biodegradability and toxicity of fossil-based lubricants present environmental problems, whereas biobased ones underperform due to low thermal stability. This study compared chemically modified vegetable and waste cooking oils to their regular versions to determine their biolubrication potential. High-oleic soybean oil-HOSOY, regular soybean oil-RSOY, and waste cooking oil-WCO were chemically modified where isopropyl groups were attached to the fatty acid chains of the oils producing branched oils, b-HOSOY, b-RSOY, and b-WCO, respectively. Friedman methods calculated activation energies, reaction rates, and pre-exponential factors. Each modified oil had lower volatilization at onset temperature than non-modified samples in an oxidative environment, according to differential thermal gravimetric (DTG) measurement. Comparative kinetic tests showed that chemically modified oils were more thermoxidatively stable than unmodified oils.

11:40 am - 12:00 pm
4203097: Improving the Friction Modification & Wear Protection of Lubricants with Ester Technology
Matthias Hof, Emery Oleochemicals GmbH, Duesseldorf, NRW, Germany

As lubricant demands continue to evolve, both original equipment manufacturers (OEMs) and end users are increasingly seeking solutions that enhance performance across a wide range of applications, including industrial equipment, automotive systems, metalworking operations, and specialty areas like food-grade lubrication. This presentation addresses the need for high-performance lubricants capable of reducing friction and wear, thereby achieving key objectives such as increased efficiency, decreased energy consumption, extended maintenance intervals, prolonged equipment life, and minimized waste + emissions. Multiple formulation technologies that leverage both existing and innovative base stock and additive chemistries are explored. By examining the tribological performance of pure esters and their blends with other components, we aim to provide insight into how these formulations can meet the stringent requirements of modern lubrication systems and contribute to improved operational effectiveness.

5F — Courtland

Tribotesting I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:40 am
4179944: Development of New 4-Ball Load Ramp Test for Tribological Analysis of Lubricating Greases and Comparison to ASTM D2596
Jacob Bonta, Valvoline Global Operations, Lexington, KY; Dirk Drees, Lais Lopes, Pedro Baião, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium

In this study, a tribological analysis for lubricants is evaluated utilizing a programmable, variable load 4-ball machine. In the lubricants industry, the 4-ball tribological techniques are employed to evaluate lubricant's ability to protect against wear and extreme pressure. Recently, issues related to varied acceleration rates across machines have called into question the use of tests like ASTM D2596. Here a method for evaluation of the scuffing and seizure load of lubricants is presented. First, reference greases are developed for consistent behavior in testing. Second, each material is evaluated: test specimens are run-in at 40kg normal load for 1 minute followed by a fixed rate ramping normal load until failure or the maximum is reached. Finally, these data are compared to data from legacy 4-ball test machines in ASTM D2596. These data suggest this method may provide a comparable rapid tribological analysis, giving critical first guidance on lubricant material properties.

8:40 - 9:00 am
4237303: The New Electrified Tribometry Development for EV Fluid and Lubricants
Jun Xiao, Tushar Khosla, Vishal Khosla, Rtec-Instruments, San Jose, CA

The evolving fields of electric vehicles, wind turbines, and high-speed rail have intensified the need for high-performance lubricants and wear-resistant materials. Conventional tribological testing methods fall short in evaluating lubricant performance within electrified devices. Advancements in research on lubrication and materials under electrified conditions enable the development of optimized formulations that deliver improved stability, durability, and prolonged service life for critical components such as motors and bearings, thereby enhancing system reliability and efficiency.
To address these demands, this presentation introduces several innovative testing methodologies specifically designed for evaluating friction and lubrication under electrified conditions. These methods provide valuable insights into the performance of materials across various applications, driving progress in electrified technologies.

9:00 - 9:20 am
4205233: Mission SLIMpossible - New Analysis Tools for Robust RGB Colorimetric Interferometry of Additive and Lubricant Films
Alexander MacLaren, Matthew Smeeth, PCS Instruments, London, United Kingdom

The Spacer Layer Imaging Method (SLIM) is a widely-used technique for the optical measurement of the thickness of thin lubricant and additive films to nanometre range and resolution. This study, following recent advances in colorimetric analysis of the SLIM interferogram, applies these new methods to experimentally quantify the change in outlet constriction shape in EHL point contacts at high sliding speeds. The influence on film thickness of high entrainment speeds is explored, with important implications for the design of components with large kinematically predefined slide-roll ratios such as gears. The use of new software tools which allow easy-to-use, explicit and robust analysis of large datasets is demonstrated, and salient considerations for optimal accuracy regarding both experiment and analysis are discussed.

9:20 - 9:40 am
4205037: Effect of Current Changes on Wear Values for Different Formulated Lubricants by Tribo-testing
Ameneh Schneider, Optimol Instruments, München, Germany

The electrical current passing through a lubricant can vary depending on the application. In tribological testing, the type (AC, DC) and amount of current are systematically altered, and the corresponding changes in electrical resistance are recorded. Microscopic investigations on wear values and morphology are followed. Focused the investigation were on lubricating oils and greases formulated with and without ZDDP. The chosen Tribo-testing were standard test methods for fretting (ASTM D7594) and Anti-wear (ASTM D5707). Formulations containing ZDDP show higher wear values, highlighting the impact of additive chemistry on performance under varying current conditions.

9:40 - 10:00 am
4237626: Effect of Electric field Application on Micropitting Behavior Using a Rolling/Sliding Friction Tester
Shinya Sasaki, Kaisei Sato, Tokyo University of Science, Tokyo, Japan; Takuto Kunii, Rtec-Instruments K.K., Kashiwa, Chiba, Japan; Tushar Khosla, Jun Xiao, Rtec-Instruments, San Jose, CA

As the electrification of automobiles advances, ensuring the durability of gears and bearings in the reducers of e-Axle units, which are responsible for the vehicle's propulsion, has become a key challenge due to the higher speeds of the motors. To address these challenges, it is necessary to modify gear surfaces and optimize lubricant additive formulations, and a reliable evaluation device for screening these factors through lab testing is required. In this presentation, we report the results of our investigation into the effects of lubrication conditions and electric field application on micropitting, conducted using a rolling/sliding friction tester.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4205166: Algorithms to Automate the Characterization of Tribofilm or Wear from Stylus Profilometer Measurements
Tianshi Fang, Oluwaseyi Ogunsola, Shell Global Solutions (US) Inc., Houston, TX

Surface profile measurement is a common methodology to characterize tribofilm or wear. In Stylus Profilometers, because of the infeasibility to precisely locate the boundaries of the wear track, a surface profile measurement typically contains both the wear track and parts of the intact surface on the two sides. The selection of the wear track from the complete measurement was traditionally implemented manually. It was time-consuming and tedious. It requires significant human hours and delays progress. Moreover, the results may lack consistency if different measurement results are processed by different people. Shell developed computer algorithms to automate the selection of wear tracks. The software saves a significant amount of time and human work. The accuracy and reliability of the software has been validated with various types of measurement results.

11:00 - 11:20 am
4204866: Modification of Abrasiveness of SLA Additive Manufacturing Produced Components through Resin Formulation
Kanoa Parker, Miranda Brandt, Leilani Elkaslasy, Gordon Krauss, Harvey Mudd College, Claremont, CA

Additive manufactured/SLA components are advantageous for rapid prototyping, offering benefits over traditional machining with respect to complex geometry and speed. The ability to produce ceramic components broadens SLA’s applications. Wear resistance, abrasiveness, and friction of the component surfaces are tribological properties of interest. This study investigated how SLA resin additives can alter ceramic surfaces' abrasiveness and sliding friction against 52100 steel balls. Disk specimens were fabricated using a commercially available 3D ceramic material and a DLP resin printer. These disks had a top layer doped with varying ceramic compositions relative to the rest of the disk body (bulk). Post-firing, the surfaces underwent abrasiveness testing using a

Universal Micro-Tribometer (UMT-2) with the Pin-on-Disk method. Three porcelain compositions were evaluated. Results show how different surface ceramic compositions impacted abrasiveness under the same firing conditions.

11:20 - 11:40 am
4204873: Development of a Tribological Testing Method for Engine Lubricants Using OEM-Specific Cylinder-Ring Liner Metallurgy and Its Correlation with Friction Torque Test (FTT)
Rameshwar Chaudhary, Indian Oil Corporation Ltd (R&D Centre), Faridabad, Haryana, India

This study investigates the reduction of frictional losses in lubricants by optimizing viscosity and boundary additives, focusing on enhancing efficiency in hydrodynamic lubrication regimes. A 0W16 viscosity grade oil, designed for better fuel efficiency and longevity, was compared to an industry reference. To assess performance, a Friction Torque Test (FTT) was conducted using a motorized gasoline engine across varying speeds and temperatures. FTT evaluates engine oil, but its long duration limits testing. Therefore, the study introduces a faster screening method utilizing benchtop tribometers, correlating their results with FTT. Low viscosity (0W16) candidates for passenger cars were tested for frictional losses under hydrodynamic and boundary conditions using the HFFM rig and MTM Test rig. The findings revealed a strong correlation with FTT results, suggesting that this faster approach can identify oils with lower friction more efficiently, reserving FTT for top candidates.

11:40 am - 12:00 pm
4200478: Development of a Grease Testing Method Using a Three-Ring-on-Roller Configuration: Optimizing Grease Supply and Evaluating Electrical Effects
Nicholaos Demas, Aaron Greco, Argonne National Laboratory, Argonne, IL

This work presents the development of a method for testing grease using a machine that employs a three-ring-on-roller configuration. Several approaches were tested to introduce grease into the contact area, including packing grease manually and using various holders, but these methods resulted in insufficient lubrication and inconsistent results. A syringe pump was ultimately adopted, providing a controlled and continuous supply of grease. The study explored a wide range of lubrication regimes, with the most consistent results observed in the boundary lubrication regime. Flow rate optimization was critical for ensuring adequate lubrication, with an optimal supply rate identified. Electricity was also applied between the roller and one of the rings, offering an understanding of its effects on lubrication performance. This method offers a reliable way to test grease, providing valuable insights into grease performance under different lubrication conditions.

5G — Regency V

Materials Tribology V

Session Chair: John Curry, Sandia National Laboratories, Albuquerque, NM
Session Vice Chair: Samuel Leventini, University of California Merced, Merced, CA

8:00 - 8:40 am
4194018: From Polymer to Metals Matrices: Enhanced Tribological Behavior Using 2D Nanomaterial-Reinforced Composites
Max Marian, Leibniz University Hannover, Hannover, Germany; Sangharatna Ramteke, Pontificia Universidad Catolica De Chile, Santiago, Chile

The incorporation of two-dimensional (2D) materials into metal and polymer matrices has gained significant attention due to their potential to enhance mechanical and tribological properties in biomedical and industrial applications. This presentation focuses on the fabrication and characterization of composites reinforced with MXenes $Ti_3C_2T_x$ MXenes and MoS_2 in ultrahigh molecular weight polyethylene (UHMWPE), cobalt-chromium (CoCr) alloy, and 316L stainless steel matrices. In UHMWPE, MXene-reinforced nanocomposites demonstrated significant reductions in friction and wear, attributed to the formation of easy-shear transfer films. In metal matrix composites fabricated via additive manufacturing, MoS_2-reinforced 316L steel as well as MXene - reinforced CoCr achieved a remarkable reduction in wear by 72% and 77%, respectively. This highlights the versatility of 2D material-reinforced composites towards improved durability and performance in biomedical and industrial applications.

8:40 - 9:00 am
4199555: Unraveling the Mystery of Water Transport in MoS_2: A ToF-SIMS Investigation
Nicolas Molina Vergara, Andrei Dolocan, Loukas Kallivokas, Gregory Rodin, Filippo Mangolini, The University of Texas at Austin, Austin, TX; Tomas Babuska, John Curry, Michael Dugger, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) coatings find extensive use in applications demanding low friction in inert or vacuum environments. Nonetheless, the water sorption within the coating during handling or periods of dormancy leads to a pronounced increase in friction, which results in reliability issues of sliding components. Despite the number of studies that quantitatively evaluated water sorption/desorption in MoS_2, a quantification of the water diffusivity in MoS_2 and its dependency on the material microstructure/chemistry is still lacking. To fill this knowledge gap, ToF-SIMS depth-profile analyses were conducted after dosing MoS_2 films with a water isotopic tracer. The resulting depth profiles are modelled using a Fickian diffusion model that allows for the quantification of the dependence of diffusion coefficient on coating morphology and depth-dependent chemistry.
Research funded by SNL, managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

9:00 - 9:20 am
4190594: Friction and Wear of Composite MXene/MoS2 Coating Under Low Viscosity Fuels Under Reciprocating Sliding
Ali Zayaan Macknojia, Andrey Voevodin, Samir Aouadi, Diana Berman, University of North Texas, Denton, TX; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Friction and wear-related failures remain major challenges in moving mechanical assemblies operating under various conditions. For example, the components of fuel systems made of AISI 52100 steel are susceptible to scuffing-induced wear when operated in fuel environment. This study demonstrates the decreased friction and wear characteristics achieved by spray-coating 52100-grade steel surfaces with solution-processed multilayer Ti3C2Tx-MoS2 blends. Study analyzed lower friction performance of the coating under high contact stresses and sliding speeds in different fuels. Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy results revealed the formation of an in-situ robust tribolayer responsible for the lower friction performance observed at high contact pressures and sliding speeds, where MXene helps protect the MoS_2 from oxidation and increases its longevity.

9:20 - 9:40 am
4200470: Chromium-Enabled MoS2 Coatings for Enhanced Durability and Reduced Friction in Aluminum
Sujan Ghosh, Nihal Ahmed, University of Arkansas at Little Rock, Little Rock, AR

This study explores the enhancement of tribological properties in aluminum through multifunctional MoS2 thin film coatings, addressing the challenges of high coefficient of friction (COF) and wear. MoS2 coatings, recognized for their lubricating capabilities, often exhibit low adhesion and susceptibility to oxidation at room temperature. A chromium underlayer was introduced between aluminum and MoS2 to improve performance, using physical vapor deposition (sputtering) for the coating application. The chromium underlayer significantly enhanced adhesion and doubled the durability of the MoS2 coating, reducing the COF from 0.7 to 0.28 without compromising performance. However, adding a chromium top layer did not positively affect the coating's durability or COF. This research demonstrates that strategic integration of chromium layers can substantially improve the tribological characteristics of aluminum components for automotive and aerospace applications.

9:40 - 10:00 am
4218571: Aging-Related Coating Failure of MoS_2 Nanocomposites: Understanding the Role of Dopants on Coating Toughness
Tomas Babuska, Michael Dugger, Frank DelRio, Steven Larson, Alexander Mings, John Curry, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) nanocomposite coatings doped with Sb_2O_3 and Au are used in aerospace and defense applications to reduce friction and improve wear resistance. Often, these coatings are used in mechanisms (such as deployment latches) that experience periods of dormancy where exposure to terrestrial environments leads to oxidation (i.e., aging). While post-aging performance of MoS_2/Sb_2O_3/Au coatings is usually characterized by high initial friction and prolonged run-in behavior, less common phenomenon such as severe cracking has been observed with no explanation. In this work, we investigate the importance of toughness measured via nanoindentation cracking experiments on the pre and post aging performance of PVD deposited MoS_2/Sb_2O_3/Au coatings. The Sb_2O_3 and Au content are varied to understand the role of dopants on toughness, hardness, adhesion and aging-induced tribological performance changes. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4202839: Effects of Temperature, Contact Pressure, and Lubricant Type on a CNT Coating's Superlubricity
Seokhoon Jang, Chanaka Kumara, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

In our previous study, a sacrificial coating composed of carbon nanotubes (CNTs) vertically grown on stainless steel disks demonstrated superlubricity (coefficient of friction, COF <0.01) in a macro-scale sliding with a polyalphaolefin oil at the room temperature. This work explores the dependence of the CNT coating's superlubricity on the temperature, contact pressure, and lubricant type. It was observed that the COF generally increased with the temperature, but the superlubricity was restored when the temperature dropped back down. The COF also gradually increased with the load but regained superlubricity after an extended running-in period. The CNT coating's superlubricity was achieved in several lubricating oils though the running-in behavior and steady-state COF varied, which can be correlated to the lubricant chemistry. These findings offer fundamental insights into the applicability and limitations of this sacrificial superlubricity CNT coating.

11:00 - 11:20 am
4203929: Exploring the Impact of Spray Process Parameters on Graphite Coatings: Morphology, Thickness, and Tribological Performance
Adedoyin Abe, Josue Goss, Min Zou, University of Arkansas, Fayetteville, AR

This study examines the effects of process parameters on the morphology, thickness, and tribological performance of graphite coatings sprayed on rough steel substrates. Graphite concentrations and spray flow rates were varied via a full factorial design for coating deposition. Coating morphology, roughness, thickness, coefficient of friction (COF), and wear behavior were analyzed. Low-flow-rate coatings had a porous structure and higher roughness, while high-flow-rate coatings were denser with lower roughness. A COF of 0.09, an 86% reduction from uncoated steel, highlights the coating's friction-reducing potential. Thickness significantly influenced friction and wear resistance, while flow rate affected coating structure and graphite compaction in the wear track. SEM and elemental analysis confirmed that embedded graphite provided effective wear protection. Optimizing graphite concentration and flow rate is essential for tailoring coating morphology and tribological performance.

11:20 - 11:40 am
4206504: The Influence of Resin on the Fretting Resistance of Molybdenum Disulfide
Melissa Mushrush, DuPont de Nemours Inc, Wilmington, DE

Of the solid lubricants commonly used in pastes and antifriction coatings, molybdenum disulfide has superior fretting resistance compared to graphite or PTFE. When these solids are affixed at the contact surface in a resin as an antifriction coating, however, the overall coating does not have the expected fretting resistance. This work aims to look at the influence of the resin on fretting performance as a function of load, speed, and displacement, especially displacement right at the transition regime between fretting and reciprocating wear.

11:40 am - 12:00 pm
4173570: Wide-range Controllable Modulation of Slip Length at MoS_2-Water Interface via Self-Assembled Monolayers
Yishu Han, Dameng Liu, Tsinghua University, Beijing, China

Understanding and controlling slip behavior at solid-liquid interfaces is crucial in fields such as micro/nanofluidics, surface science, and energy engineering. In this work, three self-assembled monolayers with different dipole moments were used to control the electron concentration at the molybdenum disulfide-water interface, resulting in a tunable slip length ranging from 6.6 to 27.1 times compared with the pristine interface. This regulation on slip length offers a novel approach to demonstrating the significance of electrons in slip length. In addition, it was found that the lifetime of electrons dissipated through the A^- exciton channel tends to increase on surfaces with larger slip lengths, leading to a reduction in total electron energy dissipation. This finding establishes a qualitative relationship between the interfacial slip length and the electron energy dissipation and reveals the electron dissipation mechanism at the solid-liquid interface from the quantum level.

5H — Regency VI

Aerospace III

Session Chair: Juan Bosch Giner, The University of Akron, Akron, OH
Session Vice Chair: Abrar Faiyad, University of California Merced, Merced, CA

8:00 - 8:40 am
4201648: Optimization of Grease Lubrication Tasks for the Chinook H-47 Helicopter through Component Sampling and a Seven Parameter Evaluation Matrix.
Richard Wurzbach, MRG Labs, York, PA

Operators of the H-47 Chinook heavy-lift helicopters initiated and participated in a grease sampling and analysis effort to optimize historically determined usage-based lubrication tasks. Operators produced over 1100 grease samples obtained using the ASTM D7718 standard for Inservice Grease Sampling. The 1-gram samples were tested using ASTM D7918, along with additional methods that evaluated wear condition, contaminant quantities, changes in grease consistency, and oxidation condition through additive quantification. This resulted in the reduction of the number of greasing tasks per 1000 flight hours being cut nearly in half, and the availability of the aircraft extended from 50 continuous flight hours to 120 flight hours. Other findings confirmed the improved flight safety and sustainability of the aircraft, and the revised greasing maintenance recommendations were accepted by the participating operators, resulting in an estimated savings of US$100 million per year across the fleet.

8:40 - 9:00 am
4212341: AI-Driven Discovery of Low-Vapor-Pressure Lubricants for Aerospace Applications
Daniel Miliate, Ashlie Martini, University of California Merced, Merced, CA

In space applications, liquid-based lubricants are often chosen for high-cycle, high speed components because of their ability to reflow into contact points. However, there are very few lubricants available with a vapor pressure low enough for the vacuum conditions of space. This work introduces a data-driven approach to discovering new liquid space lubricants with machine learning (ML). Using high-throughput ML models to predict vapor pressure, the discovery process was accelerated compared to traditional computational and experimental approaches. The ML models were trained on data that integrated both molecular dynamics simulations and experimental databases. The models were simplified to enable interpretability of the predictions. Model interpretation revealed the key connections between chemical structure and vapor pressure. New liquid lubricants are proposed that could lead to the next generation of space lubricants.

9:00 - 9:20 am
4200677: Tribological Performance of Gelled Oils for Space Mechanisms Lubrication
Julie Laporte-Fedry, Mikaël PETIT, INS, Genay, France

Bearing lubrication is an important point in space applications where lubricants must maintain their performance in very low temperatures and under high vacuum. For this, an innovative test bench was developed to characterize friction torque, noise, and endurance life of lubricants in bearings in high vacuum environment. The bench is used to compare new gelled oils with PTFE greases reference. Currently used greases exhibit frictional torque peaks in bearings at low speeds related to their composition and structure: bi-phasic with PTFE/MoS2 particles in suspension in base oil. Tribological tests performed on gelled oils (oil thicken with soluble polymers allowing it to have higher viscosity than the oil alone) showed performance superior to the reference grease with a rolling bearing behavior close to the pure oil and a very good stability in the evaluated speed range. The new lubricants are also assessed with long-terms tests representative of the application in our high vacuum bench.

9:20 - 9:40 am
4204964: Optimization of Fabrication Parameters for Spark Plasma Sintered Self-Lubricating Metal Matrix Composites for Aircraft Landing Gear Applications
Will Gray, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

This work showcases the sintering optimization of an aluminum-based metal matrix composite with embedded silicon carbide and tungsten disulfide, for use in self-lubricated aircraft landing gear bushings. Aluminum acts as a material matrix, whilst the silicon carbide increases the material hardness and tungsten disulfide acts as a solid lubricant to improve friction and wear performance, thus enhancing the mechanical and tribological properties, respectively. Spark plasma sintering was used as the fabrication method, with comparisons performed on the sinter

temperature, temperature ramp rate, dwell time, sinter pressure and the sintering DC pulse on-off time. Tribological assessment was performed at room and elevated temperature under a moderate and high load for complete material assessment. This works sets the foundation for future material blend optimizations, and eventually the tribological assessment of full bush testing.

9:40 - 10:00 am
4190809: Tribological Performance of a Novel Aeroengine Bearing Steel - ARCTIC15
Arnaud Ruellan, Jean-Baptiste Coudert, Yves Maheo, SKF Aerospace, Chateauneuf-sur-Isere, France; Samantha Melnik, SKF Aeroengine, Falconer, NY

The development of new generation very high bypass ratio aeroengines requires bearing solutions with increased speed and load capabilities. A temperature-resistant and corrosion-tolerant carburizing steel has been developed to enable a minimum of 15% increase of contact pressure capability compared to conventional aeroengine bearing steels. This novel bearing steel called ARCTIC15 opens the door to smaller engines with reduced fuel consumption and emissions. First industrial melts have been produced and underwent an extensive range of verifications.
Here, the performance of ARCTIC15 is compared to that of conventional M50 and M50NiL bearing steels. A focus is made on the tribological performances and material properties related to bearing reliability, mainly being resistance in rolling contact fatigue, spall propagation, oil starvation and smearing. The correlation between elemental, subscale, and full-scale tests results will be discussed.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4199860: Powder Lubrication Operating Regime of Carbon-Graphite Annular Seals
Mihai Arghir, Ibrahim Diallo, Universite de Poitiers, Futuroscope Chasseneuil, France; Lassad Amami, CETIM, Nantes, France; Mohamed ANDASMAS, Safran Aircraft Engines, Villaroche, France

Annular segmented seals are made of carbon-graphite and operate with a negligible radial clearance from the rotor surface. Thus, the asperities of the surfaces come into contact and the wear of the segment produces a carbon-graphite powder acting as a solid lubricant. The present paper presents the results of the measurements performed for characterizing the compressibility, the fluidity, the yield stress, and the wall friction coefficient of carbon graphite powder. The measurements were conducted on a rheometer following the powder characterization protocol. The powder was obtained by grinding carbon-graphite samples and the particles size distribution was measured by laser diffraction.
The powder was assimilated with a visco-plastic continuum with a rheology described by the Hershel-Bulkley model. A generalized Reynolds equation was used for describing the flow between the rough segment and rotor surfaces. The results show that islands of powder are transferred to the rotor surface.

11:00 - 11:20 am
4201871: The Latest Trends in the Development of Hydrodynamic Mechanical Face Seals for Turbopumps for Reusable Rocket Engines in Japan
Yuichiro Tokunaga, Tadatsugu Imura, Hidetoshi Kasahara, Eagle Industry Co., Ltd., Sakado-shi, Saitama-ken, Japan; Ato Tazawa, Hiromitsu Kakudo, Satoshi Takada, Japan Aerospace Exploration Agency, Kakuda-shi, Japan

As reusable rocket engines become more common, maintaining long-term performance in repeated engine use is a challenging task. Among them, seals for turbopumps are one of the most important and technically challenging components, which operate in harsh environments of cryogenic temperatures and high-speed sliding conditions. This presentation describes the development of a hydrodynamic mechanical face seal for reusable rocket engines in Japan. This

technology enables control of sealing performance and prevention of surface damage by maintaining the sliding surfaces in a non-contacting state. This study presents test results of hydrodynamic mechanical face seals using various cryogenic fluids. The seal performance of the textured geometry, tested in detail under a variety of conditions, shows promising results that are in good agreement with numerical predictions. Stable leakage characteristics and high durability were demonstrated even after 80 cycles of startup and shutdown.

11:20 - 11:40 am
4205159: Optimizing Labyrinth Seals to Minimize Lubricant Evaporation in Space Mechanisms
Josef Pouzar, David Kostal, Ivan Krupka, Brno University of Technology, Brno, South Moravia, Czechia; Lars-Göran Westerberg, Erik Nyberg, Luleå University of Technology, Luleå, Sweden

Surface lubrication in space applications requires either solid or liquid lubricants, selected based on specific boundary conditions. However, liquid lubricants are particularly susceptible to vacuum evaporation in space, where ambient pressure is lower than their vapor pressure. Tribological failures are a leading cause of malfunctions in space technology, and enhancing our understanding of space tribology can help prevent these issues while reducing space debris, costs, and environmental impact. Labyrinth seals play a crucial role in minimizing lubricant loss and ensuring the long-term durability of space systems. This study integrates theoretical analysis, molecular flow simulations, and experimental validation to optimize labyrinth seal geometry and mitigate lubricant evaporation. Our experiments validate the simulation models, demonstrating that an optimized labyrinth seal can significantly reduce lubricant loss, enhancing system reliability and extending mission lifetimes.

11:40 am - 12:00 pm
4203580: A Study on Oil Sealing Performance of Surface Textured Mechanical Face Seals in Vacuum
Noriko Matsuoka, Hiroshi Shiomi, Koji Matsumoto, Japan Aerospace Exploration Agency, Tsukuba, Ibaraki, Japan; Kenta Uchida, Ayami Tokuda, Akihiro Nishiuchi, Hidetoshi Kasahara, Yuichiro Tokunaga, Eagle Industry Co., Ltd., Sakado-shi, Saitama-ken, Japan

Frictional torque and oil leak amount of surface textured mechanical face seals operated under differential pressure including vacuum were investigated. Especially we focused on the pumping effect of surface texture in vacuum. The mechanical face seals were demonstrated by configuration of a SiC ring and a flat glass disk. Two types of surface textured rings which have different pumping mechanisms were evaluated. The sealing fluid was Polyalphaolefin (PAO). The oil film and the cavity regions generated in the sliding surfaces were observed with an optical method, and the frictional torque was measured simultaneously. Both types of surface textures generated pumping effect in vacuum as well as atmosphere. On the other hand, the frictional torque and oil leak amount were dependent on surface texture pattern and pressure condition. The performance of surface textured mechanical face seals and the mechanism for generation of the pumping effect in vacuum will be discussed in detail.

5I — Regency VII

Electric Vehicles V

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:40 am
4213627: Lubricant Electrical Properties and their Potential Impact on Bearing Discharge
Chris McFadden, Lubrizol, Wickliffe, OH

Bearing damage due to electric discharge is an old topic. While a bearing is rotating, the rotor and stator are separated by an insulating fluid that can allow a potential difference. This can have many causes, but the most common is from coupling to a motor. If the potential difference between rotor and stator is large enough, it will discharge through the fluid film. This can be an issue for rolling element bearings in the drivetrains of electrified vehicles. Although oils have high dielectric strength (10-40 kV/mm vs ~3kV/mm for air), oil film thickness in rolling element bearings is submicron. So arcing can occur with less than ten volts. OEMs mostly rely on hardware solutions to address bearing discharge. Some are also interested in the electrical properties of the lubricants. In this talk we will present typical values for the electrical properties of EV drivetrain lubricants and discuss whether they can be adjusted sufficiently to have an impact on bearing discharge.

8:40 - 9:00 am
4223991: System-level approach to EV powertrain bearing friction optimization
Jason Brady, Tom Schmitz, Mikael Holgerson, Lars Norrman, SKF, Plymouth, MI

As mechanical complexity has decreased with EV powertrain systems compared to conventional ICE systems, the contribution of rolling element bearing friction to the overall powertrain efficiency has become much more significant. This study presents a case study and methodology to identify and optimize selected bearings in the powertrain to maximize overall system energy savings over the full application duty cycle from conceptual study to hardware verification.

9:00 - 9:20 am
4229207: Bearing Evaluations for High-Speed Electrified Drive Unit Applications
Thomas Wellmann, FEV, Auburn Hills, MI; Bernd Katthoefer, Ruediger Beykirch, FEV Europe, Aachen, Germany

Electric drive units are often operated at high speeds. The bearing system for high speeds needs optimization with respect to cooling, lubrication, and appropriately evaluated throughout the product development. Simulation tools and test benches are required for successful bearing system design. Typical speed ranges of electric motors, and considerations that limit high-speed operation are given. A newly developed bearing test stand is introduced, and capabilities required for bearing tests for the test stand are highlighted. The test stand allows for changing loads of the bearings under high-speed operation, while also altering the lubrication and flow rates. Bearing validation tests, and optimizing the system for efficiency, with focus on the flow and fluid parameters can be performed. Further, simulation methods such as CFD with focus on bearing lubrication and cooling are highlighted,. The prediction of drag loss and thermal behavior of the bearing system are discussed.

9:20 - 9:40 am
4180980: Optimizing Bearing Life and Power Loss in Electric Vehicle Gearboxes
Alexander Waye, The Timken Company, North Canton, OH

Electric vehicle (EV) powertrains are becoming increasingly complex, often featuring multiple parallel shafts in thin section aluminum housings. This study varies system parameters for the intermediate shaft and differential and identifies key system features for optimizing bearing life and power loss. System features like bearing K factor, gear helix angles, and gearbox layout were varied. Regression models were fit to the collected data. Key findings indicate that for EV differentials, bearing K factor should be selected to complement helix angle selection, and that optimal gear location is critical for bearing life. For the intermediate shaft, the study found that steeper cup angles could be selected and that mesh angles should be carefully selected to meet both

packaging constraints and bearing life. A case study shows how these factors can further impact bearing power loss. These findings can guide the design and configuration of EV gearboxes to enhance performance and durability.

9:40 - 10:00 am
4200736: Twin Disc Evaluation of Scuffing Performance of Lubricants as a Precursor to FZG
Debdutt Patro, Sravan Josyula, Ducom Instruments, New York, NY; Fabio Alemanno, Deepak Veeregowda, Ducom Instruments (EUROPE) B.V., Groningen, Netherlands

In this study, Ducom twin disc RoR 2.0 was used to determine the scuffing capability of oils by replicating ISO 14635-1 conditions used in FGZ test rig. A line contact with flat-on-flat rollers and load steps up to 5 kN corresponding to contact pressure of 2465 MPa was used. Tests were conducted at different slips ratios and a circumferential velocity of 6.5 m/s with lubrication temperature of 80°C (from stage 5). Friction and vibration data was captured in real-time during the test. The disc surfaces were examined under a microscope after each load step. Four lubricants, including a base oil and three with additives were tested. While friction results show no significant difference with increasing loads, vibration showed a significant increase. Microscopy revealed surface failures at such load steps. The talk will describe the scuffing method on twin disc and compare the results with FZG tests for oils having different load carrying capability.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4188531: The Shift from Conventional to Low-Conductivity Coolants in Battery Electric Vehicles
Christoph Rohbogner, Oelcheck GmbH, Brannenburg, N/A, Germany

The electrification of road transport is a critical step in reducing carbon emissions. To surpass conventional internal combustion engine (ICE) vehicles, battery electric vehicles (BEVs) must offer competitive recharging times for their energy storage systems. Modern lithium-ion batteries depend on advanced battery thermal management systems (BTMS) to maintain optimal operating conditions, enhance efficiency and lifespan, and prevent thermal runaway. Various cooling concepts are currently employed in battery electric vehicles (BEVs), with liquid cooling systems using (conventional) ethylene glycol-based coolant water mixtures being the most popular. Understanding the differences in the chemical composition of newly developed low-conductivity coolants is essential for creating effective laboratory testing methods and selecting appropriate fluid candidates for future applications.

11:00 - 11:20 am
4205113: Surface-Functionalized CNT as a PAG Additive for Improved Thermal Properties
Chanaka Kumara, Seokhoon Jang, Wenbo Wang, Harry Meyer III, Michael Lance, Hsin Wang, James Haynes, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; Xiaoqian Wang, Ning Ren, Jacob Bonta, Edward Murphy, Roger England, Valvoline Global Operations, Lexington, KY

Carbon nanotubes (CNTs) possess outstanding thermal properties, but their limited oil suspensibility hindered the realization of their full potential as an oil additive. Additionally, CNTs are inherently hydrophobic and tend to aggregate in polar oils such as Polyalkylene Glycol (PAG). To address these challenges, polar functional groups were covalently attached to the CNTs to enhance the CNT-PAG compatibilities. As a result, the surface-functionalized CNTs exhibited good suspension and dispersion in a PAG oil at both room temperature and 100 °C. The functionalized CNTs at 0.1wt% concentration was found to increase PAG thermal conductivity up to 19% and volumetric heat capacity up to 29%. Addition of CNTs would increase the oil viscosity, which is detrimental to the heat transfer efficiency. The functionalized CNTs have been found to cause

significantly less oil thickening compared with the unmodified CNTs, offering a promising avenue for leveraging CNTs properties for heat transfer.

11:20 – 11:40 am
4199447: New Antifoam Technologies for Non-Aqueous Additive Packages
Stefanie Velez, MUNZING CHEMIE GmbH, Bloomfield, NJ; Safia Peerzada, Munzing North America, LP, Bloomfield, NJ

Foam stabilization is a critical issue in non-aqueous lubricants which can be heavily impacted by the additive packages' components in these lubricants. The higher molecular weight components such as detergents, dispersants, friction modifiers, and viscosity modifiers can directly impact the foam and entrained air tendency of the fluid. Antifoams can be used in these additive packages to inhibit the foam formation and entrained air. Traditional polyacrylate antifoams have been used in additive packages due to their excellent stability, but typically additional antifoam is required once fluid is formulated and used in real world applications. Based on the ever-changing technology in the market, new additive packages are being introduced to the market. This allows for new antifoam technology to be introduced into the additive packages. A comprehensive study using new antifoam chemistries that provide similar or improved foam control while maintaining good stability will be presented.

11:40 am – 12:00 pm - Available

5J The Learning Center

Gears I

Session Chair: Xue Han, Cummins, Inc., Columbus, IN
Session Vice Chair: Aaron Isaacson, Penn State University, State College, PA

8:00 - 8:40 am
4233367: SB>1 DEFIANT JMR Technology Demonstrator Aircraft Main Rotor Gearbox Technology Insertions & Teardown Results
Scott Bouwer, Kevin Ignatuk, The Boeing Company, Ridley Park, PA

The Sikorsky Boeing SB>1 DEFIANT is a technology demonstrator aircraft that was built under the Joint Multi-Role Technology Demonstrator (JMR TD) program to address the next generation performance requirements of the US Army Future Vertical Lift (FVL) initiative. The Main Rotor Gearbox (MRGB) incorporated several low Technology Readiness Level (TRL) technologies to improve power density and meet challenging program requirements for gearbox empty weight fraction. After the conclusion of the flight test program the ground test Main Rotor Gearbox was disassembled and evaluated to raise the TRL level of these technologies. The technology insertions, teardown observations, and laboratory test results are discussed.

8:40 - 9:20 am
4233346: Evaluation and Implementation of Low Core Hardness Gears in the SB>1 DEFIANT JMR Technology Demonstrator Aircraft
Scott Bouwer, Kevin Ignatuk, The Boeing Company, Ridley Park, PA

The Sikorsky Boeing SB>1 DEFIANT is a technology demonstrator aircraft that was built under the Joint Multi-Role Technology Demonstrator (JMR TD) program to address the next generation performance requirements of the US Army Future Vertical Lift (FVL) initiative. During the

development of the SB>1 DEFIANT technology demonstrator aircraft several manufacturing lots of gears were produced with a core hardness that was 10-30% below the minimum engineering requirement. The defect was not detected until a large population of gears was near completion. To prevent significant program cost and schedule impacts, a safe load capacity for the discrepant gears was determined via test and the SB>1 DEFIANT technology demonstrator aircraft entered qualification testing with the low hardness gears. The low hardness issue, root cause, and test method to establish a safe operating load limit are discussed.

9:20 - 10:00 am
4209664: Experimental Evaluation of Gear Tooth Bulk Temperature via In-situ Gear Tooth Temperature Measurement
Cody Wassel, Aaron Isaacson, Matthew Wagner, Penn State University, State College, PA

Dynamic tests were conducted on a four-square or power-circulating gear test rig. Six thermocouples, positioned at two roll angles and three depths below the surface were embedded in the specimen gear. The thermocouple readings were recorded in-situ using a slip ring. Two sets of gears were used in the testing, one as-ground, one with processed with isotropic superfinishing. Each set was run in 60 different combinations of speeds, contact stresses, oil temperatures, and lubrication types (oil sump, oil jet, and oil mist). The temperature data collected in these tests was used to calculate the oil bulk temperature, followed by the flash and contact temperature. This contact temperature was compared against legacy calculation methods, which use an estimated bulk temperature.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4191181: Development of a New Type of FZG high-Speed Gear Tension Test Rig for Testing and Characterizing High-Performance Lubricants
Sebastian Preintner, Thomas Tobie, Karsten Stahl, Technical University of Munich, Garching, Germany

Due to the rapid advancements in E-Mobility, there is an increasing demand for lubricants specialized for usage under operating conditions in battery electric vehicle (BEV) drivetrains. Electric motors, particularly those designed for high speeds, impose rigorous requirements on these lubricants. The fluids used must not only reduce friction and wear but also contribute to the thermal management of both the gearbox and the electric motor. Consequently, lubricants for E-Mobility applications are typically characterized by very low viscosities to minimize gearbox losses. Despite this, they must still effectively protect against gear scuffing, a type of wear that can cause sudden and catastrophic damage. As a result, the demands on the corresponding test methodology and the test rigs used for this purpose are also increasing. In a cooperation project between the Gear Research Center (FZG) and Strama-MPS, a new type of FZG high-speed gear test rig was developed.

11:00 - 11:20 am
4203134: Localization of Gear Pitting Damage During Operation
Lukas Merkle, Martin Dazer, University of Stuttgart, Stuttgart, Germany

Gear pitting usually only occurs on individual or adjacent teeth on a gear wheel. Particularly in applications with large gearbox dimensions such as wind, mining or steel production, the precise localization of damage in the complex tribological systems can be the gamechanger towards a more sustainable operation of the plant. Operation can be adapted and the load on the damaged area can be reduced in a targeted manner. The aim of the study is to develop and evaluate various methods for localizing a damaged tribo-contact on the circumference of a gear wheel. For this purpose, an extensive series of tests is carried out on an electrical load test bench with two electric

motors. A single stage spur gear box is tested with different operating conditions. The localization will be carried out by special evaluation methods of high-frequency vibration data. Localizing the damage during operation enables great potential for increasing service life through the application of PHM strategies.

11:20 - 11:40 am
4184834: An Investigation into the Correlation Between Gear Wear and the Presence of Deposits Located Just Beneath the Tooth Surface.
Kenji Matsumoto, Tokyo Denki University, Adachi-ku, Tokyo, Japan; Takeo Kiuchi, Toyo Corporation, Taito-ku, Tokyo, Japan; Yuji Mihara, Tokyo City University, Setagata-ku, Tokyo, Japan

Comprehensive observations utilizing transmission electron microscopy (TEM) indicated that the behavior of precipitates located just beneath the tooth surface of gears subjected to prolonged use significantly influences wear. Specifically, it was observed that precipitates alter the path of crack propagation and significantly influence the release of wear debris. In this presentation, I will discuss the structural changes in metals, with a particular focus on TEM images.

11:40 am - 12:00 pm
4176314: Repair of Helical Gear Teeth with Notched Substrate by Laser-Directed Energy Deposition
Igor Ortiz, Diego Montoya-Zapata, Piera Alvarez, Maria Azpeleta, Ikergune, Elgoibar, Guipuzkoa, Spain; Marta Garcia, Talens Systems, Guipuzkoa, Spain; Francisco Cordovilla, José Luis Ocaña, Universidad Politécnica de Madrid, Madrid, Spain

Gears are useful for changing rotational speed and power by transferring the power generated by the engine. The whole replacement of a wind power gear transmission can be between $150000-$500000. Previous studies have shown that Laser powder direct energy deposition (LP-DED) has the capability to repair, and manufacture worn gear straight teeth. Helical gears, on the other hand, have a more complex geometry than straight gears which hinders the toolpath generation for the repair process. In this work, we study the toolpath to repair helical gear teeth in a notched geometry substrate that mimics the substrate for the manufacturing of the new tooth. Multiple gear teeth were manufactured to study toolpath and slicing strategies in helical gear teeth repair. We used AISI 316L with previously optimized parameters validating the strategies. We also performed metallographic analyses to check for manufacturing faults. We are currently studying specific powders for gear repair and manufacturing.

5K — Dunwoody

Power Generation I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:40 am
4204317: Impact of Fluid Selection on Hydraulic Pump and Motor Efficiency: A Study Using ASTM D7721-22
Paul Michael, Pawan Panwar, Milwaukee School of Engineering, Milwaukee, WI; Ricardo Gomes, Frank-Olaf Maehling, Evonik Oil Additives, Horsham, PA

The standard method for determining the effect of fluid selection on hydraulic pump and motor efficiency is ASTM D7721-22. This method was used to study friction and flow losses in a

dynamometer that incorporated an axial piston pump and axial piston motor. The dynamometer was operated under various conditions of pressure, speed, and temperature. The performance of ISO VG 32 and 46 straight- and multigrade fluids was compared. Differences in friction and flow losses were observed, depending on operating conditions. Fluid properties were characterized at the beginning and conclusion of testing. High-shear viscosity and low-speed traction coefficient measurements were found to correlate with system flow losses and motor torque losses. These results provide an insight into the interactions between hydraulic system operating conditions, lubrication regimes, and the fluid properties that impact efficiency.

8:40 - 9:00 am
4184936: Study of Additive Chemistry in Low Varnish Turbine Oils for High Bearing Temperature Applications and Its Impact on Tribological Properties
M N K Prasad Bolisetty, Chanakya Tripathi, Kavita Rai, Rahul Meshram, Subinoy Paul, A. Arora, Mukul Maheshwari, Indian Oil Corporation Ltd., Faridabad, Haryana, India

Modern gas and steam turbines place increasing demands on lubricants, exposing them to higher bearing temperatures, reduced reservoir sizes and critical varnish deposit issues. Selecting a high-performance, long-life turbine oil can help to mitigate future problems and the onus is on the turbine oil formulators to strike a balance between low varnish and antiwear/EP performance at elevated bearing temperatures. The present research paper deals with effect of different categories of additives on varnish formation tendency, oxidation life and tribological properties for geared turbines by different techniques like Dry TOST analysis (ASTM D7873), MPC (ASTM D7843), RPVOT (ASTM D2272) and scuffing load carrying capacity (FZG), respectively. This paper also highlights the synergistic and antagonistic effect of additives on the important performance properties of turbine oil which will help to formulate turbine oils for high bearing temperatures up to 250° C in modern turbines.

9:00 - 9:20 am
4205602: Universal Lubricant Additives for Varnish and Deposit Mitigation
Justin Kontra, Justin Langston, Frank-Olaf Maehling, David Eckes, Evonik Oil Additives, Horsham, PA

Varnish and deposits present significant challenges in the operation and maintenance of industrial equipment, leading to reduced efficiency and increased downtime. This study explores the beneficial role of dispersant additives in mitigating these issues. Dispersant additives enhance the solubility of insoluble particles, preventing agglomeration and subsequent deposit formation. We demonstrate that these additives effectively reduce varnish and deposit buildup, particularly in high-temperature environments. The findings indicate a marked improvement in equipment performance, longevity, and reliability.

9:20 - 9:40 am
4202494: Integrated Simulation of Hydrodynamic Plain Bearings in Wind Turbines
Hannes Grillenberger, Matthias Schubert, Mario Kittsteiner, Marcel Indenbirken, Michael Plogmann, Schaeffler Technologies AG & Co KG, Herzogenaurach, Bavaria, Germany

Hydrodynamic plain bearings are becoming an emerging bearing solution for wind turbine gearboxes – especially at the planet bearing position. To fully simulate and design the bearing including its profiles, an integrated simulation of the complete gearbox is important to capture the interactions of bearing, gears and elastic housings, planet carriers and shafts.
The implementation in the simulation tool considers factors like exact geometry, materials, and load scenario, and is fully integrated in the gearbox simulation. This integration ensures a detailed and reliable bearing design process, crucial for enhancing the torque-density of wind turbine gearboxes.
The presentation shows the general implementation of the method. Analysis and interpretation of design and performance properties for plain bearings like hydrodynamic pressure or edge

pressures are discussed. The talk closes with the validation of the implemented method with other simulations and tests.

9:40 - 10:00 am
4173886: Updates and Developments in the Turbine Generator Lubrication System Maintenance Guide from the Electric Power Research Institute
Richard Wurzbach, MRG Labs, York, PA

The Electric Power Research Institute publishes many guidelines in support of the Power Generation industry. With the advancements in lubricant formulations, analysis and sensor options, and lubricant filtration and reclamation technologies, a recent effort was undertaken to update from the 2012 publication of this guide. The author and editor of this update shall present the key changes in this version to help those responsible for such systems to best utilize this document to achieve operational, maintenance and reliability goals for Turbine Generator Lubrication Systems.

10:00 - 10:40 am - **Break**

10:40 - 11:00 am
4199376: Enhancement of Filtration Performance Characteristics of Glass Fiber-Based Filter Media, Part 1: Mechanical Modification with Electrospun Nanofibers
John Duchowski, Laura Weiter, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany; Stephan Leyer, University of Luxembourg, Luxembourg, Luxembourg

Modifications of glass fiber filter media through incorporation of electrospun PA66 nanofibers (NF) are described. PA66 NF were selected because of ready commercial availability and relatively low cost. Other polymers (PP, PET and PBT) could likewise be used. Two sample sets were prepared: the first with various wt% of NF mixed into the fiber matrices, the second by lNF deposition onto the downstream side of the substrate. The aim was to improve the separation efficiency, differential pressure and dirt holding capacity. The modified media were evaluated with textile characterization techniques and filtration performance evaluation procedures. The results showed several tens of percentage points difference achieved with the modification methods. Differences were also observed with the percentage of NF admixed to the substrate. The results strongly suggest that new filter media with enhanced properties can be prepared by incorporating NFs directly into the matrix.

11:00 - 11:20 am
4199523: Enhancement of Filtration Performance Characteristics of Glass Fiber-Based Filter Media, Part 2: Chemical Modification with Surface-Active Treatment
John Duchowski, Laura Weiter, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany; Stephan Leyer, University of Luxembourg, Luxembourg, Luxembourg

Standard glass fiber filter media were chemically modified with surface active agents with the aim to improve separation efficiency, differential pressure dirt holding capacity. The increase in separation efficiency was determined quantitatively in terms of work of adhesion between the contaminant and the substrate. The behavior was confirmed experimentally by an increase in separation efficiency especially for particles in the smaller size ranges well below the mean porosity of the original substrate. In addition, the effect of different surface modifications, especially those of the opposite ends of the surface energy values, has clearly manifested itself in separation efficiency results shown in the multipass test evaluations. Collectively, the obtained surface energy and separation efficiency results are indicative of a wide range of performance enhancements that can be achieved through suitably applied surface-active modifications of the standard materials.

11:20 - 11:40 am
4205630: Reducing Power Losses in Tilting Pad Bearings
Michael Blumenfeld, Weixue Tian, Harry Hawkins, Exxon Mobil, Annandale, NJ; Bruce Fabijonas, Kingsbury, Inc., Philadelphia, PA

Bearing losses are significant in the power generation sector where small changes in efficiency can scale rapidly. In fluid film bearings, losses are related to the Hersey number μ(T)●V/L , where μ(T) is the temperature dependent viscosity, V is the sliding velocity of the collar, and L is the applied load. We will discuss in this talk the potential for achieving efficiency improvements in fluid film bearings by reducing the Hersey number through viscosity reduction in the lubricant. Modeled data will be compared to experimental determinations of power loss and bearing pad temperature measured on a test rig. Finally, novel approaches to turbine lubricant design will be proposed that may enable step-change improvements in efficiency while still maintaining the durability required for reliable operation.

11:40 am - 12:00 pm
4200370: Conclusions from Hydraulic Fluid Dynamometer Testing and Correlation with Excavator Performance Demonstrations Data
Ricardo Gomes, Frank-Olaf Maehling, Thilo Krapfl, Evonik Oil Additives, Horsham, PA; Paul Michael, Pawan Panwar, Milwaukee School of Engineering, Milwaukee, WI

The fluid power industry sees an increasing need for reliable energy-efficient solutions driven by rising energy costs and environmental awareness. The efficiency of hydraulic fluids can be quantitatively compared according to ASTM D7721 which defines technical requirements for conducting tests with two or more hydraulic fluids, in particular, the last revision describes equipment investigations in the field.
A comparative investigation of hydraulic fluids was completed with a dynamometer test rig and an excavator in the field. This presentation draws conclusions from the findings with results comparing monograde and shear stable high VI hydraulic fluids. The selection of a shear stable high VI hydraulic fluid is key to reduce power losses and maximize equipment efficiency over long drain intervals. HF dynamometer results show that shear stable high VI fluids allow equipment to make highly accurate movements and to run at optimum controllability and consequently high productivity.

6A — Hanover AB

Lubrication Fundamentals II

Session Chair: Chanaka Kumara, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: Kuldeep Mistry, Chevron Oronite Company, Richmond, CA

1:40 - 2:20 pm
4189998: Atomic-Scale Modelling of Lubricants at High Pressure: On the Competition of Shear Thinning, Thermal Thinning and Wall Slip
Michael Moseler, Stefan Peeters, Lars Kruse, Franziska Stief, Thomas Reichenbach, Gianpietro Moras, Kerstin Falk, Fraunhofer IWM, Freiburg, Germany

A fundamental understanding of the rheological properties of lubricants in narrow gaps under high pressures and elevated temperatures is mandatory for a predictive modelling as well as a knowledge-based design of boundary lubricated devices. Especially, the identification of the relevant velocity accommodation mode is a challenging task, since it results from an intimate

interplay of pressure-induced viscosity increases, temperature-induced and shear-induced viscosity decreases as well as shear-induced wall slip. Molecular dynamics simulations are ideally suited to shed light into and study the balance of these different mechanisms [A.Codrignani et al. , Science Adv. 9, eadi2649 (2023)]. This presentation reports our activities for the predictive modelling of the high pressure rheology of mineral oils and water bases lubricants – including the calculation of viscosities at high pressures and shear rates as well as wall slip under extreme confinement and pressures.

2:20 - 2:40 pm
4186167: Optimizing EHL Performance with Slip Conditions
Rayan Ajeeb, Tomaz Pozar, Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Elastohydrodynamic lubrication is vital for reducing friction and enhancing mechanical system performance. Slip has emerged as a key mechanism for friction reduction, particularly with diamond-like carbon (DLC) coatings, that have low surface energy and promote slip at the lubricant-coating interface [1]. Experimental evidence indicates that DLC coatings significantly decrease the coefficient of friction [2]. However, investigating slip in EHL experimentally is challenging due to nanoscale contact accessibility. This research utilizes a computational approach, applying the Navier-Stokes equation to analyze EHL fluid domain with slip. The slip model used is the one proposed by Spikes [3], it indicates that both lyophobic and lyophilic substrates exhibit slip yield stress, with lyophobic substrates showing lower values. Findings reveal critical variables affecting EHL contact behavior and provide insights for optimizing coatings to reduce friction while avoiding asperity contact.

2:40 - 3:00 pm
4203066: Transient Effects in EHL Contacts in High Entrainment Speed Conditions
Roland Jones, Hugh Spikes, Amir Kadiric, Imperial College London, London, United Kingdom; Guillermo Morales-Espejel, SKF AB, Houten, Netherlands

EHL film thickness behaviour under steady-state conditions is well understood and predictable using conventional theories. However, in many practical situations, lubricated contacts are subjected to transient conditions which may include rapid acceleration as well as changes to the inlet supply conditions. Such conditions increase the risk of reduction and potential collapse of the EHL oil film leading to surface damage.
In this research, a new high-speed ball-on-disc optical interferometry rig was used to investigate the effect of acceleration as well as varying lubricant supply in the inlet on the EHL films at entrainment speeds of up to 20 m/s. The results are presented to quantify EHL film thickness and illustrate the film shapes over a wide range of transient speeds and oil supply conditions.

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

3:40 - 4:00 pm
4188714: Choosing Right Viscosity Modifier Based on PSSI and Shear Rate of Application
Jacob Scherger, Functional Products Inc, Macedonia, OH

Viscosity modifiers (VM) are additives used to enhance VI, provide thickening in low viscosity oils, and provide better lower temperature fluidity than heavy oils. The industry trend toward highly refined base stocks with lower initial viscosities demands more VMs to reach target ISO VGs. The trade-off in using VMs for performance is the added complexity of shear effects. PSSI or “permanent shear stability index” is an industry standard benchmark for classifying the tendency of polymers to undergo mechanical damage and loss of viscosity. It is a rule-of-thumb to help formulators select an appropriate VM for a given application. This study investigates the fundamental material science between 1) polymer molecular weight and PSSI rating; 2) thickening efficiency and VI improvement; and 3) permanent and temporary shear thinning characteristics.

This work will answer the question of when and where is it appropriate to use low cost, high PSSI polymers versus more shear stable chemistries.

4:00 - 4:20 pm
4175248: Demystifying Minimum Film Thickness in Elastohydrodynamic Lubricated Conjunctions
Wassim Habchi, Lebanese American University, Byblos, Lebanon; Sperka Petr, Brno University of Technology, Brno, Czechia; Scott Bair, Georgia Institute of Technology, Atlanta, GA

Till now, minimum film thickness in elastohydrodynamic lubricated (EHL) conjunctions was believed to be governed by lubricant low-pressure rheology. This is because two fluids with the same low-pressure response, but a different high-pressure one would produce the same film thickness. In here, it is shown that this is only true for theoretical line contacts, where there is no out-of-contact lateral flow. In real contacts, though central film thickness is governed by low-pressure rheology, minimum film thickness is also affected by the high-pressure response of the lubricant. The greater the high-pressure viscosity, the lower the minimum film thickness, because of reduced out-of-contact lateral flow. Narrow/slender elliptical contacts have a higher sensitivity to this phenomenon, compared to circular or wide elliptical contacts. Machine learning is then used to identify the governing parameters of EHL minimum film thickness, to be used in analytical formulae or machine learning models.

4:20 - 4:40 pm
4243300: Assessing Engine Oil Formulations to Mitigate Aeration
Eliane Gendreau, Robert Mainwaring, Sarah Matthews, Shell Research Limited, London, United Kingdom

While low levels of oil aeration are not problematic, excessive aeration can be detrimental to the performance of lubricants. The current trend in numerous applications is to engineer lubrication systems that are more compact, utilize a reduced volume of oil, and can operate at higher speeds with lower viscosity lubricants. These conditions exacerbate air handling concerns, so there is a need for robust formulations that can eliminate aeration as a problem while preserving the lubrication efficacy. In this project, we focus on low viscosity engine oils. Formulation levers are examined with a statistical analysis of engine test results. The effect of antifoam additive technology, antifoam treat rate, base oil selection, and oil aging, will be presented. The fundamental insights obtained in this study are relevant to other applications where aeration poses a challenge.

4:40 - 5:00 pm
4177331: Modeling the Mixed-EHL Performance of the Plunger-bore Interface of a Radial Pump
Henry Soewardiman, Shuangbiao Liu, Yip-Wah Chung, Wei Chen, Q. Jane Wang, Northwestern University, Evanston, IL; Jie Chen, Virginia Tech, Blacksburg, VA; Nikhil Murthy, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

The plunger of a high-pressure radial pump is a critical component for efficient and reliable fuel delivery. To minimize leakage, the plunger has a clearance with the bore of at most a few micrometers. However, the combination of tight tolerance along with misalignment of the plunger during operation causes the plunger to be vulnerable to scuffing during reciprocating motion. A numerical model of the pump plunger-bore interface has been developed to understand and quantify the behaviors of contact and lubrication at the plunger-bore interface during a full pumping cycle. This model was created to comprehensively analyze the fuel pumping mechanism and critical rubbing conditions within the plunger-bore interface, including the impact of elasticity of the plunger and the bore caused by the hydrodynamic fluid pressure and solid-solid contact. The interface performance was evaluated through the film thickness, pressure, asperity contact area,

and leakage for several candidate fuels.

6B — Hanover C

Commercial Marketing Forum VI

All time slots available.

6C — Hanover D

Fluid Film Bearings-Seals I

Session Chair: TBD
Session Vice Chair: TBD

Session starts at 2:00 pm

2:00 - 2:20 pm
4182328: Experimental Rotordynamic Response of a Rotor Supported on Simple Rigid Surface Gas Bearings
Keun Ryu, Youngseok Song, Hanyang University, Seoul, Republic of Korea

Gas bearings offer significant advantages in rotating machinery, including compact size, light weight, extended speed limits, and longer lifecycles compared to traditional rolling element bearings. This work presents experimental measurements of the rotordynamic response and drag torque of a small, rigid rotor supported on simple, cost-effective gas journal and thrust bearings. The rotor was driven by a high-speed automotive turbocharger up to 150,000 RPM. Experimental results demonstrate the stability of the rotor-gas bearing system, with no observed subsynchronous instability. Rotordynamic predictions for imbalance response amplitudes and rigid mode damped natural frequencies show close agreement with the experimental data. These findings highlight the reliability and favorable rotordynamic characteristics of simple rigid surface gas bearings, making them well-suited for compact, high-speed rotating machinery applications.

2:20 - 2:40 pm
4202492: A Multi-Level Coupling Model for Stiffness and Damping Analysis of Ship Stern Bearings under Mixed Lubrication Conditions
Zhenjiang Zhou, Xincong Zhou, Shaopeng Xing, Lun Wang, Wuhan University of Technology, Wuhan, Hubei, China; Konstantinos Gryllias, KU Leuven, Leuven, Belgium

In ship stern bearing systems, the lubrication film reduces wear by isolating the shaft journal from the bearing surface and provides essential stiffness and damping.. Under mixed lubrication, decreased film thickness and localized solid contact make traditional methods for calculating stiffness and damping coefficients inadequate for dynamic load responses. This study proposes a multi-level coupling model based on hydrodynamic lubrication and contact theories, solved using finite difference and small perturbation methods. A harmonic test measured lubrication film stiffness and damping with a maximum error of 11.89%, validating model accuracy. Finally, the effects of varying eccentricities and surface roughness on bearing damping and stiffness were analyzed. Results show that radial stiffness and damping initially increase slowly, then rapidly with higher eccentricity, and increase with surface roughness, with amplified effects as eccentricity

grows.

2:40 - 3:00 pm
4202525: Analytical Solution for an Infinitely Long Journal Bearing Lubricated by a Power Law Fluid
Austin Zapata, Andrea Vacca, Purdue University, West Lafayette, IN

In the simulation of external gear machines, predicting the gear positions is crucial for determining both the displacing action of the fluid volumes and the configuration of the lateral lubricating gaps. Journal bearings typically support the gears in the radial direction, whose load with respect to eccentricity and squeeze is typically predicted by solving the Reynolds equation. When EGMs are operating with non-Newtonian fluids, though, further assumptions on the fluid must be made to derive a Reynolds-type equation, and thus to provide an accurate estimate of the load. This study seeks to establish the accuracy of different Reynolds-type equations for power-law fluids by examining the case of an infinitely-long journal bearing, for which an analytical solution is derived, and provide a novel approach for finding the load supported by a finite-width journal bearing lubricated by a non-Newtonian journal bearing with applications to external gear machine simulations.

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

3:40 - 4:00 pm
4205158: Enhancing Plain Bearing Performance: The Role of Isotropic Superfinishing in Optimizing Friction Behavior and Expanding Application Limits
Benjamin Klinghart, Georg Jacobs, Florian König, RWTH Aachen University, Aachen, Germany

Achieving climate goals and mitigating climate change are among the greatest challenges of our time. Increasing efficiency is therefore pursued in all areas. In the field of drive technology, plain bearings offer a significant opportunity to save resources, costs, and installation space. Compared to rolling bearings, they offer a particularly good ratio between load capacity and size. However, they only work effectively when the contact surfaces are fully separated by lubricant. At varying speeds and extreme forces, such as in an engine with a start-stop system or in a wind turbine, plain bearings reach their limits. In order to extend the range of applications, it is necessary to increase the range of optimum operating conditions. Therefore, this study investigates the influence of isotropic superfinishing on the friction behavior and the transition to mixed lubrication in plain bearings.

4:00 - 4:20 pm
4204920: Solid Particle Wear in Hydrodynamic Thrust Bearings
Haykal Bouajila, Jean Bouyer, Bálint Pap, Pprime Institute, Futuroscope Chasseneuil Cedex, France; Pascal Jolly, Institut Pprime - CNRS - Université de Poitiers, Chasseneuil du Poitou, France

Hydrodynamic thrust bearings are well-known for their longevity and reliability due to the absence of contact between the stator and rotor during normal operation. During their service life, (that can be measured in tens of years) they can be damaged even in normal operation: the solid particle pollution of the lubricant can impact the thrust bearings behavior [1, 2, 3 4], thus reducing its service life. In the present study, solid particles were injected in the thrust bearing during lubricated operation and the resulting damage was analyzed through different optical and physical measurements. The influence of thrust bearing geometries, operating conditions (rotational speed, film thickness), particle materials (steel, hardened steel, ceramic) and thrust bearing coating (soft, hard and uncoated) show the importance of understanding particle wear mechanisms in hydrodynamic thrust bearings in order to improve their service life.

4:20 - 4:40 pm
4204950: Evaluation of Lining Materials for Tilting Pad Main Journal Bearings in Wind Turbines Using Modelled Transient Wind Loading Conditions
Emily Priest, Rob Dwyer-Joyce, University of Sheffield, Sheffield, South Yorkshire, United Kingdom; Edward Hart, The University of Strathclyde, Glasgow, United Kingdom

There has been recent interest in the use of tilting pad journal bearings rather than conventional rolling bearings for use in large wind turbines. However, they must operate at low speed with start-stops due to wind cut in and out. This causes lubrication film to break down leading to wear and potential failure. Therefore, it is likely to require the tilting pad be lined with protective material. Wind loading is complex and cyclical, so the main bearing loading is time varying. This presentation will report the findings from applying simulated wind data to a new simplified analytical bearing model. These results and SCADA data were used to produce a test matrix for evaluating material linings. A range of materials were selected and tested on a TE67 Phoenix Tribology Tribometer, using a conformal block on disk arrangement. The wear and friction properties of the different materials will be compared, to propose suitable materials for this application.

4:40 pm - Fluid Film Bearings/Seals Committee Meeting

6D — Hanover E

Tribochemistry II

Session Chair: Nicolas Molina Vergara, University of Texas at Austin, Austin, TX
Session Vice Chair: John Curry, Sandia National Laboratories, Albuquerque, NM

1:40 - 2:20 pm
4203796: Simulation of Film Reorientation in Vertically Aligned Polycrystalline MoS_2 Films Due to Shear
James Schall, Shima Karimi, North Carolina Agricultural and Technical State University, Greensboro, NC; Brandon Krick, Florida State University, Tallahassee, FL

PVD MoS2 films are found in a wide range of structures. The size and orientation of the film depends on the growth kinetics set by the deposition parameters. Growth along the edges is energetically favored relative to highly passivated basal plane which leads to vertical alignment. During sliding, the films reorient to form horizontal layers. Here we will present MD simulations of the reorientation process during contact and sliding between vertically aligned MoS2 films. We observe that bonding between the exposed edges of the opposing surfaces drives pull-out of individual MoS2 sheets from the surface. These flakes are then entrained into the sliding interface and are reoriented horizontally during subsequent sliding which results in lowered friction. This effect is more pronounced in films with larger grain sizes. We hypothesis that the disorder present in smaller grain sized films produces a higher degree of initial passivation which in turn reduces sheet pull out and reorientation.

2:20 - 2:40 pm
4187580: Resistance to Oxidation of MoS_2 Nanoparticles under Severe Oxidizing and Stress Conditions: Relationship Between Chemical Composition and Lubricating Properties.
Fabrice Dassenoy, Jules Galipaud, LTDS/ECL, Ecully, France; Marina Benmansour, Ecole Centrale de Lyon, Ecully, France; Pavel Afanasiev, IRCELYON, Lyon, France; Lucile Joly-Pottuz, MATEIS/INSA, Lyon, France

The purpose of this work was to investigate the tribological behavior of MoS_2 nanoparticles when subjected to severe oxidizing and stress conditions. Friction tests were conducted in dry and strictly controlled environments with an environmentally controlled analytical tribometer. The effects of the oxygen pressure and the temperature on the chemical composition of the nanoparticles and their tribological properties were investigated. XPS was used to follow the evolution of the composition of the MoS_2 nanoparticles during friction tests. Results show a good chemical stability of the nanoparticles from the ultra-high vacuum up to 1 mbar of oxygen, together with stable tribological performance. At higher pressures (i.e., 200 mbar), a slight increase in the friction coefficient associated to a pronounced oxidation is observed. By comparing the results to lubricated environment conditions, it is concluded that the oxygen of the air is not the only oxidation source of the nanoparticles.

2:40 - 3:00 pm
4205110: Origin of Superlubricity of Diamond-Like Carbon (DLC)
Seokhoon Jang, Seong Kim, Pennsylvania State University, State College, PA; Zhe Chen, Zhejiang University, Hangzhou, China

Hydrogenated diamond-like carbon (H-DLC) is produced as a thin film using plasma-enhanced chemical vapor deposition. H-DLC often exhibits superlubricity, but is this an intrinsic property? This talk suggests that while H-DLC itself is not inherently superlubricious, its structure enables the interface to transform into a superlubricious state under certain shearing conditions. Thus, its superlubricity is considered extrinsic. To support this, the frictional behavior of graphite, amorphous carbon, and diamond is analyzed, along with the run-in process and environmental sensitivity of H-DLC friction. While the superlubricious state is typically associated with a graphitic structure, its exact structure remains unclear and requires further investigation. Understanding the mechanisms behind superlubricity in H-DLC offers valuable insights for developing other lubricious carbon-based materials using alternative synthesis methods.

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

3:40 - 4:00 pm
4187660: Effectiveness of a Succinimide Dispersant on the Dispersion of MoS_2 Nanoparticles in Base Oil: Impact on the Tribological Performances.
Fabrice Dassenoy, Marina Benmansour, Beatrice Vacher, LTDS/ECL, Ecully, France; Pavel Afanasiev, IRCELYON, Lyon, France; Jules Galipaud, LTDS/ECL, Ecully, France; Lucile Joly-Pottuz, MATEIS/INSA, Lyon, France

Nanoparticles are considered as a real alternative to the use of traditional friction-reducing and anti-wear lubrication additives. They have shown to have exceptional friction-reducing performances allowing them to be considered in many applications, particularly in extreme environments. However, the formulation of lubricants containing nanoparticles involves ensuring the good dispersion of the nanoparticles in the base oil as well as their long-term stability. In this work, we propose to study the effectiveness of a PIB succinimide dispersant on a dispersion of MoS_2 nanoparticles in a PAO base oil and to understand its influence on the tribological performances of the lubricant. For this purpose, an important characterization work of the rubbed surfaces (XPS, TEM, etc.) was carried out.

4:00 - 4:20 pm
4189898: Shear-induced Surface Aromatization as a Superlubricity Mechanism of Amorphous Carbon
Takuya Kuwahara, Osaka Metropolitan University, Sakai, Osaka, Japan; Gianpietro Moras, Michael Moseler, Fraunhofer IWM, Freiburg, Germany

Amorphous carbon (a-C) exhibits superlubricity, friction coefficient below 0.01, in various environments and conditions. However, underlying atomic-scale mechanisms remain controversial. Here our quantum mechanical molecular dynamics simulations propose shear-induced surface aromatization as an alternative superlubricity mechanism and highlight the importance of doping of a-C with low-valent elements. Low-valent elements such as hydrogen, oxygen, and nitrogen lead to the formation of pore embryos and thus non-aromatic sp^2 carbon walls under shear. Subsequently, these pore embryos can be stabilized and grown by local accumulation of dopants. Further growth of pores and formation of aromatic sp^2 carbon walls trigger the formation of a superlubric interface. Interestingly, non-, and silicon-doped a-C do not undergo surface aromatization since these tetravalent elements cannot stabilize pore embryos. Hence, this study paves the way for mechanochemical synthesis of superlubric 2D materials.

4:20 - 4:40 pm
4199923: Enhanced Tribological Performance and Durability of Nanocrystalline Coatings Deposited on 52100 Steel via Tribocatalytic Interactions with Hydrocarbon Lubricants
Zaid Al Hassan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

We present the development and tribological evaluation of Ni-Cr-Mo nanocrystalline coatings deposited on AISI 52100 steel via physical vapor deposition. The coating composition was designed to enable continuous formation of wear-protective tribofilms through tribocatalytic interactions between the coating and lubricant. To increase hardness and tribocatalytic behavior, the coating architecture was optimized to achieve an average grain size of 20 nm and eliminate columnar domains. Reciprocating tribotests using F-24 lubricant demonstrated a consistent 35% reduction in friction compared to uncoated AISI 52100. Post-test Raman spectroscopy confirmed the formation of carbon tribofilms at the contact surfaces, contributing to the observed friction reduction. This development underscores the potential of nanocrystalline coatings to significantly enhance the tribological performance of steel components with base hydrocarbon fluids, reducing the need for lubricant additives.

4:40 - 5:00 pm
4190004: Atomic-Scale Mechanisms Behind Macroscopic Superlubricity: The Case of Glycerol Lubrication
Gianpietro Moras, Thomas Reichenbach, Michael Moseler, Fraunhofer IWM, Freiburg, Germany; Takuya Kuwahara, Osaka Metropolitan University, Sakai, Osaka, Japan

Achieving superlubricity (friction coefficient < 0.01) in mechanical components is a challenge with clear energy-saving implications that has been recently undertaken by many research groups. Stable superlubricity over a wide range of operation conditions has been recently achieved at Fraunhofer IWM in plain-bearing test rigs. Robust results were obtained for glycerol lubrication of diamond-like carbon and silicon nitride. I will present an atomistic simulation study that analyses different superlubricity mechanisms proposed so far for these tribological systems. We estimate that hydrodynamic lubrication at high speed and lubricant films thinner than 100 nm is only possible at high temperature and in the presence of water. However, tribochemical reactions involving glycerol can produce aromatic carbon surface regions that are smooth and unreactive. These enable superlubricity also when asperity contacts run dry or are separated by nanometric, highly viscous glycerol films.

Environmentally Friendly Fluids-Synthetics II

Session Chair: Daniel Garbark, Battelle Memorial Institute, Columbus, OH
Session Vice Chair: Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA

1:40 - 2:20 pm
4220055: Environmentally Acceptable Lubricants: HEES vs HEPR
John Fang, Nathan Knotts, Christina Li, Chevron Products Company, Richmond, CA

Environmentally Acceptable Lubricant (EAL) market has been growing rapidly due to increased government mandate and public awareness. Major types of EALs are vegetable oil, synthetic ester, polyglycols, and PAO-related hydrocarbons; while they all have their own pros and cons, unsatisfactory performance, such as hydrolytic, thermal, and oxidation stability, product longevity, seal compatibility, et al, has been restraining the growth of this market. This presentation will provide an overview of major regulatory specifications for EAL and introduce a new type of HEPR EAL, which offers significantly improved performance, as well as its application as hydraulic fluids.

2:20 - 2:40 pm
4202771: Innovative Sustainable Additives: Renewable Technology for Lubricants
Kathleen Havelka, Richard Butler, Advancion, Algonquin, IL

Amino alcohols and their derivatives offer a range of structures, including water and oil-soluble amino alcohols, amides, and oxazolines. The versatility, performance and structural diversity of these chemistries make them ideal for various applications where improved sustainability is essential, such as metalworking, chain lubricants, and hydraulic fluids. The sustainability profile of these materials is further enhanced by incorporating renewable raw materials into the production process to create an environmentally responsible amino alcohol technology platform. These innovative additives offer performance that frequently exceeds that of traditional additives while reducing reliance on petroleum. This talk will explore how this environmentally responsible amino alcohol technology platform can serve as a high-performance, cost-effective solution for developing more environmentally responsible additives and can be leveraged to facilitate market adoption of more sustainable lubricants.

2:40 - 3:00 pm
4178581: Cutting Fluids from Soybean-based Lubricants and Emulsifiers
Jeff Cafmeyer, Daniel Marzolf, Battelle Memorial Institute, Columbus, OH

Metalworking or cutting fluids play crucial roles in lubricating and facilitating heat transfer during the machining of metal substrates. Soybean oil, with its sustainability profile, film-forming properties, and biodegradability, presents a compelling base oil option for this application. Cutting fluids benefit from various traits inherent to soybean oil and its variants (e.g., commodity and high oleic) as well as the chemical modifications Battelle has made to address performance characteristics (e.g., viscosity, pour point, surface tension) and potential issues such as oxidative and hydrolytic stability. Battelle has recently shown that soy-based lubricants and surfactants can perform effectively when cutting cold-rolled steel in both oil-based and water-based formulations. This presentation will offer an update on the efforts to develop a sustainable, soy-based alternative for cutting fluid applications.

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

3:40 - 4:00 pm
4200533: Hydrolytic Stability of VSP Esters Compared to Standard Diesters and Polyol esters
Andy Johnson, Zschimmer-Schwarz, Ivey, GA

Synthetic esters are well known for their high performance and environmentally friendly characteristics as lubricant additives and base stocks. Diesters and Polyol esters are widely used in industrial and automotive lubricant applications due to their ability to improve viscometrics, reduce deposits and enhance the solubility of additives in paraffinic oil mixtures. The molecular structure and residual acid composition of certain standard esters leads to hydrolytic stability concerns. The molecular structure of VSP esters based on secondary alcohols results in ester groups with high steric hindrance and resistance to hydrolysis.
Hydrolytic stability test data has been generated comparing VSP esters to a variety of commercial dibasic acid esters and polyol esters. The data presented will support the use of VSP esters in environments where the presence of water demands good hydrolytic stability, such as metalworking, hydraulic fluids, marine, tractor fluid and engine oil applications.

4:00 - 4:20 pm
4205156: Development and Performance Testing of Estolides Derived from a Functionalized Fatty Acid Source
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Environmentally friendly fluids are derived from biodegradable and renewable substances that allow them to be sustainable and safe alternatives to fluids derived from petroleum sources. Estolides are exclusively elite in the realm of environmentally friendly fluids. Estolides serve as an exceptional biobased choice for delivering high performance in a multitude of applications, protecting the environment, improving worker health and safety, and increased sustainability efforts for the formulator. Within this talk, Biosynthetic Technologies will share details regarding the development and performance testing of a series of estolide materials derived from a sustainable and biobased functionalized fatty acid and how these estolides compare to other estolides produced from other biobased feedstocks.

4:20 - 4:40 pm
4201460: Impact of Seawater Content in Lubricants without and with Eco-friendly Ionic Liquids on Chemistry, Viscosity, Wettability, Corrosion, and Tribological Performance
Wenbo Wang, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Recently, eco-friendly ionic liquids (ILs) were successfully invented as additives for tidal turbine lubrication, showing encouraging lubricating performance in lab-scale tribological tests compared with baseline gear oils and commercial additives. However, seawater contamination resulting from moisture penetration due to seal aging and long maintenance intervals is a potential challenge. To study the impact, the lubricant chemistry, viscosity, wettability, corrosion, as well as the tribological behavior of PAG oils without and with ILs were investigated when contaminated with seawater at a range of 0.5-3 wt.%. The ILs helped the seawater solubility in PAG and significantly reduced the seawater-induced corrosion.

4:40 - 5:00 pm
4202837: Volatility Characteristics of VSP Esters Compared to Standard Diesters and Polyol esters.
Andy Johnson, Zschimmer-Schwarz, Ivey, GA

Synthetic esters are widely used as base stocks in high temperature lubricant applications due to their low volatility characteristics. Esters can be designed to provide better low temperature viscometrics and lower volatility compared to hydrocarbons of similar viscosity at 40°C and 100°C. The novel molecular structure of VSP esters based on secondary alcohols results in lower volatility

compared to standard dibasic acid esters ad polyol esters with similar viscosity.
The data presented will support the use of VSP esters in applications where Noack volatility drives formulation design. VSP esters offer a combination of performance advantages including oxidative and hydrolytic stability combined with natural energy efficiency advantages of low density and high viscosity index.

6F Courtland

Tribotesting II

Session Chair: TBD
Session Vice Chair: TBD

1:40 - 2:20 pm
4189975: Assessment of Stick-Slip Behaviour of Hydraulic Oils using a Tribometer
Arman Mohammad Khan, Shell, Bengaluru, India

Stick-slip phenomenon in hydraulic systems is a detrimental occurrence, wherein two surfaces fail to slide smoothly due to fluctuations in frictional forces. This results in vibrations, noise, and oscillations leading to erratic machine operation. An optimized hydraulic fluid formulation can reduce stick-slip behaviour; however, lack of a standard stick-slip screening test method presents a significant challenge in evaluating the efficacy of formulations during the development phase. Custom test rigs are often employed for this purpose, but they tend to be complex and introduce considerable variability in results. The authors here propose a simple yet effective test method that utilizes a standard tribometer to evaluate stick slip behaviour of lubricants in a reproducible manner. This method, in turn, enables correlating dependency of different components in a hydraulic oil formulation on its stick-slip control. Few examples are shown to demonstrate the effectiveness of this method.

2:20 - 2:40 pm
4205564: Grease Tribological Performance in Electrified Conditions Evaluated Using Four-Ball Tests
Alex Hartzler, Amani Byron, Ashlie Martini, University of California Merced, Merced, CA; Christina Cheung, Anoop Kumar, Chevron, Richmond, CA

Electrified conditions can affect the interactions between mechanical components and lubricants. To better understand these effects, we conducted four-ball tribotests with grease under both electrified and unelectrified conditions. We observed and recorded trends in electrical contact resistance, friction, wear scar diameter, and wear volume. Scanning electron microscopy was used to identify potential wear mechanisms. Results revealed differences in grease performance based on the presence of applied current or voltage and grease formulation. These findings contribute to optimizing grease formulations for use in electrified environments, offering insights into improved lubrication strategies for electric vehicles and other machinery exposed to electrical conditions.

2:40 - 3:00 pm
4200299: Effect of Ammonia Degradation on Anti-Scuffing Performance of Marine Engine Oil.
James Morley, George Plint, Suresh Chhetri, Phoenix Tribology, Kingsclere, United Kingdom

Ammonia is fast becoming a fuel used in marine applications as a replacement for other fuels. The effect of using ammonia both from unburnt fuel and combustion products on the tribological properties of the lubricating oil is not well known. It is known (Tornatore et al., 2022) that ammonia

engines must run high compression ratios, increasing piston-ring blow-by. Marine oils generally contain a variety of anti-wear additives, and are alkaline, in order to minimize corrosion caused by NOx. The aim of this research is to evaluate how a marine oil, exposed to ammonia for periods of time behaves in a simulated ring-liner contact in boundary and mixed lubrication. The experiments used a tribometer to run line contact tests, running nitrided steel against a hard and ground cast iron plate.
Lubricant pre-conditioning was carried out using a proprietary preconditioner, with gas of ammonia/ nitrogen mix (2000 ppm ammonia) bubbled through a fixed volume of oil for times of 1, 2, 5 and 10 hours.

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

3:40 - 4:00 pm
4200840: Identifying Extreme Pressure Additive Activation via the Mini Traction Machine
Victoria Parker, Sasol, Westlake, LA

Extreme pressure (EP) additives are an important component of applications performing in the boundary lubrication regime. Additives which are considered EP are molecules such as chlorinated paraffins and sulfur-based EP additives which have varying affinities for the metal surface. These molecules activate at different temperatures and pressures. Once activated they form a tribofim to prevent cold-welding and galling. The activation and performance of these additives can also be affected by other additives in the system. This paper considers methods to identify the activation of these EP additives and determine if other additives are enhancing or deteriorating the system.

4:00 - 4:20 pm
4200523: High-Throughput Metal Analysis of In-Service Oils and Coolants with a Nitrogen-Based Plasma Optical Emission Spectrometer
Mike Plantz, Radom Corporation, Pewaukee, WI

Performance of elemental tribology is typically performed on hundreds of samples at a time, demanding high-speed sample throughput from the laboratory instrumentation. This talk focuses on the use of a novel nitrogen ICP -OES system coupled with advanced autosamplers optimized for the fastest sample handling capabilities. The Radom MICAP-OES 1000 microwave ICP-OES system operates with a highly cost-effective nitrogen plasma system that eliminates the need for a water chiller. Its simultaneous, high-resolution spectrometer provides quick and accurate results for in-service oils and coolants. Unique sample handling automation techniques utilized deliver the ultra-high throughput ICP sample introduction performance required by these laboratories.

4:20 - 4:40 pm
4239350: Elucidation of Molecular Structure and Frictional Properties at Solid-Liquid Interfaces Using FM-AFM and LFM
Kaisei Sato, Yuya Yamaguchi, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

We developed a system that integrates Frequency Modulation Atomic Force Microscopy (FM-AFM) with Lateral Force Microscopy (LFM), enabling high-sensitivity measurement of lateral forces with molecular resolution. Using this FM-AFM-LFM system, we aimed to elucidate the relationship between the structure of adsorbed molecules at frictional interfaces and their frictional properties

4:40 - 5:00 pm
4178030: Mini Traction Machine-Pin on Disc Test Method to Evaluate the Clutch Friction Properties of Two-wheeler Lubricants and Establishing Correlation with SAE No 2 - JASO T903 Friction Test
Bhupender Singh, TotalEnergies Marketing India Pvt Ltd, Mumbai, India

Passenger cars have separate lubrication systems for engine and transmission, but a motorcycle relies on the same oil (balance of desirable friction and lubricity properties) to lubricate the engine, clutch, and gearbox. The SAE No. 2 machine with globally recognized standard JASO T903 is used to evaluate clutch friction properties of motorcycle lubricants and categorizes lubricants into MA & MB. MA and MB indicate high and low frictional performance, respectively. The JASO T903 is a time consuming and costly method and hence could not be used for formulation optimization therefore, a method on MTM2-Pin on Disc is developed to screen MA & MB lubricants. Coefficient of friction is measured using steel on steel contact in MTM2-POD to find a correlation between dynamic and static friction Index results of lubricants tested on SAE2. Correlation established indicating POD test as an efficient screener for JASO T903 saving time and cost during formulation optimization of motorcycle lubricants.

6G — Regency V

Materials Tribology VI

Session Chair: Nikhil Murthy, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD
Session Vice Chair: Mary Makowiec, Pratt & Whitney, East Hartford, CT

1:40 - 2:20 pm
4204551: Do Oxide Coatings Strengthen Metal Nanoparticles?
Tevis Jacobs, Ruikang Ding, University of Pittsburgh, Pittsburgh, PA; Ashlie Martini, University of California Merced, Merced, CA

Technology-relevant nanoparticles deform at low loads, impairing their use in industrial applications. While much is known about the effect of particle size on strength, relatively little is known about the effect of coatings. Prior work has suggested that oxide coatings on the surface could impede deformation mechanisms (dislocation nucleation and surface diffusion), thus strengthening nanoparticles. In this investigation, we coated platinum nanoparticles in silicon oxide and compressed them inside of a transmission electron microscope. We coupled the instantaneous stress and strain measurements to real-time high-resolution video of the shape and structure of the particle. The results reveal the separate but interacting influences of size and surface coating.

2:20 - 2:40 pm
4200400: In Situ Formation and Durability of Tribocoatings using $BaTiO_3$ Nanocrystal Additives
Pezhman Palahang, Parker LaMascus, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Marjeta Fusha, Dedrick Morgan, Robert Wiacek, Pixelligent Technologies LLC, Baltimore, MD

Protective surface coatings are typically applied using resource-intensive methods. We have discovered that $BaTiO_3$ nanocrystals (NCs) can form surface-bound antiwear "tribocoatings" via stress-driven sintering at temperatures below 5% of their melting point, where scuffing protection is needed. Using 5 nm ligand-capped $BaTiO_3$ NCs dispersed in base oil in a rolling-sliding ball-on-disc tribometer (a mini-traction machine - MTM), we found that higher temperature enhances the growth rate, thickness, and durability of the coatings, ensuring continued wear protection even without NCs in the oil. We hypothesize that high surface diffusivity allows NCs to sinter together to create the coating. We employed multiple techniques to assess the structure, composition, and piezoelectric properties of the coatings, showing that $BaTiO_3$ NCs offer a promising alternative to pre-deposited coatings on tribological components.

2:40 - 3:00 pm
4189547: On the High Temperature Tribology of Ceramics and Composite Systems
Surojit Gupta, University of North Dakota, Grand Forks, ND

There is an urgent need for materials which can be used in different types of complex tribological environment like fluidic and high temperature conditions. This presentation will be divided into two parts. In the first part, high temperature tribology of ceramics-based materials will be studied. In the second part, high temperature tribology of polymeric systems like PEEK will be presented. Detailed microstructural and wear rate kinetics will be presented for both cases. It is expected that such fundamental studies can be used for bearings and gears which can be used in complex environment.

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

3:40 - 4:00 pm
4235586: Effects of Powder Reuse on Tribological Properties in Electron Beam Powder Bed Fusion Process of Ti6Al4V
Mohammad Sayem Bin Abdullah, University of Washington, Seattle, WA

Powder resume in Electron Beam Powder Bed Fusion (EB-PBF) process is key to the sustainability of the process to additively manufacture titanium alloy, i.e., Ti6Al4V. The characteristics of the spherical titanium powder change due to oxidation and particle deformation, which results in decreased ductility and mechanical anisotropy in EB-PBF Ti6Al4V. As the tribological properties are dependent on mechanical properties, the powder reuse may impact the tribological properties as well. To understand the effects of powder reuse, tribological experiments, sliding wear and erosive wear, were conducted. The EB-PBF Ti6Al4V specimens have been evaluated through advanced microscopy, optical profiler, and microstructural analysis to understand the influence of powder reuse on tribological properties. The paper will also discuss the associated mechanism in the light of powder reuse.

4:00 - 4:20 pm
4200709: Triboelectrification Mechanisms: A Computational Approach to Advanced Material Engineering
Giulio Fatti, Daniele Dini, Imperial College London, London, United Kingdom

Triboelectrification, the generation of static charges through friction, plays a critical role in various industrial and energy applications, from damaging electronics and pharmaceutical processes to sensors and energy harvesting technologies. Despite this relevance, its underlying mechanisms remain elusive. Here, we explore how first-principles simulations offer valuable insights into triboelectrification processes at the atomistic level. Using ab initio methods, we uncover the influence of tribochemical reactions and strain effects on charge transfer, providing a detailed understanding of these interactions. By elucidating these mechanisms, simulations can guide the design of advanced materials that optimize triboelectric properties, leading to more efficient and sustainable engineering solutions. The results offer promising pathways for innovation in tribology and material science.

4:20 - 4:40 pm
4204826: Tribological Behavior of Borided Steel under Inert Gas Atmosphere and Electrical Conditions
Merve Uysal Komurlu, Ali Erdemir, Texas A&M University, College Station, TX; César David Reséndiz Calderón, Leonardo Israel Farfan Cabrera, Tecnológico de Monterrey, Monterrey, Mexico

In this study, we investigated the effects of boriding on the tribological behavior of AISI 4140 steel under electrified sliding conditions. Boriding was performed by the pack-boriding process at 950°C

for 3 hours, producing 120-150 µm thick Fe_2B layers. Pin-on-disc tests were conducted in open air (45% RH) and dry Argon with and without contact electrification. When tested in ambient air, borided samples exhibited very low friction coefficients (~0.15) while unborided test pairs had friction coefficients of ~0.8 in air but increased to ~0.9 in Argon. Boriding reduced wear losses dramatically, especially during tests under electrification up to 3 A in air. Raman analysis confirmed severe tribo-oxidation in control samples, while borided samples showed the formation of a slick tribolayer. The low-friction behaviors of borided steel are due to this layer. When tested in argon, minimal tribochemistry or slick layer formation was observed.

4:40 - 5:00 pm
4199972: Material Characterization Using Replicated Low-lubricity Interfaces for Diesel Engine Fuel Delivery Systems
Caleb Matzke, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Nikhil Murthy, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD

An experimental tribology method to represent a fuel lubricated piston-cylinder interface was designed to characterize the best material pairs for use in diesel engine fuel delivery systems. Flat cylindrical specimens were run against cylindrical pins using a reciprocating line contact sliding parallel to the pin's center axis as opposed to the more common perpendicular motion. AISI 52100 steel flat pucks and pins were used, as well as 52100 coated with CrN, DLC, and various WC coatings. The interfaces were lubricated with either aviation fuel or fuel components such as decane or ethanol. The interfaces were analyzed using optical microscopes, SEM, EDS, and white light Interferometer to determine the wear performance of each material pair. The top material pairings were determined out of 18 different material pair combinations for piston-cylinder interface in diesel engine fuel delivery systems.

5:00 pm - Materials Tribology Committee Meeting

6H — Regency VI

AI and Machine Learning V

Session Chair: Prathima Nalam, SUNY at Buffalo, Buffalo, NY
Session Vice Chair: Nikolay Garabedian, Karlsruhe Institute of Technology, Karlsruhe, Germany

1:40 - 2:20 pm
4186400: Clustering of Wear Characteristics from Measured Forces with Machine Learning Models
Philipp Sieberg, Shuai Zhu, Morteza Abedini, Stefanie Hanke, University of Duisburg-Essen, Duisburg, Germany

As a system’s response, wear behavior is influenced by material properties and additional factors such as lubrication conditions. Modeling and predicting a material's wear behavior with traditional numerical methods is difficult due to the complexity. Recent developments in machine learning offer the possibility of solving higher-order nonlinear problems. In the DFG funded project(525173005), the complex pattern of the wear test data will be used for the categorization of wear mechanisms with data-driven methods. Wear tests are carried out with different materials for data acquisition. Several statistical analyses are then performed on the recorded forces and friction coefficient to extract appropriate features. Clustering algorithms are implemented to categorize the wear behavior. For each cluster, similarity equations are formulated based on the statistical distribution of the features. As a result, the wear behavior of unseen samples can be categorized

based on the existent clusters.

2:20 - 2:40 pm
4205394: Emergence of Coefficient of Restitution as a Key AI-suggested Parameter in Wear Resistance Optimization of High-Speed Engineering Polymer Composites
Tanil Ozkan, Steve Pouliot, Jonathan Penaranda, Burak Bekisli, Dover Innovation Laboratory, Houston, TX

The longevity of high-performance engineering polymer composites in demanding tribological settings and their mechanical underpinnings are of great interest to polymer tribologists. This study explores the application of AI-based semantic clustering search in conjunction with existing polymer composite damage mechanics models to evaluate the parameters that can contribute to longevity. Our findings highlight a more critical role than generally thought for the coefficient of restitution (CoR) in determining the wear resistance and durability of these composites. To support these findings, an experimental investigation conducted with a PEEK-based composite system revealed that the inclusion of nanoscale elastomeric constituents significantly changes the CoR and alters the wear resistance especially at high speeds. These experimental results suggest that incorporation of nanoscale elastomeric materials in polymeric matrices can be a viable approach.

2:40 - 3:00 pm
4205221: A Data-Driven Approach to Relating as-Built Surface Topography Parameters to Additive Manufacturing Process Parameters
Samsul Arfin Mahmood, Bart Raeymaekers, Virginia Tech, Blacksburg, VA

LPBF is an additive manufacturing process that enables fabricating parts with complex geometry. However, costly post-processing to modify the microstructure and surface topography drives the need for tailored as-built surfaces. This study presents data-driven models linking the surface topography to LPBF process parameters. Inconel 718 specimens were printed with varied build orientation, laser power and scan speed, and energy density. Areal, deterministic, and hybrid topography parameters were measured to characterize the as-built surfaces. Machine learning algorithms capture the non-linear relationships between process and topography parameters in both forward and inverse data-driven models. The forward model (XGBoost) results in the highest prediction accuracy where the build orientation and laser power are the primary drivers of the surface topography. Additionally, inverse model (ANN) predicts viable process parameter ranges that print surfaces with tailored as-built topography.

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

3:40 - 4:00 pm
4199743: AI, Data-driven Design of Surface Textured Face Seal.
Iwa Ou, Eagle Industry Co., Ltd., Sakado-shi, Saitama-Ken, Japan; Kentaro Yaji, Osaka University, Suita, Osaka, Japan

A face seal with both low leakage and low friction was realized by surface texturing technology. A surface texture consists of several micro-grooves. The friction coefficient and leakage rate are estimated by pressure distribution solved by the Reynolds equation. Since the operating conditions differ for each application, shape optimization based on generic algorithm is performed for each case, and a large amount of analysis data (big data) is generated. The author has shown that it is possible to support or accelerate the design process by utilizing this big data using machine learning. Several examples will be presented: shape optimization based on surrogate model and prediction of pressure distribution by machine learning. Recently, generative AI has been a hot topic. The author has also verified its usage and present preliminary results combined with genetic algorithm and topology optimization.

4:00 - 5:00 pm - **Special Data Session**

6I **Regency VII**

Engine & Drive Train VI: Engine Oil, HEV, and Water-Based

Session Chair: TBD
Session Vice Chair: TBD

1:40 - 2:20 pm
4200829: New Dispersant with Improved Oxidative Stability
Tim Coffy, Wayne Ouellette, TPC Group, Houston, TX

Automotive OEMs have been developing smaller engines that are more powerful, fuel efficient and have lower emissions. These smaller engines have tighter tolerances and run at higher temperatures, so they require lower viscosity oils that allow engine components to move with less resistance. Over time, high engine temperature combined with high shear while under oxidation conditions will thicken formulated engine oil, lower fuel efficiency and can be detrimental to engine components. These conditions especially challenge engine oil dispersants as they are known to increase viscosity under such conditions.
TPC Group has developed a new polyisobutylene (PIB) based dispersant that has shown significantly improved oxidation stability compared to the commonly used dispersant, polyisobutylene succinimide (PIBSI). TPC's new technology was evaluated under CEC-L48 oxidation testing conditions The dispersant structure, characterization and testing performance will be described.

2:20 - 2:40 pm
4200806: Structure-Performance Correlations of Substituted Diphenylamines as Lubricant Antioxidants
Mary Jane Felipe, SI Group, Houston, TX

Lubricating oils are susceptible to oxidative degradation when exposed to oxygen and metal surfaces, leading to the formation of acidic compounds resulting in many issues such as corrosion, deposit formation and viscosity impacts. Substituted diphenylamine antioxidants (SDPAs) are commonly used to enhance the oxidative stability of engine oils. Given rising regulatory concerns surrounding commercially available SDPAs, it is essential to continuously develop and understand the drivers of antioxidant performance. This study investigates the structure-property correlations of various synthesized SDPAs focusing on the impact of alkyl chain length, molecular architecture of substituents, and nitrogen content on oxidation induction time and other performance metrics, including deposit analysis. Furthermore, we will discuss how these correlations vary across different base oil groups, contributing to a deeper understanding of effective antioxidant design for next generation lubricant formulations.

2:40 - 3:00 pm
4187434: What's in your Cylinder Bore? Surface Texture Control in a Most Demanding Application
Mark Malburg, Digital Metrology Solutions, Columbus, IN

Engine cylinder bores require extreme sealing, low friction sliding, and long-term durability …all inside one of the most demanding environments. As a result these bore surfaces are among the most engineered surfaces in the world. Yet there is still much to be learned and performance to be

gained. In this talk we will review the common textures and methods for describing, analyzing and ultimately controlling these surfaces for optimal performance.

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

3:40 - 4:00 pm
4200633: Evaluation of FEI Performance of Ex-High VI Formulations with MoDTC in HEVs and Large Pickup Trucks
Kenji Yamamoto, Koichi Takano, Shinji Iino, Yukiya Moriizumi, ADEKA Corporation, Tokyo, Japan

HEVs will be a major powertrain segment in the coming decades. Since the engine in an HEV operates at relatively low temperatures, high viscosity index oil is crucial for enhancing fuel economy without sacrificing surface protection by the oil film at high temperatures. The FEI performance of extremely high viscosity index (Ex-high VI) formulations with MoDTC was evaluated in two engines: one for an HEV and the other for a pure ICE large pickup truck. Both motor engine tests and chassis dynamo tests were conducted. The measurement points for the motor engine test were selected from the chassis dynamo test conditions under WLTP using the k-means method. The results indicated that Ex-high VI formulations with MoDTC can improve FEI performance not only for HEVs but also for large pickup trucks across a wide range of engine operating conditions.

4:00 - 4:20 pm
4202895: Influence Of Surface Texture On Cylinder Liner / Piston Ring Contact Friction & Wear
Lake Speed, Total Seal, Phoenix, AZ

Extensive testing of various cylinder liner honing techniques revealed interesting effects on both friction and wear depending upon the piston ring face material. Different honing techniques were employed to create Rough, Plateau and Smooth cylinder liner surface textures. These liner sections were tested with stainless steel rings with and without face coatings. Of those face coatings, two PVD applied, one CVD applied, and one post lapped hard chrome faced ring were tested in select tribo-pairs. The performance in terms of both friction and wear shifted dramatically between different pairings. These results yield value insights which can be utilized to improve efficiency and durability of internal combustion engines.

4:20 - 4:40 pm
4189901: Understanding the Mechanisms of Surface Damage with Aqueous Based Lubricants Pertinent to EV Applications
Haochen Yao, Amir Kadiric, Imperial College London, London, United Kingdom; Christine Matta, Frank Berens, SKF Research and Technology Center, Houten, Netherlands

Effective lubrication of electric vehicle drive units (EDUs) presents unique challenges in lubricant formulation. The key requirements for an EDU fluid are surface protection at high torque - low speeds, low churning loss at high speeds, and optimum motor cooling. The last two of these can in theory be satisfied by water-based lubricants (WBLs) better than conventional oils. In addition, WBLs exhibit very low friction in full film regime. However, the low pressure-viscosity coefficient of WBLs leads to poor hydrodynamic film formation while the presence of water can affect boundary lubrication performance. This paper investigates surface damage mechanisms with WBLs using a triple-disc fatigue rig and a high-pressure ball-on-disc tribometer with SLIM, in combination with a set of surface analysis techniques. Results indicate that WBLs can exhibit a complex set of damage mechanisms where the competition between adhesive wear and surface fatigue is key to determining contact reliability.

4:40 - 5:00 pm
4199372: Exploring Water-Based Lubricants for Enhanced Performance in Electric Vehicles
Xin He, Christelle Chretien, Syensqo, Levittown, PA

Water-based lubricants (WBL) have gained increasing attention as a sustainable and thermally efficient solution for electric vehicles (EVs). However, concerns over electrical current leakage have limited their use in EVs. This study investigates the feasibility of applying WBLs in dry e-motors or motors with polymer-insulated copper wiring. Various additives have been evaluated in this study. The top-performing candidates demonstrated significant wear and friction coefficient reductions while enhancing extreme pressure properties. The foaming condition can be effectively controlled to ensure consistent operational performance. Due to the high thermal conductivity of water, the WBL demonstrated superior heat dissipation compared to oil-based lubricants of similar viscosity. The results indicate that WBL technology can enhance energy efficiency and thermal management in certain e-motors, offering a promising alternative for future EV applications.

5:00 pm - Engine Oil and Drivetrain Business Meeting

6J The Learning Center

Gears II

Session Chair: Aaron Isaacson, Penn State University, State College, PA
Session Vice Chair: Xue Han, Cummins, Inc., Columbus, IN

1:40 - 2:20 pm
4177258: Thermal Modeling of Aero Engine Gear Pair under Injection Lubrication: An Investigation of Oil Filtration Effects
Bahadir Karba, Uludağ University, Ankara, Turkey; Burak Kaplan, Yildrim Beyazit University, Ankara, Turkey; Ahmet Yavuz Kanyilmaz, Gazi University, Ankara, Turkey; Ali Furkan Inceel, Istanbul Technical University, Istanbul, Turkey

The thermal behavior of aero engine gear pairs under injection lubrication is not yet understood, particularly when considering particles flow into the pump or last chance filter, where some are captured, and others return to the reservoir where they continue to recirculate. Oil debris have conducted as a solid particle on gear contact zone within in-mesh and out-of-mesh to understand injection lubrication friction phenomenon either coloumb or viscous state. This study presents a comprehensive thermal modeling approach to investigate the performance of a gear pair under injection lubrication, incorporating the impact of filtration. FEA has simulated the heat balance in the gear pair, considering effects of lubricant flow, oil viscosity, and filtration efficiency using outputs of particle-based solver. This research provides valuable insights into the thermal management of aero engine gearboxes, enabling the optimization of injection lubrication systems and oil filtration designs.

2:20 - 2:40 pm
4205051: Simulating Gear Micropitting Wear on a 3 Ring on Roller Rig
Marc Ingram, Ingram Tribology Ltd, Carmarthen, United Kingdom; Thomas Baldwin, National Physical Laboratory, London, United Kingdom; Clive Hamer, Matthew Smeeth, Thomas Welham, Benjamin Wainwright, PCS Instruments, London, United Kingdom

Micropitting is a type of surface fatigue mechanism where small pits are formed on the surface of gears. The formation of pits leads to a loss of material and a change of geometry on the surface of

the gear tooth. This can cause macropits to form and ultimately failure of the part. In this paper we describe the development of a new micropitting test to evaluate the ability of lubricants to prevent micropitting. A three ring on roller test machine is used to investigate the mechanism and accelerate the micropitting process on case carburised 16MnCr5 parts. The test conditions are chosen by first calculating the contact conditions of a gear contact and then emulating these as closely as possible on the screening test rig. Multiple iterations of the screening method have been investigated, with the aim of producing a good correlation to the FZG gear test as defined in FVA 54/7. The screening methods are found to give good correlation in terms of the mechanism and extent of micropitting.

2:40 - 3:00 pm
4194432: Roll Slide Contacts Simulated with Gear-Cam Modification – Prescreening Lubricants for High Speed Roll-Slide Contacts.
Dirk Drees, Lais Lopes, Pedro Baião, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Mike Anderson, Falex Corporation, Sugar Grove, IL

Several applications in industry rely on rolling-sliding contacts that need to be lubricated to prevent scuffing, wear and also pitting or micropitting. Conventional test setups may use gears (FZG), rollers (such as the MPR) or ball-on-disk configurations (MTM) but each of them has their limitations. The FZG and MPR methods require fairly complex test pieces, whereas the simpler MTM does not reach typical pressures or speeds that can be found in some applications. This presentation shows a middle way to approach the roll-slide mechanism, using a non-definite two-roller on two-ring contact in a multicontact MCTT test machine. Here, a slide-roll ratio in the range of 0.3 to 0.4 can be achieved with fairly simple means and test pieces, so that different lubricants can be quickly compared directly under varying test conditions of speed and contact pressures. A start is made with correlating some results of this method with FZG test results, as well as with pitting and micropitting events.

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

3:40 - 4:20 pm
4200233: Effect of Tooth Root Fillet on Tooth Root Stress in Short-Fiber-Reinforced Plastic Gears - and What We Can Learn From Biology
Oliver Koch, Wassiem Kassem, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany; Manuel Oehler, Ruhr-Universität Bochum, Bochum, Germany

The geometry of plastic gears used today is usually based on conventional steel gears, which are bound to the restrictions of the machining production of gears. The injection molding process provides more design freedom here. In this work, simulative results are shown for the occurring tooth root stress in plastic gears with various tooth root fillet designs. The simulation method is based on finite element analysis and takes into account the different fiber orientation as well as the complex material behavior of short fiber reinforced plastics.
The analysis includes fully rounded, elliptical and bionic tooth root fillets. The calculation is carried out with homogeneous material as well as with short-fiber reinforced plastics. In addition to the tooth root stress in the initial state, results are also presented for the geometry changed by abrasive wear during operation. It is possible to reduce the tooth root stress by up to 24% by bionic inspired tooth root fillets.

4:20 - 5:00 pm - **Gears Committee Meeting**

6K — Dunwoody

Power Generation II

Session Chair: TBD
Session Vice Chair: TBD

1:40 - 2:20 pm
4199905: A Journey of Varnish Formation and Mitigation - Case Study
Elaine Hepley, Solana Consulting Services LLC, Indianapolis, IN

This presentation will go over a case study of a Hydraulic Forge System that has been experiencing varnish symptoms for the past 8 years, will review test methods, review of data interpretation and timeline of varnish mitigation.

2:20 - 3:00 pm
4232186: Tackling WEC With Copper Filming Lubricant Technology
Leyla Alieva, Sergei Mamykin, Neol Copper Technologies Limited, London, United Kingdom

Numerous studies on the causes of the significant number of early failures in the bearing assemblies of large electric machines have shown that the primary cause is White Structure Flaking (WSF) caused by axial cracking and White Etching Cracks (WEC), with corresponding microstructural changes known as White Etching Areas (WEA). This is believed to result from a combination of mechanical, tribochemical, and electrical effects. Despite ongoing research on these phenomena in various fields of science and technology over the past decades, the driving forces and mechanisms of their formation remain highly controversial. We will describe the mechanics of the underlying tribochemical process through the lens of scientific knowledge about hydrogen wear. We will also describe a method of protecting friction surfaces from micro and macro-pitting, WSF, WEC, and WEA by introducing oil-soluble copper salts into the lubricant resulting in nano-film being formed from copper, which solves the issue.

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

3:40 - 4:20 pm - **Power Gen Panel**

4:20 - 5:00 pm - **Power Generation Committee Meeting**

Discussion Roundtable – An Ideation Event — Centennial Ballroom

5:00 – 6:00 pm

The ideation event will be held in the format of discussion round tables. This format enables both an open discussion with many participants and an easy recap and documentation. For every table, a host proposes a topic for his discussion round table and the participants will discuss and share their opinions on this. The benefit for the host is that they may propose a topic of interest and receive the opinions and views of all other participants. The Ideation Session typically takes 60 minutes but is open ended.